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Jukka M. Krisp *Editor*

Progress in Location-Based Services

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Editor

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Editor
Jukka M. Krisp
Cartography
Technische Universität München
Munich
Germany

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Preface

This book offers a collection of peer-reviewed front-end research articles related to Location-Based Services (LBS). As an overview this book includes an introductory essay by Jukka Krisp and Liqiu Meng and two invited essays from Harvey Miller and Georg Gartner exploring what LBS will be like in the year 2030. The contributed articles document research activities from various fields. Therefore this book is divided into five sections.

Part I investigates progress in *Spatiotemporal Data Acquisition*, *Processing*, *and Analysis*. This part includes a contribution from Eva Hauthal and Dirk Burghardt on the *Extraction of Location-Based Emotions from Photo Platforms*, in which the distribution of emotions within the valence-arousal-space represents the kinds of emotions occurring in the study area of Dresden. Chun Liu and Zhiwei Jian contribute a paper on Combining Float Car Data and Multispectral Satellite Images to Extract Road Features and Networks, which presents an automatic methodology for the extraction of spatial road features and networks from floating car data (FCD) that was integrated with multispectral remote sensing images in metropolitan areas. Christian E. Murphy documents the *Space–Time Mapping of Mass Event Data*, in which conventional cartographic symbolization meets the space–time cube to create a holistic three-dimensional spatiotemporal visualization model. The two-dimensional proportional symbol mapping technique is adopted and extruded into the third dimension to model the temporal factor. Yeran Sun, Hongchao Fan, Marco, Helbich, and Alexander Zipf provide a *Study on Analyzing Spatiotemporal Tourism Activities Using Volunteered Geographic Information*, which uses Flickr photos as an example to explore the possibilities of Volunteered Geographic Information (VGI) to analyze spatiotemporal patterns of tourists' accommodation in Vienna. A paper by Claire Ellul, Suneeta Gupta, Mordechai Haklay, Kevin Bryson investigate *A Platform for Location-Based App Development for Citizen Science and Community Mapping*, providing a description of the development of a LBS App platform. Colin Kuntzsch and Alexander Bohn examine A *Framework for On-line Detection of Custom Group Movement Patterns*, describing an approach for custom definition and detection of group patterns in a real-time analysis scenario. Khatereh Polous, Peter Mooney, Jukka Krisp, and Liqiu Meng study event-related knowledge from OSM to mine hidden patterns of social activities and the interests of contributors to share event-related knowledge within OSM community as one of the most prominent examples of user generated spatial data.

Part II contemplates contributions on *Positioning and Indoor Positioning*. Khuong Nguyen and Zhiyuan Luo evaluate *Bluetooth Properties for Indoor Localization*, in which Bluetooth properties are related to indoor localization are investigated from a statistical perspective. Michailas Romanovas, Vadim Goridko, Lasse Klingbeil, Mohamed Bourouah, Ahmed Al-Jawad, Martin Traechtler, and Yiannos Manoli investigate *Pedestrian Indoor Localization Using Foot Mounted Inertial Sensors in Combination with a Magnetometer, a Barometer, and RFID*. The work presents a custom sensor system development, describes the developed algorithms and evaluates several methods to reduce the drift, which usually comes with the integration of low-cost sensors. Thomas Hillebrandt, Heiko Will, and Marcel Kyas document a *Quantitative and Spatial Evaluation of Distance-Based Localization Algorithms* and present a detailed investigation on the error distribution and the real world behavior of these algorithms. Andreas Bilke and Jürgen Sieck use the *Magnetic Field for Indoor Localization on a Mobile Phone*. This paper presents a locating system which is based on identifying geomagnetic field disturbances and ambient light.

Part III includes contributions on *Way-finding/Navigation (indoor/outdoor) and Smart Mobile Phone Navigation Related to LBS Technologies*. Marcus Goetz and Alexander Zipf investigate *Indoor Route Planning with Volunteered Geographic Information (VGI) on a Web-Based Platform*. They present an application for indoor environments, by providing indoor maps and route planning services with indoor OSM data, and demonstrate the possibilities arising from VGI. Jussi Nikander, Juha Järvi, Muhammad Usman, Kirsi Virrantaus examine an *Indoor and Outdoor Mobile Navigation by Using a Combination of Floor Plans and Street Maps* and introduces a prototype for combined indoor and outdoor mobile navigation system for a university campus. Padraig Corcoran, Peter Mooney, Michela Bertolotto, Basel Magableh offer a paper on *Augmented Maps with Route Sketches*. They propose a representation for route descriptions called an Augmented Route Sketch Map (ARSM). In this representation, a route is composed of a sketch-map drawn over a detailed base-map. Horst Steuer investigates *High Precision 3D Indoor Routing on Reduced Visibility Graphs* and shows how the concept of visibility graphs can be applied to indoor routing and how it results in highly accurate shortest paths. Lijuan Zhang, Sagi Dalyot, and Monika Sester explore *Travel-Mode Classification for Optimizing Vehicular Travel Route Planning*. They suggest extracting this information from the navigational behavior of users, which is accessible via an analysis of GPS traces analysis of car commuters in relation to their point of departure and destination by analyzing the walking path they took from and to their parked car in relation to a specific address. Zhiyong Wang and Sisi Zlatanova document a *Taxonomy of Navigation for First Responders*, which introduces a taxonomy of navigation among obstacles, categorizes navigation cases on basis of type and multiplicity of first responders, destinations, and obstacles.

Part IV comprises papers on interactions, user studies, and evaluations. Alexandra Lorenz, Cornelia Thierbach, Nina Baur, and Thomas H. Kolbe investigate Paper Maps as *Alternative to Electronic Indoor Navigation Aids and Their Empirical Evaluation with Large User Bases*. They focus on media characteristics and users' media preferences and indicate that 11–15-year-old teenagers show a higher tendency toward paper maps than toward smartphone apps. Daniela Richter, Maria Vasardani, Lesley Stirlng, Kai-Florian Richter, and Stephan Winter provide the paper, *Zooming In—Zooming Out Hierarchies in Place Descriptions*, in which they analyze place descriptions collected in a mobile game and investigate hierarchies based on a classification of spatial granularity. Peter Mooney and Padraig Corcoran investigate the *Understanding the Roles of Communities in Volunteered Geographic Information Projects*. They examine types of contributors and interactions amongst members of OSM. Their results show that there are very small groups of individuals creating and editing over 85 % of all OSM objects in three case-study cities. Karl Rehrl, Simon Gröchenig, Hartwig Hochmair, Sven Leitinger, Renate Steinmann, and Andreas Wagner explore a *Conceptual Model for Analyzing Contribution Patterns in the Context of VGI*. The conceptual model is based on a set of action and domain concepts, which are combined to a task-model describing typical tasks of volunteered geographic information contribution.

Part V gathers *Innovative LBS Systems and Applications*. Bernd Resch investigates *People as Sensors and Collective Sensing—Contextual Observations that are Complementing Geo-Sensor Network Measurements*. The concept defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but also in which humans can contribute their individual 'measurements' such as their subjective sensations, current perceptions, or personal observations. Jianwei Zhang, Theo Arentze *Design, and Implement a Daily Activity Scheduler in the Context of a Personal Travel Information System*. They present a prototype based on travel information system, where point of interest (POI) information and travel information have been integrated into an individual agenda service. Min Lu and Masatoshi Arikawa consider a *Map-Based Storytelling Tool for Real-World Walking Tour*. They propose a new framework for supporting walking tours with stories and maps implemented on a smartphone. Andreas Donaubauer, Florian Straub, Nadia Panchaud, Claude Vessaz investigate a *3D Indoor Routing Service with 2D Visualization Based on the Multi-layered Space-Event Model*. They present a draft for a conceptual model for indoor navigation, the multi-layered space-event model (MLSM), is combined with standards for Geo Web Services in order to define a framework for a 3D Indoor Routing with Rule-Based 2D Visualizations. Ming Li, Marcus Goetz, Hongchao Fan, and Alexander Zipf investigate the *Adaptation of OSM-3D to the Mobile World—Challenges and Potentials*. This paper provides a framework and proposal toward context-aware OSM-3D mobile applications.

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Munich, Germany, September 2012 Jukka M. Krisp

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Reviewers

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Rein Ahas, University of Tartu, Estonia
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Kirsi Virrantaus, Aalto University, School of Engineering, Finland
Stephan Winter, The University of Melbourne, Australia
Alexander Zipf, University of Heidelberg, Germany
Sisi Zlatanova, Delft University of Technology, Netherlands

Contributors

Ahmed Al-Jawad Institute of Microsystems and Information Technology, Hahn-Schickard-Gesellschaft e.V., Villingen-Schwenningen, Germany

Theo Arentze Urban Planning Group, Eindhoven University of Technology, Den Dolech 2, 5612, AZ, Eindhoven, The Netherlands, e-mail: t.a.arentze@tue.nl

Masatoshi Arikawa Center for Spatial Information Science, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, Chiba 277-8568, Japan, e-mail: arikawa@csis.u-tokyo.ac.jp

Nina Baur Department of Sociology, Technische Universität Berlin, Fraunhoferstr. 33–36, 10587 Berlin, Germany

Michela Bertolotto School of Computer Science and Informatics, University College Dublin, Dublin, Ireland

Andreas Bilke INKA Research Group, Hochschule für Technik und Wirtschaft Berlin, Wilhelminenhofstraße 75a, 12459 Berlin, Germany, e-mail: bilke@htw-berlin.de

Alexander Bohn Institute of Cartography and Geoinformatics, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany

Mohamed Bourouah Institute of Microsystems and Information Technology, Hahn-Schickard-Gesellschaft e.V., Villingen-Schwenningen, Germany

Kevin Bryson Department of Computer Science, University College London, Gower Street, London, UK

Dirk Burghardt Institute of Cartography, Technische Universität Dresden, Helmholtzstraße 10, 01069 Dresden, Germany, e-mail: dirk.burghardt@tu-dresden.de

Padraig Corcoran School of Computer Science and Informatics, University College Dublin, Dublin, Ireland; School of Computer Science and Informatics, University College Dublin (UCD), Dublin 4, Ireland, e-mail: padraig.corcoran@ucd.ie

Sagi Dalyot Institut für Kartographie und Geoinformatik (IKG), Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany

Andreas Donaubauer Technische Universität München, Arcisstraße 21, 80333 Munich, Germany, e-mail: andreas.donaubauer@tum.de

Claire Ellul Department of Civil, Environmental and Geomatic Engineering, University College London, Gower Street, London, UK, e-mail: c.ellul@ucl.ac.uk

Hongchao Fan Chair of GIScience, Department of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany; Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany

Marcus Goetz GIScience Group, Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany; Chair of GIScience, Department of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany, e-mail: m.goetz@uni-heidelberg.de

Vadim Goridko Institute of Microsystems and Information Technology, Hahn-Schickard-Gesellschaft e.V., Villingen-Schwenningen, Germany

Simon Groechenig Carinthia University of Applied Science, Europastraße 4, 9524 Villach, Austria, e-mail: simon.groechenig@edu.fh-kaernten.ac.at

Suneeta Gupta Department of Computer Science, University College London, Gower Street, London, UK

Mordechai Muki Haklay Department of Civil, Environmental and Geomatic Engineering, University College London, Gower Street, London, UK

Eva Hauthal Institute of Cartography, Technische Universität Dresden, Helmholtzstraße 10, 01069 Dresden, Germany, e-mail: eva.hauthal@tu-dresden.de

Marco Helbich Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany

Thomas Hillebrandt Department of Computer Science, Freie Universität Berlin, Takustr. 9, 14195 Berlin, Germany, e-mail: thomas.hillebrandt@fu-berlin.de

Hartwig Hochmair Fort Lauderdale Research and Education Center, University of Florida, 3205 College Avenue, Fort Lauderdale, FL 33314–7799, USA, e-mail: hhhochmair@ufl.edu

Juha Järvi Department of Real Estate, Planning and Geoinformatics, Aalto University School of Engineering, Espoo, Finland, e-mail: Juha.Jarvi@aalto.fi

Zhiwei Jian Department of Surveying and Geoinfomatics, Tongji University, Shanghai 200092, China

Lasse Klingbeil Institute of Geodesy and Geoinformation, Rheinische Friedrich-Wilhelms-Universitaet Bonn, Bonn, Germany

Thomas H. Kolbe Department of Geodesy and Geoinformation Science, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany

Jukka M. Krisp Department of Cartography, Technische Universität München, Arcisstraße 21 80333, Munich, Germany, e-mail: Krisp@bvtum.de

Colin Kuntzsch Institute of Cartography and Geoinformatics, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany, e-mail: colin.kuntzsch@ikg.uni-hannover.de

Marcel Kyas Department of Computer Science, Freie Universität Berlin, Takustr. 9, 14195 Berlin, Germany, e-mail: marcel.kyas@fu-berlin.de

Sven Leitinger Salzburg Research, Jakob Haringer-Straße 5, 5020 Salzburg, Austria, e-mail: sven.leitinger@salzburgresearch.at

Ming Li Chair of GIScience, Department of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany; Chair of GIScience, Department of Geography, University of Heidelberg, Berliner Straße 48, 69120 Heidelberg, Germany, e-mail: ming.li@geog.uni-heidelberg.de

Chun Liu Department of Surveying and Geoinfomatics, Tongji University, Shanghai 200092, China, e-mail: Liuchun@tongji.edu.cn

Alexandra Lorenz Department of Geodesy and Geoinformation Science, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany, e-mail: alexandra.lorenz@tu-berlin.de

Min Lu Center for Spatial Information Science, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, Chiba 277-8568, Japan, e-mail: lu@csis.u-tokyo.ac.jp

Zhiyuan Luo Department of Computer Science, Royal Holloway, University of London, Egham TW20 0EX, UK, e-mail: zhiyuan@cs.rhul.ac.uk

Basel Magableh School of Computer Science and Informatics, University College Dublin, Dublin, Ireland

Yiannos Manoli Fritz Huettinger Chair of Microelectronics, Department of Microsystems Engineering (IMTEK), Albert-Ludwigs-Universitaet Freiburg, Freiburg, Germany

Liqiu Meng Department of Cartography, Technische Universität München, Arcisstraße 21 80333, Munich, Germany, e-mail: Meng@bvtum.de

Xiaolin Meng Nottingham Geospatial Institute, The University of Nottingham, Nottingham NG7 2TU, UK

Peter Mooney Department of Computer Science, National University of Ireland Maynooth (NUIM), Co. Kildare, Ireland; Department of Computer Science, National University of Ireland Maynooth, Maynooth, Ireland, e-mail: peter.mooney@nuim.ie; peter.mooney@tnuim.ie

Christian E. Murphy Department of Cartography, Technische Universität München, Arcisstraße 21, 80333 Munich, Germany, e-mail: Christian.Murphy@bv.tum.de

Khuong Nguyen Department of Computer Science, Royal Holloway, University of London, Egham TW20 0EX, UK, e-mail: khuong@cantab.net

Jussi Nikander Department of Real Estate, Planning and Geoinformatics, Aalto University School of Engineering, Espoo, Finland, e-mail: Jussi.Nikander@aalto.fi

Nadia Panchaud Eidgenössische Technische, Wolfgang-Pauli-Strasse 15, 8093 Zurich, Switzerland, e-mail: nadiap@student.ethz.ch

Khatereh Polous Department of Cartography, Technische Universität München, Arcisstraße 21 80333, Munich, Germany, e-mail: Polous@bvtum.de

Karl Rehrl Salzburg Research, Jakob Haringer-Straße 5, 5020 Salzburg, Austria, e-mail: karl.rehrl@salzburgresearch.at

Bernd Resch SENSEable City Lab, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139, USA; Institute of Geography–GIScience, University of Heidelberg, Berliner Street 48, 69120 Heidelberg, Germany; Institute for Geoinformatics and Remote Sensing, University of Osnabrück, Barbara Street 22b, 49076 Osnabrück, Germany, e-mail: bernd.resch@geog.uni-heidelberg.de

Daniela Richter Institute of Photogrammetry and Remote Sensing, Karlsruhe Institute of Technology, Karlsruhe, Germany; Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia, e-mail: daniela.richter@kit.edu

Kai-Florian Richter Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia, e-mail: krichter@unimelb.edu.au

Michailas Romanovas Institute of Microsystems and Information Technology, Hahn-Schickard-Gesellschaft e.V., Villingen-Schwenningen, Germany, e-mail: michailas.romanovas@hsg-imit.de

Monika Sester Institut für Kartographie und Geoinformatik (IKG), Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany

Jürgen Sieck INKA Research Group, Hochschule für Technik und Wirtschaft Berlin, Wilhelminenhofstraße 75a, 12459 Berlin, Germany, e-mail: j.sieck@htw-berlin.de

Renate Steinmann Salzburg Research, Jakob Haringer-Straße 5, 5020 Salzburg, Austria, e-mail: renate.steinmann@salzburgresearch.at

Horst Steuer Fachgebiet Geoinformationssysteme, Technische Universität München, Arcisstraße 21, 80333 Munich, Germany, e-mail: steuer@tum.de

Lesley Stirlng School of Languages and Linguistics, The University of Melbourne, Melbourne, Australia, e-mail: lesleyfs@unimelb.edu.au

Florian Straub Eidgenössische Technische, Wolfgang-Pauli-Strasse 15, 8093 Zurich, Switzerland, e-mail: straubf@ethz.ch

Yeran Sun Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany, e-mail: yeran.sun@geog.uni-heidelberg.de

Cornelia Thierbach Department of Sociology, Technische Universität Berlin, Fraunhoferstr. 33–36, 10587 Berlin, Germany

Martin Traechtler Institute of Microsystems and Information Technology, Hahn-Schickard-Gesellschaft e.V., Villingen-Schwenningen, Germany

Muhammad Usman Department of Real Estate, Planning and Geoinformatics, Aalto University School of Engineering, Espoo, Finland, e-mail: Muhammad.Usman@aalto.fi

Maria Vasardani Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia, e-mail: mvasardani@unimelb.edu.au

Claude Vessaz Eidgenössische Technische, Wolfgang-Pauli-Strasse 15, 8093 Zurich, Switzerland, e-mail: c.vessaz@gmail.com

Kirsi Virrantaus Department of Real Estate, Planning and Geoinformatics, Aalto University School of Engineering, Espoo, Finland, e-mail: Kirsi.Virrantaus@aalto.fi

Andreas Wagner Salzburg Research, Jakob Haringer-Straße 5, 5020 Salzburg, Austria, e-mail: andreas.wagner@salzburgresearch.at

Zhiyong Wang OTB Research Institute for the Built Environment, TU delft, Jaffalaan 9, 2628BX Delft, The Netherlands, e-mail: Z.Wang-1@tudelft.nl

Heiko Will Department of Computer Science, Freie Universität Berlin, Takustr. 9, 14195 Berlin, Germany, e-mail: heiko.will@fu-berlin.de

Winter Stephan Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia, e-mail: winter@unimelb.edu.au

Lijuan Zhang Institut für Kartographie und Geoinformatik (IKG), Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany, e-mail: Lijuan.Zhang@ikg.uni-hannover.de

Jianwei Zhang Urban Planning Group, Eindhoven University of Technology, Den Dolech 2, 5612, AZ, Eindhoven, The Netherlands, e-mail: j.zhang@tue.nl

Alexander Zipf GIScience Group, Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany; Chair of GIScience, Department of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany; Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany, e-mail: zipf@uni-heidelberg.de

Sisi Zlatanova OTB Research Institute for the Built Environment, TU delft, Jaffalaan 9, 2628BX Delft, The Netherlands

Introduction

Going Local—Evolution of Location-Based Services

Jukka M. Krisp and Liqiu Meng

It is a well-known fact that spatial planning and decision-making processes can hardly take place without geo-referenced locations. Thanks to the widespread earth observing satellite missions, our living planet can now be globally scanned, thus digitized within days. The access to an up-to-date and seamlessly covered digital earth with geometric, radiometric, and relational information of many different thematic layers has become an everyday experience. However, a well-structured digital earth usually contains aggregated information over census units, administrative units, postal districts, catchment areas, etc. Not more than ten years ago, spatial planners and decision makers had to largely rely on this kind of aggregated information which may limit the precision of the planning results or decisions. The emergence of geosensor networks and open-source platforms has parallelized the trends of "going global" and "going local", and led to an exponential growth and ubiquitous distribution of the highly detailed information at individual locations, i.e. location-based data in the true sense.

Along the value-adding chain from sensory data to geo-knowledge, the research field on Location-Based Services (LBS) has been undergoing a breathtaking development during the recent decade and a large number of theoretical and empirical findings of LBS have already been accumulated in the "*Lecture Notes in Geoinformation and Cartography*", especially in books on "*Location Based Services and TeleCartography*" (Gartner et al. 2007), "*Location Based Services and TeleCartography II*" (Gartner and Rehrl 2009), "*Advances in Location-Based Services*" (Gartner and Ortag 2011), and two books on "*Map-based Mobile Services*" (Meng et al. 2005, 2008).

LBS are investigated from different perspectives that include mobile positioning and tracking technologies, data capturing and computing devices, integrated software engineering, user studies for various applications, etc. The state-of-the-art of LBS can be unfolded into the following mainstreams:

Acquisition of a meaningful digital world. While the globally networked high-end geosensor systems, including global positioning systems, international earth rotation and reference systems, various telecommunication systems, etc. will continue the systematic digitalization of earth surface at finer spatiotemporal resolutions, inexpensive mobile devices have increasingly entered into our everyday life, and marked up a low-end sensor network. Every private person with his or own sense organs and pocket devices like camera, compass, and GPS receivers may observe the selected hotspots with the largest possible details and distribute the data in the Internet. Therefore, everybody has become an active sensor which is globally networked and handles locally. Different from the electromechanical surveying instruments that deliver objective, parameterized, and formatted geo-data, human beings are able to perceive his ambience with personal interest and provide emotionally loaded experience reports for him/herself and for fellow people. They describe not only "what", "when" and "how much", but also the impressions about the illumination, weather conditions, smell, taste, noise, gesture, mood, and other perceptible phenomena that are neither measureable nor projectable. By connecting all these experience reports with each other and with the sites where they originate, we are going to gain a better insight into the world (Clark 2011). Data from individual persons are geometrically imprecise, but semantically valuable and can be flexibly applied for time-critical decision processes. For this reason, Knowledge Boys in London are still preferred by many citizens to navigation systems.

Openness of location-based data and services. Location-based data are competitively and complementarily provided by a limited number of public agencies, a larger number of private companies, and even larger number of volunteers. Public agencies are responsible for the acquisition, updating, and dissimilation of framework data, geo-referenced thematic data, as well as the development of basic services for public and private user groups. Their activities strictly follow the predefined quality standards and geodata infrastructure. Their data are usually authoritative, copyright-protected, neutral, and interoperable.

Private companies acquire and supply the location-based data for special purposes, such as navigation, software selling, consultancy, and training. They have their own formats and quality standards in line with competition regulations. Often they conduct necessary enrichment of framework data from public agencies and customize the services in order to meet the requirements of target users and specific applications.

The volunteers are individual persons or interest groups engaged in spontaneous and focused acquisition of location-based data about "what happens here and now". They disseminate their individual data in the Internet or telecommunication networks in form of geo-tagged text, photos, video-clips, etc. with or without standard or structure. This kind of crowd-sourcing seems to be purposeless and irresponsible, but proves a significant complementation to the data from public agencies and private companies. Due to its openness, flexibility, and location-based intelligence, the Volunteered Geographic Information (VGI) plays an indispensable role in the field of disaster management such as post-earthquake rescue (Meier 2010, Liu 2011).

Participatory location-based services and analysis. The rapid development in tracking mobile phones and using people as sensors has opened the door to a new research field of location-based analysis, which involves the behavior of individuals in space as well as directing the movement of individuals. Research challenges include positioning methods of individuals outdoor and indoor, the storage of this data, privacy issues, and methods to analyze this data and how to communicate the analysis processes and results, plus potential applications that can make use of the location data or acquired analysis results. Additionally the impact of decisions founded on the analysis of location data need to be investigated.

Currently emerging applications tackle “indoor navigation and way finding”. We believe it is safe to say that within the next years (we do not have to wait until 2030) indoor navigation systems will be integrated into smart mobile phones or other devices like computer pads. The currently common habit of asking someone where to find a room in an unknown building will fade to be a habit of the past. We may find a similar development as with in-car navigation system, which have become very common and the habit of “asking directions” disappears more and more.

Technical challenges still occur on the indoor navigation data acquisition, the path computation, and the communication of a potential indoor path to the user. In order to gather the unstructured data and perform queries, we need spatiotemporal modeling methods, searching machine, data mining, and cloud-computing. Map-mashups are particularly important for time critical applications where an efficient, inexpensive, complete, and timely service supply is required only when data and services from different sources can be put together.

Incremental LBS. A near-real-time LBS should grow and shrink with the data streams and show always the current state of the objects and their relations. The high speed of data amount requires a service platforms with components, such as data stream management, queries, change detection, integration algorithms, design tools, and user interface. With the increasing availability of open-source-platforms every internet user may have access to maps and data, and add his/her “own” information as cloud solution. This phenomenon of “maps for everybody and everybody for maps” brought up further research topics on VGI (Goodchild 2007).

The enabling sensory technologies and interactive open-source platforms are continuously changing the way of our thinking and living and reshaping the research scope of LBS. By reflecting the frontend research activities with different intensity in this book, we feel obliged to define a dynamic body of shared knowledge for LBS as an integrative discipline that unites research ideas from related fields, such as geography, geodetic engineering, signal processing, statistics, cartography, computer science, and cognition science.

Jukka M. Krisp
Liqiu Meng
Technische Universität München (TUM)
Cartography
Arcisstraße 21
80333, Munich, Germany

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Location Matters: LBS 2030

Georg Gartner

Think of having 2030. Information is available anytime and anywhere. In its provision and delivery it is tailored to the user's context and needs. In this the location is a key selector for which and how information is provided. Location-based Services are thus widespread and of daily use in a truly ubiquitous manner. Persons would feel spatially blind without using their LBS, which enables them to see who or what is near them, get supported, and do searches based on the current location, collect data on site accurately and timely. Mobile technologies have demonstrated their huge potential and changed how we work, how we live, and how we interact.

At the 26th International Conference on Location-based Services in 2030 selected presentations might reflect back on three main periods of development which have led to this development.

At the early stages of LBS the development have been basically driven by technology. Whenever innovative positioning-, telecommunication-, or device technologies have been introduced new ideas, applications, and products in the domain of LBS have been triggered. That period was very much characterized by efforts to deal with research questions as "How to locate or track a user?", data modeling, and data representation on small display devices. Significant progress was made in determining the positions of devices and users in outdoor and or indoor scenarios as well as in mixed environments and in 3D. The need for real-time tracking was tackled as well as attempts to combine direct and indirect positioning methods by using smart environments sensors. That first period of LBS development was especially influenced also by the rapid availability of ever more new handheld devices. Thus allowing more and better availability and accessibility to sensors, processing performance and communication channels these handheld devices became quickly smart and mass market acceptable. A number of applications have been developed influenced simply by the availability of a new smart device, including such which take the idea of LBS into the entertainment and gaming domain, the business domain, the disaster management domain, or urban and regional planning domain to name a few. Basically most of those systems have been constrained very much by the available limitations of existing technologies, forcing many users, and use scenarios to adapt to the constraints rather than developing systems for the sake of the use and the users.

The second period was characterized by data-driven approaches. Now that technologies have become available and the speed of the circle of technological innovations have become less fast, the available high quality of mass market technologies lead to a shift of the focus on the availability of data. A major discussion in this was the overcoming of obstacles between data acquisition and data consummation as well as to find ways of cooperation between the three then existing parallel worlds of authoritative, commercial, and open data providers. By developing technical, legal, and economical standards and procedures the LBS-environment benefited significantly as the accessibility and availability of data was acceptably defined. With this additional data acquisition and usage from ubiquitous sensory as well as from users behavior and pattern was not only possible, technically spoken but rather embedded in a legal and economical framework. When dealing with volunteered data new challenges arose, such as the necessity to learn about the motivation, the structure, and the representativeness of the volunteers as well as developing mechanism to be able to judge the reliability of the available data. The huge quantities of data being generated brought a requirement for enhanced data management systems. The need to address this problem drove one of the main trends—an increasing use of and reliance on Big Data technologies—technologies which enable the analysis of vast quantities of information within useable and practical timeframes. Massively scalable, distributed systems for processing unstructured and semi-structured data emerged as a result of this need, and became widely accepted and relied upon in the management and interpretation of geospatial information. Given the vast amount of data being generated, particularly through use of the Web, and the need to make sense of this data, the ability to link information on the Web became increasingly important. The network built on increasing numbers of sensors and thus, increasing data, produced a hyper-connected environment or 'Internet of Things'. Location provides a vital link between the sensors that generate the Internet of Things and thus LBS making use of the Location are key elements to make use of those networks.

Finally the third major period of LBS developments can be characterized by focusing on the human, the user. Smart LBS support decision-making either on a collaborative or an individual level, help to act in space, support spatial enabled societies, enhance spatial awareness or simply support daily routines, as everything happens somewhere, and thus location is a key selector for what we do and how. In this period context-awareness was as interesting to be tackled by research and development as use and user modeling or developing adaptive algorithms. The role of cartography and data presentation remains the language through which the data explosion will be spatially interpreted. The fact that increasing amounts of geospatial information are consumed and interpreted through mobile devices also lead to the development of new visualization techniques including such which deal 3D and especially 4D-representations.

By looking back it becomes obvious, that the successful development of LBS required integrated interdisciplinary approaches from such domains as computer science, communication science, human–computer interaction, telecommunication sciences, cognitive sciences, law, economics, geospatial information management and cartography to allow for human-centered application developments by applying innovative engineering methods and tools in a highly volatile technological framework. Especially the rapidly increasing use of geospatial information during this time leads to a growing recognition amongst both governments and the private sector that an understanding of location and place is a vital component of effective decision making. Citizens with no recognized expertise in geospatial information and who are unlikely to be even familiar with the term, are also increasingly using and interacting with geospatial information and in some cases they are contributing to its collection. A number of important technology-driven trends had a major impact, creating previously unimaginable amounts of location-referenced information, and thus put LBS in the center of the focus of research and development.

Georg Gartner
Department of Geoinformation and Cartography
Vienna University of Technology
Erzherzog-Johann-Platz 1
1040 Vienna, Austria

Location-Based Services in 2030: From Sharing to Collective Action

Harvey J. Miller

What will Location-based Services (LBS) be like in the year 2030? It is safe to assume that LBS will be better technologically. Location-based data and information will be widely available at higher volumes, fidelities, and velocities. Wide-ranging content will be delivered more effectively to individuals, localization methods (especially indoors) will be faster and more accurate, digital representations of environments will be more faithful, and user interfaces will be more humane. Locational information will be an increasingly enabling component of complex context-aware and activity-aware applications that will know a great deal about you, the world around you, and perform tasks proactively on your behalf (Dey et al. 2010; Raubal et al. 2004). There will also be surprising convergences: who would have thought in the year 1994 that cameras in mobile phones would be so fun and practical (if not sometimes embarrassing)?

Will LBS be better for humanity in the year 2030? In other words, will the good social and environmental outcomes outweigh the bad? Recent experience has confirmed Howard Rheingold's predictions about the disruptive social effects of mobile communication and instant access (Rheingold 2002). In some cases this has been bad (e.g., distracted driving) but in other cases good (e.g., fewer dictators in the world). The convergence of LBS and social media will be similarly disruptive: it will change our interactions with geography and with others by enabling more complex, fluid, and dynamic activities with respect to time and geography (Couclelis 2000; Lenz and Nobis 2007). Although we cannot completely control the social use of technology, we can maximize good outcomes by shaping their development and preparing our institutions and social processes (Kelly 2010).

Humanity faces daunting challenges in the twenty-first century. Many of these problems are collective action failures that result from behavior that it is individually rational but leads to outcomes that are mutually bad. Mobility is a classic example: it is individually rational to be as mobile as possible, but bad collective outcomes include congestion, resource depletion, damaged environments, and loss of community (Levinson 2005). These collective action failures will become more ruinous as urbanization and motorization trends continue, particularly in regions where population growth is also increasing (such as SE Asia and Africa).

One solution to collective action problem is cooperative behavior: replace competitive behavior with sharing, collaborating, and collective actions that have better mutual outcomes but require compromise. Since they are tightly coupled with mobility and communication, LBS can mitigate the daunting collective action failures associated with human mobility and related activities in our increasingly crowded and connected world. There are also deeper reasons to believe that LBS can facilitate cooperative behavior. As discussed below, there is evidence that time, space networks, and groups facilitate cooperation. In addition, the convergence of LBS and social media can facilitate natural tendencies for cooperative behavior over time, space, and networks by supporting group-forming activities (Shirky 2008).

Space-Adjusting Technologies

LBS are profound since they are a type of *space-adjusting technologies* (SATs). SATs are technologies that change the nature of experienced space with respect to the time, cost, and effort involved to overcome geography in mobility and communication. Consequently, SATs redistribute human activities in space and time (Abler 1975). SATs include civilization-changing technologies such as transportation (e.g., ships, railroads, automobiles, commercial aviation) and information/communication technologies (e.g., telegraph, telephone, the Internet, wireless communication).

Similar to other non-trivial technologies, SATs are dual natured: they have good and bad effects. We travel, interact with others and learn more about the world at rates that would have seemed magical to our ancestors (see Banister and Stead 2004; Bertolini and Dijst 2003; Hanson 2004; Nelson and Niles 2000; Schafer and Victor 1997). However, mobility and accessibility have environmental and human costs (Sperling and Gordon 2009). Wireless communication technologies are creating more knowledge and flexibility; they are also creating a fragmentation of activities across time and space, explaining in part the growing travel demands at all geographic scales (Couclelis 2000; Lenz and Nobis 2007). High mobility and accessibility may also increase the complexity and metabolism of cities, making them more unstable and difficult to manage (Townsend 2000). LBS can also contribute to livability and sustainability problems by enabling, demanding, and rewarding consumptive mobility behavior (Wilson, in press).

LBS and Sustainable Accessibility

As Couclelis (2000) argues, *sustainable accessibility* is a necessary precondition for sustainable transportation. LBS facilitate complex travel patterns and space-time activity fragmentation, but they do not offer (as yet) a competitive alternative to mobility for many types of activity participation. Managing mobility through location awareness and social media does not imply simply substituting virtual interaction for physical travel: these technologies can allow mobility to occur in a more efficient and sensitive manner with better collective outcomes (Sperling 2007; Sperling and Gordon 2009).

The convergence of LBS and social media can provide the tools to facilitate more cooperative mobility at all levels. Operationally, location tools already exist to support shared transportation, such as bicycle, car, and ride-sharing: this can wrest a large amount of the enormous wasted capacity in the private transportation system, as well as make it more flexible and inclusive. We can also use shared resources to solve the so-called "last mile problem" in public transportation, as well as include other modes such as jitneys and vanpools to create a quasi-public transportation system. At the tactical level, a seamlessly integrated multimodal system requires a much higher degree of coordination than today's loosely coupled transportation systems. Crowdsourcing is also a potential source of self-organization (and innovation) to solve operational mobility problems. Strategically, engagement and cooperation is essential to create engaged citizenship and an inclusive planning process for envisioning and planning the future of mobility, communities, and the planet.

Cooperative mobility requires locational information at different scales (from individual locations in real-time to communities and regions over decades) as well as platforms for sharing, coordination, and collaboration based on this information. Converged LBS and social media can meet these functional requirements, but a critical question is whether people will cooperate if given the appropriate locational information and tools.

Will People Cooperate?

For much of the past three centuries we have internalized the belief that nature is competitive and cooperation is rare and must be forced (Rifkin 2009). This can be traced back to the founders of social science such as seventeenth century English philosopher Thomas Hobbes. Competition is also at the heart of Charles Darwin's theory of evolution: this was pushed to unintended extremes by Herbert Spencer's "Social Darwinism". Adam Smith's metaphor of the Invisible Hand guiding markets also supports the view that competition is natural and beneficial (although few have heard of his other major treatise, the *Theory of Moral Sentiments*, which states how humans *should* act based on empathy; see Smith 1998).

The view that competitive is natural has been overturned over the past decade by theoretical and empirical research in the biological and social sciences. Cooperative behavior is not limited to our close primate cousins or "super-organisms" such as termite and ant colonies; rather, they are common in the biological world (De Waal 2009; Norwak and Highfield 2011; Wilson 2012).

Communication fosters cooperation: the positive relationship between communication rates and cooperative behavior is a robust finding in the literature (Kollock 1998). Robert Wright and Jeremy Rifkin note historical trends toward greater empathy and cooperation, facilitated in part by SATs. Wright argues that cooperation is a fundamental biological and social evolutionary force that transportation and communication technologies amplify (Wright 2000). Rifkin (2009) argues that transportation and communication are increasing both empathy and entropy (physical disorder) in the world. He raises the provocative question whether improving empathy will win the race with increasing entropy in time to save our global civilization.

The interactive nature of social media facilitates collaborative behavior by supporting group-forming activities. Humans have a natural proclivity to join groups, but this has been stymied by the high costs required for face-to-face interaction. Communication and coordination was so difficult historically that we endured the cost of top-down, bureaucratic organizations to achieve complex goals. Social media are changing this by collapsing the interaction costs required for group-forming. Social media also add the capabilities of *many-to-many* communication to the traditional modes of *one-to-one* (e.g., mail, email, telephony) and *one-to-many* (e.g., broadcasts, webpages). This fits more naturally with the communications required to support group activities (Shirky 2008).

Clay Shirky argues that we are at a critical juncture in modern humanity. The industrial and digital revolutions have led to an unprecedented amount of free time relative to the vast majority of our ancestors. However, for most of the past half-century we have spent this "cognitive surplus" on passive entertainment such as television. The rise of technologies that facilitate many-to-many communication and support group-forming activities can allow our collective cognitive surplus to be used for active engagement. The growing pervasiveness of mobile communications means that the cumulative effects can be dramatic (Shirky 2010).

Cooperation Across Time, Space, and Networks

Game theory, a theory of normative behavior in conflict situations, suggests conditions that foster cooperative behavior in competitive situations (Doebeli and Hauert 2005). Social scientists and biologists have extended classical game theory to wider situations involving repeated interactions over time, across space, and within networks. Critical for the potential role of LBS, it turns out that *time*, *space*, *and networks facilitate cooperative behavior*.

A well-studied conflict situation in game theory is the *prisoner*'*s* dilemma (PD) where two prisoners are captured by the police and asked to implicate the other in exchange for a lighter sentence. The implications of PD are pessimistic: the optimal solution is both defect (not cooperate) and implicate the other, meaning that both receive longer sentences than if both would have cooperated with each other and kept quiet (Rapoport 1989).

The PD has less discouraging outcomes when embedded in time, space, and networks. When played repeatedly among the same players, a successful and robust strategy is to start with cooperation, and only refuse to cooperate if your opponent refuses (Axelrod 1984, 1997). In other words, history and reputation become important with repeated interactions (Norwak and Highfield 2011; Rheingold 2002). Space and networks facilitate cooperation by limiting the possible interactions to neighborhoods and selective connections. This lowers the benefit/cost ratio necessary for cooperation to succeed. The spatial outcome is islands of cooperation within an otherwise competitive world. Selective connectivity via networks facilitates cooperation by allowing individuals to break connections with non-cooperative individuals (Flake 1998; Norwak and Highfield 2011; Schelling 1978).

Evolutionary game theorists have also examined the role of groups in facilitating cooperative behavior. Similar to the effect of neighborhoods in space and selective connectivity in networks, cooperative behavior is easier when there are many small groups as opposed to a few, large groups (Nowak 2006).

Lessons for LBS include the centrality of reputation systems in building trust and cooperative behavior. Game theory also suggests the importance of neighborhoods, selective connectivity, and groups in facilitating cooperative behavior. Although neighborhoods and groups used to be tightly coupled to geographic space, LBS can allow more fluid and context-specific neighborhoods, networks and groups to form based on coincident or shared activities in space and time. Intriguing questions surround the appropriate cooperative units in space and time to foster cooperative mobility and locational behavior in different contexts.

Types of Cooperative Behavior

Cooperative behavior has different levels of complexity and commitment (Shirky 2008). *Sharing* is easiest: it has the fewest demands on participants and therefore the group is simply an aggregate of participants. Sharing is popular in current LBS and social media: examples include sharing photographs, locations, events, traffic conditions, and reviews. *Cooperation* is harder: this involves changing your behavior to synchronize with people who are changing their behavior to synchronize with you; an example is ride-sharing. Cooperation requires better knowledge of other participants and also creates group identity. *Collaborative production* is more involved form of cooperation that increases the tension between the individual and group goals. The project requires the participation of many with no single person getting credit.

Collective action is the hardest type of group activity: this requires a group of people to commit themselves to undertake a specific effort together in a way that makes the group decisions binding on individual members. Collective action requires a shared vision strong enough the bind the group together despite decisions that displease some (Shirky 2008).

A well-known collective action problem is the *tragedy of the commons* where individuals use a common resource to ruin through consumption rates that are individually rational; as mentioned above, mobility is an example. Traditional ways of dealing with collective action problems with common resources are to privatize the common resource or agree to external governance (Shirky 2008). However, Nobel Prize winner Elinor Ostrom has shown the conditions under which common resources can be managed through self-organized means; these include clearly defined boundaries, locally derived rules, monitoring, and mechanisms for conflict resolution (Botsman and Rogers 2010; Kollock 1998; Ostrom 1990).

A challenge for LBS is to develop tools that facilitate cooperative behavior beyond sharing and simple cooperation. Solving collective action problems such as overconsumption of mobility requires more than sharing transportation resources. Making a system more efficient can induce greater resource consumption; an effect often referred as *Jevon's Paradox* after the nineteenth century English economist who discovered it. Consequently, efficiency increase must often be accompanied by constraints such as quotas and rationing (Alcott 2005). An intriguing question is whether LBS can help achieve appropriate levels of mobility based on self-organized and local methods for managing common resources and collective actions (Ostrom 1990).

Conclusion

LBS enhances individuals' capabilities to access activities and other people by making the world more efficient, discoverable, navigable, interactive, customized, sociable, and safe. However, LBS can also contribute to the problems facing a crowded and urbanized world by encouraging binge mobility. By the year 2030, the number of vehicles in the world will grow from roughly one billion to over 2.5 billion (Sperling and Gordon 2009). To survive this world, we need to think carefully—and quickly!—about the role of space-adjusting technologies in creating sustainable accessibility (Couclelis 2000).

Technological advances and the convergence of LBS and social media can provide capabilities to facilitate more cooperation and self-organization over time and space, avoiding or mitigating the bad collective outcomes from mobility. There are very good reasons to suggest that LBS can play a vital role in creating more cooperative behavior. However, there are challenges to create tools that go beyond sharing to support more complex types of cooperative behavior such as collective actions.

Harvey J. Miller
Department of Geography
University of Utah
Salt Lake City
UT 84112-9155
USA

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Part I
Spatio-Temporal Data Acquisition, Processing, and Analysis

Extraction of Location-Based Emotions from Photo Platforms

Eva Hauthal and Dirk Burghardt

Abstract The adaptation of location-based services considers mainly objective information and collections of facts. Subjective components such as emotions and opinions can provide alternative views, e.g. for supporting decision making. Therefore, research on affect analysis is carried out by capturing and analyzing location-based emotions from user generated content. The chapter presents the approach of extracting emotions from photo titles, descriptions and tags of Flickr and Panoramio pictures. The obtained emotions are documented in the valence-arousal-space as well as in emotional maps of geospace. The distribution of emotions within the valence-arousal-space represents the kinds of emotions occurring in the study area of Dresden whereas the emotional map shows the geospatial distribution. The investigation results offer further potential for an analysis regarding influencing demographic factors and their effect on spatial applications in the field of tourism.

Keywords Emotional cartography · User generated content · Mobile applications

E. Hauthal (✉) · D. Burghardt
Institute of Cartography, Technische Universität Dresden, Helmholtzstraße 10, 01069 Dresden, Germany
e-mail: eva.hauthal@tu-dresden.de

D. Burghardt
e-mail: dirk.burghardt@tu-dresden.de

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1 Introduction

Due to the web an increasing amount of user generated content is available, that contains not merely objective but subjective information as well, for instance in terms of product reviews, restaurant ratings and the like. This subjectivity can be utilized for different purposes, for example within touristic applications. Travel guides—whether as a book or as a mobile application—contain mainly factual information, such as the address of a sight, opening hours or entrance fees. If the guide is a mobile application, it is possibly adapted to the spatial situation of the user. Emotional aspects are not taken into account, although emotions and space are connected fundamentally. Locations have an atmosphere which evokes diverse and often strong emotions in people (Mody et al. 2009). Places can provide feelings of privacy, control and security; can attract by the opportunity for social events; places can be sensed as boring, attractive, calming, scary or dangerous and the loss of a place can be an emotional experience (Korpela 2002). Considering emotional aspects might be also interesting for adaptive information filtering on rating-platforms or for the location-based communication of emotions in social networks. The project Emotional Maps for Mobile Applications (EMMA) aims at establishing a basis for the integration of those emotional aspects for location-based services. Emotions can be captured as aggregated emotions, so to say as averaged emotions sensed by many people at one place, or as individual emotions. Those captured emotions shall be considered spatially (How do other people feel at the place the user is located at or nearby?) as well as regarding the emotional situation of the user (Does the user long for adventure and thrill or for a place of calm and relaxation?). This chapter focuses on an approach of extracting aggregated emotions from user generated content of the photo platforms Flickr[1] and Panoramio.[2]

2 State-of-the-Art

2.1 Volunteered Geographic Information

Based on mobility and interactivity, the today's map user captures data independently and therewith undergoes a transition from a pure data user to a producer and user united in person, i.e. to a ProdUser (Budhathoki et al. 2008). This trend is accompanied by the widespread success of social networks, online communities and rating platforms where users can exchange personal opinions and appraisals. In general these contents are called user generated content. The phenomenon that

[1] http://www.flickr.com/

[2] http://www.panoramio.com/

thousands of people are willing to invest time for sharing geographically referenced content in the web without any prospect of financial reward, is called volunteered geographic information (VGI) or volunteered geography by Goodchild (2007). The kind of VGI can strongly vary from photos that are geolocated by tags or a georeferencing (like for instance in the portal Flickr) up to completely user generated world maps such as OpenStreetMap[3] based on the approach of CrowdSourcing.

According to Budhathoki (2010) local knowledge is the most significant determinant for suchlike contributions. If users become aware of their possession of knowledge in consideration of faulty and incomplete mapping of a region that is interesting for them, they are encouraged to map because obviously they are able to do a job more attentive to detail and more up to date than nonlocal agencies or mapping organizations.

The data provided by those agencies and organizations are formalized, accurate and allow to describe geospace in a consistent manner. If a subjective view is requested or the way a place is sensed, these data are unsuitable. VGI provides an opportunity to access notions of locations because the content of VGI contains bias of users as individuals (Purves et al. 2011). For instance according to Rorissa (2010) Flickr tags are much richer in semantic content than index terms assigned by professionals.

2.2 Tagging

Tagging is a term for assigning keywords to content in the web with the purpose of linking, categorising and describing that content. The relation of tags to each other is not structured hierarchically but serves for grouping elements. Tags are filed as metadata and are helpful for making searched elements detectable for the user (Sjurts 2011).

Sen et al. (2006) define three general classes of tags based on the seven detailed classes of Golder and Huberman (2006). The general classes reflect the intent of use of the particular tags. These classes are summarized in Table 1. However, Sigurbjörnsson and van Zwol (2008) assigned tags to six categories: location, artefacts or objects, people or groups, actions or events, time and other.

More specific is a categorization of tags by Beaudoin (2007) particularly for Flickr-images. Beaudoin distinguishes 18 categories of tags (see Table 2). The five most used categories are place name (28.21 %), compound (14.05 %), thing (11.37 %), person (8.81 %) and event (5.69 %).

A particular kind of tags are geotags, i.e., geospatial metadata that belong to the dimension spatial tags as named in Table 2. Geotags add geographical identification data to media and usually contain latitude and longitude coordinates though

[3] http://www.openstreetmap.org/

Table 1 Tag classes

General tag classes (Sen et al. 2006)	Detailed tag classes (Golder and Huberman 2006)	Short description (Sen et al. 2006)
Factual tags	Item topics	• Indentify 'facts' about an item
	Kinds of item	• Help to describe an item and to find related ones
	Category refinement	
Subjective tags	Item qualities	• Express user opinions related to an item
Personal tags	Item ownership	• Have an intended audience of the tag applier themselves
	Self-reference	
	Task organization	• Most often used to organize a user's collection

Table 2 Category model for image tags found in Flickr (Beaudoin 2007)

Category	Definition	Examples
Adjectives	All adjectives	Cold, wet, bright
Compound	Terms with two or more words combined	Newyorkcity, My dog
Emotion	Identification of emotional state	Happy, depressed
Event	Pertaining to holidays, happenings or news occurrences	Wedding, Easter, assassination
Humour	Terms used for humorous reasons	I think bobby is great
Language	Terms in any language beyond English	Eau, gefühle, madrina
Living thing	Living, non-human creatures and plants	Bird, rose, tree, dog
Number	Terms composed of numbers	64,325, 1 + 111, 2,000
Person	Named (common and proper) individuals and groups	Baby, Elvis Costello, Girl Scouts, woman
Photographic	Terms relating to imaging/photographic devices and/or processes	Canon, SLR, I100
Place-general	Places identified with their common names	Beach, field, bedroom
Place-name	Places identified with their proper names	Amsterdam, Seoul
Poetic	Terms that are poetic in nature	Heavenly mirage, daydream
Rating	Terms which evaluate images	Topten, tag1, taggedout
Thing	Non-living objects	House, car, rock, water
Time	Terms with chronological meaning	June, 2006, night
Unknown	Unidentifiable terms	Sha78, Pp73
Verb	All verbs	Running, look, crying

altitude, accuracy data and place names as well. With the help of geotags, users can find location-based news, websites or images taken close to a certain location. Another less common term for geotagging is geocoding which more often refers to non-coordinate based geospatial identifiers like street addresses (Miller et al. 2009). Geotagged media such as travelogues or photos can be used for extracting tourism related knowledge, e.g., for analyzing travel patterns (Girardin et al.

2008), for detecting cultural differences of certain local regions (Zheng et al. 2011) or for the automatic generation of travel routes (Choudhury et al. 2010).

While most of the tags are subject related, some tags (such as 'cool' or 'fun') are indicating a user's emotional reaction to an object represented by the particular document, i.e., these are affective tags and consist of words describing an emotional state. The use of those affective tags shows that users may regard tagging and classification as a holistic process (Kipp 2007).

2.3 Emotions

The often cited statement of Fehr and Russell (1984) "Everyone knows what an emotion is, until asked to give a definition" represents appropriately the comprehensive result of literature research for finding such a definition. The enormous number of definitions might be an indication for the fact that the occurrence of emotions is not resolved completely even scientific emotion research is older than 100 years. Most of the definitions have in common that emotions are a subjective occurrence, i.e., an inner excitement that is more or less consciously experienced as pleasant or unpleasant and comes along with neurophysiologic processes (Kroeber-Riel et al. 2009). Another important aspect of emotions is a high ego-involvement of the individual (Jahr 2000). A consensus is reached that there are basic emotions which refer to inherent emotions like surprise, anger or joy, as well as emotion schemas which describe emotions that differ across cultures and individuals and appear only in interaction with other individuals like for instance shame, guilt feelings or pride (Izard 2009).

Related terms of emotion are sentiment, affect and feeling which are often used as synonyms but rather should be distinguished. Sentiments are enduring, less intense diffuse emotions (Jahr 2000) that are not related to certain issues and can influence cognitive processes like perception, information processing and memory. The term feeling means the experience-related aspect of an emotion, that is to say the interpretation of the conscious and subjective perceiving of an emotion (Kroeber-Riel et al. 2009). Affect in Anglo-American language is a hypernym for mental processes, emotions, sentiments and also for attitudes. More seldom affect means merely the valence of experiences in the sense of pleasure and displeasure or positive and negative (Mau 2009). Whereas in German affects are essential, transient and intense feelings of acceptance or rejection, i.e., an emotion that is cognitively barely controlled and hardly differed regarding content (Trimmel 2003; Mau 2009).

Due to the possibility that all these terms impact closely on each other, a clear demarcation is not feasible in every case. The occurrence of a certain feeling can be accompanied by sentiments and sensations (Jahr 2000).

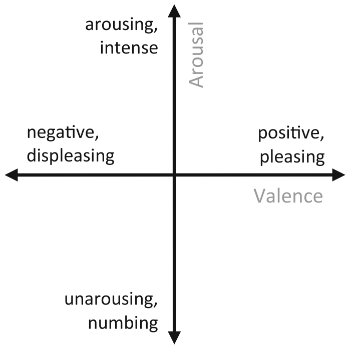

Fig. 1 The two emotional dimensions valence and arousal

2.4 Structuring Emotions

The definition of emotions allows a distinction between emotional and non-emotional states as well as structuring those emotional states. Approaches for structuring emotions can be distinguished into dimensional and differential (Schimmack 1999). Dimensional approaches try to reduce affective states to a few dimensions. Thus, each emotion can be described as a combination of different severities of those dimensions. Latest research manifests two approaches that show up as two- or three-dimensional models. In almost every case, one dimension describes the valence of emotions. However, there is disagreement on the nature of arousal which is regarded as one- or two-dimensional. While Russell (1980) considers one dimension of arousal in combination with the valence-dimension as sufficient for the description of emotions, other researchers feel confirmed in their assumption of two arousal-dimensions beside one valence-dimension by empirical results (Mau 2009). The two dimensions valence and arousal proposed by Russell (1980) can be described as ranging from positive/pleasing to negative/displeasing and from arousing/intense to unarousing/numbing (see Fig. 1).

In difference to dimensional approaches which try to ascribe emotions to a few global dimensions, differential approaches emphasize the distinguishable subjectively experienced qualities of emotions (Izard 1977). Emotions are structured according to complex similarities. This similarity can be defined by the spectrum of emotional qualities in fundamental emotions or by statistical methods based on subjective appraisal (Mau 2009).

EMMA works with the two-dimensional approach of Russell (1980) because of the advantages of dimensional emotional models (Mau 2009):

- The reduction of emotional experiences to a few dimensions simplifies the measurement and quantification of emotions. Not every possible emotional quality needs to be captured but merely the estimation of experience in two or three dimensions.
- In most cases the emotional states gathered this way are described by two or three metrically scaled variables. This simplifies the analysis.

- Due to the reference of emotional states to a few dimensions, the interpretation of results is simplified.

Dimensional approaches claim to describe completely the space of possible emotional qualities (Russell and Mehrabian 1977) but rise to doubts give results indicating that emotions which are experienced as qualitatively very different, have similar values in the dimensions of valence and arousal (Mau 2009).

2.5 Acquisition of Emotions

The overall emotional reaction has the following components (Battacchi et al. 1996, quoted by Jahr 2000):

- physiological reactions (cardiovascular,[4] respiratory,[5] electrodermal[6]),
- tonic posture reactions (tension and relaxation of body),
- instrumental motoric reactions (e.g., running away because of fear)
- expressive motoric reactions (gestures, countenance, paralinguistic events),
- expressive linguistic reactions (syntactic and lexical selection, stylistic varieties),
- subjective experience components (emotions as such, referencing to the feeling that everybody experiences during having emotions).

These reactions can be exploited for gathering emotions with verbal or non-verbal procedures. Requesting emotions is a verbal procedure but has the disadvantage that verbal statements on emotions are often difficult to access, not detailed enough, are not made perception-simultaneously with the reception (Egner and Agüeras-Netz 2008) and might be manipulated or filtered by the proband (Kroeber-Riel et al. 2009). Non-verbal procedures can be distinguished into physiological measurements, explicit emotion measurements (Egner and Agüeras-Netz 2008) and behavioural observations like the analysis of facial expression (Westerink et al. 2008). For explicit emotion measurements, emotional states are classified on a scale with the help of a slider but this procedure requires a certain amount of training by the proband. Physiological measurements interconnect a scalar value of emotion to a measureable physiological value, e.g., to electrodermal activity (Egner and Agüeras-Netz 2008). The advantage of physiological measurements is that the user does not have to recognize and interpret his emotions. However, interpreting a meaning from those data is ordinarily difficult, though the complex meaning extraction of behavioural observations and physiological measurements is counterbalanced by the real-time pureness of emotions (Westerink et al. 2008).

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[4] Relating to the circulatory system, that is the heart and blood vessels.

[5] Relating to respiration/breathing.

[6] Of or pertaining to the electrical properties of skin.

2.6 Environmental Influence on Emotion and Behaviour

In a certain way, emotional states and places can be seen as external and internal versions of one another (Gallagher 2007). The principle is simple: a good/bad environment evokes a good/bad mood triggered by good/bad memories leading to good/bad behaviour. Usually those environmental stimuli are not even sensed consciously. Especially the just mentioned memories play an important role. A dramatic example is drug addiction. The body is longing for the drug particularly in the environment where it is used to get the drug or in an environment with cues of the used one, i.e., it can be also referred to an environmental addiction. Thus, a successful drug withdrawal should involve a systematic exposure to drug-related environmental cues. Another phenomenon is that occasionally addicts take the usual fix in a strange environment and die as if they had an overdose (Siegel et al. 1982). In an experiment, photos of jungle warfare or war movies like 'Platoon' were shown to combat veterans of Vietnam War. By looking at those pictures, their memory recalled the high arousal they experienced in this exotic milieu and stimulates the nervous systems to produce surges of opiates which are meant to soothe temporal stress (van der Kolk et al. 1996).

Csikszentmihalyi (1990) gathered about 25,000 experience reports in 25 years by prompting persons eight times a day by beeper to write down where they are, what they are doing and how they are feeling (Csikszentmihalyi 1990, quoted by Gallagher 2007). This way Csikszentmihalyi (1990) found out that most of his subjects felt happiest in parks, cafés and other sociable and carefree places as well as for some reason they liked to be in a car. Furthermore, he detected that the two genders favour different places at home: men prefer the basement whereas women consider the bathroom to be the best but both of them like the bedroom as well. A similar study was carried out by MacKerron and Mourato (2011) for the UK. With the help of a smartphone app named Mappiness[7] they asked their participants several times a day how happy they are, whom they are with, where they are and what they are doing. The app determined the precise location of the participants via GPS at the moment of answering these questions. Furthermore weather data have been used for analyzing the results. MacKerron and Mourato (2011) found out that their participants are less happy at work than at home and outdoors they are most happy while doing activities typical for natural environments like gardening or running. Coastal locations are the ones rated with most happiness. Participants were particularly happy outdoors with good weather, i.e., with sunshine, without rain and fog, with high temperature and low wind (MacKerron and Mourato 2011).

It is commonly known that nature restores humans. Kaplan and Kaplan (1989) analyzed this statement by monitoring the responses of people in an 'outdoor challenging program' and found that nature indeed eases so called mental fatigue, a condition of inner weariness. The most notable reasons for this recovery is

[7] http://www.mappiness.org.uk/

detected by the Kaplans as a sense of self-discovery in nature, desire to make nature a part of future life and enthusiasm for the experience (Gallagher 2007).

Less natural is the process of urbanization which will be the most important environmental influence in the tweenty first century according to social scientists. Urban places send many stimuli changing quickly and continuously that are often very intense while in nature the majority of stimuli change gradually and periodically as well as there are not many people (Gallagher 2007). A mostly permanent stimulus of urban space is noise. Noise facilitates the outburst of aggression and if the noise comes from an uncontrollable source, physiological arousal as well as aggression increases (Bronzaft 2002; Veitch and Arkkelin 1995). Another characteristic of urban areas is a high population density and crowding. Studies have indicated that urbanites are less willing to help strangers than people in rural regions—which do not mean that they are less helpful or friendly because paying less attention to other people might be a strategy for coping with excessive stimulation. Furthermore, conditions of high social density reduce interpersonal attraction (i.e., liking another person) and increase social withdrawal. For instance students are less sociable, talkative and group oriented when they are housed in a socially dense dormitory (Veitch and Arkkelin 1995). Perhaps this phenomenon should be reduced to forced social density because a dense party with friends does usually not evoke social withdrawal.

Extreme environments evoke extreme emotions. High mountain ranges are an extreme environment as well as polar or very hot regions or even artificial environments of space flight, flying or diving. The easiest und probably most useful method for reducing aversive arousal and stress caused by such extreme environments is humour. In the transcription of astronaut communication and in some Arctic groups, a lot of humour and wit occurred. Another method is the so-called paratelic dominance which means to regard an aroused state not as fear but as excitement leading to a more certain coping behaviour (Suedfeld 1991). Positive affective states in extreme and unusual environments are courage, self-sacrifice and altruism with well-known examples: people giving scarce food to others or health professionals giving up rest or the chance to escape for helping patients (Gallagher 2007). The most salient negative affective state in extreme environments is fear. Other ones are aggression (direct or indirect) often occurring within isolated groups, and boredom after an adaptation to the extremeness leading to hypersensitiveness concerning the characteristics of coworkers and in turn to hostility (Suedfeld 1991).

Behaviour or culture may not be predefined by climate but can be affected by certain limitations set up by it (Gallagher 2007). Research shows that aggression (thus violence as well) increases by temperature and in turn decreases in blazing heat (Bell and Fusco 1986; Veitch and Arkkelin 1995). Domestic violence is significantly higher during heat waves (Bell and Fusco 1986); suicide peaks in May and June (Gallagher 2007) and in 1967 temperature rose 1–3 days before the onset of urban riots in USA and outdoor temperature was at least 27 °C (Bell and Fusco 1986; Bell and Greene 1984). Of course negative behaviour is not solely a function of ambient temperature but also of other variables such as situational factors and individual differences in heat-tolerance (Bell and Fusco 1986) as well as clothing, acclimatization, humidity or air speed (Bell and Greene 1984). For instance judges in the Near East judge impulsive crimes less strictly that were committed when the dry and hot Khamsin is blowing. Strong wind gives exposed people a feeling of loss of control and causes an increasing degree of arousal (Veitch and Arkkelin 1995).

2.7 Expression of Emotions in Language

Besides physical reaction such as facial expressions, emotions are reflected in language. Non-verbal cues like the former ones can indicate which general emotion a person is experiencing but this way typically no precise information about the specific form of an emotion is imparted. However, language makes it possible to express the richness of emotions (Valitutti et al. 2004).

For the expression of emotions in language it is useful to distinguish between the ‘production’ of expression and the ‘occurring’ expression (involuntary expression). Usually an emotional expression—as far as it occurs—is based on a communicative purpose. An emotion modifies behaviour and is expressed without remarkable purpose at all or without communicative purpose (Fiehler 1990).

There are two ways of emotional expression: primary and secondary ones, i.e., different kinds or levels of socially normalized expression. Primary and secondary expression differ from each other regarding the situations they occur in, their frequency of usage and regarding their level of conventionalization. Primary kinds of expression are common, frequently used and form the normal repertoire for expressing an emotion. If in a certain situation with appropriate social rules a primary expression is undue, a secondary expression can replace it. Secondary expressions occur especially in all forms of institutional communications. For this kind of communication, the dictate of emotional neutrality is valid which hampers the primary expression of emotions or makes it impossible. A secondary expression evolves into a primary one if the primary expression is permanently undue in certain situations because of social rules (e.g., politeness) (Fiehler 1990). For instance instead of uttering disappointed “He failed completely.” the secondary expression “He made reasonable efforts.” might be used. Nevertheless according to Dittmann (1972, quoted by Fiehler 1990) “most emotional messages are probably sent without controls, or without very little effort to control”.

In the linguistic field of language-and-emotion-research, two spheres can be distinguished: pragmatic-communicative approaches that examine empirically emotions as speech attending and influencing phenomena as well as semantic-lexically approaches that examine and describe the potential of expressive media in one or several languages. The latter investigate the emotional vocabulary of a language that is available to a linguistic community in a mental lexicon for naming emotional categories (Schwarz-Friesel 2007). Hence each culture has its own vocabulary, syntactic forms, semantics and range of pragmatic effects. Although

Table 3 Formal-grammatical means of expressions for emotions (Fiehler 1990; Fries 1996; Schwarz-Friesel 2007)

Formal-grammatical means of expression	Example
Word choice: emotion-induced choice between alternatives	Racketeer instead of renting agent
Interjections, mostly for non-intentional states like pain, cold- or warmth-sensation	Oh, yuck, ouch
Exclamations	Oh my god! What a stupid man he is!
Idiomatic appraisals	Are you crazy?
Insults	Moron
Praises and acknowledgements	You're a dear
Curses, reproaches, threats, warnings, disciplining, plaints	You will get a punch on your nose
Expressive verbs	Wish, hope, crave, yearn
Modal particles	Even, but
Affective adjectives	Marvellous, awkward
Optative sentences	I wish I could…
Combination of emotion-expressing and emotion-denoting verbs	Slimy, creepy, hate
Dimension adjectives/particles or combination of modal particles and emotive adjectives	Great anger, extremely afraid, It was a very wild party
Morphemes/prefix formations as intensification of emotional expressions	Shit work, super awesome
Intensifying genitive constructions	The book of books
Idioms	Nuts to you
Diminutive and augmentive formations	Bitsy, teensy-weensy
Repetition	A long time ago, over and over again

emotions are regarded as transcultural, their characteristic and the manner they occur are too different, so that culture and language has an influence on the categorization of emotions (Jahr 2000).

Emotional aspects of linguistic meanings of utterance, that are coded by formal-grammatical factors, are not related to discrete emotions termed by lexemes like hate, envy, anger, disgust, fear, mirth, affection, appreciation, joy, love, curiosity etc. but especially to the affective appraisal of objects or issues (Fries 1996).

Table 3 summarizes formal-grammatical means of expression for emotional meanings.

Phonetic means of expression for emotional meaning are disregarded in this paper for the reason that EMMA only concerns written language.

2.8 *Sentiment and Affect Analysis*

Research areas studying the relationship between language and emotional information and dealing with their computational processing are sentiment analysis and

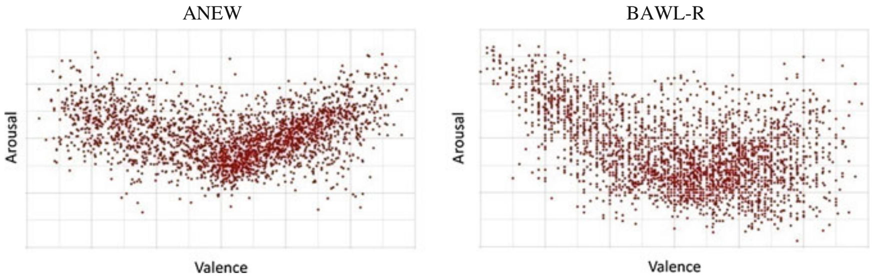

Fig. 2 Distribution of ANEW and BAWL-R words in valence-arousal-space

affect analysis. Those approaches focus on text which is an important medium for extracting emotions because the majority of computer user interfaces are based on text (Valitutti et al. 2004).

Sentiment analysis originates from text mining and computer linguistics and deals less with the content analysis of a document but rather with the overall polarity of opinions and sentiments in it, usually in the sense of positive, negative and neutral sentiments (Zafarani et al. 2010). Sentiment analysis is also called opinion mining, sentiment extraction or sentiment detection. However, affect analysis considers a significantly larger number of potential emotions, such as joy, sadness, hate, excitement, fear etc. (Abbasi et al. 2008).

Sentiment and affect analysis require linguistic resources containing emotional knowledge (Valitutti et al. 2004). Possible resources are Affective Norms for English Words (ANEW; Bradley and Lang 2010), Berlin Affective Word List Reloaded (BAWL–R; Võ et al. 2009), List of Emotional Words (LEW; Francisco and Hervás 2007) or SentiWordNet (Esuli et al. 2010). ANEW is a list containing 2,476 English words with values for the three dimensions valence, arousal and dominance. Each dimension ranges from 1 to 9 (Bradley and Lang 2010). BAWL-R with 2,901 German words covers the dimensions valence (−3…+3), arousal (1… 5), and imageability (1… 7) and contains furthermore a set of psycholinguistic factors known to influence word perception. Visualizing the values of all words of ANEW and BAWL-R in a diagram reveals a boomerang-shaped distribution (see Fig. 2) which has been reported for many languages (Võ et al. 2009).

Some of the influences of emotions on language summarized in Table 3 can be found in the just mentioned word lists (examples: see Table 4). Expressive verbs are rated with much more arousal in ANEW than inexpressive and more formal verbs. Insults and nick names are rated as similarly arousing but differ clearly in valence. Affective adjectives have more distinct values than condition or shape adjectives. Not all linguistic phenomena of Table 3 are demonstrable in ANEW or BAWL-R because those lists contain only nouns, verbs and adjectives as basic forms.

‘Beautiful picture of an ugly place’ is a project applying sentiment analysis to Flickr-photo-comments for extracting emotions related to the photo quality and emotions related to the place where the photo was taken, both on a

Table 4 Valence- and arousal-values for selected words from ANEW

Expressive verbs			Vs.	Inexpressive/formal verbs		
Example	Valence	Arousal		Example	Valence	Arousal
Wish	1.57	3.08		Sleep	1.65	1.9
Hope	1.54	3.22		Impart	−0.02	2.43
Crave	−0.09	3.57		Behave	0.375	2.465
Love	2.79	3.72		Dwell	−0.09	2.5
Insults			Vs.	Nick names		
Example	Valence	Arousal		Example	Valence	Arousal
Moron	−0.92	3.35		Sweetheart	2.57	3.25
Affective adjectives			Vs.	Condition or shape adjectives		
Example	Valence	Arousal		Example	Valence	Arousal
Awful	−1.76	3.36		Simple	1.13	2.37
Terrific	2.37	3.61		Plain	−0.46	2.26

positive–negative-scale (Kisilevich et al. 2010). Four places in Poland (Krakow, Warsaw, Wisla and Auschwitz) and one in Germany (Dachau) were chosen for testing purposes. Using linguistic features, an own lexicon of adjectives with opinion strength has been built. The two concentration camp memorials Auschwitz and Dachau have a more negative general sentiment in contrast to the popular touristic cities Warsaw and Krakow with high positive sentiments. The neutral place Wisla lies in between these extremes.

2.9 Existing Projects Combining Cartography and Emotions

The first time emotions were gathered related to space in 2004 in the context of the project Bio Mapping (Nold 2009) with the help of a device using of GPS as well as a biometric sensor for measuring electrodermal activity. The project cooperated with artists, psychogeographers, designers, cultural scientists, futurologists and neuroscientists for investigating political, social and cultural implications of visualization of body data and emotions.

The project EmoMap (Ortag and Huang 2011) addresses emotions in combination with user generated content. EmoMap is based on the assumption that every person perceives urban space in a different way. Some places are perceived as beautiful, other places as unsafe. This perception is subjective and influenced by emotions of the particular person. The idea of EmoMap is to collect emotional spatial data in a CrowdSourcing approach and to make these data publicly available in the form of an online database (Gartner and Ortag 2011). The resulting data can be used for different purposes such as urban development and planning. Abdalla and Weiser (2011) believe that future urban planning should be oriented towards the computer game Sim City which contains a so called aura-layer with emotional information. However, EmoMap focuses on the visualization of emotional data and their utility for improving pedestrian navigation systems, i.e., EmoMap aims at adding a subjective layer for providing more satisfying navigation services. The data will be collected in situ in the study area of Vienna with the help of a mobile application asking people for their feelings regarding pleasantness/unpleasantness, stress-relaxation/excitement-boredom and environmental qualities (traffic, noise, smell, attractiveness etc.) (Klettner et al. 2012).

Another project is WiMo (Mody et al. 2009) working with a mobile application as well based on a prototypical two-dimensional emotion matrix for location-based emotion tagging. One dimension contains values from ‘comfortable’ to ‘uncomfortable’; the other one ranges from ‘Like it’ to ‘Don’t like it’. The matrix is build upon the finding that those two variables are used commonly and intuitively but are not urgently correlating.

The web applications Emography[8] and Twittermood[9] extract emotional information from georeferenced Twitter[10]-messages and visualize them in coarse resolution. Twittermood distinguishes merely over- and below-average moods in the USA whereas Emography focuses on Ekman’s six basic feelings (happiness, sadness, fear, anger, disgust and surprise) all over the world.

The project EmBaGIS develops an innovative urban planning tool for identifying and removing spatial barriers for handicapped people (Bergner et al. 2011). Emotionally significant barriers are identified working with the ‘Empirical Three-Level-Analysis’. On the first level, velocity is measured based on the hypothesis that increasing kinetic energy indicates the impact of a spatial barrier. The second level represents EDA indicating attention and on the third level, changes of skin temperature are used as an indicator for stress.

3 Approach for an Emotional Analysis of Photo Metadata

The aim of EMMA is to develop a touristic application that considers emotions connected with touristic travel motivations and expectations. This application is supposed to contain emotional maps suggesting places that are sensed as pleasant, adventurous, relaxing etc. considering age and gender. Those suggested places can be laminar as well as point-related places (e. g., for ‘relaxing’: park vs. thermal bath). EMMA focuses on Dresden as a study region.

In the approach for gathering location-based emotional data that serve as base data, affect analysis is applied to metadata of user generated pictures of the photo platforms Flickr and Panoramio. Based on the assumption, that users tag and describe their photos differently when they liked a place than when they felt

8 http://vmguld.se/emography/

9 http://www.twittermood.org/

10 http://twitter.com/

uncomfortable there, certain metadata of pictures are analyzed with the help of ANEW and BAWL-R. The metadata of those photos have been downloaded with the help of the particular API and stored in a database. The most important metadata are:

- title
- description (only Flickr)
- tags
- geographical latitude and longitude.

Title, description and tags are analyzed the following way (see Fig. 3): As an initial step, all non-characters as well as hyperlinks and the like are removed from title, description and tags of each photo. The Language Detection Library[11] is used to detect whether the language of title and description of a photo is English or German. Afterwards those two items are analyzed if they contain special cases, i.e., words indicating an intensification (e.g., 'very'), alleviation (e.g., 'not really') or negation (e.g., 'not') of the affected word. With the help of Java WordNet Library (JWNL[12]) for English words and Tree Tagger for Java (tt4j[13]) for German words, the affected words are lemmatized, i.e., nouns are reduced from plural to singular, verbs are reduced to infinitive and all declinations and comparisons of adjectives are eliminated. After that, the obtained basic form of the word is looked up in ANEW or BAWL-R respectively. If the word is contained in the list, the appropriate valence and arousal values are altered according to the particular influencing language phenomenon; if not, a synonym for adjectives and adverbs or the most frequently used hypernym of verbs and nouns for the word is retrieved with JWNL for English vocabulary or respectively the most frequently used hypernym with the GermaNet Java API[14] for German terms. Subsequently the determined synonym/hypernym is looked up again. If it is not contained in the respective list, it is skipped. After detecting these special cases, all remaining words of title and description are treated the same way but without altering the valence and arousal values of ANEW and BAWL-R. The same procedure is applied to the tags of a photo but without analyzing the tags for the above mentioned special cases because now it is dealt with keywords, not with sentences, as well as without deriving hypernyms/synonyms and without language detection for the reason that most taggers use to tag in several languages. So each tag is looked up in both ANEW and BAWL-R. The formal-grammatical mean of word repetition is regarded in so far as words appearing multiple times are not reduced to one occurrence. As a last step, all obtained values of valence and arousal are averaged for each photo and stored in a database together with its photo-ID, its URL and the geographical coordinates.

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11 http://code.google.com/p/language-detection/.

12 http://sourceforge.net/projects/jwordnet/.

13 http://code.google.com/p/tt4j/.

14 http://www.sfs.uni-tuebingen.de/lsd/tools.shtml

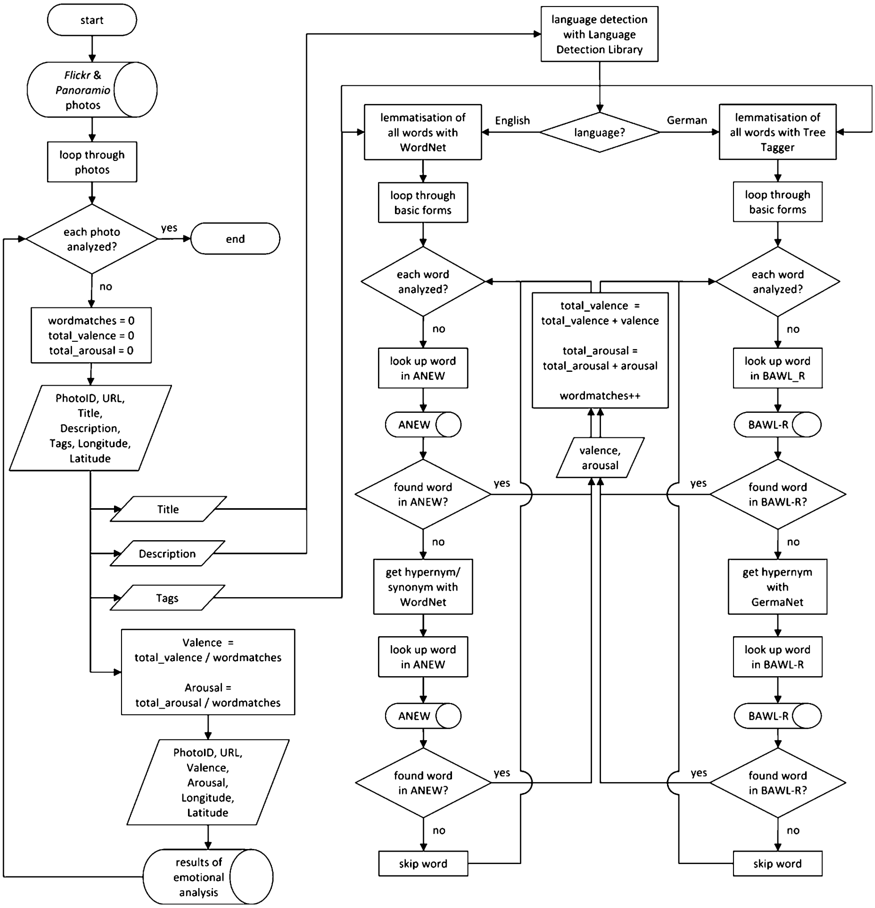

Fig. 3 Simplified flowchart of emotional analysis process

The emotional analysis is depicted schematically in Fig. 3 but in a simplified way because the process of detecting the described special cases is not addressed specifically. The analysis of those special words differs merely in altering the valence and arousal values read from ANEW or BAWL-R, otherwise the procedure is the same.

EMMA works with a valence-arousal-space ranging from 1 to 5 for arousal and from −3 to +3 for valence. Those ranges are the same as the ones of BAWL-R and were chosen for the reasons that valence represents a kind of positive–negative-feeling which can be expressed best with a bipolar scale and that arousal has a certain intensity which cannot be negative.

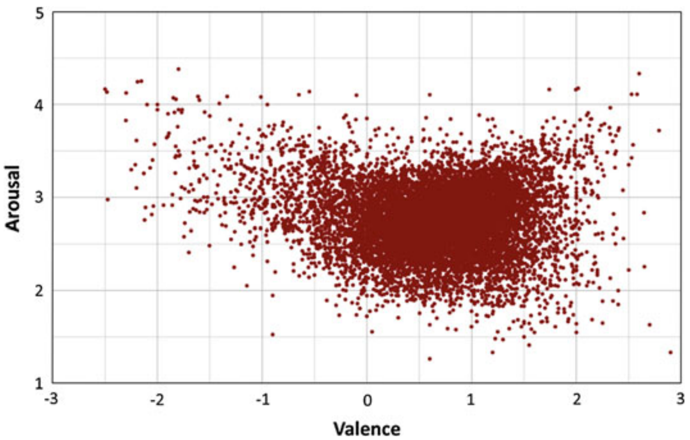

Fig. 4 Distribution of analyzed photos in valence-arousal-space

4 Results

The method described above has been applied to 45,172 photos of Dresden region (32,609 Flickr photos and 12,563 Panoramio photos). 28,983 photos (64 %) of this total amount have been suitable for the emotional analysis because their metadata include words or have hypernyms/synonyms that are contained in ANEW or BAWL-R. Averagely 4.3 words per photo could have been used for the analysis. Figure 4 shows the distribution of the analyzed photos in valence-arousal-space. The average value for valence is 0.69, for arousal it is 2.74.

Figure 5 shows a visualization of an excerpt of these results in the form of a map with colour-coded valence- and arousal-values. The map contains the borders of Dresden's districts. Arousal is coded with a brightness gradient, valence is visualized with the traffic lights principle (red-yellow-green). The structure of the gradients within the map reflects the density of photos: in dense areas the structure has a high degree of detail and precision whereas in areas of low density, the structure is rather coarse. One dense area is especially the historic city of Dresden (Innere Altstadt) where the majority of touristic attractions can be found. Exemplary photos of the hereafter outlined phenomena are placed left to the map.

The analysis provides expected results as well as unexpected ones. The places marked in Fig. 5 with 1, 2, 3, 4 and 8 are some of those expected results. 1 and 2 are places with comparatively high arousal and positive valence due to the words used for the particular photo title, description and tags. For Dresden Airport (1) those words are primarily airport (valence: 0.68, arousal: 3.49), airplane (valence: 1.07, arousal: 3.89) and sky (valence: 1.78, arousal: 2.64). Those emotional values are caused by the positive excitement connected with flying. Photos of Dresden Zoo (2) are tagged with words like reptile (valence: −0.17, arousal: 3.09), crocodile (valence: 0, arousal: 3.52), lion (valence: 0.43, arousal: 3.6) or giraffe (valence: 1.23, arousal: 3.0) which reveal Dresden Zoo to be an exciting place.

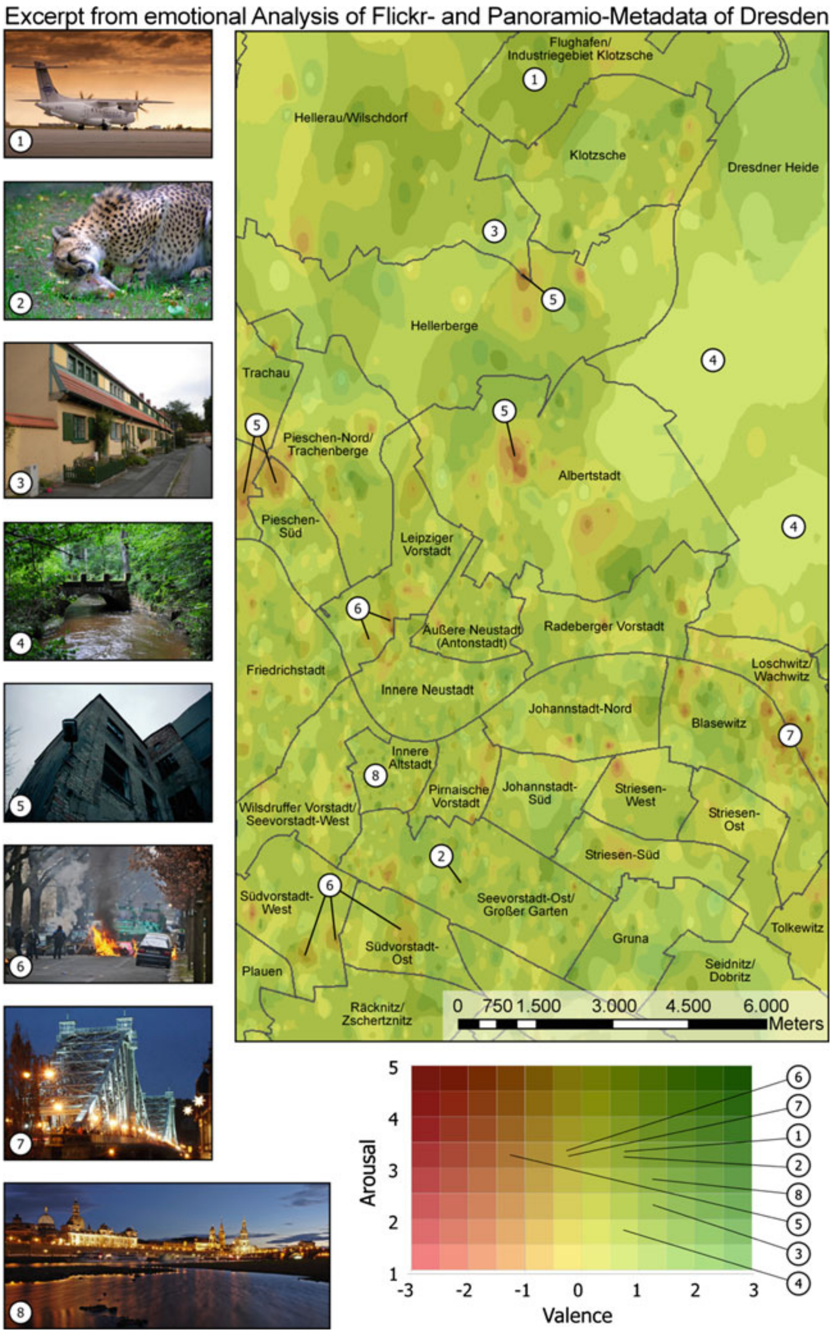

Fig. 5 Colour-coded representation of valence- and arousal-values in Dresden (Photos 1, 2, 4, 5, 6: Flickr; Photos 3, 7, 8: Panoramio; district borders: OpenStreetMap)

However, a contrary place regarding arousal is the Dresdner Heide (4), a large city forest of more than 6,000 ha in the north eastern part of Dresden. According to our analysis the Dresdner Heide is sensed as unarousing in combination with a positive valence, i.e., it is a calming and peaceful place. This result is conditioned by nature-related tags like nature (valence: 1.99, arousal: 2.69) or sun (valence: 1.91, arousal: 3.02) and by the German word Heide (valence: 1.0, arousal: 1.61) itself which is contained in the name of this forest (English: heath). Places with mid-arousal values and high valence are the district Dresden-Hellerau (3) and parts of the historic city of Dresden (8). Hellerau was founded in 1909 as the first garden city of Germany. The tags of the particular photos illustrate significant characteristics of this district: tree (valence: 0.99, arousal: 2.21) and house (valence: 1.69, arousal: 2.78) for instance. Emotional hotspots within the historic city are the Church of Our Lady, Dresden Castle and the square Theaterplatz which is surrounded by the baroque building Zwinger and the opera house Semperoper. The emotional values of these hotspots are caused by an abundance of tags and words that cannot be named at this point.

An unexpected and interesting but logic phenomenon is the detection of several ruins. The following four ruins are the most apparent ones in Dresden (5): the Sachsenbad (a former natatorium) in Dresden-Pieschen, an old tram station in Dresden-Mickten, the past ruin of Waldschänke in Dresden-Hellerau (a former restaurant) and the old granary of the former army bakery in Dresden-Albertstadt. Those ruins are tagged with decay (valence: −1.74, arousal: 2.72), ruins (valence: −0.12, arousal: 3.24) and similar German terms which result in unpleasant but arousing hotspots.

For the reason that the pure numerical values of the valence-arousal-space are hardly descriptive, an assignment of emotions to classes that each covers a field of 0.5×0.5 in valence-arousal-space has been carried out for making this space more approachable. The assignment is depicted in Fig. 6 and has been undertaken with the help of the Ontology of Emotional Categories (Francisco et al. 2010), a taxonomy that covers from basic emotions to the most specific emotional categories. As a first step, all basic emotions of this ontology (affection, anger, bravery, disgust, fear, happiness, neutral, sadness, surprise) has been looked up in ANEW and allocated to the appropriate area in valence-arousal-space (instead of neutral, the values of the synonym indifferent have been applied). After that all subordinated emotions of the ontology contained in ANEW were assigned. Remaining empty fields has been filled with words of the particular range out of ANEW that are an emotional state or are very closely connected with one. As a last step, still unfilled fields were assigned to emotional German words from BAWL-R and translated into English. Some fields are still not filled due to the fact that neither ANEW nor BAWL-R cover the entire valence-arousal-space.

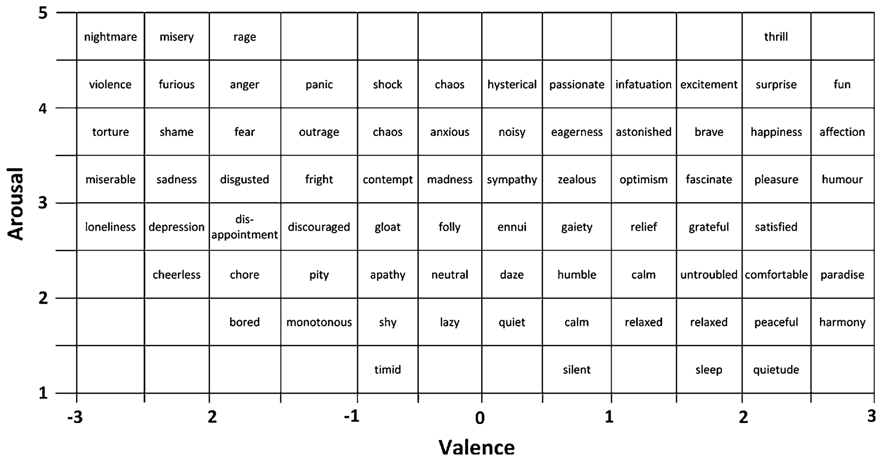

Fig. 6 Assignment of emotions to certain valence-arousal-ranges

5 Discussion and Evaluation

One further, not yet mentioned hotspot in Fig. 5 within the historic city of Dresden is the square Altmarkt, where the Striezelmarkt, Germany's oldest Christmas market, takes place every year. This case reveals that for further processing of the emotional data, temporal aspects need to be considered as well. Another example for this phenomenon are the places that are marked with (6) in Fig. 5. When visiting these places, surely nothing arousing will be found but those emotional hotspots have a strong reason. Cases like this can be referred to Clark (2011), an American journalist focusing on location-aware technologies and their power as storytelling tools, who says "Every place has a story, and every story has a place". Clark (2011) understands landscape as a structure formed over time by layers of stories like geological strata. The stories detected with the emotional analysis of EMMA have taken place the 13th and 19th of February in 2010 and 2011. On that date but in 1945, the bombing of Dresden in the Second World War was performed. Each year a remembrance of the happenings on 13th of February 1945 takes place, but since the last 15 years more and more right-wing extremists use this event for own propaganda purposes. Out of this grew counterdemonstrations. Both demonstrations also established for the 19th of February. In the last years there were arguments and riots on both sides. Those annually events are documented by tags like Polizei (English: police, valence: −0.2, arousal: 3.17) or Nazi (valence: −2.9, arousal: 4.67) and effect such a negative and arousing emotional appraisal in the map of Fig. 5.

Figure 4 reveals some outliers which are caused by misinterpreted words, incorrect language detection or missing context. For instance the photo with the lowest valence value shows Pillnitz Castle, a baroque castle at the eastern end of Dresden, which is surely no unpleasant place. The description of this photo is in

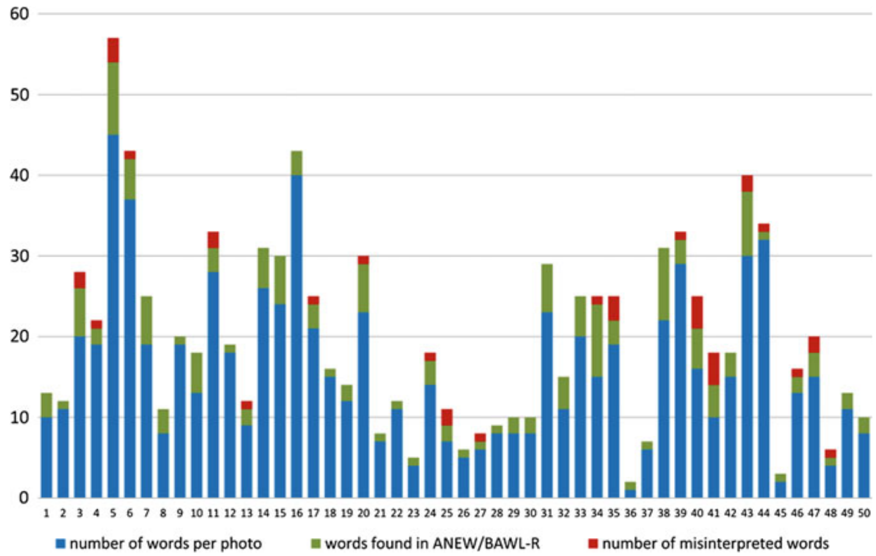

Fig. 7 Interpretation and misinterpretation rate of 50 sample photos

Dutch but has been interpreted as German, so the contained Dutch word tot (English: to, until) was looked up in BAWL-R. In German tot means dead and this of course is rated with a low valence value in BAWL-R. Another misinterpretation example is number 7 in Fig. 5: the so called Blaues Wunder (English: Blue Wonder), a blue painted cantilever truss bridge. In the map of Fig. 5, this area is marked with negative valence and high arousal although this bridge and its immediate surrounding are quite scenic and a popular photo motif. This is caused by an inappropriate basic form detected by Tree Tagger. Wunder is the German term for wonder but Tree Tagger interprets it as wunder, i.e., as the declination of the German adjective wund (English: sore). Due to the fact that this word does not exist in BAWL-R, the hypernym verletzt (English: injured) is applied which has the values −1.8 for valence and 3.94 for arousal. This misinterpretation is caused by a proper name and thus is not an isolated case.

From the total amount of all analyzed photos, 50 sample units have been selected randomly for making a statement about the misinterpretation rate as well as for finding and eliminating their reasons. 20 of the 50 analyzed photos contained misinterpreted words. According to the sample data, each photo is annotated with averagely 15.94 words. 20 % of the words or the respective synonym/hypernym were found in ANEW or BAWL-R and 22 % of those words are misinterpreted (see Fig. 7).

Four causes for misinterpretations have been identified. One is the already mentioned reason because of proper names, i.e., the lemmatization of a word or the derived synonym/hypernym is not false in principle but a context information about the occurrence of the proper name is missing, like in the case of the bridge

Blaues Wunder. The second cause is a wrong lemmatization, e.g., in one case the noun building has been interpreted as a verb and has been reduced to the infinitive build. Another reason can be the derivation of improper synonyms/hypernyms. For instance the verb abstain was used as a synonym for fast which is not false but the synonym quick was needed. Incorrect language detection can be a further reason for misinterpretations, e.g., the German term Gemäldegalerie (English: art gallery) has been processed with the English lemmatization and has been reduced to gem.

These causes of misinterpretations can be eliminated by including contextual information in the algorithm of emotional analysis so that proper names are taken into account. A further possibility is the application of POS tagging (part-of-speech tagging) for detecting to which part of speech a word corresponds to. Hence cases like the one with ‘building’ mentioned above, can be avoided. Improving language detection is difficult because many users tag in multiple languages and applying language detection to single words reduces the validity vastly.

The results of ascribing the emotional values of the exemplary photos of Fig. 5 to the assigned emotions of Fig. 6 are coherent outcomes which do not exactly fit in every case but are still satisfying. The photos of Dresden Airport (1) and Dresden Zoo (2) fall in the field of the emotion zealous, Dresden-Hellerau (3) reveals to be a calm place and photos of the Dresdner Heide (4) belong to a range of calm as well, whereas most of the photos of Dresden’s historic city are ranged in relief. The ruins (5) reveal to evoke fright, photos of the demonstrations of the 13th and 19th of February (7) belong to madness as well as photos of the bridge Blaues Wunder (6). Figure 4 shows that the majority of analyzed photos are concentrated on a certain range within valence-arousal-space. This makes it advisable, to refine the assignment of emotions with a higher resolution for this range which certainly makes the allocation of photographed places with an emotion more appropriate.

6 Conclusion and Future Work

For the study area Dresden, emotional information hidden in the word choice of photo metadata could be extracted with the help of affect analysis. Not merely one overall ‘averaged’ feeling but also emotional hotspots could be detected with high arousal and low valence and the other way around as well. Consequently the metadata of the photo platforms Flickr and Panoramio are suitable for an emotional analysis insofar as they include words or that these words have synonyms/hypernyms that can be found in ANEW or BAWL-R. Only 64 % of all photos of Dresden contained those words, because many photos are merely titled with the name of the image file given by the camera or an entire series of pictures is titled with ‘Dresden 2010’ for instance. According to Beaudoin (2007) 41 % of Flickr photos are annotated with photographic tags and 85.76 % with place names. Those words do not provide any emotional information. For this reason, georeferenced tweets from Twitter will be included in the emotional analysis as well because they contain pure written language.

The results of the emotional analysis require a further processing, especially a simplification because they are much too fine granular. For the reason that emotions can be only validated by subjectivity, it is difficult to identify if this fine granularity in regions of high photo density is caused by different individual ways of sensing a place. At the same time it is questionable if places are sensed entirely different and if the metadata of photos are significantly influenced by incisive personal experiences (like for instance an experienced car accident on the bridge Blaues Wunder).

For further processing the spatial density of photos needs to be considered as well because of the reason to take photos: people take photos when they are visually attracted by something. That means if more photos are taken at a certain location, then this place is more attractive (Zheng et al. 2011) and sensed as more pleasant.

After the tweets are included to the emotional analysis, the results will be examined regarding gender differences and seasonal differences. Furthermore it is conceivable to apply the emotional analysis to a further region which is different to Dresden, for instance the national park Saxon Switzerland located southeast of Dresden, for examining if significant emotional differences appear in nature as well or if they are a phenomenon of urban space.

The emotions retrieved by the presented emotional analysis represent aggregated emotions. For obtaining a dataset of individual location-based emotional data, physiological reactions of probands will be measured while viewing photos of Dresden, referring to the experiments of Lang et al. (1993) and van der Kolk (1996).

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Combining Float Car Data and Multispectral Satellite Images to Extract Road Features and Networks

Chun Liu, Zhiwei Jian and Xiaolin Meng

Abstract This chapter presents an automatic methodology for the extraction of spatial road features and networks from floating car data (FCD) that was integrated with multispectral remote sensing images in metropolitan areas. This methodology is divided into two basic steps. Firstly, a spatial local statistical examination is carried out to extract the nodes of each road segment. Based on the local Moran's I statistics, a new statistic method is developed to detect local clusters. Significance is assessed using a Monte Carlo approach to determine the probability through observing large samples under the null hypothesis of no pattern. When all the necessary nodes are detected, spatial road segments can then be organized by linking pairs of nodes, which are used as the candidate road segments for the next step. Secondly, pre-processed multispectral remote sensing images are utilised for testing those initial road segments. To prove the concept, a Metropolitan area is employed as a case study. Road segments with high significance values in the tests are selected to construct the spatial road network. The developed methodology could be adopted for the provision of high quality navigational road maps in a cost-effective manner and the experimental results are presented.

Keywords Local Moran's I statistics · Floating car data (FCD) · Monte Carlo approach

C. Liu (✉) · Z. Jian
College of Surveying and Geoinfomatics, Tongji University,
Shanghai 200092, China
e-mail: Liuchun@tongji.edu.cn

X. Meng
Nottingham Geospatial Institute, The University of Nottingham,
Nottingham NG7 2TU, UK

J. M. Krisp (ed.), *Progress in Location-Based Services*,
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1 Introduction

The spatial road networks, as a fundamental component of GIS, especially in the transportation GIS (GIS-T), play very important roles both in practical applications and dedicated theoretical studies. Topics related to generation of spatial road networks are therefore discussed by many researchers. Meanwhile, multispectral remote sensing images, as a new data source for the establishment of geographical information databases, have been used to provide more detailed landscape information in recent years. Due to their unique characteristics such as short acquisition periods and large land coverage, multispectral images are widely utilised in the extraction of spatial road networks, especially from high spatial resolution images. Actually, many studies on feature extraction from multispectral imagery have been carried out. For instance, a semi-automatic approach was developed by Yang and Zhu (2010) to extract main road centre lines from high-resolution satellite images. This method is based on the active window line segment matching and an improved sequential similarity detection algorithm. Mohammadzadeh et al. (2006) designed an approach using fuzzy logic and mathematical morphology to extract main road centre lines from pan-sharpened IKONOS images. Besides, multi-scale structural features and support vector machines are applied to extract road centre line (Huang and Zhang 2009). Mokhtarzade and Valadan Zoej (2007) investigated the possibility of using artificial neural networks for road feature detection from high-resolution satellite images on a part of RGB IKONOS and Quick-Bird images. Ravanbakhsh et al. (2008) proposed a zip lock-snake approach to the extraction of road junctions from Digital Mapping Camera (DMC) ortho-images. Hu et al. (2007) presented a two-step approach that includes detecting and pruning for automatic extraction of road networks from aerial images through tracking road footprints. An Artificial Intelligence (AI) and statistics oriented methodology was also developed to output road features and road networks. A hierarchical grouping strategy was also proposed to automatically extract main road centre lines from high-resolution satellite imagery (Hu and Tao 2007). A Kohonen-type self-organizing map was applied to detect the seed points in candidate road regions and presented road tracking to search for connected points in the direction and candidate domain of a road (Yun and Uchimura 2007). Tournaire and Paparoditis (2009) proposed a top-down approach for road marks such as dashed line detection based on stochastic geometry.

Furthermore, object-oriented methodology was introduced to model road objects and road networks, in which road extraction is generally based on the properties of roads and their linked networks (Peteri et al. 2003; Dal Poz et al. 2006). Shackelford and Davis (2003) combined pixel-based fuzzy and object-based methods to extract road networks from high-resolution multispectral satellite imagery. Skourikhine (2005) proposed an image vectorization approach to road network extraction from digital imagery, which is based on proximity graph analysis. In addition, knowledge-based methodologies are also very popular. Zhu et al. (2005) extracted road networks based on the binary and grey scale mathematical morphology and a line segment match method. Miriam et al. (2006) presented a user-guided method based on the region competition algorithm to extract roads. Lacoste et al. (2010) extended previously marked point processes developed for line network extraction to a process of manipulating polylines of variable dimension rather than segments. However, no matter whether date-driven approaches or knowledge-driven approaches are used, they all, to some extent, largely depend on the inherent character of grey scale images. That means radiometric information plays a vital role in feature extraction. Therefore, prior knowledge, even when some intellectual computation methods are employed, is always composed of the grey scale character of features and shapes of features. In this sense, these methods all have their own limitations.

Fortunately, Floating Car Data (FCD) concept, using a dynamic sensor such as moving vehicle to collect spatial information, is currently under a rapid development. The FCD technology requires a positioning system such as the Global Position System (GPS) and a wireless communication unit installed onboard the car. The real-time position of the car is transmitted at a regular interval to the server at a data centre, which collects and processes all the GPS data packages to facilitate the determination of the traffic pattern (Liu et al. 2008). Nowadays, research on FCD mainly focuses on the application of FCD in traffic state detection (Kerner and Rehborn 2001; Schafer et al. 2001; Kerner et al. 2005; Kwella and Lehmann 2000), FCD analysis (Fouladvand and Darooneh 2005), updating the road network in an existing GIS database (Smartt 2006) and traffic information publication (Liu et al. 2008).

In this chapter, we propose a new method to integrate the advantages of multispectral remote sensing imagery and FCD for the extraction of a spatial road network. The significance of this method lies in not only helping to extract the spatial road network using FCD and multispectral RS imagery but also assisting division of a road network automatically into reasonable road segments, which are compatible with FCD. In this chapter, discussion involved is mainly on the feasibility of integrating multispectral remote sensing imagery data with FCD and the geometric registration between them. Based on local Moran's I statistics, a new statistic is defined to carry out a spatial cluster analysis to detect nodes of the road network. The Monte Carlo simulation process is adopted to evaluate the significance. This chapter will also explain the strategy used to construct a spatial road network with nodes detected and pre-processed by multispectral imagery. Experimental results are presented and discussed. Preliminary conclusions are drawn from these above tests and analysis.

2 Integration of FCD with Multispectral RS Imagery

2.1 FCD Approaches

No matter whether in the countryside or in urban areas, the traffic status on a road network can surely be monitored by direct measurements (e.g., induction loops and radar devices). This traditional method is effective only when there are not so many vehicles and the demand on the monitoring sensors is relatively low, because those devices could not, to some degree, monitor the dynamics of the traffic flow. With the development of GPS and wireless communication technologies, real-time positions of vehicles can be transmitted at a regular interval to a central site when they are equipped with GPS devices. With sufficient vehicles being monitored, velocities on road segments can be directly estimated. This is called floating car data or FCD (Turksma 2000). FCD have become a very important data source for the establishment of traffic information systems.

Lorkowski et al. (2005) proposed two approaches for the collection of FCD, i.e., passive and active FCD approaches. The passive FCD extraction means "recognizing" a vehicle at one section of the road network and later on another one, e.g., by automatic vehicle identification or passive onboard transponders responding to roadside stationary beacons. The time interval between the events allows an estimation of the average travel time between the two sections. The active FCD extraction method, which is widely used nowadays, requires installing a positioning system such as GPS and a wireless communication unit onboard the car. The instantaneous positions of the car are transmitted at regular intervals to a data centre. The locations of the car are then superimposed on a digital road network through map matching, and the routing velocity is further obtained through the calculation of the road segment travel time. For the above implementations, a detailed digital road map database is developed and contains well organized features with strict topological relationship to support various ITS and LBS operations on its spatial and temporal features. In Fig. 1, the logical structure of the methodology discussed in this chapter is presented. In the experiments introduced in this chapter, the active method of collecting FCD is adopted. The data are used to establish the digital road map instead of operating them on the map.

2.2 Geometric Registration of FCD and Multispectral RS Imagery

The positioning information of FCD sent to the traffic centre is the geodetic coordinates in the WGS84 coordinate system. However, multispectral remote sensing imagery data are always in a projected coordinate system. Therefore, to integrate these two, they must be registered into a common coordinate system in advance. In Shenzhen City, China, the "Shenzhen Urban Transport Simulation System" (SUTSS) project was developed. In this project 5,000 taxis are equipped with GPS and wireless communication devices to obtain FCD, and millions of GPS data packages have been recorded since May 2006. These FCD and the corresponding high spatial resolution images are used to study the feasibility of integrating these two data sources. The coordinate systems of these two data types are listed in Table 1.

For convenience, FCD are projected with a simple cylindrical projection to match these two data types in the same coordinate system. The selected test area ranges between 22°31′48.00″N and 22°32′24.72″N in latitude and 113°54′34.86″E

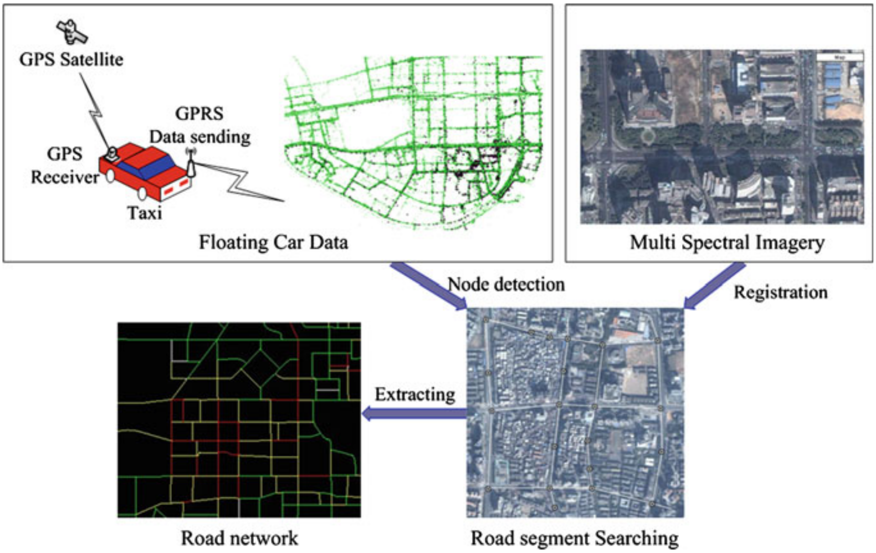

Fig. 1 The relationship of each component of the proposed approach

Table 1 Coordinate systems of FCD and RS imagery

Data type	FCD	RS image
Coordinate system	WGS84	Simple cylindrical projection with a WGS84 datum

and 113°55′13.56″E in longitude. Figure 2a, b show the area before and after overlaying FCD on a high resolution image, respectively.

From Fig. 2, it can be seen that after geometric registration, FCD are projected on the image and FCD almost covers all the roads. After measuring the distances from each FCD to its corresponding central road line and performing a statistical analysis, it was found that the accuracy of FCD positions is normally within 10 m and most of the FCD have an accuracy better than 4 m. The mean deviation of the arithmetic mean is 2.28 m, sample variance is 6.92 m and the standard deviation is 2.63 m (Fan 2007). The spatial resolution of the image used is around 1 m. Thus, taking into account the width of the road, it is evident that these two data sources match very well.

3 Local Cluster Detection from FCD

Local statistics are a useful indicator applied in many fields. Based on Moran's I statistics (Moran 1950), the local indicators of spatial association were derived by Anselin (1995) (also see Getis and Ord 1996), to resemble passing a moving

Fig. 2 Images before and after overlaying FCD on the high resolution image. **a** Before the overlay, **b** after the overlay

window across the data, and examining dependence within the chosen region for the site on which the window is centred. The specifications for the window can vary, using perhaps contiguity or a distance at some spatial lag from the considered zone or point. With this concept, a new statistic to detect clusters from FCD is proposed.

3.1 Fundamentals

The local Moran statistic can be expressed by Eq. 1:

$$I_i = \frac{n(y_i - \bar{y})}{\sum_i (y_i - \bar{y})^2} \sum_j w_{ij}(y_j - \bar{y}) \tag{1}$$

where I_i is the statistic of local Moran's I at region i, y_j is the attributes of region i, $\bar{y}$ is the expected value and w_{ij} is the weight. Based on the concept of Eq. 1 and considering the character of FCD, a new statistic is given in as follows (Eq. 2):

$$\begin{cases} L_t = \max(F_i) \\ F_i = \frac{k_i - \bar{k}}{\sqrt{\bar{k}}} \\ k_i = \sum_j w_{ij} y_j \end{cases} \tag{2}$$

where, y_i is the number of FCD within an area centred at point i, w_{ij} is the weight, $\bar{k}$ is median value of k_i and L_t is the new local statistic at test time t.

3.2 Significance Test of L_t

Due to the uncertainty of FCD, it is hard to tell what kind of distribution L_t has. Therefore, Monte Carlo simulation is employed to obtain the critical value. Monte Carlo simulation of the null hypothesis of no local clustering confirmed the actual value of L_t consistent with $\alpha = 0.05$ each time. The simulations were carried out by firstly filling the study area with randomly distributed points. The local statistics were then estimated using Eq. 2 and then the critical value for L_t was found.

Because multiple testing was employed, in which each L_t was tested whether it is significant until no significant L_t is found, to keep the experiment error rate to a specified level (usually $\alpha = 0.05$), the Bonferroni adjustment was implemented (David 1956). If k independent tests are made, instead of choosing a critical value of the test statistic using α as the Type I error probability for each test, simply α/k can be used for each test. Therefore, it is an iteration process because parameter k of the Bonferroni adjustment is involved with the times of multiple testing. An iterative procedure is needed to approximate the optimal solution.

4 Strategy to Construct a Spatial Road Network

There are two assumptions made before extracting the spatial road network.

(a) There is a traffic pattern in the centre of the local cluster, and
(b) There is no significant change of speed on each road segment linked by nodes.

In the real traffic system, these two assumptions are always easy to realize because of high FCD density. Local clusters mean that there is a significant change of speed in the clustered place. Between every two clusters and along a road, vehicles can run at a relatively stable speed. Otherwise, there must be another cluster, which should be detected. Therefore, local clusters can be regarded as nodes of road segments. After finding the nodes of road segments, each two nodes can be linked as the candidate road segments. A pre-processed multispectral image is then used to determine the final spatial road network. This can be explained by as follows (Fig. 3). In Fig. 3a, seven nodes are found with the method introduced in Sect. 3. They are *a*, *b*, *c*, *d*, *e*, *f* and *g*. Then each two nodes can be linked and 21 candidate road segments are formed. R1, R2 and R3 are the road areas determined from the pre-processed multispectral image. The strategy used for the selection of road segments can be described by the following steps:

(a) Decompose the vector data of candidate road segments into raster data.
(b) Overlay the decomposed raster data with the pre-processed multispectral image.
(c) Calculate the ratio of the number of pixels overlaid to the total number of pixels of each road segment.
(d) Select road segments whose overlay ratio is over a certain probability.

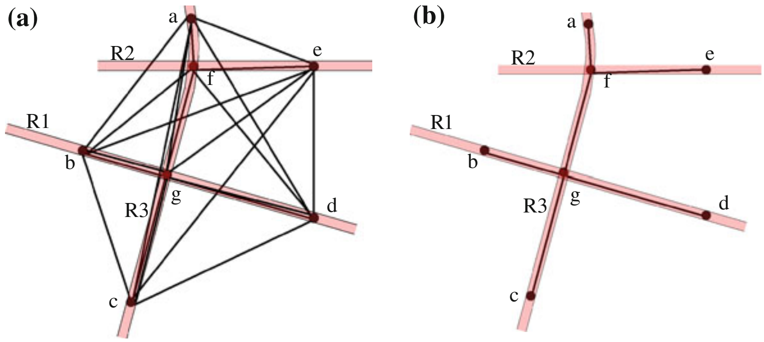

Fig. 3 Strategy to determine the final spatial road network. **a** Candidate road segments and road area, **b** detected road network

In Fig. 3b, an ideal result is shown, but actually the result from the pre-processed multispectral image may contain certain levels of noise and uncertainty, which are endurable. Therefore, if areas that cover all roads in the image can be roughly extracted, the spatial road network can be decided by calculating the probability that each candidate road segment falls in road areas at a given significance level. Figure 4 gives more detailed data processing procedure that is employed in this study.

5 Experiment and Case Study

The testing area is as described in Sect. 2.2 and a simple cylindrical projection is used. FCD were collected from 3 to 5 June 2007. There are in total 21,935 FCD (in WGS84) during this period in this region. The high spatial resolution image was obtained from Google Earth and the spatial resolution is around 1 m.

5.1 *The Structure of the Experiment*

Fig. 4, the structure of this experiment is displayed. There are three inputs for the multiple testing: (1) FCD, (2) weight matrix, and (3) critical value. The critical value is obviously from the Monte Carlo simulation process, which was introduced in Sect. 3. After the multiple testing, road segment nodes are obtained and then candidate road segments can be produced. The selection procedure is conducted according to the discussion in Sect. 4. Finally, the spatial road network is obtained.

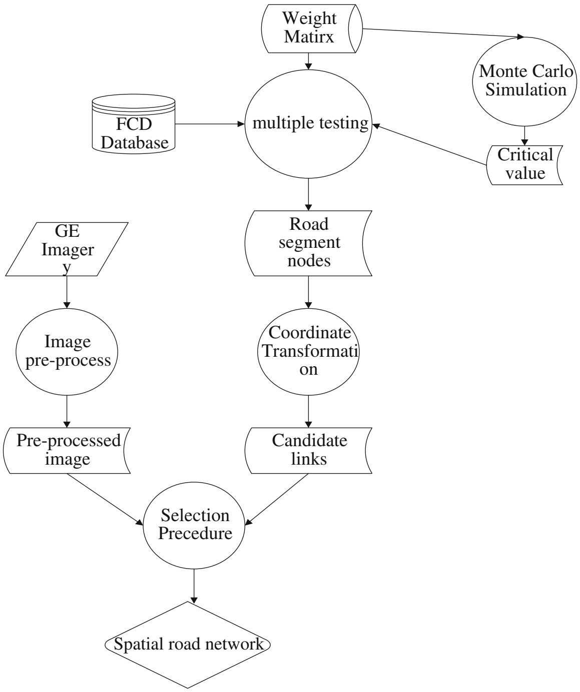

Fig. 4 Structure of the experiment

5.2 The Weight Matrix

In Fig. 4, the weight matrix is one of three inputs for the multiple testing. Actually, weight is essentially important for the multiple testing. To define the weight matrix, the character of FCD should be studied. In Fig. 5, a corner of FCD is shown.

From Fig. 5, it is apparent that at each road intersection FCD are not distributed evenly. In the centre of intersections, there are fewer FCD but more on the roads near the centre. This does make sense, because in the real traffic situation, due to the effect of traffic lights, vehicles must wait until they are permitted to go. When vehicles are allowed to go, they must go through intersections without stopping.

Based on the area from Fig. 5, a kernel density procedure with a search radius 15 m (mean accuracy of the FCD position) and output cell size of 4.5 m is made and the result is shown in Fig. 6, in which darker areas represent higher density of FCD. From the analysis of the kernel density of the whole study area, the weight matrix is defined as follows:

$$W_{ij} = \begin{cases} -0.4 & dist(i,j) < 10m \\ 1 & 10 \le dist(i,j) < 30m \end{cases} \tag{3}$$

where $dist(i, j)$ is the distance from point i–j.

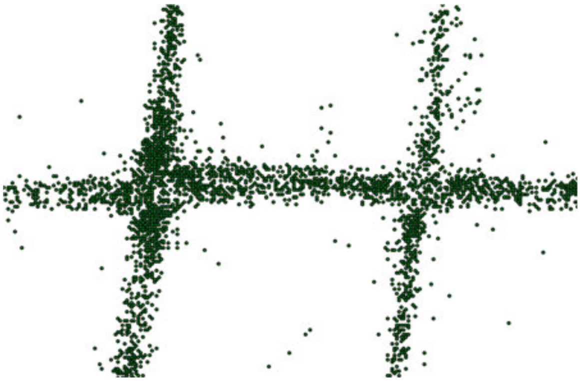

Fig. 5 Distribution of FCD at two road intersections

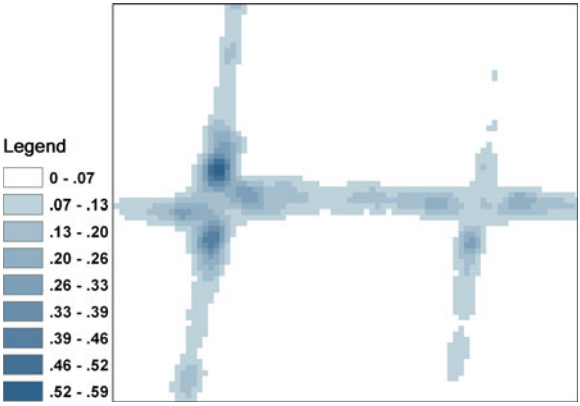

Fig. 6 Kernel density of FCD

5.3 Monte Carlo Simulation Process

As set rules have been applied to build the weight matrix, the Monte Carlo simulation process can be carried out. Firstly, 21,935 points are randomly arranged in the study area. Secondly, a weight matrix is built with Eq. 3. Finally, the local statistic L_t is calculated with Eq. 2. These three steps are repeated 1,000 times and a series of L_t can be found. The result is shown in Fig. 7. Figure 7 shows the histogram of the Monte Carlo simulation process results. The x axis stands for the value of L_t and the y axis records the corresponding occurrence times of L_t in the Monte Carlo simulation process. Taking into consideration of the Bonferroni adjustment, critical values at confidence level $\alpha = 0.05$ are given in Table 2.

As illustrated in Table 2, more tests could lead to higher critical values. This means if more tests are carried out, a higher critical value is needed to avoid conservative estimation.

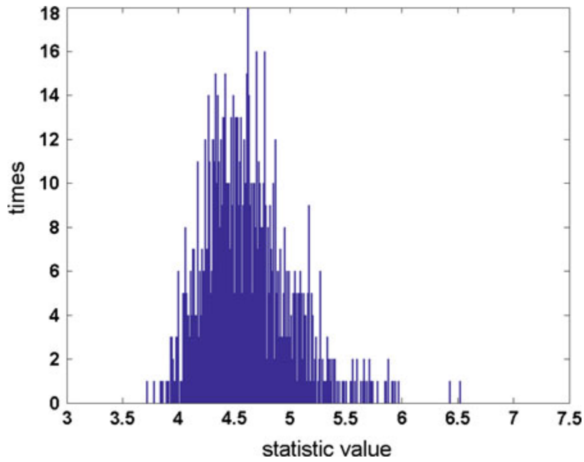

Fig. 7 Histogram of the Monte Carlo simulation process results

Table 2 Critical values considering the Bonferroni adjustment

Times of multiple testing	Critical value
10	6.0539
20	6.1526
30	6.2009
40	6.2074
50	6.2138

5.4 Node Detection

After 38 tests with a critical value of 6.2061, 38 significant local clusters are found. Their points are plotted along with all FCD points in Fig. 8.

In Fig. 8, it is evident that all local clusters have been found. Besides road intersections, some clusters are located along roads, where it can be assumed that there must be some traffic patterns. This kind of traffic pattern requires those roads to be divided into road segments to comply with FCD.

5.5 Determination of Final Spatial Road Network

Based on the strategy discussed in Sect. 4, the pre-processed imagery of the study area should be prepared. As the aim of this chapter is to introduce FCD for the road network extraction, here the road frame is roughly described by hand, and used to explain the candidate road segment selection procedure. Figure 9 shows the pre-processed imagery and the final spatial road network overlaid with high spatial resolution imagery.

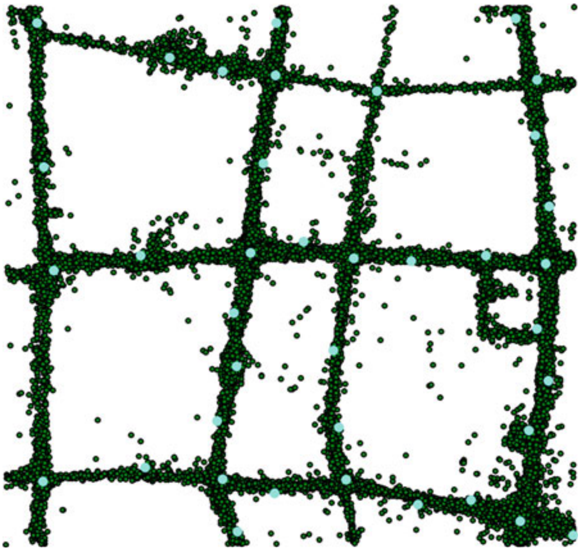

Fig. 8 Distribution of centres of local clusters

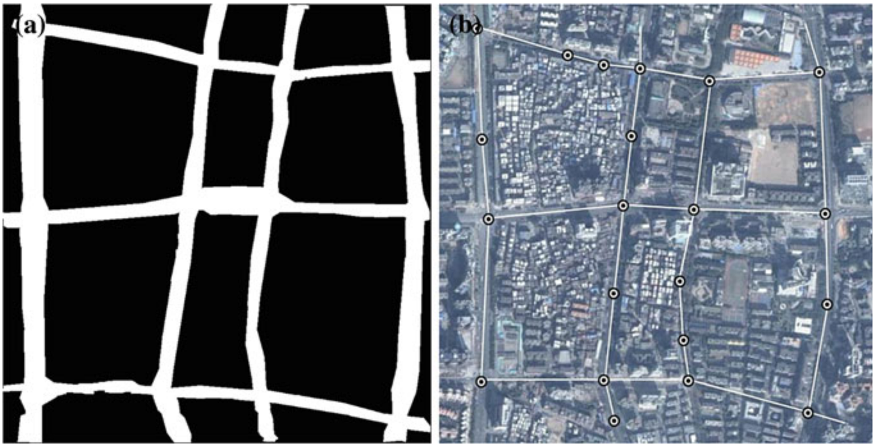

Fig. 9 Candidate road segment selection. **a** Pre-processed imagery, **b** final spatial road network

For convenience, in Fig. 9a, the pre-processed imagery is given as a binary image, in which the white area roughly covers the road area. In Fig. 9b, when the spatial road network is overlaid with the high resolution imagery, they match each other very well. Nodes of all road segments are highlighted. Each node represents a traffic pattern, such as road intersection, traffic jam, etc. This process will provide very useful information for the analysis of actual traffic conditions on the local road network for the improvement of traffic flow. Actually, by applying the method on the whole Hangzhou city, the time cost of entire network features extraction with a common PC is less than 8 h. So the computing efficiency of the proposed method is proved feasibility for a practical application on a large region.

6 Conclusions

Aiming at provision of large high precision digital databases for wide adoption of ITS and LBS for managing transport system, the authors of this chapter present a cost-effective approach through taking the advantages of FCD and high-resolution images. For achieving the goal, a new statistic is defined to describe the local cluster based on the character of road intersections. To obtain the critical value of the statistic, the Monte Carlo simulation process is employed. The Bonferroni adjustment is also utilised to keep the experimental error rate to a specified level. In the case study, kernel density analysis was carried out to acquire the key parameter for building the weight matrix. After all the road segment nodes were detected, candidate road segments were formed successfully. Assisted by the pre-processed high spatial resolution imagery, the spatial road network was finally decided. Besides the final spatial road network obtained with this methodology, it should be noted that all the road nodes are detected based on FCD. Therefore, on the one hand, these nodes are the most compatible with FCD and on the other hand, these nodes match multispectral remote sensing imagery very well. Thus the significance of this methodology is the provision of an automatic way to construct spatial road networks that is compatible with both FCD and multispectral imagery. Using real data sets gathered with FCD cars in Shenzhen City in China, this chapter demonstrated that FCD can help to construct spatial road networks with multispectral remote sensing imagery. The short cycle period and wide coverage of multispectral remote sensing imagery make the updating of spatial road networks quicker and the cost of the update less. In future work, the more convenient way to obtain the pre-processed imagery will be investigated and the robustness of this methodology will be further addressed.

Acknowledgments The work described in this chapter was supported by National Basic Research Program of China (2012CB957702).

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Space-Time Mapping of Mass Event Data

Christian E. Murphy

Abstract In conventional thematic cartography the visualisation techniques to symbolise spatio-temporal phenomena are limited. On a two dimensional map temporal changes can only be visualised adequately as time series or by animation. To simultaneously visualise thematic data in space and time a third dimension must be added. In this work conventional cartographic symbolization meets the space-time cube to create a holistic 3D spatio-temporal visualisation model. The two dimensional proportional symbol mapping technique is adopted and extruded into the third dimension to model the temporal factor. Kernel density estimation is performed on the time line to create a temporal continuous model from discrete points in time. The resulting visualisation model is implemented into an earth viewer to enable the user to freely navigate the phenomenon and visually detect anomalies without losing the overall view. This tool is evaluated by visualizing the events of a mobile phone location dataset over space and time in one single model.

Keywords Visual analytics · Geostatistics · Thematic cartography · 3D visualisation · Mobile phone location data

1 Introduction

There is a need for effective methods to exploit and use the hidden opportunities and knowledge resting in unexplored data resources (Keim et al. 2010). An effective approach to reveal the hidden information in large spatial databases is

C. E. Murphy (✉)
Department of Cartography, Technische Universität München, Arcisstraße 21, 80333 Munich, Germany
e-mail: Christian.Murphy@bv.tum.de

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to combine computational tools with human understanding into visual data exploration and sense making. This approach is part of the visual analytics field, which consists of various research areas. Visual analytics has been introduced and specified as the science of analytical reasoning facilitated by interactive reasoning techniques (Thomas and Cook 2005).

Despite various existing methods for data mining and data visualisation, both visual data exploration and statistical analysis of temporal changes of a phenomenon remain difficult. Haggett (1990) defines four types of temporal change in spatial data: constants, trends, cycles and shifts. Constants are long periods of no change while trends refer to long-term linear changes, e.g. migration of objects. Cycles describe recurring patterns like for instance daily hotspots of rush hour traffic and shifts describe random changes that misfit overall trends and cycles. In the case of a mobile phone location dataset an overall daily cyclic pattern would be expected.

It is necessary to simplify large amounts of event data. These events cannot be analysed and visualised adequately and therefore a phenomena cannot be understood. The events, each with a distinct location, can be used as points. This is why kernel density estimation has become so popular in recent years for its ability to make large amounts of point data understandable. Derived from point distances and a kernel function it assigns density values throughout the study area of the examined phenomena. The resulting density values can be classified and colour coded which leads to an isarithmic mapping technique. This density surface displays a simplified and abstract presentation of the point cloud to provide a legible and comprehensive visualisation. To provide a spatiotemporal analysis of a spatiotemporal phenomenon a current practice is to investigate space and time separately. It seems reasonable to use kernel density analysis to investigate on the spatial behaviour. A typical spatial analysis by kernel density estimation of a mobile phone call location dataset is shown in Fig. 1.

To respect the temporal aspect of a spatiotemporal analysis the spatial investigation is enriched with a temporal analysis. In many cases this consists of a histogram simply showing quantities over time. The events are then classified into discrete intervals. An example using the same mobile phone call location dataset is shown in Fig. 2.

This implemented approach of separating the spatiotemporal analysis into a spatial analysis and a temporal analysis has, regardless of its usefulness for particular cases, major drawbacks. Time is not applied as continuous in opposition to its nature. The events in time are presented in discrete manner. Information is lost as the distribution of events within a class is neglected. But the crucial drawback is that the study area cannot be explored in detail over time. Spatiotemporal hotspots are therefore not identifiable as either the overall temporal hotspots or overall spatial hotspots only can be depicted. It is not possible to detect the density of a certain place at a certain time. The divisiveness of the analysis results into a visual

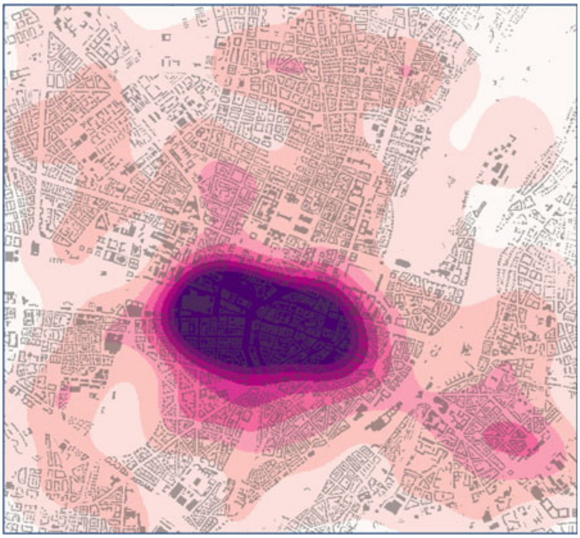

Fig. 1 Phone call densities in space

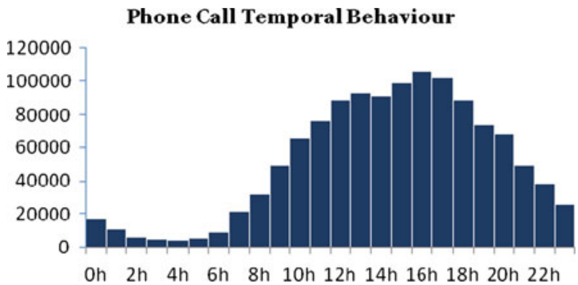

Fig. 2 A histogram showing phone call quantities over time

exploration of space *or* time rather than a visual exploration of space *and* time.

To enable the analyst to perceive for instance mobile phone call events as behaviour rather than multiple individual patterns, the analysis of all events must be presented in one display. This major principle for exploring data has been introduced for instance by Andrienko and Andrienko (2006) as "see the whole". For instance, a time-based animation for the exploration of spatiotemporal data does not fulfil this demand as different points in time can only be analysed in sequence. By the use of a temporal third dimension in a static view, time steps and positions can be explored according to the underlying scales without temporal limitations (Müller, Schumann 2003). The in a 3D presentation occurring handicaps such as occlusion and lost information on back faces can be tackled by advanced interaction techniques or additional cues (Aigner et al. 2007).

2 Input Data and Applied Method

2.1 Input Data

The in this work introduced visual analytics tool is applied on a mobile phone location dataset provided by Vodafone. For this dataset all outgoing Vodafone mobile phone calls were stored taken from an area approximately 7 × 7 km centred over Munich city centre during one week. Every mobile phone call was logged and assigned to the geographic location of a mobile phone cell. A resulting 1.5 million events occurred in 216 unique cells. For privacy issues all records were stored anonymously by removing the formal identifiers, such as phone number, phone ID, etc.

2.2 Applied Method

The coordinate pairs of the mobile phone base stations set the two dimensional distribution for all events. On the basis of the Space-Time-Cube concept, which was introduced by Hägerstrand (1970), the phone cells are presented in 2d space (along the x- and y-axis) and the height represents time (z-axis). Therefore, the time attribute of every event is used as the third dimension to enable a holistic space-time analysis. In this way the mobile phone call events can be defined as points in a 3D scatter plot.

Only if analytical methods are applied to compute expressive abstractions it is possible to analyse such large data sets efficiently (Aigner et al. 2007). In this case 1.5 million phoning events are generalised by a kernel density estimation, which is performed based on a formula stated by Scott (1992):

$$\widehat{f}_h(x) = \frac{1}{n \cdot h} \sum_{i=1}^{N} K\left(\frac{x - x_i}{h}\right) \tag{1}$$

With:

$\widehat{f}_h(x)$ = general Kernel Density
K = Kernel function
h = Kernel radius (bandwidth)
n = Number of points within kernel distance
$x_1, x_2 \ldots, x_n$ = points within the Kernel.

The kernel density function estimates a probability density function. This function is standardised by the number of points so that the integral of every probability density function is always equal to one. The kernel density function therefore represents relative point frequencies. As the density estimation is to be performed on the time axis over every base station, the density function has to be modified, to represent absolute (not relative) quantities. The in this work applied function (2) represents the absolute quantities of mobile phone call events, which allows visual comparison between different phone cells in sense of comparing absolute numbers.

$$q_h(z) = \sum_{i=1}^{N} K\left(\frac{z - z_i}{h}\right) \tag{2}$$

With:

$q_h(z)$ = Quantitative Kernel Density
K = Kernel function
h = Kernel radius (bandwidth)
$z_1, z_2 \ldots, z_n$ = points/events on the time axis within the kernel

A quantitative density function is estimated for all phone cells. It is necessary to use an identical kernel for all phone cells in order not to bias the comparison between different phone cells. A 1 h wide Gaussian kernel was used to calculate a density functions for every phone cell. These density functions are then used as rotating plane curves around z-axes perpendicular upon the two dimensional space. Each z-axis origins at a base station location so that a resulting 216 solid of revolutions represent the 3D symbols indicating the mobile phone call events in space and time. This statistical model indicates the amount of phone calls by its radius, which is the distance from time axis. The time value is given by the distance from the z-axis origin. A transverse section in x–y direction reveals the quantity of events at a certain time. This solid of revolution symbol is like an infinite number of two dimensional proportional symbol maps (one for every point in time) layered over each other.

The solid of revolutions are implemented into a Keyhole Markup Language (KML) file and rendered by the popular earth viewer Google Earth. A basic example of a solid of revolution is shown on Fig. 3. A Lambertian shading model is included to act as a diffuse reflecting texture over the solid figure and to enhance the 3D perception.

The solid of revolution persists of independently time coded sections. This empowers the user to visualise a certain time interval only. The earth viewer provides a comprehensive set of navigation tools to pan and zoom into every 3D location and to freely change the direction of sight. Therefore each solid figure of the model can be visually explored in detail. The through Google Earth supplied satellite imagery and aerial photography of the study area provides the users' orientation.

Google Earth features a time slider from Google Earth 5 and later. Whenever geodata containing time information is loaded into the viewer a time line function window called the time slider appears. The time slider enables a user to display spatio-temporal data of a specific point in time or to display a time interval. The user can also animate spatio-temporal data by playing the information in a visual sequence. In the case of the mobile phone events the user is given the power to

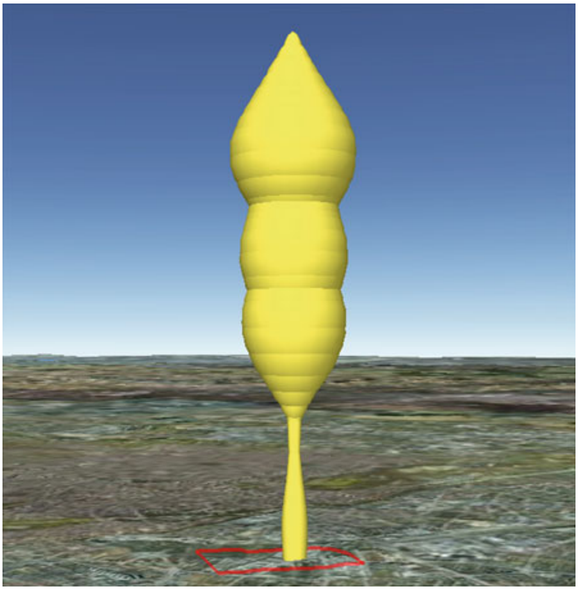

Fig. 3 A solid of revolution symbolising the mobile phone call events of a phone cell during one day, rendered in Google Earth

visualise the phone call densities at a specific day time (i.e. from 08.00 to 10.00). The user can then animate the model at his desired speed to highlight the phenomenon's density changes over the course of the day. The time interval settings stay hereby clearly in the user's visual field.

The assigning of day times to density values on the time axis is enhanced for the final visualisation by a bipolar colour scheme to identify night times in dark orange colours, early mornings in lighter orange over to a neutral light yellow colour for lunch time to a light red in the afternoons and dark red colours for late evenings (Fig. 4). This bipolar colour ramp is derived from the Lab colour space so that equal time differences are perceived as equal along the entire time axis.

3 Results

The resulting model for analysis of mobile phone events can be seen on Figs. 4 and 5. To symbolize the whole phenomena simultaneously in space and time integrated in one single model, space and time are treated as equal dimensions. The time axis is set as third dimension orthogonal to a plane two dimensional space. This Space-Time-Cube concept to represent multidimensional data has been applied by researchers prior to this approach. Tominski et al (2005) introduced the concept of 3D icons on a map display for representing spatio-temporal data. Better known as the pencil and helix icons this concept indeed has the capability to visualise higher dimensional data on distinct side surfaces of the icons based on the

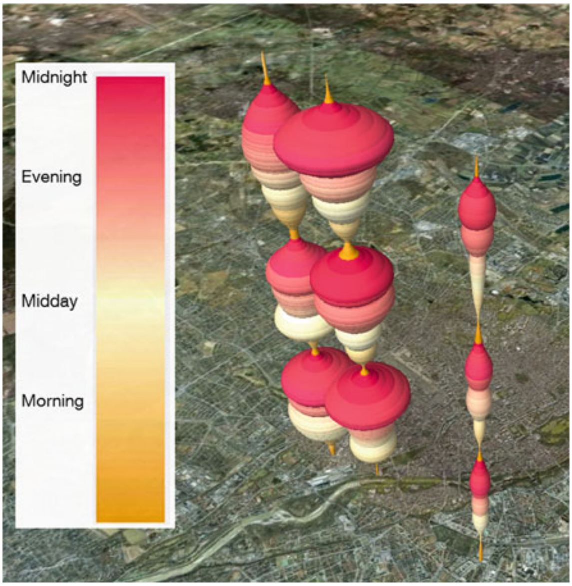

Fig. 4 Visualization of mobile phone call quantities during 3 days

visual variable colour, but has the handicap of information loss due to occlusion and hidden surfaces. Similar is the approach of Forlines and Wittenburg (2010) in which the multi-dimensional visualisation is based on the extrusion of a 2D radar chart. Here the visual variable size is used to indicate various quantitative variables in a specified horizontal angle. The in this work used solid of revolution symbols naturally show the same colour coding and convexity on every horizontal angle and therefore minimize the information loss due to occlusion and reduces the user′s cognitive workload. Also, it ensures that the general survey of the holistic spatiotemporal phenomenon remains allocated in every angle of view.

Within this approach the radii and accordingly the convexities of the solid of revolutions are derived by a kernel function from the temporal variable of occurring events. In this way it is ensured that time is treated as continuous. This is the major difference to Thakur and Ryne′s (2009) *data vases*. Although the appearance of the 3d data vases, in which polygonal disks are stacked for each time step, is alike to the here shown solids of revolution, the data vases are derived from independent values in time such as in a histogram. This has the benefit of simplicity in terms of the symbol setting but has a lack of continuity. The solids of revolution are derived from a rotating probability density function that estimates the distribution of a continuous valued random variable. In this case the variable is the amount of phone calls scattered on the time line. This avoids edge effects between different classes (for instance one hour classes) simply because no intervals are classified on the time line. The complete phenomenon is treated in respect to its continuous nature. The by the kernel inflicted data smoothing also guarantees individual events in space-time areas of sparse phone calls do not

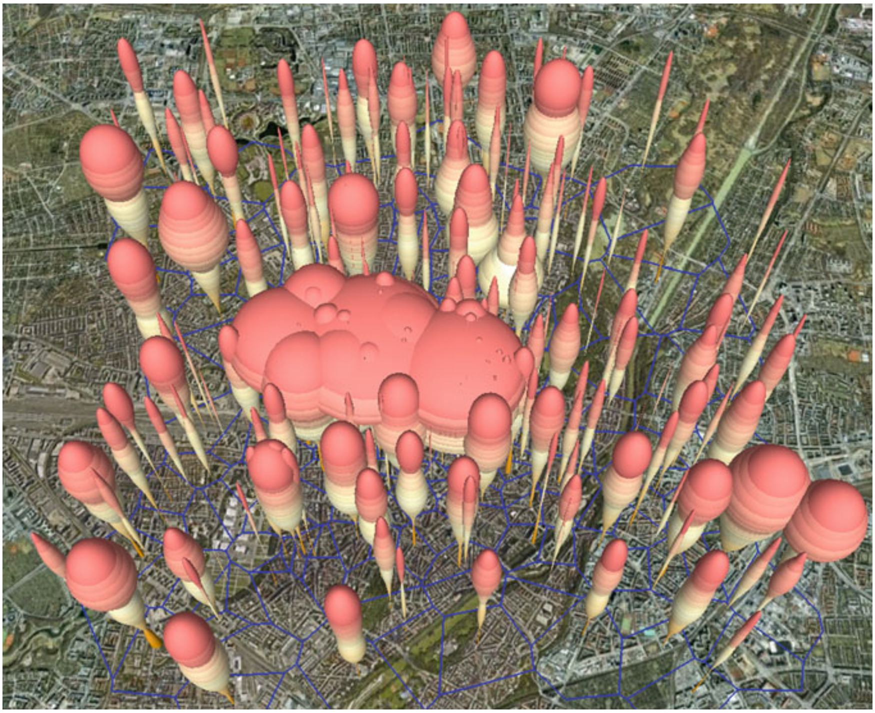

Fig. 5 Visualization of mobile phone call densities of one day until 6:00 p.m

interact strongly with the estimation. Outliers have a minimal influence on the solids of revolutions diameter. The kernel density estimation ensures that the major quantitative changes in time remain clearly visible.

One could argue that the kernel density estimation should not have only been executed on the time axis but also between phone cells in two dimensional space. But it has to be kept in mind that the events where collected through mobile phone base stations. Despite the clear boundary visualisation of cells by using Voronoi diagrams, the location of a phone call can only be determined by the coordinates of the connecting base station. The events are therefore only conceptual spatial points. O′Sullivan and Unwin (2003) state that one important criterion for using point pattern analysis (and therefore kernel density estimation) is to use true locations of event data. They further state that the points must be true incidents with real spatial coordinates. For this reason every phone cell is treated separately.

The overall analysis of the mobile phone call activities in Munich is shown on Fig. 5. A very high density can be identified in the middle of the study area which is the city centre. The perhaps not surprising phenomenon of a high mobile phone activity in city centres has been surveyed before, for instance by Ahas et al. (2010). But it is also possible to detect minor hotspots in other areas, most of them in the afternoon. At the same time regions with low mobile phone traffic can be seen.

The by common sense estimated daily cyclic behaviour of the phenomena can be better identified at a more tilted angle as depicted in Fig. 4. Peaks and valleys occur at nearly all base stations at similar times.

The mobile phone call events are symbolized by solids of revolution. The mobile phone call densities are indicated by the radius (or thickness), which is equivalent to the visual variable size. The temporal variable is indicated by a colour scheme driven by the visual variables brightness and hue. Size is classed as a quantitative visual variable by Bertin (1967/1984). Hence, the analyst is able to visually estimate the density from the solid of revolution′s radius. The visual variables brightness and hue plus saturation produce the colour. Colour empowers the observer to order (Green 1998). This insists the analyst can visually classify day times into a temporal order.

This 3D visualisation model can be used for various spatio-temporal phenomena. However, the space-time-cube based visualisation becomes limited when dealing with long period spatio-temporal phenomena. By extending the time line largely into the third dimension the resulting symbols have a great height. The model will appear oversized to the user and the overall view will be inhibited. A further problem would be the assignment of oversized symbols to their location. When dealing with long period spatio-temporal phenomena a solution to overcome this problem is to reduce the time/space ratio. As the time line has a spatial extent the vertical time scale in proportion to the horizontal space scale plays an important role on the model′s appearance. By inducing the model with a reduced time/space ratio the spatial extent of the symbols in the third dimension will be shortened to prevent the oversize symbols and to once again enable the overall view. The solids of revolution will be visualised in a more compact form. This could lead in some cases to surface artefacts simply for the reason that too much information is given on a spatially short timeline. The likeliness of overburdening the user′s visual estimation ability is high. The user would probably percept the diameter changes as noise. The decrease of the time/space ratio has therefore an impact on the choice of the kernel bandwidth. The choice of the bandwidth affects the probability density estimation strongly. The higher the time/space ratio is, the higher the kernel bandwidth must be. A larger bandwidth results into smoother changes in time. The visualisation model is more generalized with easier readable solids of revolution. Minor phenomenon changes in time are sacrificed to enable that the major phenomenon changes in time are well readable.

The Google Earth virtual globe provides the reference map to assign distinct places in Munich to every solid of revolution. Focusing on data subsets is enabled with the navigational functions onto any specific detail of the model. The analyst can freely move, view, zoom, tilt and rotate the current view to analyse the model from every angle and distance. With assistance of Google Earth′s time slider the course of the day can even be animated in this 3D environment. These tools improve the legibility immensely as the differences between neighbouring mobile phone cells can be compared more easily and the line-of-sight obstruction is minimized. The 3d visualisation exhibits its potency especially in approximately horizontal view in which identical time sections of different locations are all in one plane level and are therefore easily compared.

Every solid of revolution symbol is assigned to its location by the symbol root which is fixed to the earth surface. When using the time slider to focus on single time intervals this may not be the case. Then the symbols float at a certain height over the base map which constrains the user′s ability to identify its true location. Only tilting the model into a vertical view ensures that the user can assign a chosen time interval and symbol with its location. Here again it becomes definitive that this 3D dimensional spatio-temporal visualisation model is practicable for visual data exploration and the general overall view of a phenomenon.

Another benefit of the symbolisation method is that the solid of revolution′s smooth rotating curve respects the continuous nature of time. In addition, due to the natural geometry of a solid of revolution figure representing a mobile phone cell the horizontal angle of sight has no effect on the visual estimation. This also clears the back faces problem. Depth perception cues ensure the visual estimation of mobile phone call quantities. Especially the zooming, tilting and panning functions enable the user to obtain a 3D impression of the model by motion. Motion in combination with, the in this model offered, shading significantly reduces the errors of 3d structural information perception (Norman et al. 1995). As a consequence increases, decreases, stability and fluctuations of mobile phone calls can clearly be identified in spatiotemporal relation.

4 Conclusion

It has become easier in recent years to visualise and to disseminate geodata due to the emergence of virtual globes being able to run smoothly on various ubiquitous electronic devices. Either a standalone geographical information programme which provides the virtual globe or simply a browser plugin, which is for instance offered by Google, provides base map material for a thematic layer in a 3D virtual environment. Supported by XML notations such as KML it is possible to visualise spatiotemporal in a 3D view. The user of this visualisation can be either the professional analyst or an ordinary person. The earth viewers provide an easy to use time slider and a comprehensive set of navigation tools. To make spatio-temporal data understandable one can use all provided dimensions to enable a complete spatiotemporal analysis.

The in this work introduced visualization method ensures that the complete phenomenon can be visually examined in one view. All major and minor spatio-temporal hotspots (or coldspots) are clearly visible. The analyst can freely navigate within the phenomena to explore in detail any given location in space and time.

When visualising mass data an abstraction is essential to preserve the legibility. Kernel density estimation can generalise mass event data consisting of point clouds. This makes events displayable in a usable manner. Further research has to extend kernel density estimation applications for spatiotemporal and 3D data and should evaluate the usability of such 3D visualisations.

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Analyzing Human Activities Through Volunteered Geographic Information: Using Flickr to Analyze Spatial and Temporal Pattern of Tourist Accommodation

Yeran Sun, Hongchao Fan, Marco Helbich and Alexander Zipf

Abstract Volunteered Geographic Information (VGI) provides valuable information to analyze human activities in space and time. In this chapter, we use Flickr photos as an example to explore the possibilities of VGI to analyze spatiotemporal patterns of tourists' accommodation in Vienna, Austria as study site. Kernel density estimations and spatial scan statistics are used to explore the distribution of photos, while seasonality is considered additionally. The results show seasonal tendency of tourists for accommodation. It has been discovered that Flickr photos have, in general, the capability to improve tourism-related researches. In particular, they are useful to investigate spatiotemporal human activities, which open new possibilities for further location and event based analysis.

Keywords Volunteered geographic information · Flickr · Point pattern analysis · Spatial cluster detection · Tourist accommodation · Seasonality

1 Introduction

Web 2.0 is a bi-directional collaboration allowing users to interact as well as share information and contact with other users (Goodchild 2007a). The shared geographic information is called Volunteered Geographic Information (VGI; Goodchild 2007a). It combines elements of Web 2.0 (Scharl and Tochtermann 2007), collective intelligence (Smith 1994), and neogeography (Turner 2006). Examples

Y. Sun (✉) · H. Fan · M. Helbich · A. Zipf
Institute of Geography, University of Heidelberg, Berliner Straße 48,,
69120 Heidelberg, Germany
e-mail: yeran.sun@geog.uni-heidelberg.de

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Lecture Notes in Geoinformation and Cartography, DOI: 10.1007/978-3-642-34203-5_4,

are Wikimapia, Flickr, OpenStreetMap, Twitter, Facebook, and YouTube. With the increase of users, more and more VGI are generated and shared via the Web. VGI also contains spatiotemporal information of objects (e.g. photos, messages, videos), which can be used to analyze user behaviors in a space–time context. For instance, Flickr and YouTube provide tools that permit users to edit photos and videos by means of geotags.[1] Geotagged photos and videos are georeferenced by means of the coordinates generated by the camera, representing the location of the photo or video. These coordinates and the time when the photo and video was taken can serve as data source to explore human behavior.

Tourist accommodations affect urban form and function. In terms of both form and function, the city's image is influenced by the types of hotels and ancillary services (Wall et al. 1985). Hotels offer a variety of services and activities to local residents as well as visitors. Thus, the lodging industry alters the city function, structure, and spatial distributions of services, which affects the urban morphology and the landscape (Wall et al. 1985). On the other hand, the spatial pattern of tourists accommodation can be an indicator of urban form and function. For example, Dokmeci and Balta (1999) analyzed the spatial development of hotels in Istanbul (Turkey) and they concluded that a transformation from a monocentric to a polycentric urban structure has occurred. However, the availability of tourism data is a major research obstacle. A common approach to acquire data is that data archives from the government and surveys are expensive. However, government data often cover only the licensed and commercial hotels and do not consider unlicensed ones. The quality of survey data depends on the numbers pro bands as well as the representativeness of participants. Furthermore, it is always time-consuming to gather and preprocess these data. In contrast, VGI such as Flick photos can be a new data source to analyze tourist accommodations. The reasons are manifold: low price, high convenience, and easy preprocessing, among others.

To investigate the possibilities of VGI for human behavior analysis, the main objective of this chapter is to explore whether and how we can use Flickr data and photos, respectively, to examine spatiotemporal patterns of tourist accommodations. First, in regard to the seasonality of tourism we explore the spatial characteristics of tourist accommodations in different seasons via kernel density estimation. Second, significant "hotspots" (clusters) of tourist accommodations are detected, differentiated by seasonality.

The reminder of this chapter is organized as follows. The next section reviews previous work dealing with tourism analysis using Flickr. Subsequently, the methodology, study area, and data processing are introduced and important results are presented. Finally, this chapter concludes a comparison of VGI and traditional data.

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[1] http://geotag.sourceforge.net/.

2 State of the Art

2.1 Human Activities Detection by Means of Flickr

Recent studies illustrate the high potential of VGI to examine human behaviors. Neglecting spatial and temporal characteristics of users, Julio et al. (2007) as well as Lindgren and Lundstrom (2011) focus on the statistical analysis of social relationships and interactions, while others just take the temporal changes into consideration. Examples are the monitoring of lifestyle of crowds (users) by Lee et al. (2011) who extract crowd behavioral patterns in urban areas from Twitter. Using Flickr data, Popescu and Grefenstette (2009) examine temporal attributes of tourist sites, such as the temporal length of visits as well as the minimum, maximum, and average of visiting times. Jia et al. (2011) investigate user interaction behavior of social groups by means of Facebook. The results show that social groups show differential interactive behaviors before and after the midpoint when an event is created on Facebook and when the offline activity is going to happen. Moreover, Jia et al. (2011) also show that the involvement of the creator of the event pages is associated with higher interactive behavior of the social group. Zwol (2007) uses statistical analysis to investigate the temporal, social, and spatial behaviors of Flickr's users. Results show that users discover new photos within hours after being uploaded and that 50 % of the photo views are generated within the first two days. Additionally, the geographic distribution of views is more concentrated around a geographic location for infrequently viewed photos. However, these previous works lack of a spatial analysis of the user activities.

Event detection using VGI is a cutting-edge research field. Applying spatio-temporal clustering, geotagged photos of Flickr are used to detect events. Rattenbury et al. (2007) present an approach to extract place and event semantics from Flickr photos tags. Model comparisons (scale-structure identification (SCI) vs. standard burst detection methods) underpin that SCI outperforms the naive scan method as well as the spatial scan method. Chen and Roy (2009) employ a wavelet transform to suppress noise by identifying the tags related with events in Flickr. Afterwards, event-related tags are clustered such that each cluster, representing an event, consists of tags with similar temporal and locational patterns as well as similar associated photos. As a result, each detected tag cluster represents an event, and the photos which correspond to the cluster tags are extracted. Andrienko et al. (2009) investigate visual analytics to combine computational techniques with interactive visual displays. Kisilevich et al. (2010) extend this work and employ systematic visual analytics to accomplish different tasks in the event-based analyses of geotagged image data. Additionally, geomessages of Twitter and geotags of YouTube videos are also used to detect events (Lee et al. 2011; Tahayna et al. 2011). Lee et al. (2011) propose a geosocial event detection method to detect crowded places based on the conception of social networking sites. Tahayna et al. (2011) propose a technique (denoted as GAoptSVM) for an optimal SVM-based video event classification via an evolutionary optimization technique. Thom et al. (2012) presents an approach that allows for a real-time interactive analysis of location-based micro-blog messages. A cluster analysis approach is used to detect spatiotemporal anomalies automatically. Finally, VGI datasets are consulted to analyze trajectories of tourists. Using geovisualization of Flickr photos to reveal tourist concentrations and spatiotemporal flows in Florence, Italy, Girardin et al. (2007) present a qualitative description of tourism densities, points of interests, and trajectories of tourists. In contrast, Yin et al. (2011) generate several trajectories on the basis of Flickr and quantitatively ranked the resulting trajectory patterns to explore representative trajectory patterns.

2.2 Tourist Accommodation

One common data source of accommodations is statistical data, like survey data and records of hotels from some organizations or committees (e.g. English Tourist Board in UK). To analyze spatial and temporal patterns of accommodations, point pattern analysis and time series analysis are used (e.g. Wall et al. 1985; Pearce and Grimmeau 1985). Shoval and Cohen-Hattab (2001) investigate changes in the spatial distribution of tourism accommodations in Jerusalem, Israel, in the past 150 years. Offering insights into factors affecting operations of small hospitality businesses in developing countries, Sharma et al. (2007) conduct a spatial comparative analysis of performance of small hotel clusters in three major cities of Tanzania. Dokmeci and Balta (1999) investigate the historical and spatial development of hotels in Istanbul.

Besides, a number of researches focus on the seasonality of tourism, including accommodations. Koenig and Bischoff (2005) review seasonality of tourism, including definitions, reasons, and impacts. Some statistic methods are utilized to research tourism accommodations. For example, structural time series models and causal dynamic regression models are applied to measure seasonality. Grainger and Judge (1996) analyze the changing patterns of seasonality in hotel arrivals in Portsmouth, England, for the period 1987–1994. A time series model is estimated by Sørensen (1999) who examines regional differences in the seasonal concentration of tourists in the hotel sector in Denmark. While Coenders et al. (2001) analyze the effects of different characteristics of holiday hotels on the monthly price using a latent growth curve model as well as a random-effect model. Principal component analysis and time series analysis are used for hotel utilization studies (e.g. Jeffrey and Barden 1999). Koenig and Bischoff (2004a, b) report extensions of these methodologies. Additionally, Georgantzas (2003), Getz and Nilsson (2004), as well as Fernandez-Morales and Mayorga-Toledano (2008) focus on the economic effects of tourism accommodations.

However, this review documents that previous research has paid more attention to economic aspects than geographical characteristics of tourism accommodations.

The spatiotemporal analysis of the distribution of tourism accommodations is lacking so far. Therefore, this investigation exploring the spatiotemporal distribution of Flickr photos bridges this gap.

3 Methodology

The general aim of point pattern analysis is to explain the empirical spatial distribution of points with statistical models in order to (a) measure the consistency with a theoretical pattern and (b) to make inferences about the underlying spatial point process (Getis and Boots 1978; Helbich and Leitner 2010). It is assumed that an observed spatial point pattern is a realization of a spatial stochastic process (Gatrell et al. 1996). To describe such a point pattern, two interrelated approaches are available: The first order effects reflect the intensity of points, while the second order effects refer to the interaction between points (O'Sullivan and Unwin 2003). First order effects assume that the location of a point is independent of other points and thus spatial interactions (association) between points across space are not considered.

3.1 Kernel Density Estimation

To estimate first order effects, Kernel Density Estimation (KDE; Diggle 1985; Berman and Diggle 1989; Rowlingson and Diggle 1993) is commonly applied. KDE produces local estimates of densities, resulting in a smooth density surface of tourist accommodations. KDE helps to identify locations of possible "cluster" or at least sub-regions worth for further examination (Gatrell et al. 1996). Often the Gaussian kernel function is employed. Formally, the KDE function (Grothe and Schaab 2009) is defined as:

$$f(x) = \sum_{i=1}^{N} \alpha_i k_h(x - x_i) \tag{1}$$

and returns the estimated density at a location x. The α_i is the kernel weights with $\sum_{i=1}^{N} \alpha_i = 1$. Usually, all kernels are equally weighted, $\alpha_i = 1/N$. The kernel function $k_h\ (x)$ is required to satisfy $\int k_h\,(x)\,dx\ = 1$ and $k_h(x) \geqslant 0\, \forall \times\ \in R^2$. More important than the kernel function is the bandwidth h, which controls the degree of smoothing of the surface.

3.2 Spatial Scan Statistic

Based on the empirical results reported in Helbich and Leitner (2012), the Spatial Scan Statistic (SSS) (Kulldorf 1997) is chosen as clustering algorithm. Compared to other clustering methods, the SSS method detects local clusters and tests if such clusters are occurred by chance (Kulldorf 1997). Furthermore, the analyst does not need to determine parameters algorithmically (e.g. numbers of clusters, minimum numbers of points in a cluster, the radius of the circle). The SSS method uses a circular window to identify the most likely cluster (MLC; the cluster that maximizes the likelihood ratio). Secondary Clusters (SC) are also significant ones. Following Helbich (2012), this study uses the Bernoulli model (Kulldorff 1997) to detect significant local spatial cluster of tourist accommodations (cases) compared to a heterogeneously distributed control population (all tourist activities). The null hypothesis is that the cases are evenly distributed and follow the distribution of the control population. Thus, no spatial clusters exist. The likelihood function for the Bernoulli model is defined as:

$$A = \left(\frac{c}{n}\right)^{c} \left(\frac{n-c}{n}\right)^{n-c} \left(\frac{C-c}{N-n}\right)^{C-c} \left(\frac{(N-n)-(C-c)}{N-n}\right)^{(N-n)-(C-c)} I() \qquad (2)$$

where C is the total number of cases, c is the observed number of cases within the window, n is the total number of cases and controls within the window, and N is the combined total number of cases and controls. Monte Carlo simulations are implemented to test the significance of clusters.

4 Materials

4.1 Study Area

The city of Vienna, Austria, is chosen as study area. Overall, about 1 million photos are tagged with the label "Vienna". Approximately 245,000 of these photos are geotagged and time stamped. Each geotagged photo contains the coordinates (lon, lat) of its location in the Exchangeable Image File Format (EXIF), uploaded by the user. The EXIF metadata can be acquired via the Flickr Application Program Interface (API).

4.2 Data and Preprocessing

A keyword tag search ("accommodation", "hotel", "apartment", "room", and "bed") via the Flickr API is used to acquire geotagged photos related to tourist accommodations. Additionally, by means of a bounding box outlier coordinates are excluded. The temporal search dimension is set from 1 Jan 2000 to 31 Dec 2011. Next, photos taken by residents are excluded following the method proposed in Girardin et al. (2007). We divided the time period (2000–2011) into 30 day intervals and determined the number of periods in which the photographer took photos. If a photographer took all photos within 30 days, he/she is considered as a visitor. Contrary, if the interval is greater than 30 days between two photos, the photographer is characterized as resident. Via this approach, it is possible to discarded residents from tourists.

Moreover, three kinds of user errors must be eliminated: (1) Users may tag a series of photos taken in neighboring locations with the same coordinates and/or identical date. (2) Users upload a sequence of photos of the same object at a certain location at a continuous time period by changing focal distance or exposure. Such photos provide the same spatial and temporal information and can be replaced by only one photo out of them (e.g. the photo with the earliest timestamp). (3) Some users take photos of hotels where they do not stay. This needs the assumption that each user lives only in one of hotels which he/she has photographed. To deal with this kind of error, following procedure is used. First, photos with obvious textual tags indicating locational attributes of photographers are selected, for instance, keywords as "our hotel", "my room", "I lived", and "we stayed" that determine some information regarding photographers' accommodation are filtered. Second, indoor photos are considered as a record of the users' accommodation. Some of these indoor photos can be distinguished via the API by means of tags such as "indoor". The other indoor photos are distinguished via a visual interpretation of the context of the photo. These steps result in a set of photos reflecting the accommodation of the users. According to above assumptions, the final photo set represents the cumulative number of customers (or check-in rooms) of hotels or apartments during 2000 to 2011 in Vienna.

After all, 3,736 geotagged photos are acquired. After distinguishing between tourists and residents as well as discarding noisy photos, 1,706 photos are transformed to a spatial point set (PS). Among those photos, 418 are taken in spring (March, April, and May), 477 in summer (June, July, and August), 446 in autumn (September, October, and November), and 370 in winter (December, January, and February). This point set is then divided in four seasonal point patterns. Additionally to these point patterns, the SSS needs a control pattern, representing the background population. In doing so, geotagged photos showing tourist activities are chosen. For Vienna 195,731 geotagged photos taken during the time period from Jan 1 2000 to 31 Dec 2011 exist. To reduce computational time, a random sample of 19,573 photos is chosen (10 % of the total number of photos) and preprocessed as described above. Finally, this results in a point control pattern of 1,765 objects, subdivided in separate point patterns representing tourist accommodations for each season.

5 Results

The KDEs of the tourist accommodations for each season are calculated with different bandwidths ranging from 1 to 20 m. For instance, the results of the KDEs with $h = 10$ m are shown in Fig. 1 (basemap by OpenStreetMap). Clearly, some

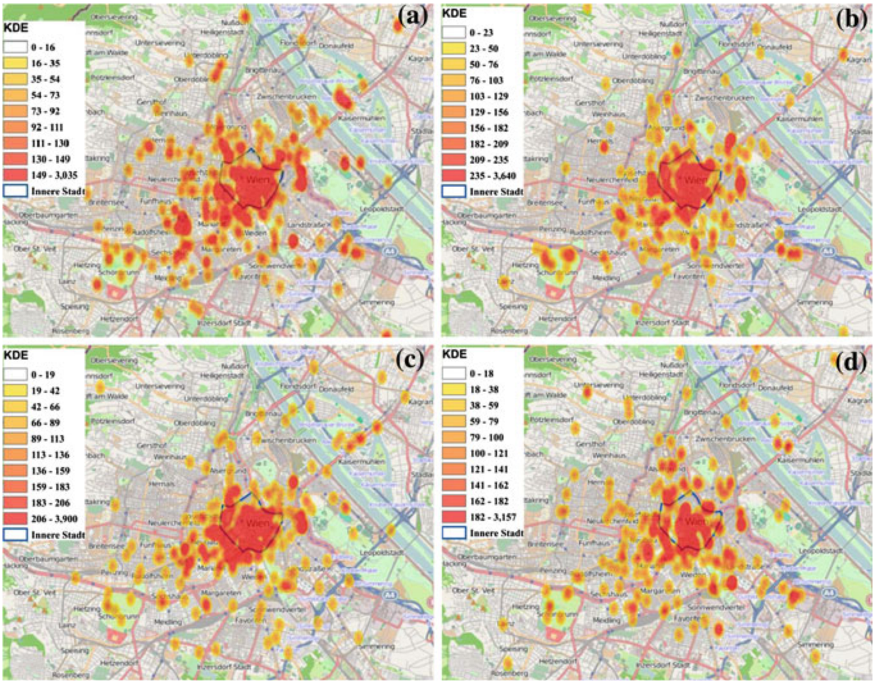

Fig. 1 Seasonal KDEs of tourist accommodations in Vienna (h0 = 10 m): **a** spring, **b** summer, **c** autumn, **d** winter

hotspots (colored in red) are noticeable. Comparing the seasonal KDE distributions, following conclusions can be mentioned: First, the district *Innere Stadt* (downtown) is always mapped as a hotspot, independently of the season. Second, several small-sized hotspots are evident. The distribution of hotspots is most dispersed in spring and most concentrated in autumn. This illustrates a seasonal tendency of the spatial pattern of tourist accommodations.

Thereafter, the significant spatial clusters of tourist accommodation within the four seasons are discussed. Significance vales are based on 999 Monte Carlo simulations. Significant clusters with a p value <0.05 are shown in Table 1.

The spatial distributions of significant clusters in four seasons are visualized in Fig. 2. It is shown that the MLCs of the four seasons are all located in areas close to downtown. Besides, MLC in winter is located in the southeast of the downtown while the MLCs of the other three seasons are located in the western parts of the downtown. Moreover, the MLC of spring has the largest number of points (142) and radius (2,221 m) compared to the other MLCs. The largest SCs are SC1 for spring, SC2 for summer, SC1 for autumn, and SC1 for winter. Besides, the largest SC of summer (SC3) has the largest number of points (242) and second largest radius (6,083 m). The largest SC in spring, summer, and autumn covers an area including downtown and large parts of the north-east of downtown. In winter this

Table 1 Spatial clusters of tourist accommodations in Vienna

Cluster	Radius (m)	Number of observations	ODE	LLR	*p* value
(a) Spring					
MLC	2,221	142	2.13	63.12	<0.001
SC1	6,322	210	1.62	41.11	<0.001
SC2	5,491	22	2.98	21.44	<0.001
SC3	854	36	2.33	18.90	<0.001
SC4	120	42	2.07	16.14	<0.001
SC5	3,893	24	2.20	10.67	0.040
(b) Summer					
MLC	851	23	4.19	27.62	<0.001
SC1	2,805	16	4.74	25.11	<0.001
SC2	6,083	242	1.37	23.93	<0.001
SC3	1,402	13	4.11	14.94	0.002
(c) Autumn					
MLC	788	61	4.26	74.30	<0.001
SC1	4,633	94	1.68	16.45	<0.001
SC2	7,796	14	4.08	15.33	<0.001
SC3	1,387	24	2.48	10.85	0.045
SC4	36	10	4.51	12.97	0.01
(d) Winter					
MLC	620	18	5.77	31.92	<0.001
SC1	2,182	63	2.49	28.96	<0.001
SC2	3,930	61	2.44	26.93	<0.001
SC3	54	17	4.67	20.63	<0.001
SC4	1,675	14	4.49	15.96	<0.001
SC5	288	11	4.23	11.46	0.019

Note ODE is the ratio of the number of observed cases to number of expected cases in the cluster. *LLR* is log-likelihood ratio

area is located between downtown and *Schönbrunn Palace* (including parts of downtown). Additionally, there are two other main areas where clusters are detected. One is in the south of *Schönbrunn Palace*, where the SCs have relatively large radii as well as relatively small number of points (e.g. see SC1 in summer). The other one represents the area in the south of downtown, including partial areas of the districts *Wieden*, *Margareten,* and *Favoriten*. SC3 of summer and SC4 of winter are located in that area too.

6 Conclusions

The chapter is aimed is to explore the possibilities of Flickr photos to analyze spatiotemporal patterns of tourist accommodations. In order to do so, seasonality of tourist accommodation is considered and significant spatial clusters are detected

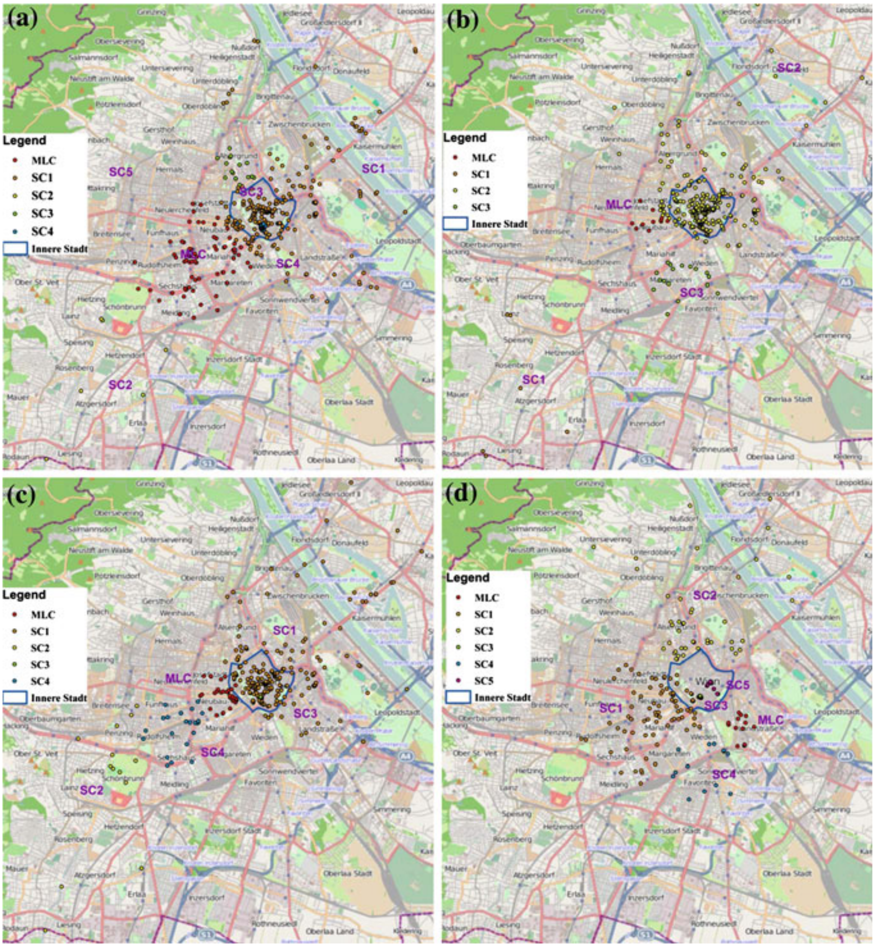

Fig. 2 Spatial clusters of tourist accommodations in Vienna: **a** spring, **b** summer, **c** autumn, **d** winter

during each particular season. This study demonstrates that Flickr photos can help to get deeper insights in tourist accommodations. The results illustrate some seasonal tendency of the spatial patterns of tourist accommodations. Moreover, the detected clusters (hotspots) indicate seasonal changes in tourist accommodations. Compared to traditional proprietary geographic data, VGI has the following advantages: First, by motivating individuals to act voluntarily and gather geodata, it clearly reduces monetary costs. Second, VGI products are almost invariably available (Goodchild 2007b). Sometimes, VGI can easily be acquired and preprocessed. In our study, the acquirement and preprocessing of traditional geographic data (e.g. survey and archive data) is more time-consuming compared to Flickr photos. Even though, VGI has some disadvantages, too. Wiersma (2010) states that one bias results from the "digital divide". He explains that the digital divide is well studied in sociology, and points out that there are differences in the levels of technological literacy as well as in access to broadband technology in remote and rural areas. As a consequence, this results in differential levels of public participation based on factors such as income, education, and place of residence. The other limitation comprises little top-down control of the data gathering process that induces a greater potential for errors and user bias to creep in, unless explicit protocols are developed for data collection along with post hoc data filtering (Wiersma 2010). Such weaknesses are also valid for this study using Flickr data. The point set is sparse and consists of less than 2,000 points in Vienna, meaning that the representativeness of Flickr photos is not very well. Furthermore, the number of the points comprising the point set might be much smaller in rural areas. Thus, the results of the KDEs and the cluster detections might have a reliability problem as well as suffer from accuracy. Even there are enough points in the point set (e.g. 100,000 points recording tourist accommodations in Vienna), the representativeness still needs to be improved. Sometimes old and luxury hotels attract more photos than new and economic hotels, while the latter provide accommodations to most of the tourists in a city. Furthermore, the number of photos might not well represent the number of customers (or check-in rooms). Finally, it can be concluded that statistical data of surveys and data archives could not be replaced by Flickr photos. But these traditional datasets can and should be supplemented by Flickr data.

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A Platform for Location Based App Development for Citizen Science and Community Mapping

Claire Ellul, Suneeta Gupta, Mordechai Muki Haklay and Kevin Bryson

Abstract Community Mapping and Citizen Science involve members of the public in projects to address real-world problems such as noise pollution, air pollution or large-scale development in their neighbourhood. Many of these are inherently location-based and maps provide a powerful tool for engagement. Most importantly, they can be tailor-made to display information required by the drivers of these projects—different groups of people with different interests. Previous Community Mapping and Citizen Science projects allowed the public to capture data for use on such maps via web based systems. However, mobile devices offer additional means of data capture and their in-built sensing devices (microphone, accelerometer, GPS) allow participants to work with additional types of information not available on web-based systems. Although many such Applications (Apps) exist, our experience with community groups shows that flexibility is key—the groups themselves must be able to decide what information they are interested in. While it is possible to meet this need by developing a bespoke App for each group, many of the group members involved in such projects are not programmers and do not have funding for bespoke development. This paper describes the development of a location based services App platform for Community Mapping and Citizen Science. The platform allows an unlimited number of bespoke Apps to be created by a non-technical administrator, without the need for programming skills.

Keywords Citizen science · LBS apps · Community mapping · Non-technical users

C. Ellul (✉) · M. M. Haklay
Department of Civil, Environmental and Geomatic Engineering, University College London, Gower Street, London, UK
e-mail: c.ellul@ucl.ac.uk

S. Gupta · K. Bryson
Department of Computer Science, University College London, Gower Street, London, UK

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1 Introduction

Citizen Science is a form of research collaboration involving members of the public in scientific research projects to address real-world problems (Wiggins and Crowston 2011), and has also been defined as the scientific activities in which non-professional scientists volunteer to participate in data collection, analysis and dissemination of a scientific project (Cohn 2008; Silvertown 2009). Such projects form an open collaboration where the goals of the scientific endeavour are often set by the communities who will benefit from the results obtained and from the additional understanding that is derived through involvement in the project. A similar approach is taken in Community Mapping activities, although here the reach of projects is broadened out beyond the traditionally 'scientific' measurement towards issues relating to perception mapping (where users describe how they feel about their environment, what they like and dislike, what changes they would like to see) as well as identifying sites for potential development and recording local history (Ellul et al. 2009b, 2011). In both cases, the ability to include a location component to data capture forms a fundamental component of any project—for example, noise and air quality measurements are spatial in nature, an individual's perception of their neighbourhood may relate to specific instances of graffiti or fly tipping. The importance of such activities when considering environmental issues and sustainability should not be underestimated—indeed, a Principle 10 of the 1992 Rio Declaration states that (United Nations 1992):

> Environmental issues are best handled with the participation of all concerned citizens. At the national level each individual shall have appropriate access to information concerning the environment [..] and the opportunity to participate in the decision making process.

Until recently, data capture for both of these project types was often undertaken by users sitting at their personal computers and digitising data of interest. Whilst this has worked very well to date (Ellul et al. 2011), the emergence of Smart Phones with in-built location sensors (via the mobile network or Global Positioning System, GPS) can greatly facilitate data capture when compared to the web-based approach.

Previous projects (Ellul et al. 2011) and our experience with community groups shows that flexibility is key to engaging people in both Citizen Science and Community Mapping projects—participants themselves must be able to decide what information they are interested in. This in turn highlights the importance of bespoke tools for each project, and in each case the required Smart Phone Application (App) must be developed and tested, requiring programming expertise. Therefore, for such projects to take advantage of location-based tools and services (and the resulting improvement in data capture methods), some level of technical skill is necessary to develop the required bespoke Apps. While such expertise (or funding to develop the Apps) may be available in some teams, this is often not the case. To maximise the reach of Smart Phone based Citizen Science and Community Mapping activities, a non-programmatic approach to bespoke web and mobile tool development is required.

We have previously reported (Ellul et al. 2009a, b, 2012) on the development of a web-based platform for Community Mapping and Citizen Science. In this paper, we report on the development of a mobile location based platform to meet the same needs—i.e. to allow non-programmers to deploy Apps configured for the requirements of a specific scientific or community activity.

The remainder of this paper is structured as follows—following a brief overview of Citizen Science and Community Mapping, we review a number of relevant location-based Apps, along with existing platforms to allow non-technical users to develop and deploy such Apps. Limitations of these approaches are discussed in the light of three specific projects in which we are currently involved. Our platform for location-based App development is then presented, and the paper concludes with considerations as to its potential, along with an outline of further work required before the platform can be deployed to a wider audience.

2 Background

2.1 Citizen Science

Although only having received attention recently, Citizen Science in fact pre-dates modern science. As Silvertown (2009) notes, until the late 19th century, science was mainly developed by people who were otherwise employed, using their free time for data collection and analysis. Even with the rise of the professional scientist, the role of volunteers has not disappeared, especially in areas such as archaeology, where it is common for enthusiasts to join excavations, or in natural science and ecology, where they collect and send samples and observations to central repositories. Activities include the Christmas Bird Watch that has been active since 1900 and the British Trust for Ornithology Survey, which was established in 1932 and has collected over 31 million records (Silvertown 2009). Astronomy is another area where volunteers have been on par with professionals—for example where the identification of galaxies, comets and asteroids are considered (BBC 2006). Meteorological observations have also relied on volunteers since the early start of systematic measurements of temperature, precipitation or extreme weather events (World Meteorological Organisation 2001). A list of additional citizen science activities can be found in Haklay (2012) and also in Scientific American (2012).

Of particular relevance to location based services is participatory sensing, where the capabilities of mobile phones are used to sense the environment (Haklay 2012). Some mobile phones have up to nine sensors integrated into them, including different transceivers (mobile network, WiFi, Bluetooth), FM and GPS receivers, camera, accelerometer, digital compass and microphone. In addition, they can link to external sensors.

2.2 Community Mapping

A United Kingdom (UK) Government White Paper entitled "Communities in Control—Real people, real power" (Communities in Control 2008) published in July 2008, and the more recent Big *Society* initiatives by the United Kingdom Government (BBC 2011) both reflect ongoing efforts by central and local government to increase community participation and generate a more vibrant local democracy. Access to information forms an important part of this process (and indeed forms the first element on the latter of citizen participation proposed by Arnstein 1969). Internet-based Geographical Information Systems (Web GIS) have long been seen as part of this information dissemination process, as well as being a tool to encourage participation in local decision making. They have importance both in the top–down 'information' dissemination processes and the bottom–up 'participation' processes forming part of local planning activities (Talen 2000). In particular, community-sourced mapping is of importance—information regarded as relevant by community groups is not necessarily identical to that provided by local government (perhaps due to issues of scale, currency or trust). Government-issued information also tends to ignore local knowledge (Elwood 2007). Community Mapping projects such as those described in Ellul et al. (2011) thus have particular relevance as they allow each group to identify their own interests, define what they would like to appear on their map and take ownership of the data capture, moderation and maintenance processes.

2.3 Bespoke Location-Based Apps for Citizen Science and Community Mapping

A number of Apps are available that, although not customisable to the requirements of individual community groups do offer a useful insight into how Location-Based Apps can be used in the context of Citizen Science and Community Mapping. An in-depth description is given here of one noise monitoring App, as this illustrates how sensors built into the mobile device can be used to replace more expensive tools (sound meters), widening the potential participant group for noise-related Citizen Science activities. This is followed by a very short overview of a number of other bespoke applications that primarily relate to data capture. We do not aim to provide a comprehensive list, in particular as Apps are emerging daily, but rather to illustrate what can be achieved in terms of developing bespoke location-based Apps for Citizen Scientists and Community Mappers.

EveryAware WideNoise (EveryAware 2012, Fig. 1) has been developed as part of the EU FP7 funded EveryAware[1] research project and permits a user to monitor

[1] See http: www.everyaware.eu [Accessed 23rd April 2012] for details.

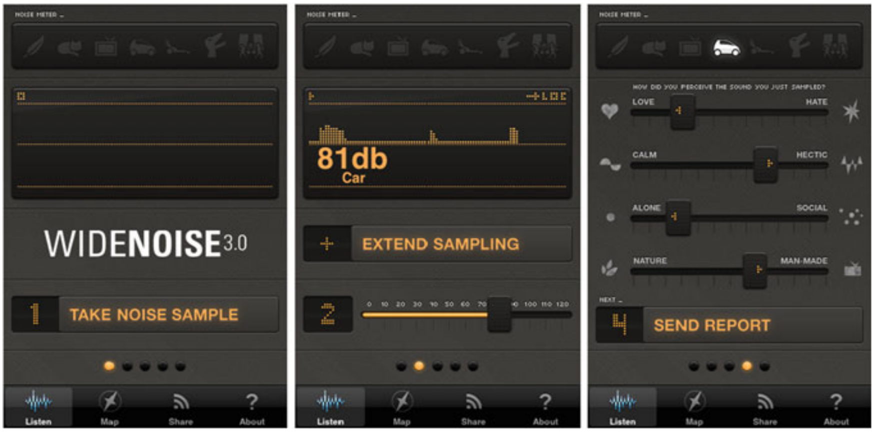

Fig. 1 EveryAware WideNoise start screen, decibel prediction screen and qualitative rating of the noise

the noise levels around them, making use of the in-built microphone on a Smart Phone.

When the EveryAware WideNoise application is first opened, a start screen allows the user to start taking noise samples (of 30 s duration). During recording, a graphical representation shows the change in sound volume (in decibels). The user is also able to extend the audio recording from the default length. At the same time, is also possible for the user to attempt a guess at the maximum decibel level the audio recording may reach. Once the user has finished recording their noise sample, a noise context rating is shown allowing comparisons e.g. a sleeping cat, rock concert area. The user is then able to restart the audio recording or carry on to qualify the noise—do they love or hate the sound, is the sound calming or hectic. The user can then send the report to EveryAware for further analysis—the recordings are also made public on the WideNoise website. The user is then able to share noise values via Facebook and Twitter to raise awareness amongst friends.

Similar noise-focussed Apps exist and can also be downloaded free of charge. NoiseTube (Maisonneuve et al. 2010), was created in 2008 at the Sony Computer Science Lab in Paris and is currently hosted by the BrusSense Team at the Vrije Universiteit Brussel. NoiseWatch, from Eye On Earth (2012) set up by the European Environment Agency to monitor air quality, noise and water quality) allows the user to take noise samples for 10 s apiece.

Looking beyond noise, Apps such as those developed by Project Noah (2012) allow people to document nature with their mobile phones and assist scientists with ongoing research. Research scientists can also use the platform to define "missions" where specific animals and wildlife are searched for in particular areas of the globe. LeafWatch (2012) is a UK-based App which allows users to identify and photograph leaves, and also to give a rating to their condition, enabling the

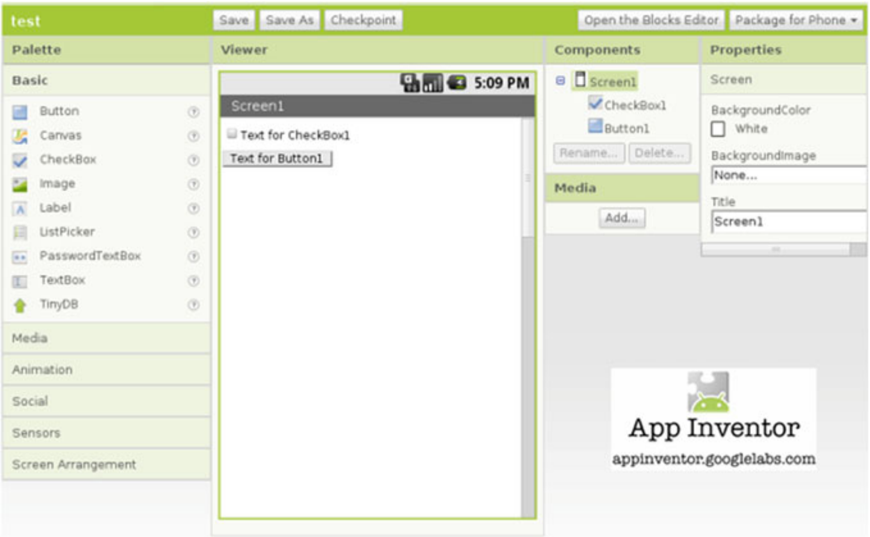

Fig. 2 App Inventor dashboard

collected data to be used to monitor tree and plant health[2]. In the context of Community Mapping, perhaps one of the best known (in the UK) Apps is Mappiness (MacKerron 2011). This App prompts users, at random intervals during the day to rate their level of happiness, and collects this information along with who the user is with, where they are and what they are doing.

2.4 *Location-Based App Development Platforms for Non-Technical Users*

A number of existing platforms to enable non-technical users to undertake App development can be identified. For example, for the Android platform, the Massachusetts Institute of Technology offer the *App Inventor* tool (App Inventor 2012), Fig. 2. App Inventor uses visual design so the designer can preview the final results.

A second alternative is offered by EpiCollect (Aanensen et al. 2009, Fig. 3) which provides a web application for the generation of forms and freely hosted project websites (using Google's AppEngine). EpiCollect allows a user to create a mobile data collection project and specify what kinds of data they'd like to collect such as text, textboxes, radio buttons and check boxes. The application can then be

[2] An more comprehensive review of nature based Apps can be found at http://musematic.net/2011/10/12/mobile-apps-for-citizen-science/.

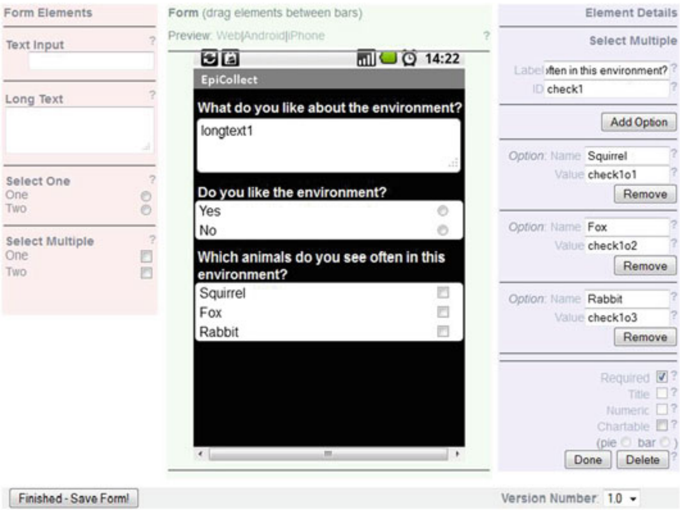

Fig. 3 The EpiCollect interface

accessed on a compatible mobile phone by downloading the EpiCollect App and loading the project. After data has been collected, the project creator can logon to their account on the EpiCollect website and see all the collected data included text and pictures in database format.

A third App development platform is offered by the Open Data Kit (ODK, Hartung et al. 2010) project, which allows organisations to develop field-based data collection toolkits. Functionality provided includes the ability to ask users to capture text, numbers, dates, location, media and bar codes and to select a single or multiple options from a list. An interactive form designer is used to create an XML version of the required form, which is then deployed to a pre-configured server. The ODK App on the device can then be configured to connect to the server, allowing users to enter data into the form and save it to your server.

Additional fee-based App development tools also available—for example do-Forms[3] allows capture of date, text, single and multiple choice, lookup tables, GPS coordinates, sketch drawings, photos, video and audio clips and also includes "skip" logic, which allows the system to respond dynamically to users' selections. A similar platform is available from MobiForms,[4] which also offers integration with databases such as Oracle and MySQL and also offers GPS integration.

[3] http://www.doforms.com/, Accessed 26th April 2012.

[4] http://www.mobiforms.com/, Accessed 26th April 2012.

3 Requirements for Location-Based Citizen Science and Community Mapping Apps

As can be seen from the range of platforms described above, a requirement for flexible, bespoke, App development by non-technical users is not unique to our research team. However, our review of existing approaches highlights three main issues—firstly, some platforms require you to upload data to a central server hosted by the platform providers. This could cause issues with regard to data confidentiality, particularly where sensitive data is concerned (see the *Monitoring of Illegal Logging* case study below). Given our existing web-based platform, we additionally require that data is integrated directly with our servers to make it immediately available to our research teams. Secondly, many of the platforms do not offer full connectivity with all the sensors available to citizen scientists on a mobile device—for example, the accelerometer or microphone. Even where sensors such as GPS can be used, this is often restricted to one 'reading' per App, which is not appropriate to many location-based Apps requiring continuous positioning traces. Thirdly, the platforms do not offer the range of functionality required to support activities where users may not have the literacy or numeracy skills required to work with standard text-based forms.

Looking specifically at the three platforms described above, while App Inventor makes very good use of all the sensors and devices on board the Smart Phone, it requires the App designer to design state machine diagrams and link them to various variables/methods and to also be able integrate with web services. Additionally, Apps cannot as yet be uploaded to the Android Market[5] and multi-screen Apps are not available.[6] For EpiCollect the data can be exported to CSV or Excel format, but there are limitations in terms of the types of data that can be collected—namely text and pictures. It is also not possible to associate multiple GPS readings (e.g. a GPS trace) with the data and all data must be uploaded to the EpiCollect server (although as the project is open source this could be altered). A similar restriction on the GPS trace option exists for the ODK platform and although this tool does allow you to save the data directly to your own server, it does not integrate well with the on-phone devices—indeed, camera (photo or video) options are not provided, and no options are included to integrate with the on-board microphone or accelerometer.

Specific requirements for two Location-Based Apps *Noise Measurement* and *Monitoring Illegal Logging and Poaching*, and one Community Mapping App *Perception Mapping* are described here to illustrate the importance of these issues:

5 http://beta.appinventor.mit.edu/learn/userfaq.html, Accessed 26th April 2012.

6 http://beta.appinventor.mit.edu/learn/userfaq.html, Accessed 26th April 2012.

3.1 Noise Measurement

As can be seen from the list of bespoke location-based noise Apps described above, noise forms a key area of interest to Citizen Scientists, and capturing noise readings using appropriately calibrated equipment can be used to empower citizens to remove a noise nuisance in their neighbourhood (Haklay et al. 2008). Mobile phones, with their in-built microphones, provide an appropriate tool for this type of activity. However, work previously carried out by our team highlights the fact that in the case of community-led citizen science, a generic Noise App does not meet requirements. Two issues arise: depending on the source of the noise nuisance, different protocols may be required for measurement. In some cases (e.g. flight noise), taking three 1 min samples at random times during the day may be appropriate. In other cases, a longer measurement time may be required (e.g. 5 min sampling time). Fixed length noise measurement (e.g. 10 s from Noise-Watch) does not offer this flexibility. Secondly, as shown above, Noise Apps include both quantitative data capture [the dB(A) measurement] and qualitative information. The latter will vary depending on the requirements of the individual community and the "standard" values such as *love/hate, calm/hectic, alone/social, natural/man-made* offered by EveryAware WideNoise do not match those required by groups monitoring flight noise, where tags requested by the group included *enjoyable, annoying, threatening, high-pitched, shrill* and many others, along with a requirement to select multiple options rather than the pairs suggested by EveryAware (Fig. 1). Indeed, it is important for each community to be able to define its own qualitative text and word groupings.

3.2 Monitoring of Illegal Logging and Poaching by Non-Literate Users

Dr. Jerome Lewis is an anthropologist working with UCL's Extreme Citizen Science (ExCiteS) group. He has established a long-term working relationship with a group of pygmy hunter gatherers in the Congo basin, investigating (amongst other things) discrimination, economic and legal marginalization. As part of this effort, he has developed a series of tools to support data gathering of conservation-related information such as resource damage in logging, illegal logging, poaching. These custom-built tools, developed in conjunction with Helveta, have been designed specifically for use by non-literate groups (Lewis 2007). A second phase of the research is designed to further empower the hunter gatherers by allowing them to visualize patterns of illegal activity across space and time. As part of this, there is a requirement to move from the custom Helveta platform for data capture to a more mainstream platform such as Android. The current tools use icons to allow data logging by non-literate hunter gatherers, and it is expected that the new tools will make use of the same *image picker* approach. A series of appropriate

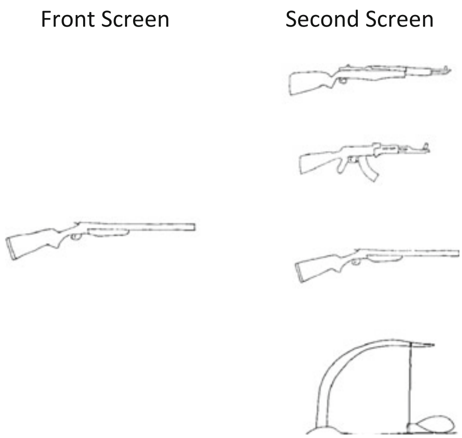

Fig. 4 Sample draft icons for the illegal logging and poaching app (courtesy of Dr. Jerome Lewis)

icons to cover poaching, illegal logging and other activities have thus been developed in conjunction with the tribes people themselves. Image picker functionality is required as follows (Fig. 4):

- The application should start with a screen showing six icons.
- Clicking one of these icons takes the user to a second level page of icons relating to that specific topic.
- Clicking a level 2 icon takes the user to a level 3 icon, which the user can then click on to capture the data point in question.
- As part of the level 3 click, the GPS reading of the device should also be saved.

As many of the poaching sites are some days' walk into the forest, any tools developed cannot assume that a mobile phone network will always be available. Data must be saved to the local device. The nature of the data captured is also very sensitive.

3.3 Perception Mapping

Perception mapping is an important component of Community Mapping, and allows users to comment on the positive and negative aspects of their local environment, often providing a mechanism to identify issues of concern to each community group. Such information could then be used by, for example, Local Authorities who could prioritise areas for improvement. Previous work with community groups has highlighted that the information of interest to one group may not be identical to another. One neighbourhood may have a problem with graffiti, while another has a problem with illegal rubbish disposal. Although perception mapping can be done as a paper-based exercise (giving people post-it notes to place on a map) or on a web based Community Map, Smart Phones offer a much more interactive, real-time option to collect such data. The App should allow the user to walk around their neighbourhood, and take a video (with voice recording of their commentary) as they walk, tracking their location as they move using GPS in order to be able to tag elements of the video to specific locations. Having a voice-based commentary overcomes issues that many users have with typing large quantities of data using the small touch-based keyboards on a Smart Phone, and the video allows them to focus on specific areas related to their voice-over commentary.

4 The Resulting Platform

A key decision to be made at the outset of the project was between an HTML5 web application and native App programming. HTML5 Apps are written with web standards, primarily HTML, CSS, and JavaScript, and can be deployed on all mobile platforms. This makes them cheaper to produce and easier to deploy to wider audiences. However, currently issues can be identified with integration with a number of sensors (e.g. GPS, accelerometer, camera) on mobile devices, and the wide range of browsers on the devices means that not all HTML5 functionality is available on all platforms as yet (although the standard is continually evolving). An always-on connection may also be assumed.

It was therefore decided to initially develop the App using Java and XML for the Android platform. This decision was driven in part by the lower cost of Android Smart Phones compared to the main rival Apple (at the time of writing, a Samsung Galaxy Europa Black phone with Android can be bought as a pay-as-you-go phone for £49.99,[7] versus an Apple iPhone 3GS for £299.99[8]), and their greater level of uptake (Android powered 59 % of all mobile devices shipped in the fourth quarter of 2011, versus 23.8 % from Apple[9]) meaning that Apps could be deployed to a greater number of users. Android/Java development also permits direct access to the required sensors. Crucially, working with the native development environment means that the App does not assume an ‘always on’ data connection.

Figure 5 shows a Use-Case diagram for the developed platform. As can be seen, two groups of functionality have been identified—web-based administrator functionality which allows non-specialist coordinators of Citizen Science and Community Mapping activities to generate Apps and deploy them to the general public, and the Mobile Application itself, which combines the requested functionality in the order required.

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7 http://store.three.co.uk/view/searchDevice?sort=payGPriceValue-ascending&priceplan=PAYG&greatForServices=&manufacturerName=&type=HANDSET, Accessed 22nd April 2012.

8 http://store.three.co.uk/view/product/ql_catalog/threecatdevice/2105 Accessed 22nd April 2012.

9 http://www.guardian.co.uk/technology/2012/feb/15/android-smartphones-apple-2011 Accessed 22nd April 2012.

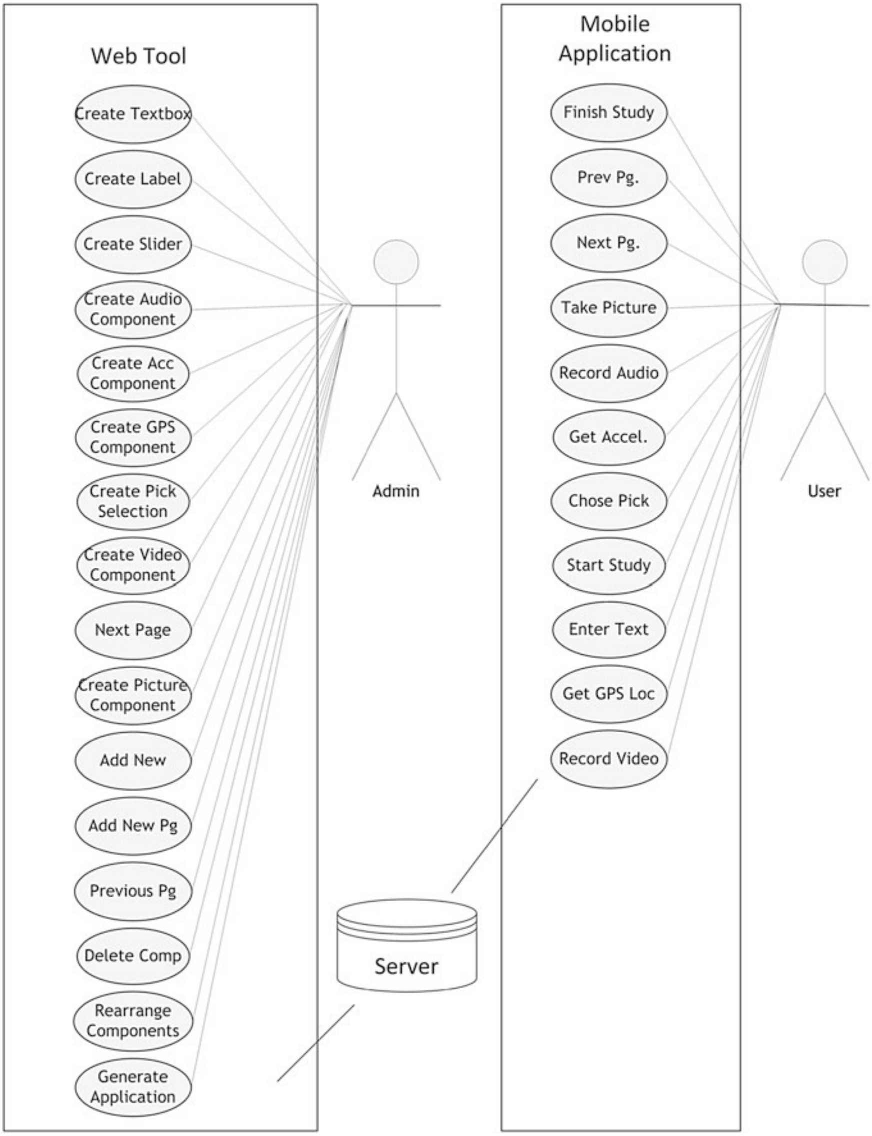


Fig. 5 Use case diagram for the platform

Figure 6 gives more detail about the functions available to each Smart Phone App. Currently this includes login functionality, the ability to capture text and dates, single drop-downs and multiple selections, photographs, audio recording, video recording, capturing a single GPS reading, capturing a GPS trail, record accelerometer readings, picking an image from a set of images (which can in turn link to further sets of images), saving the captured data, and uploading the data to the server.

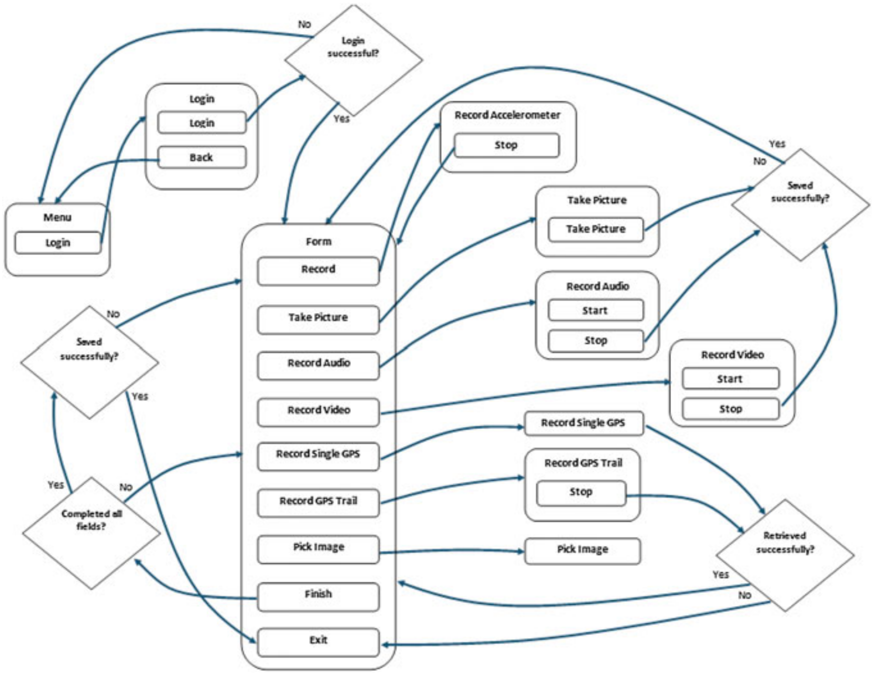


Fig. 6 Functions available for each Smart Phone App

Each bespoke App developed using the platform makes use of two components. Firstly, a series of XML documents are generated, detailing the layout of each page in the App and the order in which the pages are linked. The required XML documents are generated by the web-based administration application, and then embedded into the.apk file, which is the zip file that makes up a deployable Android application. Secondly, a set of Java classes have been written to process the XML and launch appropriate functionality and activities depending on the required content. When the App is run, the Java code parses the XML files to generate the appropriate forms, and generic code handles data capture on the forms, depending on the type of data (photo, GPS point, GPS trace and so forth).

A worked example is given here to illustrate the end to end process for one form. The following XML (Fig. 7) is used to generate the form shown in Fig. 8a. The ID values of the of the elements, which are used to determine the type of data being captured and the element TAGS are used to provide the field names into which the resulting data is to be inserted once submitted into the database.

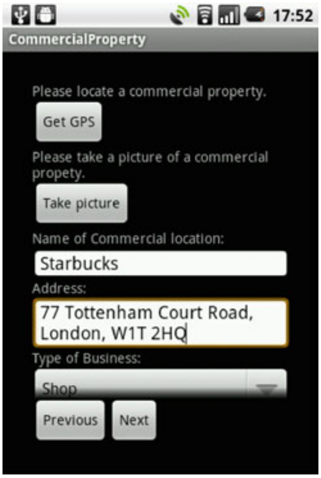
The resulting form appears as shown in Fig. 8a. Once the user has finished capturing data, data is stored on the devices' SD card for upload to the server once a Wi-Fi connection becomes available. Once the user finalizes data entry, the Java code parses the elements on the form, and generates a name/value pair text file which is stored on the SD card on the device for upload at an appropriate time (e.g. when Wi-Fi is available). The data file from the form is shown in Fig. 8b.

```
<LinearLayout
                android:orientation="vertical"
                android:layout_height="wrap_content"
                android:layout_width="fill_parent"
                android:layout_gravity="center">
                <!--adding components to LinearLayout-->
        <Button
                android:id="@+id/gpsSingle<1>"
                android:layout_width="wrap_content"
                android:layout_height="wrap_content"
                android:onClick="getLocation"
                android:text="Get GPS">
       </Button>
        <Button
                android:id="@+id/picture<1>"
                android:layout_width="wrap_content"
                android:layout_height="wrap_content"
                android:onClick="takePicture"
                android:text="Take picture">
        </Button>
        <TextView
                android:layout_width="fill_parent"
                android:layout_height="wrap_content"
                android:text="Name of Commercial location" />
        <EditText android:id="@+id/textbox<1>"
                android:layout_width="fill_parent"
                android:tag="commercial_location_name"
                android:layout_height="wrap_content"
        android:background="@android:drawable/editbox_background"
                android:text=""/>
        <TextView
                android:layout_width="fill_parent"
                android:layout_height="wrap_content"
                android:text="Address" />
        <EditText android:id="@+id/textbox<2>"
                android:tag="commercial_address"
                android:layout_width="fill_parent"
                android:layout_height="wrap_content"
        android:background="@android:drawable/editbox_background"
                android:text=""/>
        <Spinner
                android:id="@+id/spinner<1>"
                android:tag="type_of_business"
                android:layout_width="fill_parent"
                android:layout_height="wrap_content"
                android:entries="@array/spinner<1>_entries"
                android:prompt="@string/spinner<1>_prompt">
        </Spinner>
</LinearLayout>
```

Fig. 7 XML form creation

A similar approach is taken for other types of data capture. Fig. 9 shows the layout settings required for the Accelerometer and the GPS trail data capture types.

In each case, clicking on the respective button calls a method which starts an activity of the required type. For the accelerometer, it is changes in orientation of



(a)

```
<?xml version="1.0" encoding ="UTF-8"?>
<Data>
        <Record>
        date=18-03-2012 21:29:02,
        gpsSingle<1>=0.020,51.63392,
        picture1=/mnt/sdcard/Pictures/CommercialProperty – picture1 – 18-03-2012.jpg&timestamp=18-03-2012 21:27;&pgs=0.020,51.63392,
        commercial_location_name=Starbucks,
        commercial_address=77 Tottenham Court Road, London, W1T 2HQ
        type_of_business=shop,
        </Record>
</Data>
```

(b)

Fig. 8 **a** The Resulting Form and **b** the captured data

```
<Button
android:id="@+id/accelerometer1"
android:layout_width="wrap_content"
android:layout_height="wrap_content"
android:onClick="getAccelerometer"
android:text="Get Accelerometer">
</Button>
```

(a)

```
<Button
android:id="@+id/gpsTrail<#>"
android:layout_width="wrap_content"
android:layout_height="wrap_content"
android:onClick="getLocationTrail"
android:text="Get GPS Trail">
</Button>
```

(b)

Fig. 9 **a** XML layout for accelerometer and **b** XML layout for GPS trail

the device that are recorded—i.e. a listener is set up which records any changes in the X, Y and Z orientation values. For the GPS Trail, a location is requested and recorded every second, through a location listener. The GPS Trail functionality can be run in stand-alone mode, but can also be combined with other data capture types such as audio or video recording.

For all data capture, when a suitable network connection is enabled (either 3G or Wi-Fi, depending on the user's preferences), the data is posted to the server as a series of name value pairs. Although XML could be considered a more appropriate, generic format for data submission, the pairs allow existing code (for data submission on the Community Mapping web application, see Ellul et al. 2009a) to be used to update the platform database, using the standard storage formats defined for previous projects. This means that uploaded data will be immediately available to the web-based platform (subject to privacy issues where data will not be published).

5 Discussion

Although still a prototype, the development of a very flexible generic platform for App creation for a location-based data capture for Citizen Science and Community Mapping has proved feasible in the chosen environment (Android). Importantly, the platform is configurable via XML files, which in turn can be generated by a web-based administration tool, and can make use of all the inbuilt sensing devices on the Smart Phone. XML configuration negates the need for Citizen Scientists and Community Mappers to employ programmers and developers for each new project, and opens up data capture to a much wider user base. Given that initiators of, and participants in such activities often do so in their own time rather than via funded research projects, minimising development and deployment costs using this generic platform is appropriate.

The platform has been developed to be as flexible as possible in terms of the types of data that can be captured as in Community Mapping and Citizen Science activities the context, driven by the end users, is as valuable as the measurements that are collected by the community. The data types that can be collected currently include numbers, text, video, photography, pull-down lists, multiple selection lists, GPS readings, GPS traces, accelerometer readings and image pickers, providing great flexibility as to the range of information that can be gathered. The single generic "platform" code base will also be easier to maintain in future than different bespoke Apps developed for different activities.

A number of key functions differentiate our approach from those available to date. Firstly, the ability to work offline is fundamental to working in situations where a network is not available—both in the Congo Basin but also in some cases in the United Kingdom such as on the London Underground. Secondly, the image picker functionality, where clicking on an icon brings up a second and a third tier of options, is very useful when working with non-literate users, who can also actively participate in the icon design. Again, such functionality could also be useful when working with groups in the UK having low levels of literacy—or example new immigrants. Thirdly, the ability to record both individual GPS readings (associated with a photograph, for example) and GPS trails opens up the potential for continual measurements—for example, an App could be developed which measures noise exposure during a person's commute to work, tracking the points on their route where recommendations are exceeded.

Allmap-baseddataiscapturedandheldinnativespatialdataformatinsidethedatabase. This opens up the data to be shared across researchers in the group, who can then take advantageofvisualisationandanalysisfunctionalitybuiltintoGeographicalInformation Systems to examine and interrogate the data. The central data repository also permits questions relating to the quality of user-generated location-based Citizen Science and CommunityMappingdatatobeexamined.

An additional advantage of the database-based approach is the integration with a very well established Community Mapping and Citizen Science platform (Ellul et al. 2011). While many citizen science tools are available, they are not integrated into an online Community Mapping framework that allows rich data collection and post-collection annotation in bottom-up activities. Our framework provides the opportunity for further annotation of data, beyond that possibly by touch typing into a small Smart Phone or recoding a commentary as the user walks. Indeed, two avenues of data capture are automatically provided—an App based approach and a web-based approach, increasing the reach of any project to those who don't own a Smart Phone.

Although designed for Citizen Science and Community Mapping activities, the platform provides enough flexibility for use with other data collection tasks. As projects evolve and new requirements emerge, these can be added to the existing platform—the platform can also be easily extended to handle other types of data, such as that from external sensors coupled to the Smart Phone.

One issue common to many Location-Based Services also impacts the Apps developed using this platform—the accuracy of positioning technology, and in particular its limitations in an indoor setting. Network based positioning (using the mobile phone signal) can overcome these issues in some cases. Additionally, the coupling with the editable online Community Maps allows users to validate that their data was indeed recorded correctly, and make corrections if necessary.

A second issue that may arise is the size of the App itself—with traditional bespoke applications, only the code required by the App is included in the package. In our case, however, the generic code to handle all potential data sources and capture must be included, as the App does not know what data types it will be working with until it reads the XML configuration file when it is loaded.

However, perhaps the most important issue to be addressed within the project is the selection of Android as a development environment. While this does ensure the maximum reach for a single environment, the number of users of other devices (Apple, Research in Motion) cannot be ignored, and if required further versions of the above platform may be developed to address this issue.

In addition to multi-environment development, a number of important steps remain to be carried out before the platform can be deployed. Key amongst these is the skinning and design of the interfaces presented to users. Our platform currently generates prototype Apps using basic Android interface widgets (buttons, text boxes), which although usable are not very attractive. These need redesigning, perhaps to include the option of App or Community Group-specific 'branding' options that are currently available for the web based version of this platform.[10] Further integration is also required with the Community Maps themselves—moving from a basic manual integration to automatic data upload with the possibility for users to choose whether to share their data with the world or to submit data to the project without sharing. As part of this, the current administration tools

[10] For an example of personalised Community Maps, compare: http://www.communitymaps.org.uk/version5/includes/MiniSite.php?minisitename=East%20London%20Waterways&minisite_group = andhttp://www.communitymaps.org.uk/version5/includes/MiniSite.php?minisitename=East%20London%20Waterways&minisite_group=British%20Waterways

require expansion to fully automate the generation of the XML configuration files used to generate each App by the platform. Testing of the resulting Apps is also required—particularly in situations where battery life, lack of GPS or network signal is an issue.

Haklay (2012) notes the importance of knowing the accuracy of the instrumentation (in particular in the case of LBS-based Apps, the GPS receiver) in order to be clear about the quality of information that is being captured. For example, calibration (as described for NoiseTube, Maisonneuve et al. 2010, and Every-Aware WideNoise, EveryAware 2012) of microphones for noise measurement is important—such microphones are optimised to the frequencies used in normal speech, filtering ambient sound, and in addition may vary from device to device.

6 Conclusion

The range existing of Apps (both bespoke and generic) listed above highlights the importance of Location Based Services for Citizen Science and Community Mapping, and facilitating the use of such Apps can help policy makers as well as citizens, due to the resulting combination of residents' local knowledge and first-hand experience with recommendations from professional scientists (Coburn 2005). Both areas of research and engagement are focussed on the needs and requirements of the general public rather than of specific research groups within an academic environment. They are thus well placed to take advantage of the overall growth in uptake of Smart Phones, and to make use of the wide range of existing functionality these phones offer over standard mobile devices. Having a flexible App created specifically for a single project allows these end users to set the scientific agenda rather than (as is done with Project Noah, EveryAware Wide-Noise, NoiseTube) than just to participate more passively as data collectors. Giving the Citizen Scientists and Community Mappers the flexibility to define the specifications of the tools they will use will also help to move research towards the top of the Citizen Science ladder of participation proposed by Haklay (2012—where the lowest level limits the participants to one way data collection via sensors, higher levels increase their involvement in the project by increasingly participating in problem definition and at the highest level–*collaborative science*—they are involved in collective problem definition, data collection and analysis as full partners with the 'scientists'.

We conclude, however, with a note of caution—making use of the location-based technology described in this paper does indeed help to progress the work of Citizen Scientists and Community Mappers. However, in the United Kingdom, only a third of adults use Smart Phones (of any brand).[11] This means that fully two thirds of the population are excluded from using location-based technology on

[11] http://www.bbc.co.uk/news/technology-14397101, Accessed 24th April 2012.

such devices. This is even more the case in locations such as the Congo basin. The second-level digital divide (Hargittai 2002) should also be considered—people may have access to the required devices, but may not have the skills to interact with the Apps. When designing any Citizen Science or Community Mapping project, it is important, therefore, to use a range of tools and activities, from highly technical location based services to very low technology such as diffusion tubes or wipes for pollution measurement or post-it notes on paper maps for perception mapping. This, at least in part, will help to ensure that such projects reach a maximum number of participants with all levels of skill and interest.

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A Framework for On-line Detection of Custom Group Movement Patterns

Colin Kuntzsch and Alexander Bohn

Abstract This chapter describes a lightweight approach for custom definition and detection of group patterns in a real-time analysis scenario, using a simple, yet flexible notion for groups of moving point objects (MPOs) travelling together. Groups are defined as sets of MPOs that are directly or transitively related to each other via freely definable binary relations. Group candidates are identified within a snapshot view of the MPOs at discrete time instances. By backtracking over previous snapshots, stable group compositions over previous time instances are identified and reported. We give insight about the used data structures and algorithms for the group candidate calculation and backtracking steps and illustrate the approach's functionality with examples from a real data set.

Keywords Pattern recognition · Group motion · Real-time movement analysis

1 Introduction

Pattern analysis has been a major focus of research in recent years, stimulated by the increased availability of location information provided by ubiquitous sensors (e.g. GPS in mobile devices). Processing and analysis of location information, either online or offline, is highly beneficial for numerous scenarios of application. Analysis of movement data gives hints about the underlying complex behavior (motivation, intentions, reasons for e.g. selected routes in a scene or detection of

C. Kuntzsch (✉) · A. Bohn
Institute of Cartography and Geoinformatics, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany
e-mail: colin.kuntzsch@ikg.uni-hannover.de

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security-relevant behavior in surveillance scenarios). One topic among researchers during the last years are studies of interaction between moving entities, resulting in collective group movement patterns like groups of people travelling together due to social relations or external influences (e.g. collaborative movement behavior in crowded scenes, see Helbing and Molnar (1995)).

In our research, we deal with the realization of a smart video surveillance system, including an automatic movement analysis module that produces real-time statements about observed higher-level movement behavior resulting from location information provided by a distributed smart-camera network. In this system, the optimization of sensor hardware resource management is an important topic, balancing a maximum coverage of the observed area (in order to detect MPOs) with a maximum coverage and tracking of the (already detected) MPOs within the scene. In order to support the camera-network reconfiguration task, the central analysis module is supposed to give insight on group patterns formed by sets of MPOs. This allows tracking of entire groups instead of their individual members, resulting in a lower overall complexity of the optimization task. Additionally, statements about group patterns within the observed scene may be relevant to the operators of the surveillance system. However, as we design the surveillance system with no single specific domain of application in mind, we need to provide interfaces for customization of the analysis module, allowing to e.g. specify patterns that are relevant within the observed scenario.

In this chapter, we report on results of our research. We developed a lightweight group pattern detection framework based on a flexible group concept. It is general enough to allow definition of a number of relevant group patterns and provides means of detecting groups with stable composition over time in real-time. We demonstrate our approach by emulating a number of well-known group movement patterns known from literature.

This work is structured as follows. After a short overview over the literature on group patterns, we give insight about our group notion, detailing on the used data structures and algorithms used within the implementation of the group candidate calculation and backtracking steps. We illustrate the approach's functionality with examples from real data sets.

2 Related Work

During the last decade, groups and group patterns within MPO data sets have been extensively studied from a multitude of perspectives, ranging from purely conceptual views on the topic, exploring the spatio-temporal properties of movement up to algorithmic works of the computational geometry community dealing with optimized solutions for specific patterns. Those results have in turn been applied to various practical applications in order to classify and interpret observed movement behavior. Dodge et al. (2008) presented a taxonomy of movement patterns, including patterns of collective movement, detailing on conceptual features of the presented patterns and provided insight into the relationship between the abstract spatio-temporal description of patterns and underlying semantics on an abstract level. In addition to more conceptual/theoretical works on how to deal with the pattern recognition problem (e.g. Gudmundsson et al. 2004) and to visual analytics approaches (e.g. Andrienko and Andrienko 2007), there are works that deal with efficient data structures and algorithms for the fully automated detection of specific patterns, which are discussed in the following section.

These works introduce similar concepts for groups of entities that travel together for a certain amount of time that only vary slightly with respect to their properties. Additional features of the respective group concept/pattern usually require or allow new algorithms and data structures for efficient detection. Common property of all of those concepts is that a group consists of at least two individuals that move spatially close to each other at every time instance of the group's existence and that the group exists over a certain amount of time, although different group concepts vary with respect to whether group composition needs to be constant over all time instances and how the spatial relationship between group members is defined within the pattern's context. In this sense, grouping of MPOs is a type of spatial clustering of entities that are related to each other with respect to their movement behavior. Clustering is performed within snapshots (a static view on the observed movement at discrete time instances), which leads to consistent results (the degree of required consistency is expressed by the underlying pattern definition) over a number of subsequent time instances. The most strict group definition is the *flock* (Laube and Imfeld 2002; Gudmundsson and Kreveld 2006; Vieira et al. 2009; Romero 2011), which is defined as a set of MPOs that remain within a disk of given radius for a certain number of subsequent observations/time instances. The composition of the flock is constant for all time instances. This pattern can easily be modified by relaxing different aspects of the flock definition. A *swarm* (Li et al. 2010) is a flock whose members may (spatially) leave the group (i.e. leave the aforementioned disk), if the return at a later point in time. A *moving cluster* (Kalnis et al. 2005) is a flock that is represented as an entity itself within the spatial domain, whose members may vary over time, i.e. MPOs may freely join or leave the cluster, as long the cluster's movement is consistent. A herd (Huang et al. 2008) is a spatially concentrated group of MPOs with flexible composition over time. The authors differentiate between the processes of movement and change in composition; group identity is based on a quantitative metric based on numbers of constant and changing group members. Finally, the *convoy* concept (Jeung et al. 2008; Yoon and Shahabi 2009; Aung and Tan 2010; Tang et al. 2012) removes the constraint on the geometric property (disk shape) of the flock by instead resorting to the weaker requirement of density-reachability between group members. Like in the original flock definition, group composition needs to be constant over all subsequent time instances.

Identifying these patterns is generally a non-trivial problem, since patterns possess several degrees of freedom over both space and time feature space, while features in both domains change continuously. Additionally, datasets in the field of movement pattern analysis may easily become very large. It has been proven that not all of the described patterns can be computed efficiently. For these cases, only approximate solutions are possible.

3 Group Movement Pattern Definition and Detection

In this section we describe our approach for detecting custom group patterns in real-time on streamed, synchronized location information of MPOs within a video surveillance scenario. Specific properties of the used data are highlighted and special requirements within our scenario of application are explained. We then introduce our group notion in great detail, reporting on used data structures and algorithms.

3.1 Characterization of Input Data

In our surveillance scenario, observations are made by a distributed and synchronized sensor network. Necessary preprocessing steps producing a global snapshot of the scene, consisting of a set of MPOs at discrete time instances, are considered finished prior to the group analysis step. MPOs are described by their observed position at time instances t_i as well as a unique identifier, which allows the reconstruction of MPO trajectories over time.

As our approach utilizes a snapshot perspective, it is adaptable to systems without explicit synchronization of individual observations by interpolation between consecutive observations. For real-time processing this introducing a certain delay in the order of magnitude of the sampling rate. Alternatively, in scenarios with asynchronous but high-frequent measurements, our approach may also work on discrete time intervals instead of time instances.

3.2 Problem Statement

We are looking for (general) group patterns within the produced stream of synchronous MPO observations, which consist of $n > 1$ entities in a certain spatio-temporal configuration which is stable over a certain time interval. The analysis is supposed to be complete, i.e. all groups with respect to the pattern have to be identified. Figures 1 and 2 show typical problematic cases for group movement we want to be able to correctly process.

There are two additional requirements within our surveillance scenario: Firstly, analysis results are supposed to be produced in near real-time, i.e. results need to

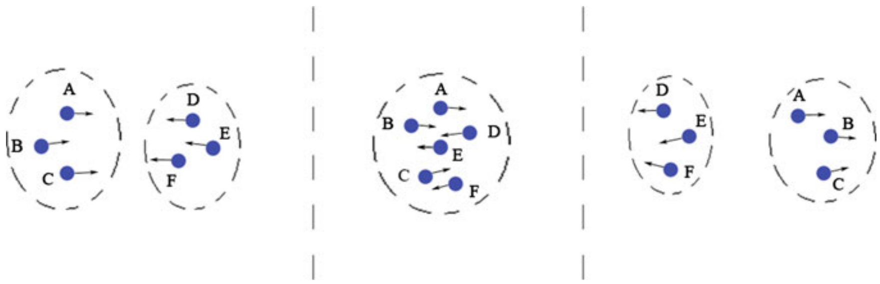

Fig. 1 Three subsequent snapshots of two groups ({A, B, C} and {D, E, F}) moving together. Although both groups overlap spatially over a certain amount of time, we are looking for algorithms that can distinguish from the temporal context

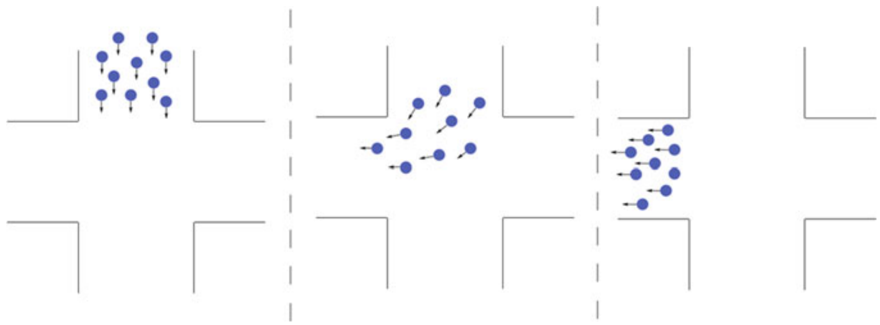

Fig. 2 Three subsequent snapshots of a single group travelling together on top of a road network. As the group's spatial extent is large, the geometric configuration of the MPOs changes over time. Our group detection algorithm is supposed to still consistently cluster entities into one single large group

be computed at (at least) the same frequency than the observations are produced. The approach has been developed with this constraint in mind. It is applicable for post-processing of datasets, but may not be optimal in terms of computational efficiency. Secondly, we are not looking for a specific group pattern, as the field of application of the surveillance system is not specified. In literature, a substantial amount of research on specific group patterns has been published, aiming at efficiency for specific analyses, in most cases depending on certain properties of the respective pattern. Instead, we want to allow a definition of group patterns in order to allow the end user of the surveillance system to customize analysis capabilities. This way, our approach can be considered a framework for a class of generic group patterns. In the next section we demonstrate how to utilize the pattern definition in order to create a working detector for a number of well-known group patterns.

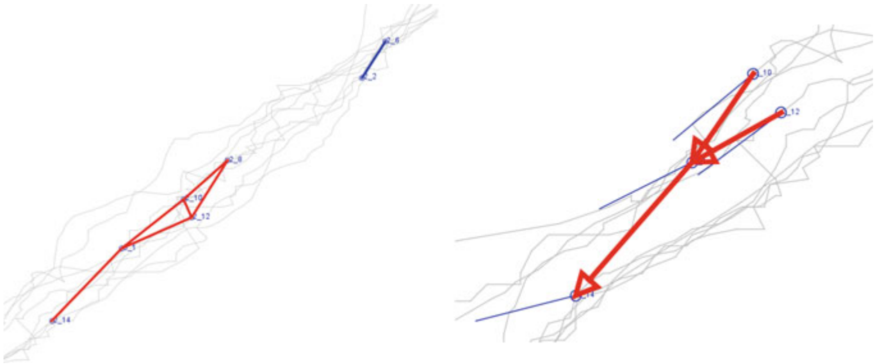

Fig. 3 (*left*) Two examples for groups based on a simple distance threshold base relation. The *gray lines* in the background visualize the MPO trajectories from the entire dataset. (*right*) A more complex (asymmetric) base relation realizing the Leader/Follower pattern. MPO *A* fulfills this relation with MPO *B*, if both move in a similar direction, move at a spatial distance below a given threshold and *A* moves towards *B* (within a certain angular tolerance). In this example, two MPOs have been identified to follow the same MPO, which also follows another MPO itself. Direction of the relation/edges is expressed by *arrows*

3.3 Group Definition

Given synchronized sets of MPOs at discrete time instances, we define a group as the set of entities that are related to each other by means of either spatial features (e.g. location and spatial configuration between MPOs), looking at a single snapshots at a time, or spatio-temporal features in a short-term temporal context, looking at two adjacent snapshots (allowing e.g. estimations for speed or direction of movement). Based on the available spatio-temporal movement features, we define a binary base relation for construction of groups of entities that are directly or indirectly (transitively) related to each other by e.g. similarity of movement parameters.

This leads to a static/snapshot view of the dynamic system, where MPOs are coarsely clustered into candidates for groups in a first step of group calculation. Results from this static view are then refined in a second processing step, by back-tracking over previous snapshots, where we employ a data structure storing a history of previously created snapshot views from previous iterations. This two-step process, i.e. calculating maximum group candidates for the snapshot view independently from the larger temporal context (step 1) and refinement of those candidates in order to find maximum groups with stable composition of a certain number of subsequent time (step 2), is performed whenever a new set of MPOs has been observed during the most recent snapshot.

The presented algorithms work independently from the specific base relation used for group pattern definition, allowing a certain degree of configurability. Not only allows the approach real-time reports on duration and composition of groups that are still relevant (as they are still present at the most recent snapshot), but also gives rise to event detection mechanisms based on changes of group compositions.

4 Base Relation Properties and Group Candidate Calculation Step

We utilize a binary relation R (base relation) for definition of a group pattern P. R specifies whether two MPOs belong to the same group at a given time instance t_i (snapshot view). We define a group G with respect to a given group pattern P and a single time instance as set of at least two MPOs ($G = \{mpo_1, mpo_2[,\ldots]\}$). No MPO may be part of at most one group at any given time instance, i.e. identified groups (with respect to a single pattern) at any time instance are disjoint. Resulting groups are clusters with respect to R and a single snapshot t_i.

Definition 1 $R(mpo_1, mpo_2) \Rightarrow \exists \text{group } G \in t_i\text{: } \{mpo_1, mpo_2\} \subseteq G$

This definition implies transitivity of group membership, i.e. two MPOs mpo_1, mpo_2 may be contained within the same group G, even if not $R(mpo_1, mpo_2)$, if there exists a set of MPOs that pairwise fulfill R, transitively including mpo_1 and mpo_2 in the same group. The transitivity of the group definition does not relate to the property of transitivity of R. This group concept is very similar to the *convoy* idea (Jeung et al. 2008), using our definition of transitivity-reachability instead of density-reachability.

This definition can be easily visualized by considering MPOs as nodes of a graph whose edges represent R. It contains an edge between nodes corresponding to mpo_1 and mpo_2 iff $R(mpo_1, mpo_2)$, i.e. $\exists$edge between the nodes corresponding to mpo_1 and $mpo_2 \Leftrightarrow R(mpo_1, mpo_2)$. In this view, two MPOs are part of the same group, if they are part of the same connected component within the graph. By using a single base relation, the MPOs within each snapshot are decomposed into disjoint groups with at least two members and "free" MPOs not contained within any group (i.e. not in relation with any other MPO). The following algorithm is performed in real-time for each set of synchronized MPO observations according to Algorithm 1.

Algorithm 1. Group candidate calculation

Input	R, the base relation of the custom group movement pattern. A set S of MPOs (current snapshot), with movement features for each MPO known from S (and, optionally, the previous snapshot, if spatio-temporal features are needed within R).
Output	A set of disjoint subsets of S represent groups within S.

1. GROUPS $\leftarrow \phi$
2. UNTOUCHED_MPOS $\leftarrow$ S
3. while (UNTOUCHED_MPOS $\neq \phi$)

```
m ← first element in UNTOUCHED_MPOS
CURRENT_GROUP ← {m}
NEW_GROUP_MEMBERS ← {m}
while (NEW_GROUP_MEMBERS ≠ ϕ)
current_mpo ← first element in NEW_GROUP_MEMBERS
UNTOUCHED_MPOS ← UNTOUCHED_MPOS\{current_mpo}
NEW_GROUP_MEMBERS ← NEW_GROUP_MEMBERS\{current_mpo}
for each MPO n ∈ UNTOUCHED_MPOS
if R(m, n):
CURRENT_GROUP∪{n}
NEW_GROUP_MEMBERS ← NEW_GROUP_MEMBERS∪{n}
UNTOUCHED_MPOS ← UNTOUCHED_MPOS\{n}
if (size(CURRENT_GROUP) > 1)
GROUPS ← GROUPS∪CURRENT_GROUP
return GROUPS
```

Consider a concrete base relation $R = \{(a, b)$: MPOs $A, B \in$ snapshot S with dist$(A, B) \leq dist_{threshold}\}$ With this base relation, two MPO are members of the same group if they have a spatial distance of at most $dist_{threshold}$ or if there exists a set of MPOs that transitively connect A and B, forming a way connecting A and B within the graph representation of R. R is defined using a parameter $dist_{threshold}$, introducing yet another degree of customization.

Further simple base relations can be defined for relations between other spatio-temporal features of MPO movement, like similarity of speed, similarity of movement direction or even non-spatial properties of MPOs. There is no requirement to consider spatial distance between MPOs. In any case, the base relation, however defined, allows an aggregation of MPOs that are similar to each other wrt. the features included within the base relation. This allows similar analyses that Laube et al. (2004) proposed with their REMO concept, but limited to the concurrence pattern, as our approach only compares MPOs within temporal snapshots. Instead of requiring a global reference system for features, our approach models pairwise similarities, where groups may contain a larger variance wrt. these features. However, global references for features can also be used within the base relation, if one wishes to reproduce results from the REMO approach.

The base relation does not need to be symmetric. If R is symmetric, i.e. $R(mpo_1, mpo_2) \Leftrightarrow R(mpo_2, mpo_1)$, we can simply use undirected edges within the graph view (see Fig. 3, left). If R is asymmetric, we need to introduce directed edges within the graph representation (see Fig. 3, right), allowing double edges if necessary. Symmetry also has implications for semantics of the defined pattern, as we can assign roles to the components of pairs of elements within a (directed) group according to the configuration within the directed graph, e.g. "leader" or "follower", allowing the realization of the corresponding leader/follower or single-file movement pattern (see e.g. Andersson et al. 2008; Buchin et al. 2008, respectively).

Assuming a number of already existing/predefined relations, we can also combine multiple relations into a more complex base relation by intersection. This has implications on the base relation definition interface, as possibly relevant base relations can be integrated in order to form a more powerful (yet more restrictive) base relation $R_{complex} = R_1 \cap R_2$, i.e. MPOs A and B are members of the same group, if $R_1(A, B)$ and $R_2(A, B)$. This e.g. allows integration/combination of all group movement patterns defined by distance, direction of movement, binary spatial configurations between each other etc.

In terms of patterns realizable with only the base relation, we need to consider that groups are defined and identified using the snapshot view on MPOs. This directly excludes complex movement patterns based on asynchronous, collaborative behavior, i.e. action/reaction effects among a set of MPOs (see e.g. trend-setter pattern, see Dodge et al. 2008), as relations between different snapshots are not considered within our approach. We can, however, use movement parameters directly observable from a single snapshot (position) or a pair of adjacent snapshots (e.g. velocity), as well as further MPO features accessible within the scenario of application, like personal data in personalized LBSs.

4.1 Group Candidate Refinement by Back-Tracking

In summary, during the first step the composition of R is calculated for each snapshot t_i independently, leading to a complete set of pairs (mpo_k, mpo_l) with mpo_k, $mpo_l \in t_i$ and R(mpo_k, mpo_l), which implicitly represents the static group composition with respect to R at t_i. However, in a dynamic system of MPOs we cannot make statements about groups based solely on this snapshot view, as e.g. different groups of MPOs travelling together may overlap with respect to the feature space considered within R, i.e. individual groups may be clustered within a larger group at certain time intervals (see example in Fig. 1). We now need a data structure allowing to keep track of group compositions over time intervals in the presence of temporary group combination.

To this end, we propose a group history data structure that allows identification of MPO subsets travelling together within the same group over a certain number of time instances. The group history stores group compositions for all single time instances up to the most recent composition. The number max_H of stored entries is naturally limited/bounded by the available computational resources (storage, computation speed) of the system, as in a continuously running system the number and frequency of observations is not limited. This, in turn, means that group composition information is available for at most max_H time instances.

This basic idea leads to the first (naive) realization of the group history: it consists of an array of max_H sets of disjoint groups formed with respect to R at time instances $t_{i-maxH+1}$, $t_{i-maxH+2}$,… t_i, which is updated with each new snapshot t_{i+1}, by deleting the oldest group composition entry ($t_{i-maxH+1}$) as well as calculating and adding the group composition for t_{i+1}.

Group history analysis starts with the entries for the most recent snapshot t_i. For each group at t_i, we are looking for equal compositions within the previous snapshot.

Table 1 A simple example group configuration of six MPOs over four subsequent snapshots (left), and the stored group information within the group history, single-element groups omitted (right)

Snapshot	Group candidates (including single MPOs)	Groups stored within history
t_{i-3}	{A, B, C}, {D, E}, {F}	{A, B, C}, {D, E}
t_{i-2}	{A, B}, {C, D, E}, {F}	{A, B}, {C, D, E}
t_{i-1}	{A, B}, {C}, {D, E, F}	{A, B}, {D, E, F}
t_i	{A, B, C}, {D, E, F}	{A, B, C}, {D, E, F}

We consider only groups, i.e. MPO sets with at least two elements within t_i. Two cases may occur: either the entire group in t_i is equal or part of a t_{i-1} group or subsets of the t_i group are distributed over two or more different groups in t_{i-1}. A special case is a single MPO being "split off" the group, i.e. a single "free" MPO has joined the group between t_{i-1} and t_i, or the group membership of a single MPO has changed from one group to another. Additional group members in previous time instances are not considered. For both cases, we can find examples in Table 1:

Free C joins {A, B}:
t_{i-1}: {A, B}, {C} → t_i: {A, B, C}

C leaves {A, B, C} and joins {D, E} to form {C, D, E}
t_{i-3}: {A, B, C}, {D, E} → t_{i-2}: {C, D, E}

This process is repeated iteratively using the (possibly distributed) remaining subsets of the original groups in t_i with at least two elements, until either all time instances stored within the group history have been iterated through or until all subsets have vanished into single-element sets. Again we use the small group configuration example from Table 1 in order to illustrate the back-tracking process (schematically shown in Fig. 4). Group {D, E, F} can also be found in t_{i-1}. We continue searching for {D, E, F} in t_{i-2}. There only the subset {D, E} remains together, i.e. we continue looking for occasions of only the {D, E} subset. The fact, that additional MPOs (C) have been together with {D, E} is not relevant, as {C, D, E} has not been a group composition in the more recent snapshots. After the first entry of the history is reached (without any information on previous snapshots), we report {D, E, F} with a duration of two snapshots and {D, E} with a duration of four snapshots. Similarly, the left branch ({A, B, C}) leads to {A, B, C} with a duration of one snapshot and {A, B} with a duration of four snapshots. MPOs marked with an exclamation mark are subsets of the original groups in t_i which are split off the other group members. We do not continue back-tracking for single-element subsets. Additionally, MPOs in brackets have left groups before the most recent snapshot. They are not relevant for the current group configuration, as all groups containing them have been reported in an earlier iteration of the process.

At t_{i-1} and t_{i-2} respectively, C and F are split off from their respective t_i groups. Single-element subsets are not tracked further within the history. Subsets {A, B} and {D, E} remain constant over the entire history; they have been part of the same

Fig. 4 Illustration of the back-tracking process of groups from t_i over previous snapshots stored within the group history

```
t_i      A, B, C                D, E, F
         |       \              |
t_i-1    A, B     C!            D, E, F
         |                      /       \
t_i-2    A, B          [C,] D, E          F!
         |             |
t_i-3    A, B [,C]     D, E
```

groups for all four time instances. Although C has been together with {A, B} in t_{i-3}, it is not a constant member of the same group for the entire time interval.

Instead of searching the entire data set for all possible subsets, we use the groups in t_i as initial group hypothesis (as statements about groups from earlier snapshots have already been processed in an earlier iteration). Because we stop backtracking as soon as single MPOs get "split off" their respective groups, we need to backtrack for at most $N/2$ groups (assuming all N entities are involved in two-entity groups) for at most max_H time steps, the overall runtime of the analysis per iteration (live analysis) is about $O(N/2*max_H)$ in the worst case.

As single-element MPO sets ("free" MPOs) are not regarded as groups within the algorithm, we can easily omit them from all history entries, which potentially reduces storage requirements, depending on the coverage of snapshots with groups. However, the snapshot view within the group history is limited to MPOs contained within groups; a reconstruction of "free" MPOs from history is no longer possible. This leads to the simple history management from Algorithm 2.

Algorithm 2. Group history creation

Input *GROUPS*, the result from Algorithm 1 for the current snapshot.
max_H, the maximum number of stored snapshots.

Output A map *HISTORY*, mapping sets of groups for snapshots t_i onto their respective snapshot identifier (here: the snapshot timestamp). *HISTORY* contains at mostmax_H preceding snapshots.

---

1. HISTORY ← HISTORY ∪ (current_snapshot_timestamp, {GROUPS})
2. if (size(HISTORY) > max_H)
3. HISTORY ← HISTORY\{oldest entry ∈ HISTORY}
4. return HISTORY

Several results can be extracted from this approach: the algorithm identifies constant groups over N time instances that are still together at t_i (see Algorithm 3). With small modifications, several questions about groups within the systems can be answered like finding all groups with at least n members with a lifetime of at least m time instances or finding the group with the longest lifetime among groups with at least n members. The group history data structure also allows for qualitative statements about changes of group compositions, e.g. detections of split-offs or joins of MPOs or groups of MPOs, which may be used as events in a surveillance system ("MPO x has left a group it has previously travelled with"). To this end, only the transition between the two most recent snapshots needs to be analyzed. This analysis is repeated for each new snapshot in order to detect group composition change events in real-time (see Algorithm 4).

Algorithm 3. Searching for MPO sets that are travelling together in the current snapshot

Input *GROUPS*, the result from Algorithm 1 for the current snapshot.
t_i, the most recent snapshot timestamp.
t_n, the timestamp at which to start searching the history (this is important for the recursive call from within the function, $t_n = t_i$ in the call of the function from outside the function).

Output A set of subsets of the elements in *GROUPS* together with the maximum number of snapshots they have travelled together.

---

1. for each group g ∈ GROUPS
2. dur ← t_i −t_n
3. current_snapshot ← HISTORY.getSnapshot(t_i).getPreviousSnapshot()
4. while (g ∈ currentSnapshot)
5. dur ← HISTORY.currentSnapshot().getTimestamp() − current_snapshot.getTimestamp()
6. current_snapshot ← currentSnapshot.getPreviousSnapshot()
7. report group g with duration dur
8. LIT_GROUPS ← identify all maximum subsets of g within current_snapshot with at least two members
9. //recursive call for all subsets of g with at least two members still remaining in //snapshot t_i-dur; reports on duration for the remaining subsets are created within //the recursive call
10. Algorithm_3(SPLIT_GROUPS, t_i, t_i −dur)

Algorithm 4. Group composition change event detection

Input *GROUPS*, the result from Algorithm 1 for the current snapshot.

Output Qualitative statements about changes in group composition between t_i and t_{i-1}.

---

1. for each group g ∈ GROUPS
2. if g ∈ HISTORY.getSnapshot(t_{i-1})
3. return statement EQUAL(g)//g has not changed between t_{i-1} and t_i
4. if ∃superset SUP ∈ HISTORY.getSnapshot(t_{i-1}) with g ⊂ SUP
5. return statement SPLIT(SUP, g, SUP\g)//g has left SUP
6. if ∃subset SUB ∈ HISTORY.getSnapshot(t_{i-1}) with SUB ⊂ g>
7. return statement MERGE(g, SUB, g\SUB)//SUB has merged with other //MPOs, creating g

Fig. 5 An overview over the used data set. (*left*) A plot of the original taxi trajectory data showing the Beijing road network. (*center*) A single snapshot from the dataset including group candidates. Individual cars are shown as *dots*, group candidates are randomly *colored* for better visual distinction. (*right*) A closer view on the graph structure formed by pair-wise application of the base relation (here: simple distance threshold)

5 Experiment Setup

In order to demonstrate and evaluate the viability of the proposed algorithms (especially for real-time group detection), we implemented a prototype which performs the proposed algorithms on a large data set. Performance for both calculation steps (group candidate calculation and group candidate refinement) is evaluated in independent experiments with varying parametrization.

5.1 Data Characterization

We evaluate the proposed approach using a real dataset collected within the Microsoft T-Drive project (Yuan et al. 2010, 2011). It consists of individual GPS trajectories gathered from about 10,000 taxi cabs in the city of Beijing over a time period of about one week with average sampling rates of about 5 min, totaling 16.3 mio GPS measurements (see Fig. 5). The used dataset is publicly available (Zheng 2011).

We performed some preprocessing steps on the data in order to obtain synchronized position information by resampling (to one per minute), using linear interpolation between provided GPS positions. This leads to the required snapshot representation of trajectories where for each discrete time instance an estimation for the position of each active car is available. Additionally, the single GPS trajectories provided for individual taxis have been split into multiple segments whenever no GPS position is available for longer period of time, e.g. because a portion of the used GPS sensors were configured to only record/transmit data while the car is moving, resulting in 400,000 individual trajectories (i.e. individual trips) overall. Due to the segmentation, the average number of simultaneously active cars is about 6,000–8,000 for all time instances.

The entire dataset was imported into a spatial database (PostGIS) for selective access. For the experiments, data has been processed in chunks (time intervals of limited duration; here: 2.4 h) manageable within the used computer's RAM in order to not include database access times into experiment results. The experiments are performed on a PC with Intel E8400 Duo CPU, 3.00 GHz and 8.00 GB RAM (available RAM for Java VM was deliberately limited to 1 GB). The operating system is Windows 7 Enterprise. All algorithms are implemented in Java on Eclipse Indigo platform with JDK 1.7.0.

5.2 Experiment on Group Candidate Calculation

We apply our approach for identifying groups on the dataset for varying base relation parameters and numbers of objects in order to evaluate its computational performance. We use a simple distance threshold based relation, as further spatio-temporal parameters (e.g. speed, direction) are not available due to GPS accuracy and low sampling frequency within the original data. Some results and statistics for the group candidate calculation with different distance thresholds within the used base relation can be found in Table 2. A larger distance threshold leads to larger groups, but the number of groups also depends on the local density of objects (a single very large group at 250 m threshold is replaced by multiple groups in the 100 m scenario).

5.3 Experiment on Group Candidate Refinement

We expect to be able to find three types of groups within the taxi's collective movement, that could, in an additional step, be classified based on aggregated group features: (a) short-time groupings that naturally occur due to spatial proximity at crossroads or while overtaking a slower or even parking car, (b) cars parking within spatial proximity of each other for an extended amount of time while not moving, (c) cars actually driving the same route for an extended amount of time, while being spatially close for the entirety of the grouping.

Table 3 shows the performance of the group candidate refinement step for all groups within a single snapshot, i.e. the full history for all 831 group candidates within this snapshot are calculated respectively. A single history request returns all maximum subsets of the original group that have been grouped together with the respective maximum durations. We report on the duration of the entire calculation (per group) as well as the depth of the search-tree. The table shows only results for the ten largest original groups, including maximum search-tree depth and maximum computation duration of all 831 group histories. The second group's search-tree has a high degree of branching, i.e. several subsets that split off each other yet remain together for a very long time.

Table 2 Comparison of performance and typical results of the algorithm during group candidate detection for different distance thresholds within a simple base relation

$dist_{threshold}$	50 m	100 m	250 m
Duration for group candidate calculation (single snapshot)	686 ms	754 ms	880 ms
avg. number of groups per snapshot	393	762	752
avg. group size	2.5	3	6
max. group size	127	132	438

Average number of objects is about 6,100 over a time interval of 2.4 h, resampled at a rate of one per minute. The value for average group size does not include isolated MPOs; minimum group size is 2

Table 3 Example for performance and results of the history analysis for the ten largest groups from a single snapshot

Original group size	Duration to compute full history (ms)	max. search-tree depth
162	327	72
147	1,573	131
119	217	36
79	151	54
75	166	42
74	207	41
70	184	99
61	87	29
56	99	41
46	59	10

Results are based on a 250 m distance threshold relation with a sampling rate of one per minute

5.4 Discussion of Results

The experiment shows, that given a time series with synchronized timestamps, our approach gives extensive insight on group structures within the data in reasonable time. The feasibility of the approach for real-time group detection requires a sampling rate below the calculation time for a single snapshot. This step could additionally be sped up by using spatial indexing structures, if the used base relation contains a spatial distance threshold.

For the group candidate refinement step, the group history calculation is reasonable fast in most cases. However, there exist worst-case degrees of branching within the search-tree that may lead to spikes in calculation time. As the proposed algorithm uses recursive back-tracking within the history, we suggest using quadratic programming (i.e. storing intermediate results for use in later iterations) in order to avoid redundant history calculations.

6 Conclusion

In this chapter, we have presented an approach for flexible group definition based on binary relations, together with a set of algorithms capable of identifying sets of MPOs that are candidates for collective movement behavior. These initial groups are calculated in a greedy way from single snapshots (similar to the suggestions of Jeung et al. 2008). By comparing groupings from subsequent snapshots, groups can be identified that are stable wrt. their composition over a temporal interval. The group definition is flexible wrt. the used features, which may be spatio-temporal or even non-spatial attributes of the MPOs, corresponding to the ideas of Laube et al. (2004).

In comparison with optimized group pattern detection algorithms, we have a more general, adaptable group concept, which allows us to define specific properties of group movement patterns that are relevant to the domain of application. Physical proximity, which is common for most group concepts, is only an optional component within our approach, as it may or may not be included within the used based relation. It is easily possible to emulate/reproduce several well-known group patterns without modifying the underlying group/event detection mechanisms.

A weakness to our approach is its requirement for synchronized data, which can be circumvented by resampling and interpolation (see Tang et al. (2012) for further ideas on this topic). Furthermore, our approach currently is capable of finding patterns of synchronized movement, i.e. there is no temporal gap between the movements among group members. This limits us to the detection of concurrence patterns, where MPOs are similar to each other (wrt. certain features) for every time instance over a time interval. Additionally, certain optimization techniques exploiting specific group pattern properties which are used in the related works are not applicable in our approach as this would limit its generality.

We have demonstrated the viability of our approach for real-time detection of groups by results from a prototype based on our ideas applied to a large real data set. Ideas for performance improvements of the approach for more specific problems are provided.

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Mining Event-Related Knowledge from OpenStreetMap

Khatereh Polous, Peter Mooney, Jukka M. Krisp and Liqiu Meng

Abstract With an explosive growth in the number of contributors for creating and assembling of spatial data, freely available databases and open source products have drawn the attention among decision makers for facility management and service planning. Many location-based services are using Volunteered Geographic Information (VGI) as spatial data sources. The key motivation of this work is to mine hidden patterns of social activities and the interests of contributors to share event-related knowledge within OSM community as one of the most prominent examples of user generated spatial data. In this study, the term event referred to anomalous user activities, number of contributors plus number of contributions, which happened at a time point or within a specific period of time. We focused on events which have happened and the events for which we had prior knowledge. For the purpose of retrospective event detection, it is necessary to analyse the history of OSM for the area of the event. In our case, the entire OSM history of Vechta, Munich, Los Angeles, and Sendai, around the area where the events happened was extracted to

K. Polous (✉) · J. M. Krisp · L. Meng
Department of Cartography, Technische Universität München,
Arcisstraße 21 80333, Munich, Germany
e-mail: Polous@bvtum.de

J. M. Krisp
e-mail: Krisp@bvtum.de

L. Meng
e-mail: Meng@bvtum.de

P. Mooney
Department of Computer Science, National University of Ireland Maynooth (NUIM),
Co. Kildare, Ireland
e-mail: peter.mooney@nuim.iepeter.mooney@tnuim.ie

P. Mooney
Department of Computer Science, National University of Ireland Maynooth,
Maynooth, Ireland

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examine the potential of OSM database for event detection. Our experimental analysis reveals that while changes to OSM can be effectively rendered on the globally visible OSM maps in a few hours, citizens would not naturally use OSM as a tool to mark an event. In fact, the contributors do not treat this community in the same way as they do with other user-friendly electronic exchange platforms such as Twitter, Face book, or Flickr. The obtained results also show that for big events such as tsunami in Sendai during which the geometry of objects is affected, post-disaster, structural and environmental damages (demolished buildings, road infrastructure changes, etc.) are detectable through OSM.

Keywords Event detection · Volunteered geographic information (VGI) · OpenStreetMap (OSM) · Location-based services (LBS) · Web 2.0

1 Introduction

With the rapid spread concept that uses web as "participatory platform", a growing amount of information is uploaded on the internet. This "participatory platform" provides colloquial read-and-write functionality for individual users to collaboratively generate the content. Texting, social networks, photos, video, blog entries are amongst the most popular forms of user generated contents. In parallel, advances in location-aware devices, web mapping technologies and mobile cartography have facilitated the contribution of none professional volunteers in providing and distributing geographic information around the world (Goodchild 2007a; Coleman et al. 2009; Goodchild and Glennon 2010). VGI the term coined by Goodchild (2007a, b) refers to the recent empowerment of citizens in the collaborative collection of geographic information. He argues that VGI has enormous potential to become a "significant source of geographers understanding of the surface of the Earth". Crucially, "by motivating individuals to act voluntarily, it is far cheaper than any alternative, and its products are almost invariably freely available". Considering advantage of comprehensive knowledge, consumed time and budget of local contributors, a transition phase of none specialists contributing to the collection of geo-referenced information has occurred. Crowd-sourced and volunteered data are in many cases more up-to-date and often broader and richer in the meta-data than the authoritative sources of information. They are capable of incorporating features of interest which are not covered by mapping agencies (Goodchild and Glennon 2010).

VGI can range from simple user generated contents where geographical coordinates are automatically embedded in a digital photograph made available in some online repository to most complex forms of spatial data such as annotated GPS trajectories. OpenStreetMap (OSM) as one of the most prominent examples of user generated spatial data on the Internet in recent years has been subject to analysis by many leading GIS researchers (Fritz et al. 2009 , Mooney et al. 2010a, b). OSM aims to build a freely accessible, open map database for the entire world. Anyone can be a contributor to OSM. The contributors to OSM form a very large community of citizens collecting (and subsequently editing) spatial data. Volunteers in the OSM community collect geographic information and submit this to the global OSM database (Ciepluch et al. 2009). Most studies focus on a current snapshot of the OSM but when a longer term historical view of OSM data is considered, patterns of crowd contribution and OSM completeness become evident (Mooney and Corcoran 2012).

Changes occur in OSM due to the upload of new spatial data and/or the updating of existing contributions (location and attributes) by the original creator or another contributor. Some of the reasons for these changes could be: contributor disagreement, changes to geometry (shortening of roads, resizing, etc.), actual real-world changes reflected in the data, combination of polylines/polygons into multi polygon relations. Mistakes can be made by contributors due to insufficient understanding of spatial data handling operations or incorrect use of the editor software. For the time being, OSM is primarily used for the rendering of various map visualizations (Auer et al. 2009) and it provides a highly dynamic source of spatial data for Location-based Services (LBS) (Jacob et al. 2010, Mooney and Corcoran 2011).

The aim of this study is to detect retrospective events from OSM for the specific sites in Vechta and Munich in Germany, Los Angeles in USA, and Sendai in Japan. Indeed, this work concentrates on the detection of different types of events, which are bound to a specific time and place and hidden in the information generated by internet users. In order to examine the potential of the OSM history for event detection, two annual social events— “Stoppelmarkt” in Vechta and “Oktoberfest” in Munich, one temporary event—freeway closure in San Diego (I-405) for 2 days, and one natural event—Tsunami in Sendai, Japan were studied. By social events, we refer mostly to those planned or attended by people. People tend to use social media to capture, document, or discuss around these events.

Following this introduction, the next section is devoted to investigating the importance of event detection. Section 3 describes the spatial data and contributor characteristics of Vechta, Munich, Los Angeles and Sendai. Section 4 presents the experimental analysis of the OSM historical data. Finally, Sect. 5 presents the key findings of the paper with a discussion about some of the issues for future work on this topic.

2 Even Detection

The continuous increase in the number of contributors and the huge amounts of uploaded information on the internet has drawn the attention of decision makers to utilize this information for facility management and service planning (Sieber 2006; Coleman et al. 2010; Jiang and Mcgill 2010; Starbird and Stamberger 2010; Mclaren 2011; Ostermann and Spinsanti 2011). From the scientific point of view, the availability of accurate and/or up-to-date mass data stimulates the development of innovative approaches for the assessment of spatio-temporal processes and detailed change detection. Many studies have been already conducted concerning the detection, monitoring and visualization of changes from time series data (Coppin et al. 2004; Liu et al. 2008; Tanatho et al. 2009). Still, open questions remain on how the detected changes should be decomposed and formulated to reveal an event.

Events and their behavior patterns represent a higher level of knowledge than changes, and thus more valuable for decision makers. To explore the mechanism of changes, one must investigate the mechanism of events. Indeed, events underlie changes (Chrisman 1998; Worboys and Hornsby 2004). Highly complex and irregular patterns can still be represented visually for further analysis or exploration. In addition, for the efficient planning and management of a complex system composed of engineering, natural and social components, it is necessary to consider the relationships between an event and the reactive behavior of different involved components. For instance, various types of spatiotemporal events such as volcanic eruption and storms as examples of "natural events" while parliament election and civil demonstration are examples for "social events" that can also occur in a complex system. On the other hand, each event may require or trigger a decision, for example, opening or closing dam gates or the presence of police in the streets as operational controls.

Event detection is an interesting concept in the era of Web 2.0 and ubiquitous Internet. The wide distribution of simplified editing tools and user-friendly electronic exchange platforms (blogs, wikis, etc.) has led to a steep rise in the availability of user generated content. In some cases they are used by academic researchers who look for access to large databases of user generated content. To extract, information, meaning and knowledge from these collections of user-generated content is a challenge. The classical data mining and knowledge discovery strategies are confronted with large databases of heterogeneous and volatile online contents which do not respect any a priori classification schemes (Glassey 2012).

"Tags" are a crucial key of the data from which we want to detect events. As Glassey (2012) argues; "tags" are almost universal in user-generated content as a user-driven means of indexing their information. Without "tags" the information is essentially meaningless. Tags, in user generated content and VGI, do not follow any preset rules other than the ones chosen at the moment of their creation by the contributors themselves. As there is no formal norm for generating tags (OSM for example has a guide but these are not strictly enforced rules), users generally utilize colloquial terminology and other informal language.

As events play a prominent role in various research areas such as physics, philosophy, psychology, linguistics, literature, probability theory, artificial intelligence, deductive databases, and history, one can find many technically refined concepts of events and objects in each discipline. Conversation about events is vague; they are located in space and time but in ordinary circumstances it is difficult to determine their exact spatiotemporal extents (Borghini and Varzi 2006). Many scientists are searching to find a commensurable notion across disciplines about events and objects, and their properties (Lewis 1986; Casati and Varzi 2008; Casati 2005). Events can be studied on various scales (local, national, global) and consequently in different level of details. But in the context of this study, the term event refers to anomalous user activities, which happened at a time point or within a specific period of time. The term “User Activity” is used as the number of contributors plus number of edits/uploaded GPX traces. It is assumed that the number of visitors would increase for a specific region and its surrounding areas during the event time, which should consequently lead to an increase in the contributions to VGI datasets and projects.

3 Methodology

OSM has been chosen as the case-study VGI dataset. For the purposes of retrospective event detection, it is necessary to analyze the history of OSM for the area of the event. It might be very difficult to detect any traces of events, if the analysis is limited to the currently available snapshot of OSM that only shows the most up-to-date version of the OSM database. The OSM History is a very rich spatial database as every edit for the entire planet is recorded in this database, where an edit is referred to as the creation of objects and their subsequent update. In most cases the history of OSM stretches back to 2006. So, it provides a good opportunity to study how OSM has evolved during specific periods of time (including overlapping with specific events).

3.1 Case Studies

The following case studies were selected for a number of specific events:

The first case was devoted to detecting event from the “Stoppelmarkt” in Vechta, Germany. The Stoppelmarkt is a folk festival and one of the oldest funfairs in Germany (since 1298). The market is held once a year from Thursday to Tuesday in the week of 15th August. It has a size of approximately 160,000 m^2. In terms of size, it is one of the biggest folk festivals in Germany. At the time of event, the market area is filled with about 500 stands and fairground booths. More than 800,000 people annually visit the “Stoppelmarkt” in “Vechta”.

The second case was related to the “Oktoberfest” held in Munich, Germany. It is one of the most famous events in Germany and also the world largest folk festival. It begins every year from mid-September and lasts until first week of October. More than 6 million people attend this fair annually and celebrate the Oktoberfest. The Oktoberfest has been held since 1810, and is considered as an important part of the Bavarian culture. An initial assumption we made was that there would be an increase of editing items in OSM during the festival each year. The reason of selecting two different festivals like “Stoppelmarkt” and “Oktoberfest” is to evaluate the impact of event popularity and the number of participants on the possibility of event detection from OSM history. These two locations were chosen for the study as Germany is considered as one of the most active OSM communities in Europe (Mooney and Corcoran 2011).

The third case refers to an unexpected temporary event which was not a result of any social or natural factors but highly effected the local and regional motion patterns of moving objects (cars, trucks, people, etc.). The unexpected temporary event is the closure of Interstate 405 in Los Angeles, United States. Because of the I-405 Sepulveda Pass Improvements Project, 10 miles of the 405 Freeway was closed between 15 and 18th July in 2011. Interstate 405 is a north–south highway in Southern California, connecting western and southern parts of Los Angeles to the northern San Fernando. This highway is ranked as one of the most "heavily" traveled freeways in the United States with an average daily traffic of more than 300,000 vehicles. The traffic was very congested for the 16 and 17th of July. Many people were forced to either stay at home or change their moving behaviors during these days.

For the fourth case, the earthquake and tsunami in Japan, 2011, was selected as a natural event in which the geometry and the semantic information of affected objects dramatically changed after the event. It is one of the most devastating earthquakes in the world since the introduction of modern seismological measuring technologies. As a consequence of the earthquake, the powerful tsunami waves traveled up to 10 km inland in the Sendai area and caused extensive and severe damage to roads, railways, and other infrastructures. Over one hundred thousand of buildings collapsed totally or partly.

3.2 Experiments

The OSM historical data for the entire world in XML format was downloaded from planet OSM history files. These history files are globally updated every 2 or 3 months. Considering the size of entire history and required time for processing it is necessary to extract the area of interest (Mooney and Corcoran 2011). Each history file was divided into two separate parts containing Nodes and Ways (OSM terminology for polygons and polylines). The extracted OSM-XML was then stored and processed in a Postgresql PostGIS database for further analysis. For each element (node, way), geometry and corresponding semantic information were extracted for the entire history period. The collected information consisted of the history of the contribution, location of elements (latitude and longitude coordinates), OSM user id, timestamp when the information was uploaded, embedded tags and corresponding change set number. We hypothesize that there is an increase in the number of contributions in OSM during the events outlined in the previous section.

OSM provides access to all of the GPX traces uploaded by contributors over time to the OSM database. Unfortunately the GPS traces are not organized in the same structural manner as the OSM history. One must execute calls to the OSM API service to download these GPS traces. A Python script with an assigned bounding box was developed to handle this step automatically. The script downloaded all of the GPS traces which were inside or intersected with the bounding box. Since the GPS traces were not time stamped in their exchange format GPX, it was impossible to ascertain their temporal relevance. The downloaded GPX was directly imported to QGIS for further exploration and visualization.

4 Results and Discussions

This section is devoted to illustrating and discussing the results obtained from the four case studies. The overall characteristics of contributor activities in terms of the number of contributors and the number of contributions for all cases will be investigated in this section.

4.1 Stoppelmarkt in Vechta

Figure 1 illustrates the number of contributors (y-axis) and contributions (size of the bubbles) over time for the area where the Stoppelmarkt is held. It was expected that potentially the influx of visitors to the event might encourage those with an interest in OSM to edit the base-map to reflect the fact that a large event would be taking place. The history of OSM between 2006 and 2010 for the market and surroundings area shows that there was not any easily detectible indication of unexpected increases in the amount of contributions for the time of event. The number of contributions and contributors only change slowly over time. In January 2011 a significant increase in the number of contributions (1805 edits) can be seen, which has been done with five contributors. According to the definition of event, this phenomenon does not correspond to any event (Fig. 1).

Mining the tags showed that different contributors have provided some relevant information about temporal characteristic of stands and the markets. However, the corresponding tags were only available in the history of OSM or in the advanced editing modus. Since they are not automatically displayed on the map, the OSM users cannot simply find the temporal information without going to the advanced editing modus of the map. The tags indicate that the event started in August 11th and ended in August 16th, 2011 and they do not convey any information about annual pattern of the event (objects exist constantly on the map). Although the Stoppelmarkt in Vechta is a very famous and big fair in Germany with more than hundreds of thousands attendants yearly currently, there is no possibility to detect any pattern of the event in the history of OSM.

Figure 2 and Table 1 illustrate the “Stoppelmarkt, Vechta” in view and editing modus of OSM with the corresponding tags respectively.

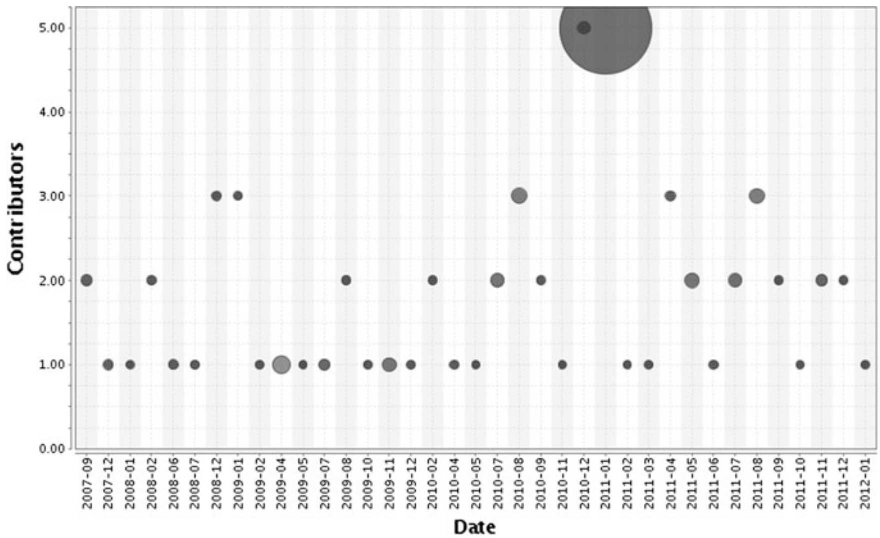

Fig. 1 Contribution characteristics of surrounding areas of Stoppelmarkt in Vechta

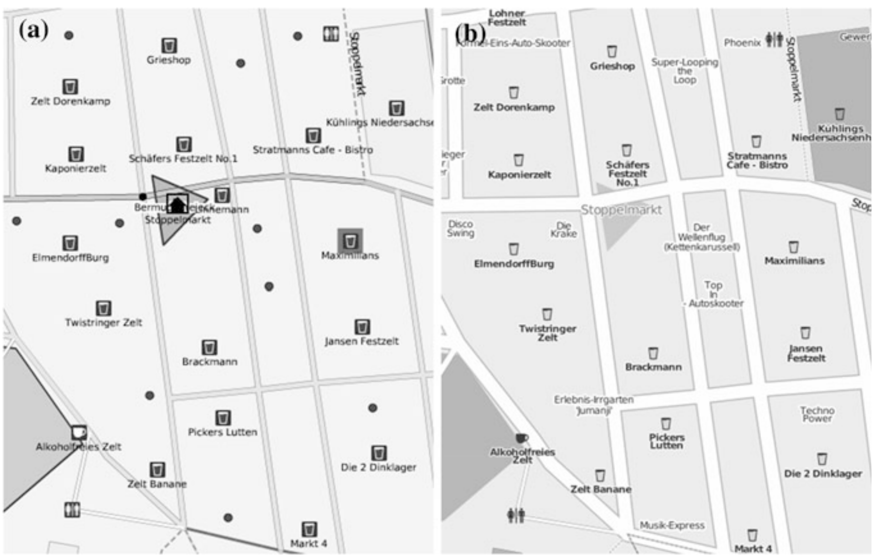

Fig. 2 Vechta Stoppelmarkt in **a** view modus and **b** editing modus

Table 1 Maximilian's Pub OSM history in "Vechta Stoppelmarkt"

Edited at:		04 Aug 11	05 Aug 11	05 Aug 11	28 Jan 12
Edited by:		Duetzer	Duetzer	Duetzer	Nolbelt San
Version:		1	2	3	4
In changeset:		8916581	8925849	8925909	10524834
Comment:		–	–	–	Small changes
Tags:	Amenity	pub	Pub	Pub	Pub
	Name	Maximilian's	Maximilian's	Maximilian's	Maximilian's
	Opening_days	–	–	11–16 Aug 11	11–16 Aug 11
Coordinates		52.74777, 8.29669	52.74777, 8.29669	52.74777, 8.29669	52.74777, 8.29669

4.2 Oktoberfest

The Oktoberfest in Munich is the theme of our second case study. The results of our analysis on this theme are almost the same as Vechta Stoppelmarkt. This shows that the size or popularity of an event does not have any impact on the possibility of event detection in OSM.

An initial assumption we made was that there would be an increase number of editing activities in OSM during the festival each year. However, our analysis showed that this was not actually the case. Figure 3 illustrates that in general there is an upward trend in the number of contributions and amount of contributors over time for the area of Oktoberfest. Actually it is the same trend with general increases in the number of unique contributors to OSM for Germany over time since 2006 for both ways and nodes (Mooney and Corcoran 2011). As can be seen in Fig. 3 the ratio between the number of contributions and the number of contributors decreases over time. This could be a result of the fact that the majority of

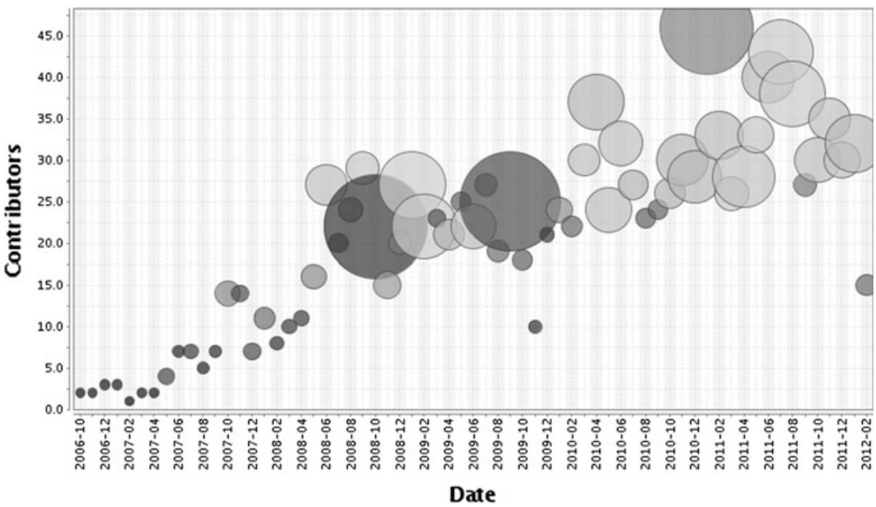

Fig. 3 Contribution characteristics of surrounding areas of Oktoberfest in Munich

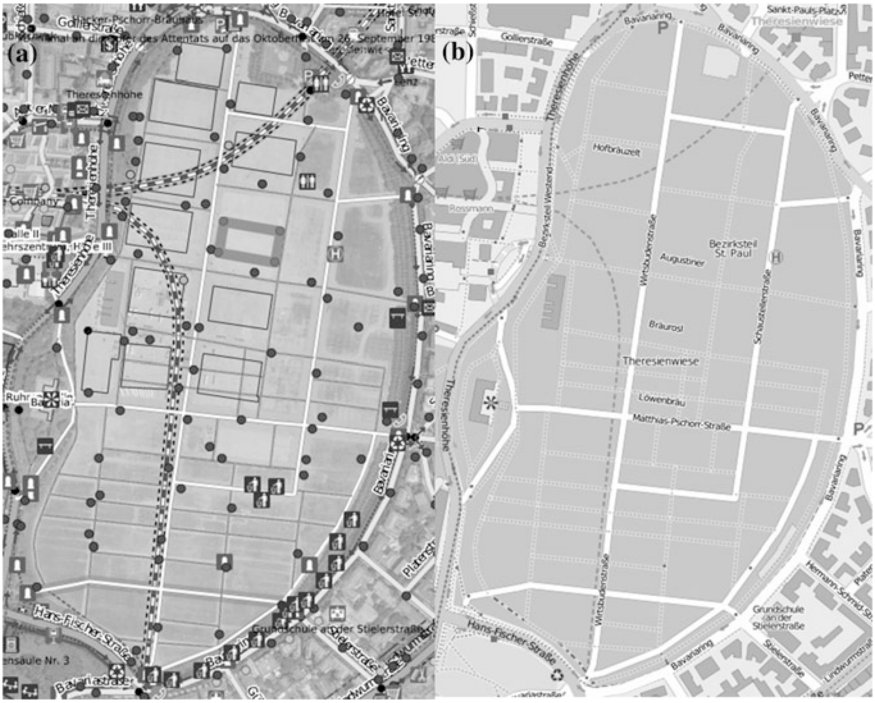

Fig. 4 Oktoberfest in **a** view modus and **b** editing modus

features in Munich are mapped and the new generations of OSM contributors are busy with enhancing and maintenance of OSM maps.

As can be seen from Fig. 4 the tents of the fair are not visible in the view modus of the map but they exist in the editing modus. The volunteers who have mapped this event have identified the start and end dates of the event, and have hidden the temporal tents in the place of Oktoberfest. It illustrates that although neither Stoppelmarkt nor Oktoberfest could be detected through our initial definition of events, there is a great potential for the tracing of these events through tag mining. In the case of Oktoberfest the innovative way of mapping and tagging the tents makes it possible to visualize the temporal buildings only during the fair. In addition, the process of updating the status of the tents (being hidden or not) can convey the spatio-temporal pattern of the event.

Table 2 shows the description of the Tent Augustiner. A note has been also added to this Tent which says that during the fair, the hidden tag must be altered from “yes” to “no” and after the event the date must be adapted for the next year. Table 2 presents that the tents were created for the first time in September 2010 by Mackerski (a mapper from Ireland who has lived in Germany) and has been subsequently updated regularly for the next events by different users.

Table 2 Augustiner tent OSM history in "Oktoberfest" Munich

Edited at:		27 Sep 10	28 Sep 10	04 Okt 10	04 Nov 10	01 Jan 11	17 Sep 11	26 Sep 11	07 Nov 11
Edited by:		Mackerski	Mackerski	Mackerski	Sendelhorst	Spunsel	Chan	Mackerski	Swus
Version:		1	2	3	4	5	6	7	8
In changeset:		5894426	5901895	5954479	6292634	6828639	9326733	9402214	9766624
Comment:		–	–	–	Hide	Update dates	Unhide	Unhide	Hide
Tags:	Start_date	–	01 Sep 10	01 Sep 10	01 Sep 10	17 Sep 11	17 Sep 11	17 Sep 11	22 Sep 12
	End_date	–	20 Okt 10	20 Okt 10	20 Okt 10	03 Okt 11	03 Okt 11	03 Okt 11	07 Okt 12
	Hidden	–	–	–	yes	yes	No	No	Yes
	Name	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner
	operator	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner	Augustiner
	building	beer_tent	beer_tent	beer_tent	–	–	–	beer_tent	–
	seasonal_building	–	–	–	–	–	–	–	beer_tent
	temp_building	–	–	–	beer_tent	beer_tent	beer_tent	–	–
	note	–	update	update	update	update	update	Update	update

4.3 Closure of Freeway 405 in Los Angeles

The closure of freeway 405 in Los Angeles is the theme of our third case study. Changes in the map database, such as changes to road infrastructure could imply changes in motion patterns of moving objects and vice versa. With the case of I-405, we aimed to find the trace of freeway closure within the OSM database. Due to the nature of the event and the place where event happened, no anomalous activity was explored in the number of contributions. Tag mining of OSM history for the area where the freeway was closed showed that no one recorded anything to update the status of the freeway for the time when event happened in L.A. Only two contributions were recorded during July 2011, which were not referred to the event. In addition, uploaded GPS traces into OSM within the area of event were downloaded as auxiliary data for further exploration. Only one GPS trace was uploaded for the given bounding box within the duration of this event, but it wasn't related to the event in question.

4.4 Sendai Tsunami

Figure 5 illustrates the edits in OSM history for a period of 13 months from December 2010 to 2011. In this example, an obvious increase in the number of contributors and contributions over a very short period of time was detected. It implies that "something" has caused these people to contribute to OSM on a large scale. Figure 6 presents the OSM activity before (February, 2010) and after (March 2010) the event. The community of contributors was quick to reconstruct the OSM map of Sendai to indicate the scale of the destruction caused to infrastructure by the earthquake and tsunami. The OSM maps were then made available to aid agencies and local government officials to provide an accurate base-map of the on-the-ground reality. Although OSM activity levels in terms of the number of

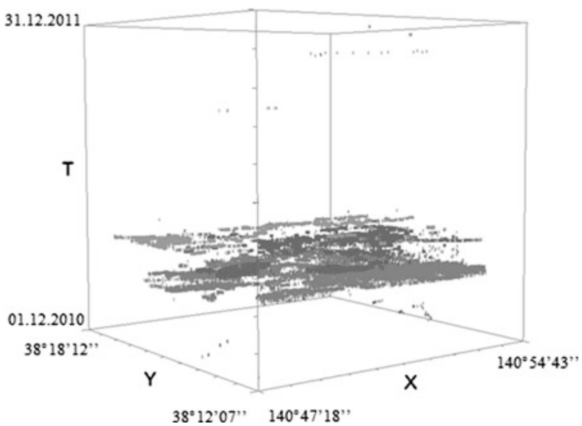

Fig. 5 Contribution characteristics of surrounding areas of Tsunami in Sendai

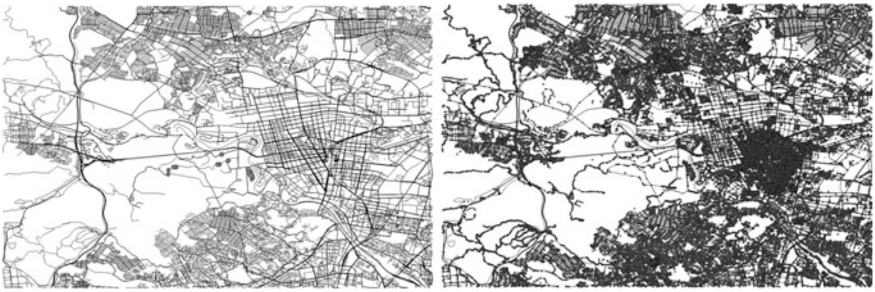

Fig. 6 Contribution characteristics of OSM activity before (February, 2010) and after (March 2010) the event

edits and the number of editors, would naturally increase as well in any other given area over a given length of time, it is very unlikely that such an increase would match the scale in the case of the Sendai earthquakes.

5 Conclusion and Further Work

In this study, we analyzed different event types which have happened and for which we had knowledge (spatial size, impact, type of event). Changes to OSM can be effectively rendered on the globally visible OSM maps with a delay of only a few hours. In addition, OSM, like other sharing open source platforms, allows tagging the mapped objects. These functionalities have made OSM a powerful community for collecting both geometry and semantic information of physical mapped objects. The key motivation of this work was to mine hidden patterns of social activities and the interests of contributors to share event-related knowledge within OSM community. We attempted to detect events from OSM in the same way as from other social platforms. We used the number of active contributors as an indicator combined with an analysis of the history about the number of contributions.

The obtained results revealed that OSM is not a tool which internet users would naturally turn to mark an event or even provide the attributes for the involved spatial objects. The contributors do not treat this community in the same way as they do with the user-friendly electronic exchange platforms such as Twitter, Face book, or Flickr. According to the results, in the cases of Munich and Vechta, the activities of contributors (the number of contributors plus the number of edits) for a specific period of time cannot be considered as an appropriate indicator for detecting social/temporary events in OSM community. There was no detectible indication of unexpected increase in the number of contributions and the number of contributors during the lifespan of the event. Mining the tags for both events showed that the contributors have mapped the temporary objects and reported the events in their tags and comments but unfortunately the information is only available in the advanced editing modus of the map for the registered contributors. This implies that in the context of OSM, a new definition for this kind of event must be considered.

For the case of tsunami in Sendai, a natural event in which the geometry of objects is affected, post-disaster, the structural and environmental damages (demolished buildings, road infrastructure changes, etc.) were detectable from OSM platform. It can be concluded that for the natural events the "activity" is considered as the first pre-processing step towards event detection. While the tags mining is used for further exploration such as the type of events, the required facilities for the understanding and the management of the events. In this case, an obvious increase in the number of contributors and contributions over a very short space of time show that "something" had caused these people to contribute to OSM at a large scale.

Regarding pattern recognition, the mapped objects of "Vechta" festival are constantly displayed on the map while they are only available during the festival time. Indeed, no repetitive pattern was recognized from constant existence of the involving objects. Based on the history file, the mapped objects are static objects which have been created after a sudden event (not repetitive). In the case of Oktoberfest, the tents are not visible in the view modus of the map as the volunteers have identified the start and end dates of the event, and have hidden the temporal tents in the place of Oktoberfest. In fact, pattern of the event can be identified as the contributors have regularly updated the status of the tents for being hidden and unhidden regarding the event time. It can be a good starting point for the management of event-related knowledge in OSM but this attempt has a number of deficits:

- Unregistered users do not have any access to the embedded information (e.g., start and end date of events) as they are only visible in the editing modus.
- Continuous maintenance is needed to update the map for each period of time. For the Oktoberfest and Stoppelmarkt, the maintenance interval is yearly but for ir/regular daily events, the maintenance is almost impossible.
- Mapping of temporary objects for repetitive periodical events affects the quality of OSM for the users who are not frequently updating their downloaded maps.
- Some events such as a meeting in a hall, are difficult to manage by means of the hiding and unhiding mechanism. In these cases, the event is unidirectionally connected with an object. A meeting needs a building to be held, but a building can exist without the meeting event.

Our experiments have revealed the fact that there appears to be a lack of event detection and pattern recognition possibility for OSM community, especially for the social and temporary events. This disability may be explained with two reasons. The first is the way people treat OSM for creating spatial data and sharing corresponding information which are bound to the objects at specific time and space. There are many physical objects that could be mapped in OSM if contributors are willing to do. The second refers to the functionality of OSM for collecting this knowledge and making it accessible to other users. One might be interested in mapping the temporary objects and reporting the relevant events, but OSM is unable to properly provide the information to the users. The temporary objects either are displayed constantly on the map (Vechta case) or have to be continuously manipulated by contributors before and after the events (Oktoberfest case). One remedy for handling the task might be to add a new attribute layer and adequately design it for the management of temporal semantic information based on a new ontology for temporary objects.

Overall, we just stirred up the surface of the VGI community with our case studies. There are many different forms of data beyond OSM that could also be considered. However, to make the best use of the huge amount of information hidden in these databases, we need the development of new information retrieval systems with the capability of reasoning and representing latent knowledge.

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Part II
Positioning/Indoor Positioning

Evaluation of Bluetooth Properties for Indoor Localisation

Khuong Nguyen and Zhiyuan Luo

Abstract Current indoor localisation systems make use of common wireless signals such as Bluetooth, WiFi to track the users inside a building. Amongst those, Bluetooth has been widely known for its low-power consumption, small maintenance cost, as well as its wide-spread amongst the commodity devices. Understanding the properties of such wireless signal definitely aids the tracking system design. However, little research has been done to understand the properties of Bluetooth wireless signal amongst the current Bluetooth-based tracking systems. In this chapter, the most important Bluetooth properties related to indoor localisation are experimentally investigated from a statistical perspective. A Bluetooth-based tracking system is proposed and evaluated with the location fingerprinting technique to incorporate the Bluetooth properties described in the chapter.

Keywords Indoor localisation · Bluetooth properties · Location fingerprinting

1 Introduction

Indoor localisation is the state-of-the-art to identify and observe a moving human or object inside a building. Global Positioning System (GPS) has long been an optimal solution for outdoor localisation, yet the indoor counterpart remains an

K. Nguyen (✉) · Z. Luo
Department of Computer Science, Royal Holloway, University of London,
Egham TW20 0EX, UK
e-mail: khuong@cantab.net

Z. Luo
e-mail: zhiyuan@cs.rhul.ac.uk

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open research problem because the sophisticated building infrastructure hinders the GPS signal, as well as making indoor signals modelling difficult. The 10 m limitation accuracy of the GPS is another consideration for those looking to apply the technology, as 1–2 m accuracy is desirable for room-level tracking.

Within the past decade, there have been numerous attempts to solve the problem with extensive hardware implementations such as the Active Badge system (Want et al. 1992; Addlesee et al. 2001), the Cricket system (Priyantha 2005) which measure the time-of-flight from a tag to the beacons using ultrasonic sensors. Despite an extreme accuracy up to 3 cm, 95 % of the time, these systems are expensive and hard to maintain and deploy. There have been pure software solutions such as Fingerprinting to utilise the built-in Wireless LAN of the building to create a signal-to-position mapping database beforehand, then applies pattern-matching algorithms to filter the most probable position for a real-time signal fingerprint (Bahl and Padmanabhan 2000; Youssef and Agrawala 2005; Brunato and Kallo 2002; Lin and Lin 2005). The Wireless LAN signal, however, uses much power, and is hard to install and configure in the first place. Another alternative is the Bluetooth wireless signal, which has been widely known for its low-power consumption, small maintenance and installation cost, as well as its ubiquitous amongst the commodity devices, such as mobile phones, head phones and laptops. There have been many Bluetooth-based indoor tracking systems (Orozco-Ochoa et al. 2011; Wang et al. 2011; Frost et al. 2012; Bargh and Groote 2008), yet, those systems did not pay much attention to the Bluetooth properties and assumed they are similar to other wireless signal. Understanding the properties of the wireless signal definitely aids the tracking system design. In this chapter, the most important Bluetooth properties related to indoor localisation are experimentally investigated from a statistical perspective. We aim to answer the question: Is Bluetooth signal robust enough for the indoor localisation purpose? In addition, a Bluetooth-based tracking system is proposed and evaluated with the location fingerprinting technique to incorporate the Bluetooth properties described in this chapter. The performance of such system is compared to the RADAR indoor tracking's counterpart, which is one of the first indoor tracking systems (Bahl and Padmanabhan 2000).

The contribution of this chapter is two folds. First, we investigate the most important Bluetooth properties from an indoor localisation perspective. Second, we propose a novel Bluetooth-based indoor tracking system to incorporate the Bluetooth properties demonstrated in this chapter.

2 Localisation with the Wireless Signal

Wireless signal is ubiquitous now-a-days, and benefits many indoor tracking applications. This section outlines the application of wireless signal into localisation and compares Bluetooth technology with Wireless LAN, which are the most popular wireless signal, in terms of localisation perspective.

2.1 Fine-Grained Tracking and Coarse-Grained Tracking

Based on the station broadcasting range, whenever an user and a station can communicate, which means they are in range, the user location can be interpreted as the station location itself. This method is known as proximity-based tracking. Despite its simplicity, the solution has two drawbacks. First, the system accuracy is exactly the broadcasting range of the station. A Class 2 Bluetooth device has a 10 m range, which is not very useful for indoor localisation. This method is enhanced by dividing the tracking space into grids. The stations are strategically placed in such a way that each grid block is overlapped by the signal from as many different stations as possible (Fig. 1). Thus, instead of coarsely predicting the user's location to be somewhere within the station's broadcasting range, the accuracy is improved by interpreting the user's location to be inside the overlapped area.

The idea still has one flaw, since many stations must be deployed to have a good tracking result. The coarse-grained tracking idea is great for observing users at room-level resolution. However, to identify an user location at sub-room-level up to 1–2 m, a more fine-grained tracking is needed. The solution can be further enhanced by analysing the wireless signal between each station to the user's unknown location. This idea bases on the fact that the wireless signal attenuates and gets weaker as it travels in the air. There are two measurements to roughly represent the distance between an user and a station: the received signal strength indication (RSSI) and the link quality (LQ). A simple, yet efficient method known as Location Fingerprinting makes use of these measurements. It utilises the built-in wireless signal of the building to create a signal-to-position mapping database beforehand, then applies pattern-matching algorithms to filter the most probable position for a real-time signal fingerprint. In comparison to proximity-based tracking, this solution offers much higher fine-grained tracking even with a few stations. In the next section, we discuss the difference between Bluetooth and Wireless LAN, which are the most popular wireless signals, for the purpose of fine-grained indoor localisation.

2.2 A comparison of Bluetooth and Wireless LAN

Bluetooth technology is a means for devices to wirelessly communicate over short distances. Many tracking systems require the user to carry 'a tag' for observation. However, the users often forget to wear it, making localisation impossible.

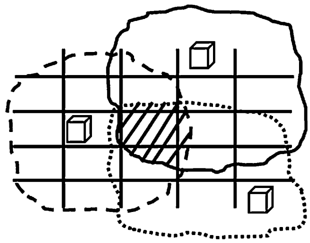

Fig. 1 Overlapping signal of 3 stations

Table 1 Bluetooth classes comparsion

	Working range (m)	Power consumption (mW)
Class 1	100	100
Class 2	10	2.5
Class 3	1	1

Compared to WiFi, Bluetooth technology has been more widely adopted amongst the commodity hardware such as mobile phones, head phones and laptops, which is a benefit as almost everyone carries a mobile phone these days. For large scale deployment, the ease of installation and the affordability also make Bluetooth-based approach stand out. Two Bluetooth devices are virtually ready to communicate upon plugging in, while a Wireless LAN network requires an adapter, and a router/wireless spot, which also needs more configuration. Further, the low cost (£3/Belkin dongle) is an advantage, which also consumes as little as 2.5 mW for a Class 2 dongle, compared to 1,675 mW for a Wireless LAN card while transferring data (Chandra 2003), which is 670 times higher in power consumption. Table 1 compares the power consumption level of the three Bluetooth classes. Class 2 Bluetooth is widely used nowadays, while Class 3 Bluetooth devices are obsolete and are no longer manufactured.

One big problem for any signal-based indoor tracking system is the attenuation of the wireless signal in the air. To increase the signal robustness, Bluetooth employs the ‘adaptive frequency hopping’ technique, in which the transceiver hops through 79 channels 1,600 times per second, while avoiding those channels with high interference. The transmission is broken down into very small packets to increase the signal robustness. Although both Bluetooth and WiFi use the license-free 2.4 GHz spectrum, WiFi devices stick to one channel during the session. The robustness of the adaptive frequency hopping technique will be investigated in this chapter.

However, when it comes to real-time tracking, WiFi offers almost instant RSSI and LQ inquiry, while a Bluetooth device takes 10.24 s for a full scan. Although it is possible to quickly target a particular user with the Bluetooth’s MAC address to perform a direct connection request, 1.28 s are still needed to determine whether the user is within range (Hay and Harle 2009). This weakness can be compensated by either modifying the Page Scan parameter of the Bluetooth dongle; or using more than one ‘scanner’ to boost the discovery rate. Table 2 summaries the difference between Bluetooth and Wireless LAN technology, in terms of indoor localisation perspective.

3 Properties of Bluetooth Signal at a Static Position

This section surveys the Bluetooth properties from a statistical perspective. We discuss what have been learned and how to benefit them in the actual implementation.

Table 2 Bluetooth and wireless LAN comparsion

	Bluetooth	Wireless LAN
Indoor range	10 m	100 m
Power consumption	2.5 mW	1,675 mW
Data transfer	Frequency hopping	Sequence spreading
Frequency	2.4 Ghz	2.4 Ghz
Ease of usage	Simple	Complex
Cost	Low (£3/dongle)	High (£20/card)
Inquiry time	1.28 s (direct inquiry)	Instant

3.1 The Distribution of Bluetooth Signal

Figure 2 shows the histogram distribution of the Bluetooth signal in a clear area with 30 cm distance between the transmitter and the receiver. We sampled the RSSI reading every 10.24 s over 24 h with a total of 8,897 samples. This is the standard Bluetooth inquiry rate. We recorded 52 histogram distributions over 4 months, with 96 % of the histogram samples showed a near-Gaussian distribution, 82 % of those were left-skewed, 11 % of those were almost-symmetric, and only 7 % were right-skewed. This skewness should be considered when modelling the indoor Bluetooth signal. Other indoor WiFi survey reports a similar distribution pattern (Kaemarungsi and Krishnamurthy 2004). The range of Bluetooth RSSI can be as wide as 10 dBm, with very few isolated individual RSSI, which is similar to the WiFi indoor signal. Since the histogram contains a concentrated peak around the highest RSSI value, with a high 50 % probability, it is possible to average the whole distribution as a single RSSI value, which performs well for Weighted K-nearest neighbour's algorithm.

These experiments used a Belkin Class 2 Bluetooth dongle. However, other dongles were tested to show a similar result.

3.2 The Antenna Orientation of the Bluetooth Device

An important property of the Bluetooth signal strength is the direction the device is facing. To the best of our knowledge, by surveying the internal design of popular Class 1 and Class 2 branded Bluetooth dongles in the market (Belkin, BlueNext, Nexxus, Asus, BlueWalker, Daffodil, Kensington, StarTech) from different Bluetooth chip manufacturers (Broadcom, Cambridge Silicon Radio (CSR), Texas Instruments (TI)), none of the current Bluetooth dongle is equipped with an omnidirectional antenna. The Bluetooth antenna is physically shaped as a plate (Fig. 3), which broadcasts the wireless signal in a cone-shaped wave. The broadcasting angle is around 30°, and is highly concentrated at the centre. Therefore, it is understandable that the RSSI is strongest when two devices are totally parallel and opposite each other.

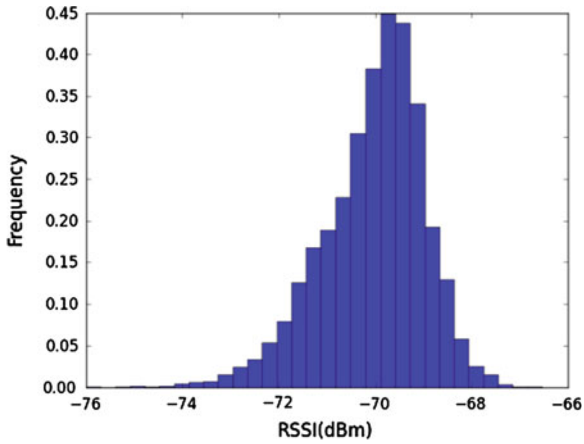

Fig. 2 Bluetooth RSSI distribution

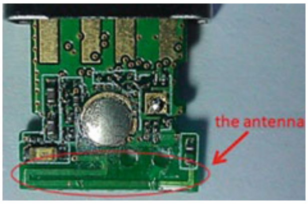

Fig. 3 Belkin dongle's antenna

To study the change of the Bluetooth signal upon the antenna orientation, we divide the 2D space into eight directions, parallel to the floor. At a clear distance of 30 cm between two opposite devices at the same height, the signal variation can be as large as 10 dBm (Fig. 4). The RSSI gradually decreases when one device rotates from the West-side to the East-side, with the weakest RSSI observed at the furthest East-side.

By moving one device out of the 30° broadcasting range of the other device, the signal variation still behaves as expected, although it is not as clear as when they are totally opposite each other (Fig. 5). A similar result was observed when changing the device's altitude.

Based on this observation, it is recommended that the Bluetooth stations to be placed at the corners, with the antenna pointing towards the centre of the room for the best signal broadcasting.

3.3 *The Variation of the Bluetooth Signal upon Distance*

When an user is further away from a fixed station, the attenuation weakens the wireless signal. However, it is not possible to fit a mathematical equation to calculate the exact signal strength loss, given the distance. We can only expect a

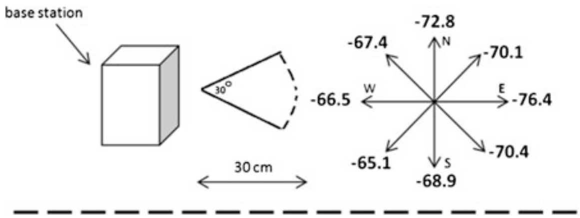

Fig. 4 RSSI orientation at the same height, opposite each other

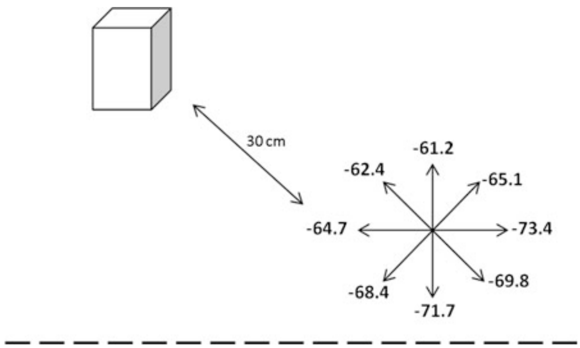

Fig. 5 RSSI orientation at the same height, not opposite each other

rough decreasing pattern as the distance increases. In general, the changes of Bluetooth RSSI can be separated into two categories; given the user can move a short or a long distance.

3.3.1 Small Scale Variation

It is not surprising that a very small distance on the order of a wavelength can cause the Bluetooth signal to vary to as much as 10 dBm. Small-scale variation is caused mostly by the multipath effect. When the two devices can directly see each other, the strongest signal follows a shortest unobstructed straight line-of-sight from one end to the other. However, in an indoor environment with many obstacles, the signal propagates in different paths because of reflection, scattering, diffraction and eventually reaches the destination (Fig. 6).

It was suggested measuring the readings every few metres apart to avoid capturing this variation (Youssef and Agrawala 2005). However, it makes the tracking capability very coarse with probabilistic algorithms such as the Bayesian approach, since they predict the unknown real-time location to be just one of the

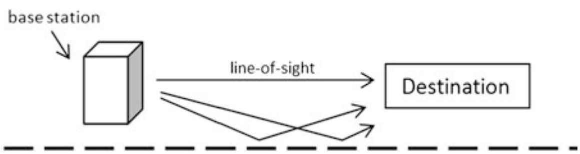

Fig. 6 Multipath fading

records in the database. Another solution is based on the Weighted K-nearest neighbour algorithm, which takes the average weighted measurements of K locations, and returns an estimated position in the middle of these K locations. The best solution is increasing the resolution of the tracking grid, such as taking measurements every 10 cm, which increases the system's maximum accuracy to 10 cm. However, this process is very time-consuming and results in a bigger database. We solve this issue with a robot to automatically collect the data, to be discussed later.

3.3.2 Large Scale Variation

When the user moves a long distance, it is expected that the signal strength gets weaker gradually. For the purpose of coarse-grained tracking, this serves as a warning that the user is leaving the tracking area. The large scale variation is very important for any fine-grained tracking purpose, as there is a correlation between the signal strength and the travelling distance at any location. However, the complex indoor structure makes modelling the wireless signal a very difficult and inaccurate task. Two distinct indoor locations further apart might have a similar signal strength pattern, due to multipath and other signal fading issues. This problem is alleviated by setting up many stations to increase the signal density and the uniqueness of each location in the tracking zone. We analyse this variation in details in both 2D and 3D spaces.

3.3.3 Moving Horizontally and Parallel to the Floor

In an ideal world, by ignoring all atmospheric, water absorption and multipath, an RF signal fades as it propagates in the air, because of the free-space path loss exclusively. The signal strength loss is calculated by the Friis transmission equation

$$P_{RX} = P_{TX} \cdot G_{TX} \cdot G_{RX} \cdot \left(\frac{\lambda}{4\pi d}\right)^2 \tag{1}$$

with

P_{TX} Transmission power of sender
P_{RX} Remaining power of wave at receiver
G_{TX} Gain of transmitter
G_{RX} Gain of receiver
λ Wave length
d Distance between sender and receiver

Since the Bluetooth RSSI has a near-normal distribution shape, the large scale variation will be represented under a log-normal random variable. We fit a best

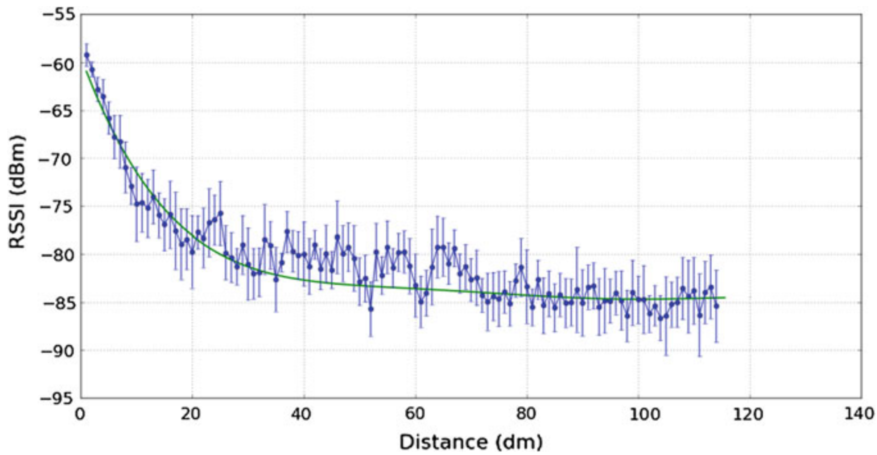

Fig. 7 Large scale variation

line to present the median path loss, calculated by the above formulae. This best fit line shows a quadratically decreasing relationship between the distance and the RSSI.

The above experiment (Fig. 7) was taken in a long office corridor, so that a clear unobstructed line-of-sight is possible. The base station was placed in the middle of the corridor and the Bluetooth device was gradually moving perpendicularly further away from the station. Overall, when the distance is more than 70 cm, we would expect to see a significant change in the RSSI. Interestingly, we found out from approximately 5 m onward, the RSSI stays almost the same. The signal is completely lost amongst all the noises at a distance of 6 m for a Class 2 Bluetooth device, which supposes to have a working range of 10 m. Another feature observed from Fig. 7 is that the standard deviation of the Bluetooth signal grows bigger as the distances increases. However, the number of recorded RSSI decreases as the distance increases. We conclude that strong Bluetooth RSSIs, which are found near the station, are more stable. Further, it is strongly recommended to set up a Bluetooth station every 5 m for the best Bluetooth signal differentiation amongst locations.

3.3.4 Moving Vertically and Perpendicularly to the Floor

Does the altitude of the device influence the Bluetooth signal? Many indoor tracking systems do not implement this feature, as they assume the height of the transceiver is fixed throughout the tracking process. This is not correct, as an user can carry his phone, which is used as the tracking tag, in either his shirt pocket or trouser's pocket. Further, the change of the signal strength upon the altitude is important for 3D tracking to detect if the user is moving upstair or downstair.

First, the range an user carries his tag can vary from 70–145 cm off the ground for an adult. Does this 75 cm difference influence the signal strength? In this experiment, a fixed station was set up at 1 m off the floor. The distance between the station and the device is 50 cm. When moving the device from the bottom floor to 2 m off the floor, the RSSI gradually increased. When the Bluetooth device and the station were parallel and opposite each other at the same height around 1 m off the ground, the highest RSSI were observed. The signal strength gradually decreased when the altitude of the device continued to increase.

Further, to investigate the effect of the altitude upon the Bluetooth station, the above experiment was repeated with the station set up at different heights, from the bottom floor to 1 m off the floor. Interestingly, we encountered many strange individual RSSIs with significant larger or smaller value, when the station was set up just 10 cm above the ground. This phenomenon can be explained by the effect of the multipath fading. The Bluetooth signal travels in different directions upon reflection, scattering, diffraction off the indoor objects and reaches the destination in different paths. Occasionally, two in-phase Bluetooth waves meet in the air, and cause a constructive interference, if both of them are using the same frequency. Destructive interference happens when two out-phase waves happen to be on the same channel, in which they will cancel each other. A station placed near the ground will increase the chance of two Bluetooth waves meeting in the air. We experimentally found out that the above phenomenon is less severe when the station's altitude is higher than 1 m off the floor (Fig. 8).

Since Sect. 3.2 reveals that the effective broadcasting angle of the Bluetooth device is around 30°, and Sect. 3.3 shows that the signal strength is strongly distinguishable within 4 m distance, the effective altitude of the Bluetooth station is calculated as

$$\mathrm{x} = \left[\frac{4}{\tan(75)}\right] = 1.07\,(\mathrm{m}) \tag{2}$$

Thus, it is strongly recommended to set up the base stations at least 1 m off the ground to lessen the multipath problem.

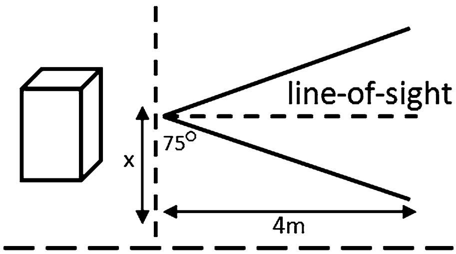

Fig. 8 Station's optimal altitude

4 Properties of Bluetooth Signal on a Mobile User

Tracking a mobile user is harder than tracking a static one. First, the 10.24 s discovery time of the Bluetooth devices is not suitable for real-time tracking. Second, the user's movement pace affects the robustness of the received signal as reported for the Wireless LAN (Kaemarungsi and Krishnamurthy 2004). The first issue is alleviated in the recent 'connection-based' approach, which reduces the discovery time to 1.28 s, following a one-off registration of the device's MAC-ID. The second problem is more difficult, because the hang-over effect makes the wireless signal unpredictable.

It was reported that the faster the walking speed, the less reliable the Bluetooth signal strength is (Madhavapeddy and Tse 2005). To verify this statement, we recorded the RSSI at two moving paces more accurately with a robot: 2 m/s for a fast walk and 0.22 m/s for a slow walk. Figure 9 shows that the difference between 'fast walk' and 'slow walk' in our experiment was much less severe than what reported above. However, we did observe a similar increasing pattern of the standard deviation, as the distance from the station increases. Further, contrast to the report that 'static measurements' failed to achieve a better result than 'slow walk', we observed a similar performance in both cases. 'Static measurement' means the robot stops for a few seconds to take readings before moving on.

There are two differences between our approach and the one reported above. First, we applied the recent connection-based inquiry to measure the RSSI in less than 1.28 s, rather than using the standard 10.24 s inquiry, which allowed us to collect more RSSI at a faster rate. Second, we opted for the RSSI measurement while the other experiment used the LQ as the signal strength measurement. The use of a robot to collect data could also have an impact in our case.

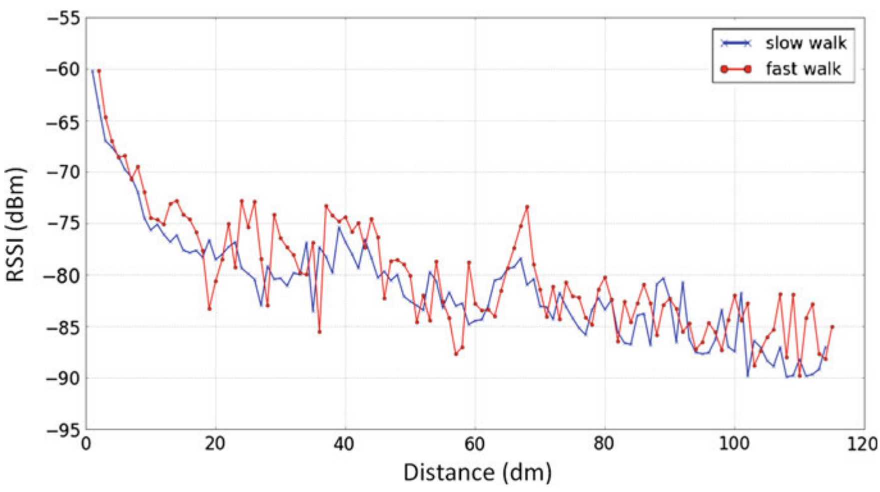

Fig. 9 Comparison of walking speeds

5 External Influences upon the Bluetooth Signals

Many indoor tracking systems assumed an ideal environment (Bruno and Delmastro 2003; Hallberg et al. 2003). In reality, the surrounding varies from time to time due to human movements, humidity, furniture re-arrangement, etc. Any database-based tracking system must frequently update the latest signal readings, or use multiple databases to reflect different environments during rush hour, early morning, late evening.

5.1 Influence from the Human Body

The human presence is a major factor for any indoor tracking system. The human body contains as much as 75 % of water, which absorbs the radio wireless signal. Many tracking systems require the user to carry a tag, which lies very close to the human body. To examine the human presence effect, two fixed base stations were set up at 1 m away in a cafeteria. Two periods of time were chosen to record the Bluetooth signal: when the cafeteria was crowded with people at mid-noon and when it was quiet in the late evening. Figure 10 below shows that the Bluetooth signal fluctuates more wildly when there are many people around, with a bigger standard deviation of 3.17, compared to 2.36 without the human presence.

We attempted the above experiment at the same location with the Wireless LAN to compare the signal variation. Interestingly, the standard deviation recorded for the Wireless LAN was bigger than the value recorded for the Bluetooth signal when the area was crowded. We observed both the WiFi and Bluetooth signals for a week with different levels of crowd. All our records showed that the Bluetooth wireless signal copes well with much noise around. However, when the distance between the two stations increased, the Wireless LAN signal was much stable with smaller standard deviation. This phenomenon shows that in a noisy environment, the Bluetooth signal is much more adaptive for short distance communication than the Wireless LAN, by breaking the transmission into small packets and frequently switching channels to avoid signal collision.

5.2 Influence Amongst the Bluetooth Signals

Deploying a Bluetooth-based tracking system involves setting up many Bluetooth stations under the same domain. Do the Bluetooth signals affect each other? Is there a relationship amongst the signals over times? This section discusses whether many Bluetooth devices can co-exist in a small domain. Since the limited Bluetooth broadcasting range demands a close distance between stations, the potential signal collision is a possibility.

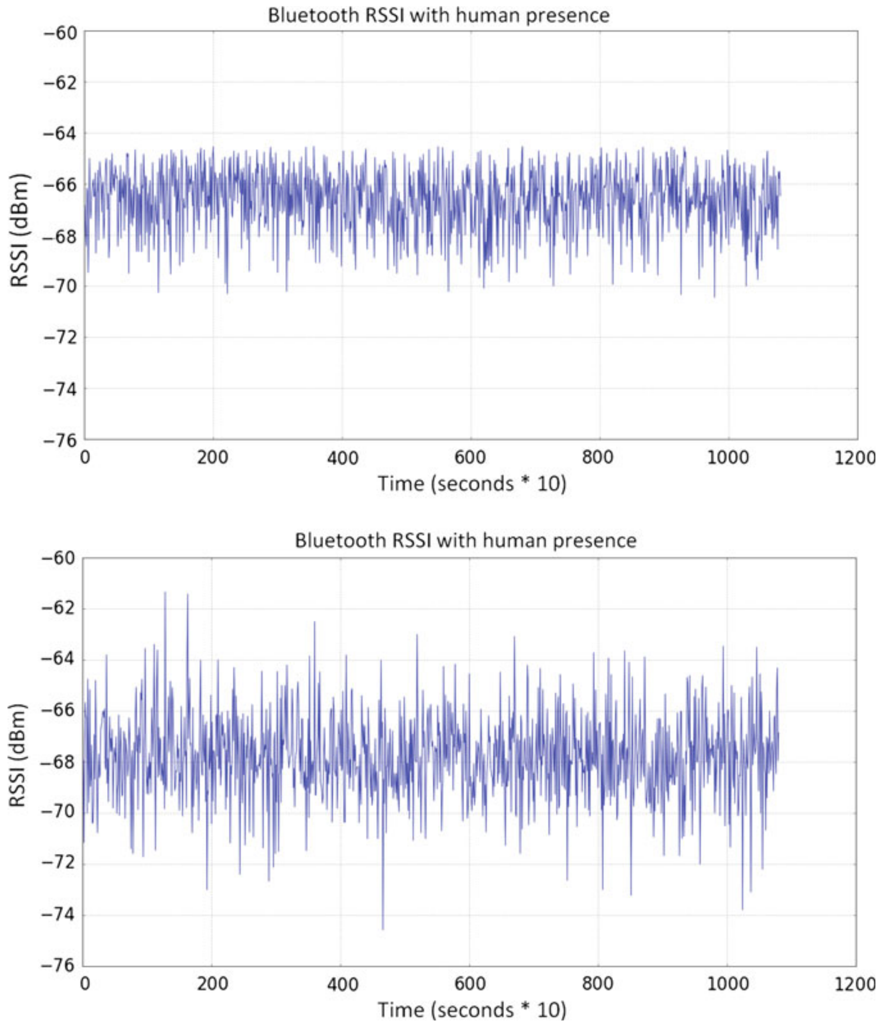

Fig. 10 Bluetooth RSSI without/with human presence

5.2.1 The Correlation of the Bluetooth RSSI at the Same Station

An indoor tracking system relying on an off-line database has to capture the signal variation in different times of the day to reflect different environments. Is it necessary to re-run the whole surveying process at the same time in different days, presuming the environment does not change as much? This condition can only be relaxed if the Bluetooth signals themselves do not cause any internal conflict. We applied the Wide-Sense Stationary (WSS) process to verify the stationary property of the Bluetooth RSSI in different times at the same station, assuming the environment is static. A Bluetooth RSSI is said to be stationary, if its histogram

Table 3 6 h segments comparsion

	6–12am	12–6pm	6pm–0am	0–6am
Mean	−67.5	−67.74	−68.1	−66.86
Standard deviation	1.14	1.04	1.09	0.95

distribution do not change with time. Two conditions must be met. First, the mean value of the RSSI distribution is a constant, regardless of the time. Second, the autocorrelation function of the WSS process is independent of the time difference at the same station. With an RSSI sequence recorded in an isolated room to eliminate most external noises over 24 h, we divided the sequence into chunks of 6 h, and compared these segments. Table 3 shows that the means and the standard deviation of the four sequences were very close, which mostly satisfies the first WSS condition. Despite our best effort to eliminate the surrounding noises, it is difficult to purify the environment, which explains the small difference in the statistical values.

Figure 11 demonstrates the correlogram of the above 6 h segments. Beside the close autocorrelation, the shapes of the 4 correlograms were also very identical. We also tested different segment sizes of 1, 2, 4, 8 and 12 h to confirm the similarity of the result. Therefore, we conclude that the Bluetooth RSSI at the same station is independent, regardless of the time difference, presuming the environment is identical.

5.2.2 The Correlation of the Bluetooth Signal at Different Stations

Section 3.3 reveals that the Bluetooth signal is completely lost amongst all the noises at a distance of 6 m onwards. The short distance characteristic of the Bluetooth signal demands the Bluetooth stations to be set up as close as 5 m to each other, which raises the question if they can potentially interfere. We set up 4 stations as shown in the first testbed (Sect. 6.1). A receiver R was placed at the lower left corner of the room to record the signal from the 4 stations over 24 h. Table 4 shows that there is no correlation between the received signal, with a strong distinction of the mean, standard deviation and the correlation. We conclude that the Bluetooth signal in different stations is independent.

5.3 Influence from Other Wireless Sources

It is common to have many wireless sources co-existing in the same environment. Bluetooth technology increases the signal's robustness by adapting the frequency-hopping to constantly switching between 79 channels 1,600 times per second to avoid collision with other wireless signals operating on the same 2.4 GHz spectrum, such as Wireless LAN, microwave oven. Some indoor tracking systems were

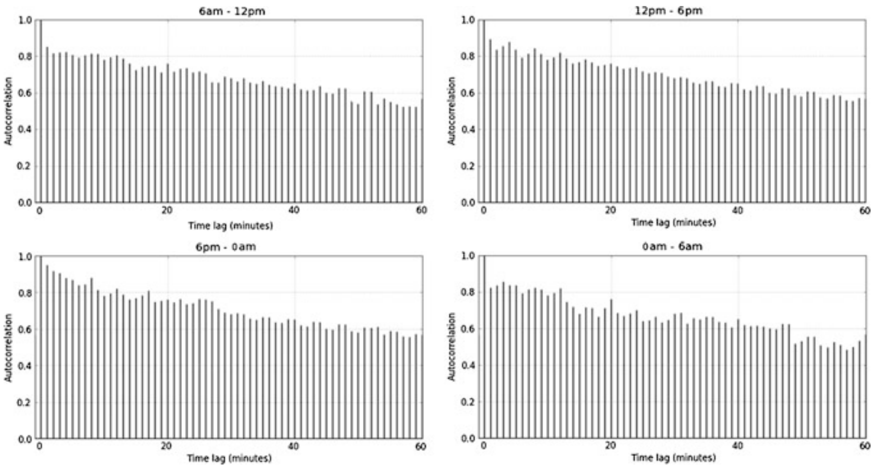

Fig. 11 6 h segments correlograms

Table 4 Signal correlation from 4 different stations

	Distance (m)	Mean	Standard deviation	Correlation
R–A	5	−82	2.84	−0.21
R–B	5.8	−86	3.28	−0.17
R–C	4	−78	2.4	+0.17
R–D	1.5	−69	1.57	+0.26

seen to in-corporate both Bluetooth and Wireless LAN (Pandya et al. 2003), yet there has not been a verification to confirm if there is any conflict between the Bluetooth and Wireless LAN signals.

To test the influence of the Wireless LAN upon the Bluetooth signal, a Bluetooth transmitter and receiver were set up to constantly measure the RSSI between them. The same environment was artificially modified by injecting many WiFi signal, with five computers equipped with the wireless LAN cards constantly ping each other. Table 5 shows that both cases have a very identical mean value and standard deviation. There is also a strong correlation R = 0.92. Therefore, we conclude that the interference caused by the Wireless LAN is almost non-existent.

6 A Bluetooth-Based Location Fingerprinting System

To incorporate the above Bluetooth features, we propose a Bluetooth-based indoor tracking system with the Fingerprinting method. Especially, to tackle the hassle of database collection, we designed a robot to automatically collect the Bluetooth data. Three classification algorithms were implemented, the Weighted K-nearest

Table 5 Bluetooth distribution with/without WiFi noises

	Mean	Standard deviation
Without WiFi	−71	2.45
With WiFi	−72	2.7

neighbours, the Bayesian approach and the Histogram matching algorithm. We compared our system performance to the RADAR system (Bahl and Padmanabhan 2000), which used a similar K-nearest neighbours approach with the Wireless LAN signal.

6.1 Data Collection

The system was installed in two different locations as described below. In both cases, a robot was used to collect the Bluetooth data along with the location's physical co-ordinate.

6.1.1 Testbed 1

The first testing environment was deployed on the second floor in the Computer Lab, University of Cambridge where we used the Bat system as a reference to provide accurate 3D location data. This testbed was, however, limited to just a single room of 15 m^2 (5 × 3 m). All locations within the tracking zone can be seen by all four Bluetooth stations (Fig. 12).

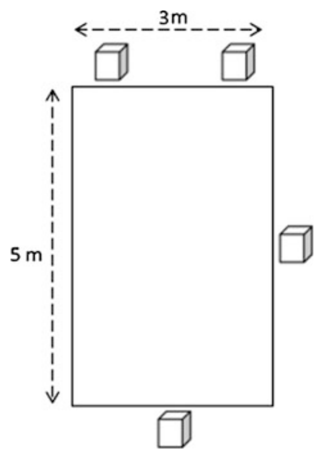

Fig. 12 First testbed

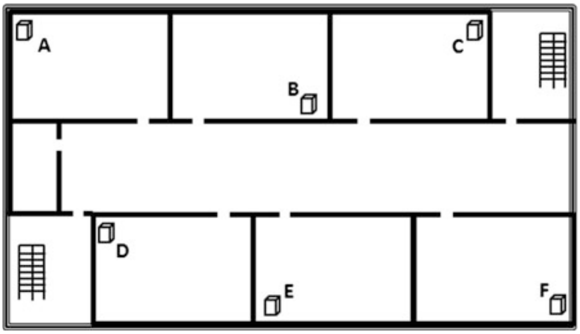

Fig. 13 Second testbed

6.1.2 Testbed 2

The second testbed aimed to deploy the system in a large environment, where each station alone cannot cover the whole tracking zone. An office of 136 m^2 (17 × 8 m) was used to deploy the system (Fig. 13).

6.1.3 Automated Robot

For a database reference method such as Fingerprinting, the system accuracy depends on the reliability of the reference entries stored in the database, as well as the number of surveyed entries. Yet, it takes much effort for a human to survey every location within the tracking area. For this reason, a robot was built from LEGO pieces (Fig. 14), which is convenient for maintenance and re-production. The robot is capable of carrying a laptop for 8 h per single charge. More details about the robot are discussed in (Nguyen 2011). The advantages of the mobile robot for indoor localisation include automated data collection, less interference with RF signals due to its small size, and adjustable body to experiment at different heights. Although in real-time tracking, an user will present instead of a robot, the signal attenuation due to human body can be compensated.

6.2 System Evaluation

We collect data from 260 random positions in the first testbed and 270 positions in the second testbed. Each position contains the Bluetooth RSSI fingerprint, and the physical 3D co-ordinate. To evaluate the system performance, we provide the Bluetooth fingerprint into the system, which returns a predicted co-ordinate based on the training database constructed beforehand. Three algorithms were implemented.

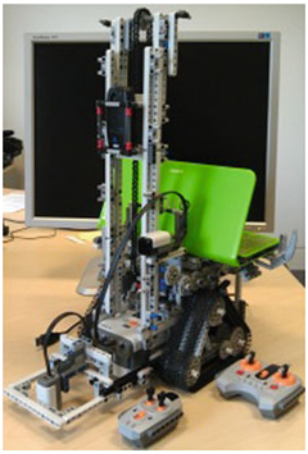

Fig. 14 LEGO robot

6.2.1 Weighted K-Nearest Neighbours

Given a Bluetooth RSSI, the Weighted K-nearest neighbour's algorithm selects K-nearest entries in the database, in terms of the Euclidean distance. A Bluetooth RSSI is represented as an n-tuple $X = (x_1, x_2,\ldots, x_n)$, with x_i is the signal strength measured from the station i. The 'distance' between two Bluetooth RSSI X and Y is measured as

$$\mathrm{dist}(X, Y) = \sqrt{(x_1 - y_1)^2 + \cdots + (x_n - y_n)^2} \tag{3}$$

It is common that many distinct locations far away might have a similar combination of signal strength, because of the indoor signal multipath problem, where the wireless signal bounces off the indoor objects and arrives at the destination in different paths. Thus, by considering the 'weight', corresponding to the inverse distance between each neighbour n_i and the unknown position l, the final estimated 3D position $E = (e_x, e_y, e_z)$ would be much more accurate. The reason to invert the distance is to prioritise closer neighbours over further away one. The 'weighted' equation is repeated for each dimension of the unknown location $L = (l_x, l_y, l_z)$

$$e_x = \frac{\sum_{i=1}^{K} \frac{1}{\mathrm{dist}(n_i, l)} l_x}{\sum_{i=1}^{K} \frac{1}{\mathrm{dist}(n_i, l)}} \tag{4}$$

Finally, an optimal K parameter is calibrated specifically for each environment and the wireless signal. In our system, we experimentally found $K = 16$ as an optimal value across all testing points. Some locations had better results with different K. Generally, starting from $K = 1$, which is equivalent to considering only the nearest entry, the accuracy tends to increase when K increases, up to a certain point ($K = 16$ in our case), then it begins to decrease with bigger K.

Compared to the normal K-nearest neighbour algorithm implemented in the early version of the RADAR system, the overall performance was enhanced by more than 25 % (Fig. 15).

6.2.2 Naive Bayesian Approach

While the Weighted K-nearest neighbour's algorithm computes an average of all nearest locations to estimate an unknown position, the Bayesian approach picks up just one entry in the database with the highest probability to represent the estimated location. The idea of 'probability' comes from a histogram table, which records the Bluetooth signal variation in terms of the small-scale variation. Assuming the base stations are independent, the probability of a given signal strength pattern $X = (x_1, x_2, \ldots, x_n)$ at a particular location L recorded in the database is calculated by the probability of each individual signal strength x_i, as follows

$$P((x_1, x_2, \ldots, x_n)|L) = P(x_1|L)\, P(x_2|L) \ldots P(x_n|L) \tag{5}$$

Each separate term $P(x_i|L)$ can be calculated independently based on the frequency of x_i recorded at the location L in the database

$$P(x_i|L) = \frac{\text{number of times } x_i \text{ appears}}{\text{total number of readings at location } L} \tag{6}$$

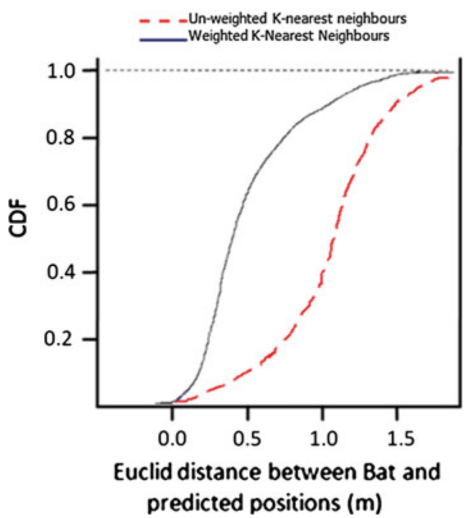

Fig. 15 Weighted K-NN versus unweighted K-NN

However, the actual purpose is to calculate the probability that the given RSSI $X = (x_1, x_2,\ldots,x_n)$ indeed belongs to the location L recorded in the database. This is the reverse probability

$$P(L|(x_1, x_2, \ldots, x_n)) = \frac{P((x_1, x_2, \ldots, x_n)|L)\, P(L)}{P(x_1, x_2, \ldots, x_n)} \quad (7)$$

The probability $P((x_1, x_2,\ldots,x_n) \mid L)$ is calculated using Eq. 5. The probability $P(L)$ of a location L itself is always $1/N$ with N = number of entries in the database, which is a constant. The probability $P(x_1, x_2,\ldots,x_n)$ is the number of times $(x_1, x_2,\ldots, x_n)$ appears in the database divided by the total number of entries in the database, which is also a constant. Thus, $P(L)$ and $P(x_1, x_2,\ldots,x_n)$ can be ignored in the computation.

To sum up, given an unknown location's signal strength pattern, the probability of every record L_i in the database $P(L_i \mid (x_1, x_2,\ldots,x_n))$ to match this unknown location is calculated. The position L_i with the highest probability is considered as the estimated position.

This Naive Bayesian approach assumes the base stations are independent. This assumption is correct as discussed in Sect. 5.2. The drawback of this solution was the big size of the database, resulting from many readings taken at a fixed position to record the signal variation. Second, the tracking zone's resolution determines the accuracy of this approach. For every 1 m measurement, the Bayesian approach cannot provide estimated position with more than 1 m accuracy, because it picks just one entry in the database as the estimated location. Ideally, we prefer a high granularity database, yet it consumes much longer to survey the tracking zone. In general, the Bayesian approach performs better than the Weighted K-nearest neighbour's counterpart, as it takes into account the signal variation, at the cost of a bigger database size.

6.2.3 Histogram Matching

The Histogram matching method adapts a similar approach as the Bayesian, by using the histogram table. Besides, it takes a further step by considering the signal variation at the unknown position too, while the Bayesian approach considers just a single RSSI snapshot. However, this solution has one flaw. Although it is possible to wait for signal arriving in the database construction stage, in real-time tracking, the mobile user moves quickly, which limits the amount of signal received at any particular moment. For tracking static user, this approach shows very good performance.

To compare the histogram tables, we implemented two algorithms. The 'Student's *T* test' is performed, if the histogram table is normally distributed, otherwise the 'Kolmogorov–Smirnov test' (K–S test) is performed. Section 3.1 implies that the Bluetooth signal strength does not have a Gaussian distribution only 4 % of the times. The experimental result shows that the performance does not degrade too much by this violation.

6.2.4 Performance Summary

In general, all three algorithms performed equally well (Fig. 16).

The Weighted K-nearest neighbours is simple and easy to implement, but deciding the optimal K parameter is challenging, which can only be achieved experimentally depending on the environment deployed and the wireless signal's properties. The histogram matching approach seems to edge out of the other two, since it uses the signal variation in both off-line and on-line stages. However, obtaining many readings in a short period of time during real-time tracking is challenging, especially for the Bluetooth signal. The Bayesian approach algorithm captures just one signal strength reading during real-time tracking, but considers the whole range of the signal variation recorded in the database to select one entry with the highest probability as the estimated location. This is the most balanced algorithm, in terms of performance and realistic deployment. The system achieved less than 1.5 m error, 88 % of the time; or 50 cm error, 43 % of the time. Compared to the RADAR system with 2 m error using the Wireless LAN signal, this performance is very promising, considering the affordability and the efficiency nature of the Bluetooth devices. It only took less than 0.04 s to estimate an unknown position on a 1.6 GHz computer.

The Bayesian approach can be further enhanced by combining with the Weighted K-nearest neighbours. Instead of picking just one location in the database, it selects *K* entries with the highest probabilities, and uses the probability measurement as the weight to average the estimated position. However, it would take more computational power to process *K* entries.

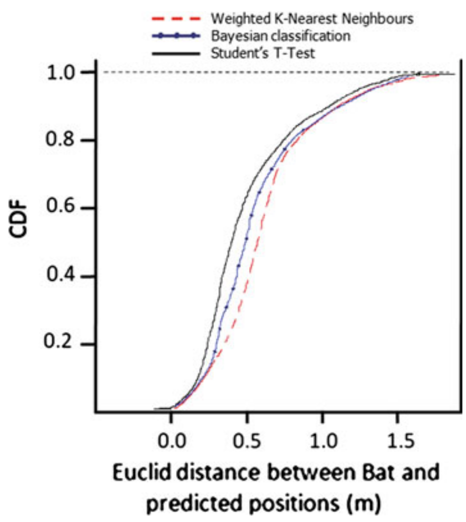

Fig. 16 System performance

7 Conclusions and Further Work

In this chapter, we investigated the Bluetooth properties for the indoor localisation purpose. The Bluetooth signal is strongly immune to the interference caused by other wireless sources, thanks to the adaptive frequency hopping. However, human presence is a major factor, which influences the Bluetooth signal strength and deviation. Compared to the Wireless LAN, Bluetooth technology has the benefits of affordability and efficiency, which suit the purpose of ubiquitous deployment. The main weakness of Bluetooth, however, is the slow inquiry time, which can take up to 10.24 s for a full scan. The recent 'connection-based' approach has reduced it to just 1.28 s, which is very important for tracking mobile users.

We implemented a Bluetooth-based indoor tracking system with Fingerprinting method and a robot to incorporate the Bluetooth properties learned from this chapter. The system performance is promising with an accuracy of less than 1.5 m error, 88 % of the time, considering the affordability and efficiency nature of the Bluetooth technology. We plan to implement machine learning algorithms to tackle the slow inquiry time, as well as minimal the signal-survey effort.

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Pedestrian Indoor Localization Using Foot Mounted Inertial Sensors in Combination with a Magnetometer, a Barometer and RFID

Michailas Romanovas, Vadim Goridko, Lasse Klingbeil, Mohamed Bourouah, Ahmed Al-Jawad, Martin Traechtler and Yiannos Manoli

Abstract A system for pedestrian indoor localization is presented, which uses the data of an inertial sensor unit mounted on the foot of a person walking through an indoor or outdoor environment. The inertial sensor data are integrated to a position/orientation information using a classical strapdown navigation approach, while several additional sensor data and constraints, such as Zero Velocity Updates, magnetometer and barometer readings and the detection of spatially distributed RFID tags, are incorporated to the solution using an Unscented Kalman Filter. The work presents a custom sensor system development, describes the developed algorithms and evaluates several methods to reduce the drift, which usually comes with the integration of low cost inertial sensors.

Keywords Pedestrian localization · Zero velocity update · Unscented kalman filtering

M. Romanovas (✉) · V. Goridko · M. Bourouah · A. Al-Jawad · M. Traechtler
Institute of Microsystems and Information Technology, Hahn-Schickard-Gesellschaft e.V., Villingen-Schwenningen, Germany
e-mail: michailas.romanovas@hsg-imit.de

L. Klingbeil
Institute of Geodesy and Geoinformation, Rheinische Friedrich-Wilhelms-Universitaet Bonn, Bonn, Germany

Y. Manoli
Fritz Huettinger Chair of Microelectronics, Department of Microsystems Engineering (IMTEK), Albert-Ludwigs-Universitaet Freiburg, Freiburg, Germany

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1 Introduction

As reliable outdoor localization can be addressed with GNSS/GPS-based techniques, the indoor or combined indoor/outdoor scenarios still seem to be far more challenging as the GNSS signals are usually too weak to penetrate the buildings and a number of different approaches compete to become the key technology in the nearest future [see (Retscher 2006) for a summary of indoor localization techniques]. Although originally robotics applications or similar scenarios [e.g., (van der Merwe and Wan 2004)] attracted most of the efforts, recent advances in affordable wearable computing, availability of infrastructure [WiFi, RFID and emerging Ultra Wideband (Gigl et al. 2007)] and significantly improved performance of MEMS sensors resulted in a growing interest of applying similar concepts also for pedestrian indoor localization scenarios (Sabatini 2009; Ahn and Yu 2007).

Currently none of the available technologies alone can completely satisfy the accuracy, flexibility, scalability and cost requirements for pedestrian indoor localization within an uncontrolled environment and combinations of several complementary technologies are often employed for increased robustness (Ahn and Yu 2007; Foxlin 2005). The sensing modalities are usually combined using Recursive Bayesian Estimation (RBE) framework, which permits to treat the sensor imperfections, dynamical model uncertainties and heuristic information regarding the environment in a consistent way (Thrun et al. 2005), enabling a performance, which is in general not achievable with a single sensing modality.

Robust indoor human tracking is believed to be a crucial requirement for the concept of so-called *Smart Environment* as well as *Pervasive Computing* (Fox et al. 2003) and biomedical applications (Sabatini 2009) and is considered to be a rather challenging problem (Ahn and Yu 2007). Potential applications include ambulatory monitoring for people with disabilities or chronic health conditions, orientation and mobility aid for blind and visually impaired people, various assistance systems (Sabatini 2009) etc. Moreover, a reliable indoor localization can be helpful for emergency first responders such as firefighters. Interestingly, within the latter scenarios one can not completely rely on localization methods based on external infrastructure such as Wireless and Ultrasound-based schemes as the availability of the power can not be in general ensured for most of the emergency situations. Moreover, some of the approaches can require complex and expensive infrastructure which can not be placed in all except of very special locations.

One of the most typical approaches to deal with the drawbacks of the external-referencing systems is to adopt integrated pedestrian dead-reckoning (PDR), where the inertial sensors (e.g., accelerometer and gyroscopes constituting the Inertial Measurement Unit–IMU) provide an internal independent reference, immune to interference and signal shadowing and are continuously available. In practice, however, solely inertial system can be hardly employed for any reasonably long time due to fast accumulating integration errors. Here the position error usually increases much faster compared to orientation ones due to the double integration of the accelerometer imperfections (e.g., offsets). Additional sensors such as barometric altimeter or magnetic compass are sometimes integrated to bound the heading error and vertical position while external referencing (in the form of absolute position or ranging measurements etc.) are used to limit the position errors. Moreover, the external sensing is also necessary for the initialization phase of the inertial-based approach as the inertial approach is able to provide only relative position with respect to the origin.

In this chapter we discuss a foot-mounted system for pedestrian indoor localization and tracking, where low-cost commercial inertial and magnetic sensors are used, and where the fusion is formulated using Unscented Kalman Filter. The system is able to provide a reliable position and orientation estimation over a reasonable period of time. We demonstrate the performance of the system for several indoor/outdoor scenarios and evaluate its performance with respect to different algorithm parameters and model structures. We also demonstrate how some of the accuracy issues can be addressed by augmenting the system with additional sensors such as a barometer and a RFID tag reader. The RFID technology has already attracted a significant attention due to its economic advantages (Subramanian et al. 2008) and was chosen due to being rather low-cost and the ability to handle potential power constraints (e.g., blackouts).

The rest of the chapter is structured as follows: Sect. 2 presents the related approaches of other authors and previous work of the authors for pedestrian indoor localization. Section 3 discusses the mathematical details of the developed localization algorithm along with the fusion filter and the associated process and measurement models. The custom developed hardware setup is briefly described in Sect. 4 with the experimental results of several representative scenarios provided in Sect. 5. Finally, the Sect. 6 sums up the findings and evaluates the potential of the technique for future positioning applications.

2 Related Work

While within robotics applications one could achieve a reasonably good performance by using an accelerometer, odometer and angular rate sensor and constraining the motion with the known kinematic information, such a direct approach would often fail when applied to pedestrian localization. One of the most straightforward approaches is to detect the step (e.g., using the accelerometer) and to calculate the displacement assuming a known step length or to estimate it using some biomechanical model. Unfortunately, such an approach provides only a very approximate position and is mainly suitable for activity monitoring or for coarse localization. Moreover, it could often fail if an unusual scenario is encountered such as a crowded environment or uphill/downhill walking patterns and often have to be tuned for a particular user.

External referencing is believed to be a more reliable option when addressing pedestrian localization. The issue is often resolved by attaching a small-size wireless tag [UWB (Gigl et al. 2007)]; CSS-based IEEE 802.15.4a (Nam and Park 2009); ZigBee, WLAN (Ali and Nobles 2007; Retscher 2006), Bluetooth) to the human body and measuring distances to fixed and known anchor points. Other approaches include systems based on computer vision and camera systems, RFID tags (Subramanian et al. 2008), ultrasound based localization (Kim and Choi 2008), passive infrared sensors (PIR), light detectors (Golding and Lesh 1999) and even temperature sensing (Golding and Lesh 1999). Clearly, one could attempt to employ a personal dead reckoning (PDR) system combined with one of the referencing techniques mentioned above (Retscher 2006).

In our previous works (Klingbeil et al. 2010a, b) we have developed a wearable system for seamless pedestrian indoor/outdoor localization. The system was intended to be placed on the chest of the person while information from the inertial sensors was used for heuristic step detection and step length estimation. The MEMS gyroscope in combination with magnetometer was employed for heading correction while the GPS and/or RF CSS modules (Nanotron Nanoloc™) were used for absolute position referencing. The fusion algorithm was formulated as a particle filter (PF) triggered with the step counting. The algorithm was also able to take into account the map constraints (in the form of occupancy grid) to restrict the motion not to cross the walls. Although being fairly complex, the system suffered from several fundamental flaws such as heuristics in step detection and length estimation, which could easily fail for a user with different gait and walking habits, poor performance of heading information due to magnetic field disturbances and noisy CSS ranging information. All the aforementioned issues resulted in difficulties of using such a system for any practical applications.

In this work we described a different strategy for pedestrian indoor localization using a foot-mounted IMU/sensor block. The approach explicitly employs assumptions regarding the human foot dynamics to constraint the estimation error only increasing linearly with the distance, usually navigating open loop only for time periods shorter than 1 s (i.e., the typical step duration during normal gait conditions) (Foxlin 2005). The presented method, commonly referred as 'Zero Velocity Update', dramatically decreases the position error by resetting the estimated velocity to zero when the stance phase of the step is detected (Bebek et al. 2010; Sabatini 2009). Note that the residual position error is still not completely eliminated and remains in general unbounded (House et al. 2011). The overall fusion concept becomes feasible due to correlation information introduced by the dynamical model which allows to correct retrospectively the sensor imperfections.

The technique, nowadays rather widely adopted throughout the research community, was made famous by Foxlin, although using a rather expensive and well-calibrated IMU [see (Foxlin 2005) for a friendly introduction]. The framework was extended in numerous recent works of multiple authors. For example, the work of (Bird and Arden 2011) extended the framework with GPS position measurements and validation mechanism for magnetic disturbances with cascaded estimation architecture proposed in (Krach and Robertson 2008). In a series of works

(Jimenez et al. 2009, 2010) the methods were further exploited with more advanced motion models, restricting the motion to follow mainly the straight trajectories. The work (Sabatini 2009) proposed an EKF-based approach with quaternion orientation parametrization with magnetometer bias estimation and adaptive measurement models. The work (Bebek et al. 2010) suggested to combine a shoe-mounted IMU with a high-resolution, thin, flexible error-correcting bio-mechanical ground reaction sensor to provide more detailed contact information compared to a detection based solely on inertial sensors only.

A combination of a foot mounted IMU with passive RFID tags was proposed in House et al. (2011). Interestingly, the authors placed the correction step outside the filter and employed a pure geometric approach based on affine transforms for trajectory segment correction between current and previous RFID detection points.

3 Algorithm Description

3.1 *Recursive Bayesian Estimation and the Unscented Kalman Filter*

The pedestrian localization scenario is formulated as the state estimation problem of the following system:

$$\mathbf{x}_k = f(\mathbf{x}_{k-1}, \mathbf{u}_{k-1}, \mathbf{w}_k), \quad \mathbf{z}_k = h(\mathbf{x}_k, \epsilon_k) \tag{1.1}$$

where $\mathbf{x}_k \in \mathbb{R}^n$ is the state at time t_k with the associated measurement $\mathbf{z}_k \in \mathbb{R}^m$, $f(\cdot)$ and $h(\cdot)$ are the nonlinear system process and measurement functions respectively, $\mathbf{w}_k$ and ϵ correspond to the process and measurement noises and $\mathbf{u}_k$ stands for control input.

Within the framework of recursive bayesian estimation (RBE) (Fox et al. 2003; Thrun et al. 2005) the estimation of the state $\mathbf{x}_k$ of a system at the time t_k based on all measurements $\mathbf{Z}_k = \mathbf{z}_0, \ldots, \mathbf{z}_k$ up to that time is represented as a probability density function (pdf) $p(\mathbf{x}_k|\mathbf{Z}_k)$, which can be calculated recursively using two steps:

Prediction The *a priori* probability $p(\widetilde{\mathbf{x}}_k)$ is calculated from the last *a posteriori* probability $p(\mathbf{x}_{k-1}|\mathbf{Z}_{k-1})$ using the process model $p(\mathbf{x}_k|\mathbf{x}_{k-1})$:

$$p(\widetilde{\mathbf{x}}_k) = p(\mathbf{x}_k|\mathbf{Z}_{k-1}) = \int p(\mathbf{x}_k|\mathbf{x}_{k-1})p(\mathbf{x}_{k-1}|\mathbf{Z}_{k-1})d\mathbf{x}_{k-1} \tag{1.2}$$

Correction The *a posteriori* probability $p(\mathbf{x}_k|\mathbf{Z}_k)$ is calculated from the *a priori* probability using the measurement model $p(\mathbf{z}_k|\mathbf{x}_k)$ and the current measurement $\mathbf{z}_k$:

$$p(\mathbf{x}_k|\mathbf{Z}_k) = \frac{p(\mathbf{z}_k|\mathbf{x}_k)p(\mathbf{x}_k|\mathbf{Z}_{k-1})}{p(\mathbf{z}_k|\mathbf{Z}_{k-1})}. \tag{1.3}$$

Various implementations of RBE algorithms differ in the way the probabilities are represented and transformed in the process and measurement models (e.g., Kalman Filters, the non-linear variants Extended Kalman Filter (EKF) (Thrun et al. 2005) and Unscented Kalman Filter (UKF) (Julier et al. 2000; van der Merwe 2004) and Sequential Monte Carlo Filters).

Although the original implementation (Foxlin 2005) of the ZUPT-based filtering with foot mounted inertial sensors was based on an EKF, we decided to implement our approach as an UKF, where the probability distribution is approximated using a set of deterministically placed points in the state space, chosen to conserve the Gaussian properties of the distribution under nonlinear transformations. This unscented transformation (UT) is in general more computational demanding than a linearization used in an EKF, but apart from the better statistical properties the formulation of the models is straightforward, since no Jacobians have to be calculated. There also exist methods for the optimization of the UKF regarding stability and computational needs, such as Square Root versions or the usage of Spherical Simplex Sigma Points. The authors have applied these methods before for orientation estimation (Romanovas et al. 2009). Please refer to this chapter and the references therein for a detailed description of the UKF equations as we omit them here due to space constraints.

The main challenge in the implementation of RBE algorithms is the formulation of the process and measurement models as well as the associated uncertainties. Below we describe the process model, which is a straightforward implementation of the classical INS strapdown integration, and a variety of measurement models incorporating various sensors and constraints. The basic strategy of the method is to integrate the inertial sensors with the rate of their availability using the process model and then perform measurement updates whenever an additional information, such as a Zero Velocity Update or a RFID tag detection is available.

3.2 Process Model: INS Strapdown Integration

A detailed structure of the process model can be found in Fig. 1. The process model is essentially based on simplified mechanization equations of an Inertial Navigation System (INS). The state of the system is as follows:

$$\mathbf{x}_k = \left[\mathbf{q}_k, \mathbf{v}_k, \mathbf{p}_k, \mathbf{b}_{\omega,k}, \mathbf{b}_{a,k}\right]^T, \quad (1.4)$$

where $\mathbf{q}_k$ stands for a quaternion representation of the orientation, and $\mathbf{v}_k$ and $\mathbf{p}_k$ are correspondingly the velocity and position in the navigation frame, while $\mathbf{b}_{a,k}$ and $\mathbf{b}_{\omega,k}$ are the bias values associated with the accelerometers and the angular rate sensors. The process model for the quaternion is a discrete integration obtained from the quaternion derivative as follows:

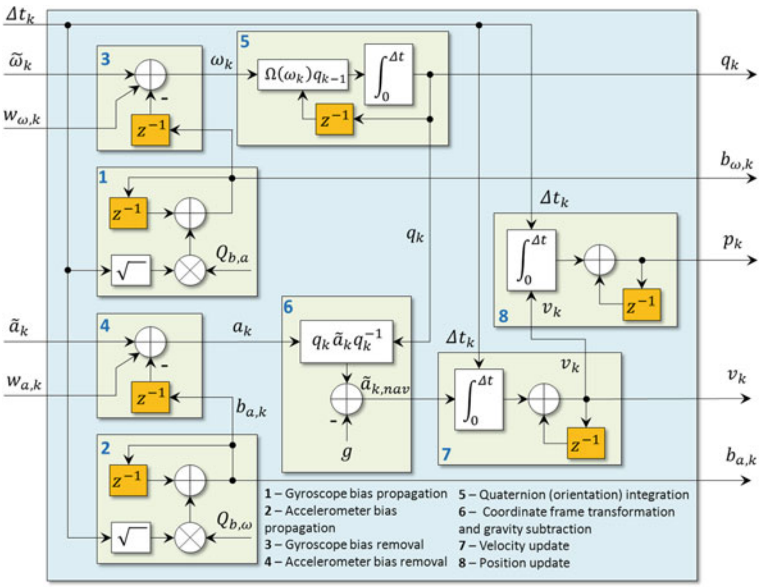

Fig. 1 Detailed process model for the prediction step of the UKF

$$\mathbf{q}_k = \frac{1}{2}\int_0^{\Delta t} \boldsymbol{\Omega}(\omega_k)\mathbf{q}_{k-1}dt, \quad \text{with} \quad \Delta t = t_k - t_{k-1}. \tag{1.5}$$

We consider the angular rate as a control input to the process model and allows to preserve highly dynamical motion of the human limbs without constructing any explicit model. The angular rate in the expression above is calculated from:

$$\boldsymbol{\omega}_k = \tilde{\boldsymbol{\omega}}_k - \mathbf{b}_{\omega,k-1} + \mathbf{w}_{\omega,k}, \quad \text{where} \quad \mathbf{w}_{\omega,k} \sim \mathcal{N}\left(0, \mathbf{Q}_{\omega,k}\right) \tag{1.6}$$

is the gyroscope noise and $\tilde{\omega}_k$ corresponds to the actual angular rate measurement. The quaternion representation of the orientation has several advantages such as quasi-linear mathematics and the absence of the gimbal lock problem. The acceleration is also treated as a control input:

$$\mathbf{a}_k = \tilde{\mathbf{a}}_k - \mathbf{b}_{a,k-1} + \mathbf{w}_{a,k}, \quad \text{with} \quad \mathbf{w}_{a,k} \sim \mathcal{N}\left(0, \mathbf{Q}_{a,k}\right). \tag{1.7}$$

The process model for the the gyroscope and accelerometer biases become:

$$\mathbf{b}_{\omega,k} = \mathbf{b}_{\omega,k-1} + \mathbf{w}_{b_\omega,k}, \quad \text{with} \quad \mathbf{w}_{b_\omega,k} \sim \mathcal{N}\left(0, \mathbf{Q}_{b_\omega,k}\right) \tag{1.8}$$

$$\mathbf{b}_{a,k} = \mathbf{b}_{a,k-1} + \mathbf{w}_{b_a,k}, \quad \text{with} \quad \mathbf{w}_{b_{a,k}} \sim \mathcal{N}\left(0, \mathbf{Q}_{b_a,k}\right) \tag{1.9}$$

The measured acceleration can be transformed to the navigation frame using:

$$\mathbf{a}_{k,nav} = \mathbf{q}_k \mathbf{a}_k \mathbf{q}_k^{-1} - \mathbf{g}, \quad \text{with} \quad \mathbf{g} = [0 \quad 0 \quad G]^T m/s^2 \text{ and } G \approx 9,81 \frac{m}{s^2} \tag{1.10}$$

Then the velocity and the position can be obtained by integration:

$$\mathbf{v}_k = \mathbf{v}_{k-1} + \int_0^{\Delta t} \mathbf{a}_{k,nav} dt, \quad \mathbf{p}_k = \mathbf{p}_{k-1} + \int_0^{\Delta t} \mathbf{v}_k dt, \tag{1.11}$$

where both $\mathbf{p}_k$ and $\mathbf{v}_k$ are in the navigation frame. The process as shown in Fig. 1 does not consider the system initialization. The system model must be initialized with the initial values of orientation quaternion $\mathbf{q}_k$, position $\mathbf{p}_k$ and velocity $\mathbf{v}_k$ as well as corresponding values for the sensor biases.

3.3 Measurement Models

We distinguish two different measurement model groups: one is called 'Zero Velocity Updates' and contains all updates which utilize only the inertial sensors and the fact, that the human foot undergoes a still phase on a regular basis. The second part uses additional sensors such as a magnetometer, a barometer and a RFID reader. In principle other localization methods, such as GNSS, signal strength or distance measurements can be added to the algorithm as measurement models, but this is beyond the scope of this chapter.

3.4 Zero Velocity Updates

Under normal condition human walking follows some pattern as shown in Fig. 2. During the stance phase we can assume the foot is not moving and therefore the velocity of the foot has to be zero. Similarly, the assumption can be extended by noticing that the angular rate should be also close to zero for the no motion conditions. Finally, under similar assumptions the measured acceleration vector should only contain the terms due to gravity and the accelerometer bias. If the IMU is attached to the foot of the person, we are able to detect the 'no motion' condition of the foot and apply the following measurement models:

Zero Velocity Update (ZUPT): this is a 'virtual' measurement where we assume the velocity $\mathbf{v}_k$ to be zero if the associated conditions are fulfilled:

$$[0 \quad 0 \quad 0]^T = \mathbf{v}_k + \epsilon_{\mathbf{ZUPT},k} \tag{1.12}$$

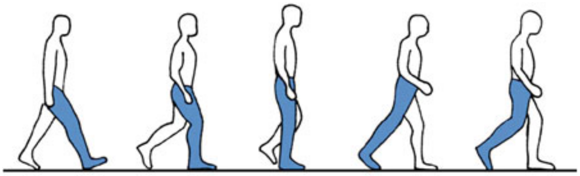

Fig. 2 A sketch of stance phases in human bipedal motion (Bebek et al. 2010)

Clearly, the triggering mechanism is not a complete guarantee that the true object velocity is zero and some measurement noise $\in_{\mathbf{ZUPT},k} \sim \mathcal{N}(0, \mathbf{R}_{ZUPT})$ has to be adopted.

Zero Angular Rate Update (ZARU): similarly to ZUPT, the measurement assumes that under some 'no motion' condition the measured angular rate is due to the sensor bias only:

$$\tilde{\omega}_k = \mathbf{b}_{\omega,k} + \epsilon_{\mathbf{ZARU},k}. \tag{1.13}$$

Again, due to imperfection of triggering mechanism and sensor noises we have to assume some non-negligible measurement noise $\in_{\mathbf{ZARU},k} \sim \mathcal{N}(0, \mathbf{R}_{ZARU})$ associated with this type of the measurement.

Gravity (G) Measurement: Similarly to conventional orientation filter we can employ the acceleration measurements to compensate pitch and roll under the condition that no significant linear acceleration is present and the accelerometer observations $\tilde{\mathbf{a}}_k$ are solely due to measured gravity $\mathbf{g}$ and the accelerometer bias:

$$\tilde{\mathbf{a}}_k = \mathbf{q}_k^{-1}\mathbf{g}\mathbf{q}_k + \mathbf{b}_{a,k-1} + \epsilon_{\mathbf{G},k}, \tag{1.14}$$

where $\epsilon_{\mathbf{G},k} \sim \mathcal{N}(0, \mathbf{R}_G)$ is the accelerometer additive noise. Unfortunately, the zero-velocity phase detection is not completely reliable using inertial sensors with some more detailed discussion on algorithm to be found in Bebek et al. (2010). We do not use a single detection mechanism for triggering all the measurements, but rather apply three different detectors, each of them being optimized for the particular condition. Fig. 3 shows the sensor measurements during the stance phase and the three different conditions, which have been detected.

The detection of the walking motion's stance phase, and thus the right time to apply the Zero Velocity Updates, is implemented according to Foxlin (2005). After one of the gyroscope or accelerometer signals have entered the predefined limits (the magnitude of the gyroscope signal should be below 0.1 rad/s, and that of the acceleration in the range from 9.6 to 10.0 m/s^2), a delay of 30 ms is imposed before the ZUPT or ZARU conditions are triggered. The signals must stay within the ranges for the associated condition to be triggered. If the delay requirement is satisfied, new thresholds are computed using the current threshold and the actual sensor output. This allows the sensor signal to satisfy the trigger condition even if it is corrupted with the noise. The new threshold conditions are computed at each iteration and are switched off when the signal values grow too fast (i.e., when the

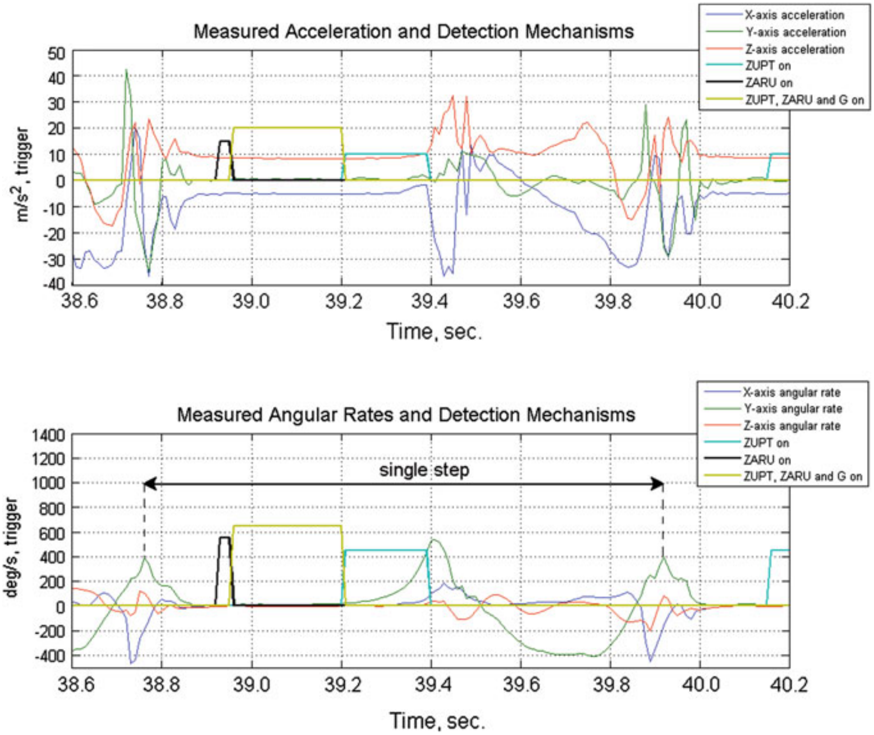

Fig. 3 Stance still detection example

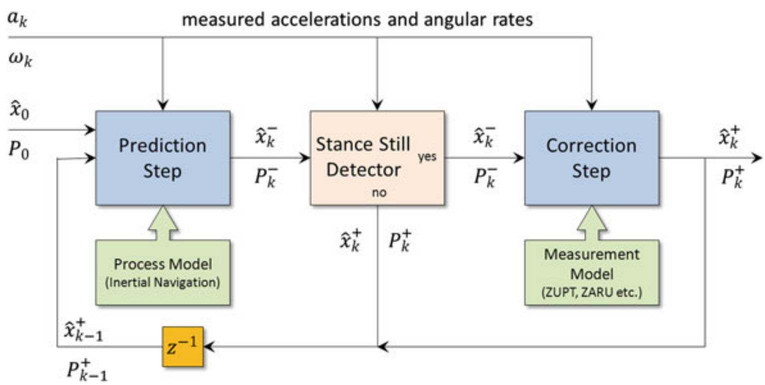

Fig. 4 Block diagram of the filter for position estimation using ZUPT

foot enters the swing phase). Note that the ZUPT and ZARU conditions are triggered separately, while when both conditions are satisfied, the effective measurement model incorporates ZUPT, ZARU and G measurements. The block diagram for the generic filtering algorithm is shown in Fig. 4.

The prediction step uses the process model is discussed above. After the prediction is performed, the detector checks one of the conditions for the correction step to be fulfilled, and if so (yes output of the stance still detector block), the predicted state estimate $\hat{\mathbf{x}}_k^-$ and associated covariance $\mathbf{P}_k^-$ are corrected using the measurements described above. If the detector fails to confirm a still motion condition, no correction is performed and the predicted values are considered as corrected ones for the next iteration of the filter cycle.

3.5 Additional Sensors

The generic filter structure using solely inertial sensors can be easily augmented with other sensors. The new measurements are incorporated into the measurement update of the algorithm as described below.

Magnetic Field Measurement For scenarios where magnetic field measurements are employed, one can construct the measurement model as follows:

$$\tilde{\mathbf{m}}_k = \mathbf{q}_k^{-1}\mathbf{m}_E\mathbf{q}_k + \epsilon_{\mathbf{M},k}, \tag{1.15}$$

where the actual measurements $\tilde{\mathbf{m}}_k$ are obtained by rotating the reference (Earth) magnetic field vector $\mathbf{m}_E$. Note that no magnetometer biases are modeled for this simple scenario but the values of $\epsilon_{\mathbf{M},k} \sim \mathcal{N}(0, \mathbf{R}_M)$ are usually set much higher compared to the true sensor noises in order to accommodate the disturbances when passing close to equipment, building structural elements etc. Here the magnetic field measurement are performed continuously and are not conditioned on any foot motion phase.

Barometric Pressure (Height) Measurement We adopt the following measurement model for height measurements using the barometric pressure P_k:

$$\tilde{p}_{z,k} = \frac{T_0}{L}\left(\left(\frac{P_k}{P_0}\right)^{-\frac{LR}{G}} - 1\right) + \epsilon_{\mathbf{h},k}, \tag{1.16}$$

which is a simplified expression for altitude in terms of atmospheric pressure measurement P_k. Here L is the lapse rate defined as the rate of temperature increase in the atmosphere with increasing altitude and is taken $L = -6.5 \times 10^{-3}$ K/m, T_0 and P_0 are correspondingly the temperature and the pressure at zero altitude, R is the gas constant for air and G is the acceleration due to gravity. For our scenarios with small vertical displacements we assume a simplified additive Gaussian noise model $\epsilon_{h,k} \sim \mathcal{N}(0, \mathbf{R}_h)$ for the vertical position.

RFID Position Measurements The sensor unit contains a RFID reader, while several RFID tags are distributed over the floor at known positions. When a RFID tag is detected by the reader this can be seen as a position measurement with an accuracy roughly corresponding to the RFID transmission range. Then a trivial position model can be assumed:

$$\tilde{\mathbf{p}}_k = \mathbf{p}_k + \epsilon_{\mathbf{p},k}. \tag{1.17}$$

Here the position measurement noise $\epsilon_{p,k} \sim \mathcal{N}(0, \mathbf{R}_p)$ mainly reflects the tag detection distance as well as our ability to detect the tag when passing close to it. Due to simplicity of the hardware we do not employ any signal strength related model.

4 Hardware Setup

While developing the custom hardware we again follow the modular system approach (Klingbeil et al. 2010a, b), where the core of the developed system consists of two main boards: a sensor unit and power unit with a Li-Polymer battery attached. The sensor unit consists of a microprocessor, responsible for the sensor readout, data pre-processing and communication, a three axis accelerometer, a three axis gyroscope and a compass module. It also contains a pressure sensor, working as a barometer. The inertial sensors a sampled at 100 Hz, while the magnetometer and the barometer are sampled at 75 and 2 Hz respectivly. The system was mounted on the shoe as shown in Fig. 5 (left).

The setup for the RFID augmentation shown in Fig. 5 (right). We used 13.56 MHz as the RFID chip carrier frequency for faster communication with the RFID tags. Whenever a tag is within the reading range of the reader, its ID is recognized in the processor. The polling rate is set to 50 ms, which seems to be a reasonable rate with respect to the foot dynamics and the typical duration of the foot stance phase (>200 ms). In the RFID experiments a number of passive tags have been placed on the floor with known positions associated with the unique ID of each tag. The effective reading range of the reader was approximately 12 cm.

Fig. 5 Custom IMU mounted on a foot (*left*) with body coordinate frame and IMU augmented with RFID reader antenna and tag beneath the foot (*right*)

This position information was used within the fusion algorithm whenever a tag was detected within the reading range and its ID was recorded by the system.

The hardware is based on low cost off-the-shelf components and the algorithm will perform better when used with higher quality and better calibrated sensors. Here we wanted to demonstrate explicitly the feasibility of the approach with components which can be easily integrated into a shoe bearing in mind its low cost profile. Note, that although one could make the RFID ranging larger in order to increase the hit rate, this would also increase the effective noise value as the measurement accuracy is reduced.

All sensor data are transmitted to PC via a Bluetooth interface. Although the UKF containing the ZUPT part of the algorithm can be made running on the microprocessor itself, the reference localization schemes require external information (e.g., position information for RFID tags, etc.) and apparently has to be implemented on a Smartphone or PDA level in an application scenario where the usage of a PC has to be avoided.

The system described in the chapter does not provide an initial position. This is assumed to be known or has to be deduced through other sensing mechanisms. The initial heading is set manually to a correct value as it can not be estimated from pure inertial data. Note that the filter needs some time to stabilize and the initial phase of this fairly complex filter is quite noisy compared to latter stages when the filter converged to true sensor biases and proper covariance values.

5 Results

The filter is initialized with the correct pitch and roll angles (quaternion equivalent) and the gyroscope bias estimates obtained from the first several seconds of the user standing still. The initial covariances are set to small values for faster algorithm convergence and in practice reflect our confidence in the initial estimates. The control noise for the accelerometer was set to $\sigma_a = 0.02$ m/s^2 and for the gyroscope to $\sigma_\omega = 3$ mrad/s. The G measurement model noise was set to $\sigma_G = 0.05$ m/s^2 due to an additional uncertainty within the detection mechanism. The process noise for the gyroscope bias was set to $\sigma_{b_\omega} = 3 \cdot 10^{-6}$ rad/s for $F_s = 100$ Hz and the accelerometer bias drift was modeled with $\sigma_{b_a} = 1 \cdot 10^{-5}$ m/s^2. The measurement models were implemented assuming $\sigma_{ZUPT} = 0.02$ m/s, $\sigma_{ZARU} = 0.02$ rad/s. Both ZUPT and ZARU are ‘virtual’ measurements with the noises essentially representing the quality of the associated ZUPT and ZARU detectors.

Usually, the performance of similar algorithms is reported with respect to more expensive highly calibrated IMUs such as the XSens MTi or equivalent (Bebek et al. 2010; Sabatini 2009). Figure 6 presents the result of our algorithm based on inertial sensors only for both the XSens MTi and the one of the in-house developed units. Although the XSens MTi also provides a complete 3D orientation, we only use the calibrated sensor readings for our algorithm. Although the well calibrated

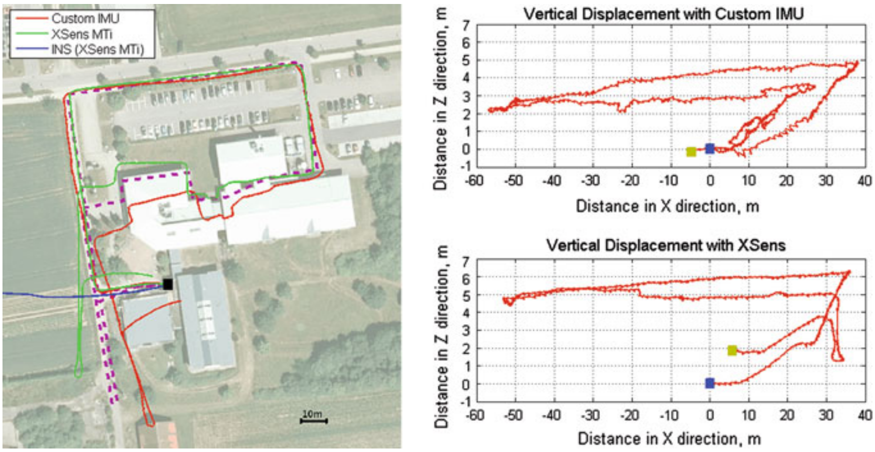

Fig. 6 Pure inertial localization using the XSens MTi and the custom unit. XY position plot (*left*). Black square marks the start of walking while the pink dashed line corresponds to true walking trajectory. Estimated vertical displacement: custom IMU (*right top*) and XSens MTi (*right bottom*). *Blue* and *green* square mark correspondingly the start and the end of the trajectory. The walking duration was $\sim$5 min

XSens MTi unit (price app. 1,500 \$) outperforms our custom system without temperature calibration, the difference is not dramatic and even a low-cost system apparently is able to provide meaningful trajectory over reasonably long period of time. Clearly, the direct INS mechanization (blue line in Fig. 6 (left)) fails to deliver a reliable position due to fast accumulating errors. The subsequent experiments are all done with our custom sensor unit in order to check the feasibility of the approach for low-cost systems. Obviously, better results can be obtained for more expensive calibrated sensor systems.

Both systems have not returned back to the starting position with the error being slightly smaller for the XSens MTi unit. The vertical position mismatch was even smaller for the custom IMU unit. This however, is merely a coincidence as, some errors have canceled each other during the experiment. The custom IMU has a more rugged vertical position estimation and several jumps which can be attributed to failures in stance detection. Interestingly, even this vertical accuracy of our custom IMU is more than enough to distinguish separate stairs (actually a couple of stairs as long as the unit is mounted on a single shoe and a single swing usually covers two stairs) as shown in Fig. 7.

The incorporation of the accelerometer bias $\mathbf{b}_{a,k}$ into the filter state can be justified by the results shown in Fig. 8 (left), where two otherwise identical filters with and without bias are compared. The presence of $\mathbf{b}_{a,k}$ slightly improves the position estimate although in practice this depends on the quality of the sensors used and comes at a price of three extra states to be estimated within the filter. The associated bias estimates for both filters are shown in Fig. 9. The elimination of the $\mathbf{b}_{a,k}$ had practically no effect on the $\mathbf{b}_{\omega,k}$ estimation as the latter is directly

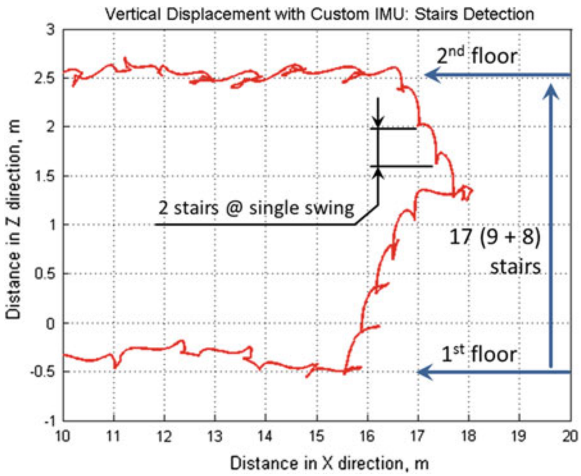

Fig. 7 Vertical displacement scenario with stairs using the custom IMU

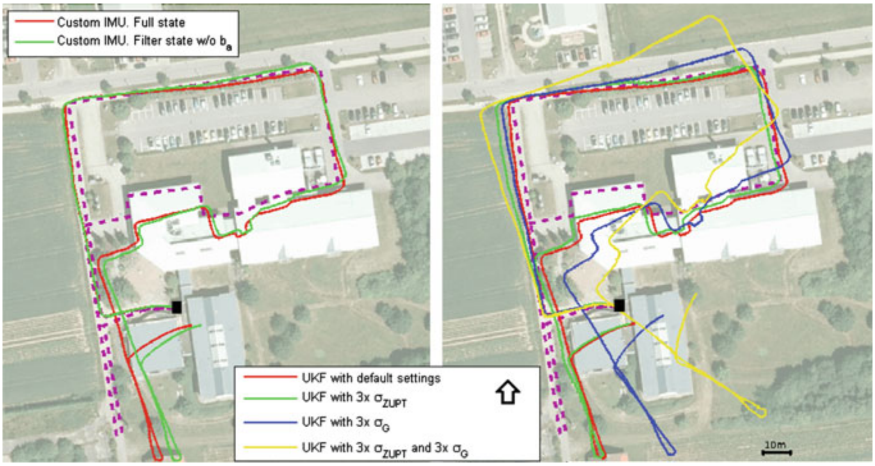

Fig. 8 Pure inertial localization for filter with and without $\mathbf{b}_{a,k}$ (*left*) and influence of measurement noise values on the performance of the tracking algorithm (*right*)

observable via the ZUPT measurement model during the still phase. The initial high dynamics of the estimates in Fig. 9 is due to a fairly high initial covariance.

Although for the ‘real’ sensors the noise models are usually mapped to the true characteristics of the sensors, the situation is somehow more complicated for the ‘virtual’ ZUPT and G measurement models where the entire SSD mechanism should be considered as a sensor per se. A rough understanding of the influence of these parameters on the localization performance can be obtained from Fig. 8 (right) which confirms that some trial-and-error efforts are necessary for filter tuning.

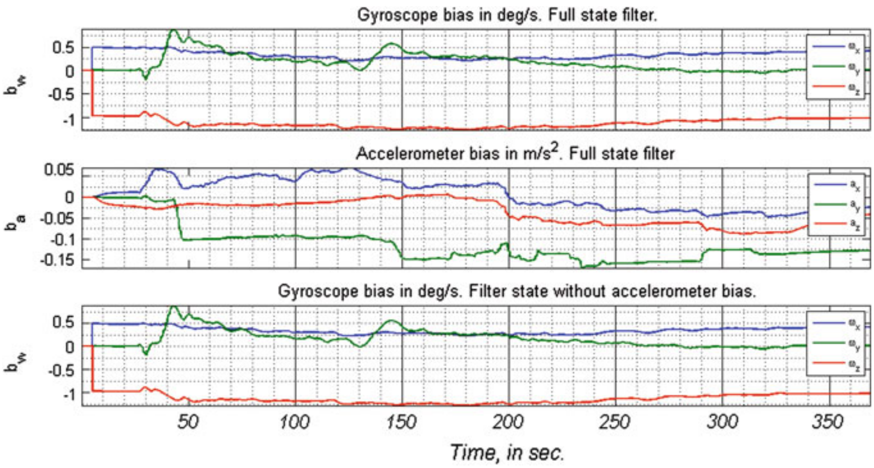

Fig. 9 Estimated biases: gyroscope bias (*top*) and accelerometer bias (*middle*) for full state formulation and only gyroscope bias for filter formulation without $\mathbf{b}_{a,k}$

In the cases above the true heading is not known to the system. The problem, at least in theory, can be addressed by measuring the Earth's magnetic field. In practice, however, these measurements are unreliable due to magnetic field disturbances as they appear especially in indoor environments. The issue is often handled by assuming very large measurement noise or employing some heuristic disturbance detectors (Sabatini 2009). Unfortunately, these methods can not handled arbitrary disturbances and are suggested to be carefully tested before deployment. However, for outdoor scenarios with minor disturbances (Fig. 10) only the heading can be corrected with associated improvement in estimated positions. One could also attempt to estimate the magnetic field disturbances along with the actual filter state, but this would increase the complexity of the filter and could result in some observability issues.

From the results above is not completely clear whether a fairly complex ZUPT+G+ZARU SSD mechanism is actually necessary. The result of using a combination of SSD techniques is shown in Fig. 11. Here we leave the ZUPT measurement for all the cases in order to avoid a too fast error accumulation due to double integration of the acceleration errors. The addition of the G measurement strongly improves the performance as the pitch and roll information becomes observable. The minor influence of the ZARU measurment can be attributed to a stable gyroscope bias $\mathbf{b}_{\omega,k}$ during the experiment.

The vertical position drift can be eliminated by augmenting the system with a barometric pressure sensor. In our setup we limit the pressure measurements to be valid only during the ZUPT+ZARU+G condition to avoid higher pressure deviations due to air circulation caused by fast foot movements. The localization results for a three floor setup and stair/elevator segments is shown in Fig. 12. The pure inertial system performs rather well for upstairs but of course fails to detect

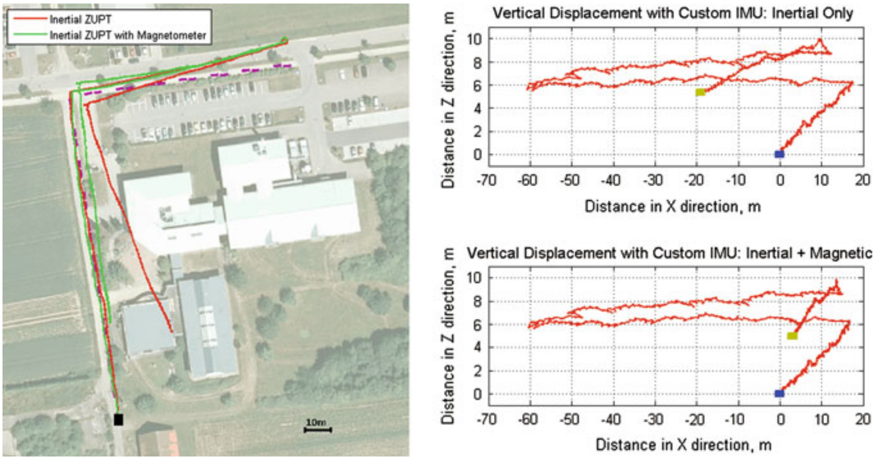

Fig. 10 Comparison of the algorithm performance with and without magnetic field information. XY position estimate results (*left*). Estimated vertical displacement for both filters (*right*): blue and green squares mark correspondingly start and the end of the trajectory. The walking duration was ~4 min

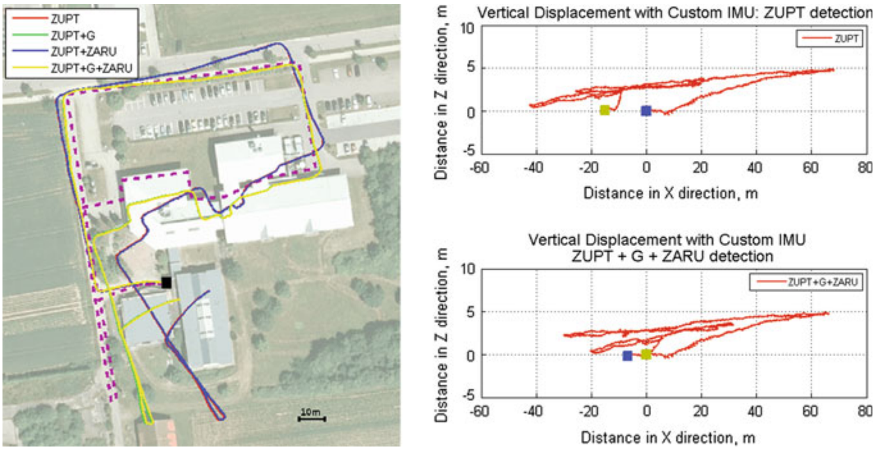

Fig. 11 Comparison of pure inertial method for different combinations of zero-velocity detectors. XY position estimate results (*left*). Estimated vertical displacement for different detection mechanisms (*right*): *blue* and *green* squares mark correspondingly start and the end of the trajectory

the elevator part. The barometer measurements (assumed $\sigma_h = 0.2$ m) clearly permit to correct the height estimation, but the sensor output are rather noisy and the sensor is sensitive to the changing environment such as a door opening. Faster height corrections can be achieved with smaller σ_h values which, however, result in a noisier height estimation (marked as 'B' in Fig. 12). On the other hand, a high

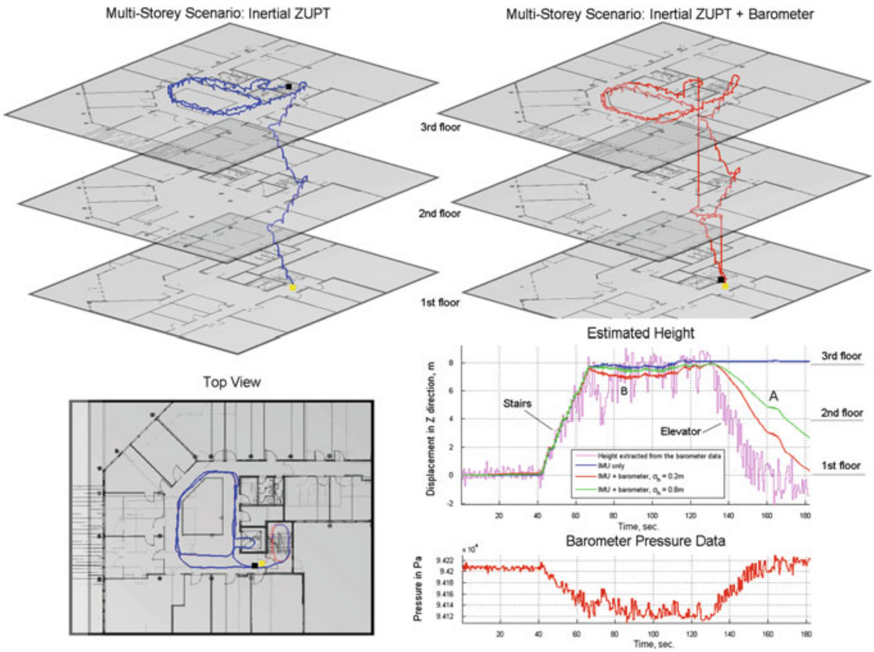

Fig. 12 Multi-storey localization scenario: perspective view for the results of pure inertial algorithm (*top left*) and system augmented with barometric pressure sensor (*top right*). The vertical scale is artificially increased for improved visual separation between the floors. The associated top view (*bottom left*) and height estimation results for different values of pressure noise (*bottom right*). The total walking duration was $\sim$3 min

uncertainty assigned to barometer measurements can have an effect similar to that denoted as 'A' in the plot, where the height correction was not in time before the person left the elevator and returned to the starting point. We also have observed almost no barometer influence on the XY displacement estimation. Note that barometer measurements can be potentially used outside the fusion filter as well, e.g., for the floor detection in a multi-storey building.

Even if the vertical position drift can be partially corrected using the barometric pressure sensor as shown above, the XY position errors are still not bounded. Below we present some preliminary results where the position reference information is obtained via the detection of passive RFID tags (Figs. 13 and 14). As the position of the tag within the environment is known thanks to its unique ID, a direct position correction can be applied. Due to RFID hardware constraints the user has to step on or reasonably close to the tag placed on the floor. The detection of the tag in the vicinity of the foot triggers the position correction mechanism with $\sigma_{RFID} = 10$ cm. The performance of the approach strongly depends on the number of tags encountered during the walking and clearly one intends to put the tags on some commonly traversed locations. Interestingly, even few RFID tags encountered during our experiments allow a significant improvement of the

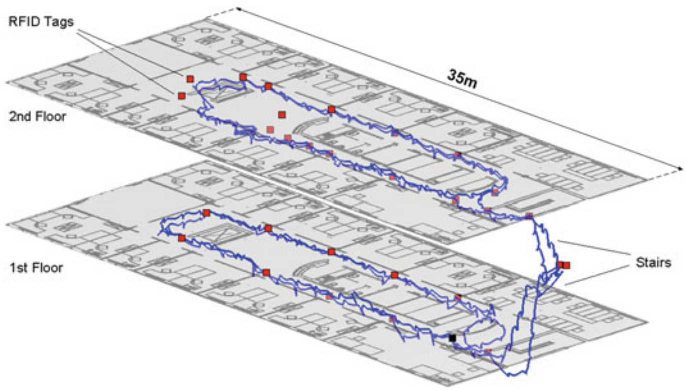

Fig. 13 Example of inertial system performance augmented with RFID reader for multi-floor scenario. *Red* squares mark the position of RFIDs while the *black* square denote the start of the walking. The vertical scale is artificially increased for improved visual separation between the floors

Fig. 14 Comparison of pure inertial localization (*left*) and approach augmented with RFID measurements (*right*) in single floor scenario. *Red* squares mark the position of RFID tags while the *blue* square denote the start of the walking trajectory

estimated trajectory. Naturally, some better performance is expected for more advanced RFID systems with RSSI measurements similar to those discussed in Subramanian et al. (2008). A combination of IMU and RFID is a perfect example of complementary sensing modalities where short term tracking with IMU is supported by an accurate location information from RFID tags.

Although the presented ZUPT mechanism, even when implemented using inertial sensors only, seems to show a significant improvement in the position estimate when compared to pedometer-based methods, it also does not guarantee the position error to be bounded when applied alone. The algorithm as formulated above, is deceptively simple. Unfortunately, the presented integration mechanism is in general susceptible to several error sources including the integration itself, sensor offsets, noises and other calibration errors.

Augmentation of the inertial system with additional sensors comes with its own disadvantages. Apart of increasing costs, size, weight and power requirements of the overall system, these sensors can make the system sensitive to unmodelled external disturbances. For example, the assumptions regarding Earth's magnetic field are often violated for indoor scenarios or in proximity of larger metallic structures and some heuristics are often necessary to validate the measurements. The introduction of heuristics into the RBE mechanism makes the performance of the overall system less predictable while the performance starts to be data and scenario dependent. The same holds for barometric pressure sensing, where local pressure disturbances due to motion affect the sensor signal. Numerous other modifications possible including more sophisticated process models. Unfortunately, the adoption of more complex models does not necessarily lead to a better practical performance as some parameters can become unobservable or their effective estimation can depend on the actual motion.

The presented experiments were performed with the user stepping on asphalt surfaces and office building floor. It stays for the future research to analyze the performance of the algorithm with challenging scenarios such as jogging and running as well as stepping on grass, sand and snow covered surfaces.

6 Conclusions and Future Work

Within the work we have demonstrated the feasibility of a foot-mounted low-cost IMU system for personal navigation applications using low cost MEMS sensors. The inertial sensor system employed a combination of Zero Velocity Updates as the basis for PDR and the performance was compared against a realization based on a more expensive and calibrated IMU. We have shown that the performance of the system can be significantly improved by using a more complex filter with simultaneous state and parameter estimation as well as augmenting the system with additional sensors for magnetic field, pressure measurement and detection of passive RFID tags placed on the floor. The chapter also describes some of the practical difficulties when dealing with realistic indoor scenarios and actual sensors as well as presented some algorithm design issues. Employment of cheap sensors puts higher requirements on the algorithm itself including the general algorithm structure, complexity of the SSD and a careful revision of all the relevant assumptions.

In future, the method is planned to be implemented on an Android-based system to employ the available WiFi infrastructure and GPS information from the platform for position correction when applicable. The computational feasibility of the approach will be handled by reformulating the existing algorithm as more tractable EKF-based fusion problem, whereas the Kalman smoothing approach is planned for offline refinement of the estimated trajectory. A better algorithm performance is also expected with the IMU placed closer to the heel. Obviously, some improvement is also expected when known explicit motion constraints (i.e., the map information) is incorporated into the filter.

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Quantitative and Spatial Evaluation of Distance-Based Localization Algorithms

Thomas Hillebrandt, Heiko Will and Marcel Kyas

Abstract Indoor localization, especially in wireless networks (WN) has become an important research focus in computer science during the past ten years. Several approaches exist to estimate a node's position relative to other devices. Most approaches are based on distance measurements and localization algorithms. In this chapter we provide an overview of common and new localization algorithms. A detailed investigation on the error distribution and the real world behaviour of these algorithms is presented. We also provide a discussion of the evaluation results that leads to open questions and future research approaches.

Keywords Wireless networks · Localization · Spatial error simulation

1 Introduction

With the broad success of location based services the demand for indoor localization functionality has become bigger and bigger. In theory most techniques to satisfy this demand are well known. There are several ways to estimate distances in wireless networks and several algorithms to calculate positions with estimated distances and the position of the corresponding anchor devices in the network.

T. Hillebrandt (✉) · H. Will · M. Kyas
Department of Computer Science, Freie Universität Berlin,
Takustr. 9 14195 Berlin, Germany
e-mail: thomas.hillebrandt@fu-berlin.de

H. Will
e-mail: heiko.will@fu-berlin.de

M. Kyas
e-mail: marcel.kyas@fu-berlin.de

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The general usability of a digital positioning system has been proved since 1994 with the general public availability of the Global Positioning System (GPS).

A positioning system for real world indoor use must have several differences to GPS. The main difference is the size of the ranging error that is part of every range estimation. While the GPS satellites use very precise and synchronized clocks, due to cost reasons, only common quartz clocks are used in WNs. Quartz clocks have higher jitter and drift, and consequently are not synchronized. Although there exist several high accuracy time synchronization protocols for use in WN, the achievable accuracy is far too low for precise range estimation. Another big issue for indoor localization is that generally there is no direct line of sight to the node whose distance is to be estimated; thus, multipath effects and signal reflection have a much bigger influence than in the GPS system.

Concerning these issues, several approaches for more error tolerant and more robust algorithms have been published. Because there are no standardized test cases and many researches obviously do not have access to radio ranging hardware, many authors rely on simulation to prove their functionality (see Sect. 2 for examples) and only a small minority uses real world deployments for their evaluation. Moreover, each simulation works with its own settings of the simulation parameters: they all differ in the choice of playing field, placement of anchors, radio range, and ranging error model. With respect to simulation results: we show that the performance of location estimation methods depends on the experimental setting. Thus, choosing a suitable algorithm for a given scenario or deployment is not possible based on these published results. It may even be impossible to conclude whether a method is consistently more precise than another one.

We provide an overview and present a structured analysis of common localization algorithms. The first two steps of our analysis are based on simulations and the third step is based on a real world deployment in an office building. All simulations and all test runs were conducted with the same parameter settings for all algorithms, so the results are comparable and strengths and weaknesses of the discussed algorithms can be seen easily.

In Sect. 2, we review related work and motivate our approach. In Sect. 3, we introduce the algorithms that we consider and explain their basic properties. In Sect. 4, we present our evaluation by simulation. The first part is a quantitative simulation of these algorithms. This simulation is similar to the simulations performed in the publications that introduce each algorithm to show their benefits. Instead of just reproducing the results of those papers, we simulate all algorithms using the same parameter settings to ensure that our comparisons are valid.

In the second part of Sect. 4, we discuss the spatial properties of the selected algorithms. The quantitative evaluation in the first part measures the average performance of each algorithm. Some algorithms show a harmonic performance, i.e., the position estimation error does not correlate well with the position and the placement of anchor nodes. Other algorithms are less harmonic; they perform badly in some areas of the playing field and exceptionally well in other areas. Thus, analyzing the distribution of the position error for each algorithm gives a refined view on the results obtained by our quantitative evaluation. We show that the error distribution doesn't only depend on the error distribution of the measured distances, but also on the geometrical constellation between node and anchors and the characteristics of the algorithm. We present a new approach that shows that the algorithm itself has a much bigger influence on the resulting error than only viewing the geometrical constellation.

In Sect. 5, we validate the simulation results using a large indoor deployment by executing every algorithm with real world data gathered in our office building. The combined analysis makes the algorithms much more comparable and delivers a much better understanding of the strengths and weaknesses of the algorithms than the original papers where they have been published. In Sect. 6 we present our conclusion.

2 Related Work

Work on evaluating and comparing localization algorithms turns out to be heterogeneous. We are aware of surveys that explain different localization methods, e.g. (Mao et al. 2007), and qualitative surveys, e.g. (Torres-Solis et al. 2010), that review existing algorithms and try to convey the context in which they are best applied. Those surveys are meta-studies and provide little quantitative evaluation.

Surveys that focus on a quantitative comparison are attempted by Biaz and Ji (2005) and by Langendoen and Reijers (2003). Both survey multi-hop methods. Their results are not directly comparable to ours, since we do not limit the radio range. Biaz and Ji are vague on the ranging errors of their simulation, only stating "The actual range error is determined dynamically during the experiment by the production of the maximum variance and a random number between -1 and 1" but they do not state the used probability distribution. Indeed, Biaz and Ji compare algorithms based on their sensitivity to ranging errors using varying settings. We share some experimental setups with Langendoen and Reijers (a centred 3×3 grid) but work with different error models.

Comparing published performance evaluations is difficult at best. Table 1 lists the evaluation methods used by the sources to our algorithms. Each publication uses a different setup of the playing field and a different error model. Also the choice of algorithms they compare to varies. Linear Least Squares (LLS) and Bounding Box/Min–Max, (Savvides et al. 2002; Langendoen and Reijers 2003), appear to be the most common choices. Thus, transferring results about, say, Adapted Multi-Lateration (AML) (Kuruoglu et al. 2009) to Least Median of Squares (LMS) (Li et al. 2005) actually requires a new simulation run, as the results were obtained in non-comparable settings.

Surveys like the ones above usually compare algorithms based on statistical evaluations of simulations. Comparing such results is difficult, because they differ in error model, geometric placement of anchors and density of anchors. These vary, sometimes leading to contradictory conclusions. Thus, we compare all algorithms under the same conditions. We highlight that results can be manipulated by the choices, effectively favouring one algorithm over the other.

Table 1 Evaluation settings of common algorithms

Algorithm	Compared to	Setup	Error model
AML	LLS, MIN–MAX	200 × 200 m, 40 anchors uniformly distributed	Zero mean Gaussian, variance = realDist * 10 %
LMS	LLS	500 × 500 m, 30 anchors randomly distributed	Zero mean Gaussian, variance = 15^2, 20^2
ICLA	Centroid, MIN–MAX	50 × 50 m, 10 anchors	Log Gaussian RSSI model; Error from 10 to 60 %
MIN–MAX LLS		6 beacons, 10 to 100 ranging nodes, 15 m maximum range	Zero mean Gaussian; standard deviation 20 mm

Navidi et al. (1998) make a very profound observation about two lateration approaches: trilateration and multilateration. They observe that anchor position influences the position estimation error and call for more research in the domain of anchor placement. This comment also inspired the work on a spatial simulation that we present in part two of Sect. 4.

Yang and Liu (2010) present a slightly similar approach to research the spatial error distribution. Instead of calculating all possible positions on the playing field and visualizing the position error distribution, they calculate one position and visualize the probability for this node to be located on all other positions of the playing field.

Some researchers use the Cramér-Rao Bound (CRB) for estimating the error distribution instead of using simulations. The CRB computes a lower bound on the covariance of the error, usually from the position of the anchors and the statistical error model. For example, an analysis of the CRB has been given by Yang and Scheuing (2005), where they apply it to compute optimal anchor positions. The CRB gives a lower bound on the covariance matrix of an idealised, unbiased position estimator, based on geometric properties of anchor nodes and statistical properties of the range measurement errors. It does not reference the algorithm under consideration. Thus, the CRB only allows to state whether an algorithm is already optimal, provided that the algorithm is analysed analytically or statistically by a simulation similar to ours. This was both observed by Dulman et al. (2008) and Vaghefi and Buehrer (2012), which all observe that the CRB is an inadequate tool for localization. In addition, Yang and Scheuing observe in Proposition 2, that the CRB is a strict lower bound under any Gaussian error model, as no unbiased estimator will attain this bound.

3 Localization Algorithms

For reasons of clarity and comprehensibility we focus our evaluation on six localization algorithms. Three of them are well known algorithms and often used for performance comparison when proposing a new localization algorithm: Multilateration using Nonlinear Least Squares (NLLS) or LLS and Min–Max algorithm. The other three algorithms are more recent and have never been benchmarked under consistent conditions till now: LMS, AML and Iterative Clustering-based Localization Algorithm (ICLA) (Haiyong et al. 2011).

1. *NLLS*: Given m anchor nodes with fixed positions at $b_i = (x_i, y_i)$ for $i = 1, 2, \ldots, m$ and possibly noisy range measurements d_i from these nodes to a non-anchor node located at $u = (x, y)$, multilateration finds the most likely position of the unknown node, denoted by $\hat{u}$. From this information we write a system of equations:

$$\begin{array}{c} (x - x_1)^2 + (y - y_1)^2 = d_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = d_2^2 \\ \vdots \\ (x - x_m)^2 + (y - y_m)^2 = d_m^2 \end{array} \tag{1}$$

This problem is usually solved by using a least squares (LS) method, that is, minimizing the sum of the squared residuals between the observed ranges d_i and the estimated distances $\|u - b_i\|$:

$$u = \arg\min_u \sum_{i=1}^{m} \left(\|\hat{u} - b_i\| - d_i^3 \right) \tag{2}$$

The minimization problem can be solved by using any of the Newton type optimization algorithms (Dennis and Schnabel 1996). These start from an initial guess at the solution and then iterate to gradually improve the estimated position until a local minimum of the objective function in Eq. (2) is found. However, there is a non-negligible probability of falling into a local minimum of the error surface when solving Eq. (2). Therefore, to find an estimate close to the global minimum, LS must run several times with different initial starting points, which is expensive in terms of computing overhead.

2. *LLS*: The nonlinear least squares problem can be linearized by subtracting one of the equations given in Eq. (1) from the remaining $m - 1$ equations. In matrix notation, the linear system can be expressed as $Au = b$ and can be solved by the LS method to provide an estimated location, as given by the closed form solution shown in Eq. (3) (i.e., normal equations).

$$\hat{u} = \left(A^T A\right)^{-1} A^T b \tag{3}$$

with:

$$A = \begin{pmatrix} x_1 - x_m & y_1 - y_m \\ x_2 - x_m & y_2 - y_m \\ \vdots & \vdots \\ x_{m-1} - x_m & y_{m-1} - y_m \end{pmatrix}, b = \frac{1}{2} \begin{pmatrix} d_m^2 - d_1^2 + \left\|b_1 - u^3\right\| \\ d_m^2 - d_2^2 + \left\|b_2 - u^3\right\| \\ \vdots \\ d_m^2 - d_{m-1}^2 + \left\|b_{m-1} - u^3\right\| \end{pmatrix} \tag{4}$$

3. *AML*: Similar to multilateration, Adapted Multi-Lateration tries to estimate the position of an unlocalized node using circle intersections. AML consists of three steps: intersection and elimination, first estimation and refinement. At the first step two intersecting circles are arbitrarily chosen. These circles may intersect at one or two points. If there is more than one point, the point with the larger distance to the third anchor is eliminated. At the first estimation step the previously computed intersection point is moved to the middle of the line connecting it with the closest point of the third anchor's circle. This is done to compensate the errors introduced by range measurements. The calculation is done using the resemblance of triangles. At the last step the position can be further refined. Therefore, the anchors that were not used in the previous steps are added to the position estimation process with the same principle utilized in the second step.
4. *Min–Max*: The Min–Max algorithm, also known as Bounding Box algorithm, is a simple and straightforward method in contrast to the quite expensive number of floating point operations of LLS or NLLS that is required. The main idea is to build a square (bounding box) given by $[x_i - d_i, y_i - d_i] \times [x_i + d_i, y_i + d_i]$ around each anchor node i using its location (x_i, y_i) and distance estimate d_i, and then to calculate the intersection of these squares. The final position of the unlocalized node is approximated by the center of the intersection box which is computed by taking the maximum of all coordinate minimums and the minimum of all maximums:

$$[\max(x_i - d_i), \max(y_i - d_i)] \times [\min(x_i + d_i), \min(y_i + d_i)] \tag{5}$$

5. *ICLA*: The ICLA algorithm transforms node localization to an issue of clustering intersection points, which is claimed to be resistant to RSSI errors. The algorithm consists of three main steps. In the first step all intersection points between every two circles centered at the anchors coordinates and with radii equal to the estimated distances are generated. These intersection points cluster around the unlocalized node. In the second step the iterative clustering model (ICM) is applied to get the most representative intersection points for localization. The final step of the algorithm calculates the position of the unlocalized node by taking the centroid of all intersection points of the biggest group that ICM has produced. ICM is the central part of the algorithm. Here, all intersection points are iteratively moved towards their moving direction and merged if a collision occurs. The collision area is a circular area with the radius equal to the size of the moving step. Points with bigger weight exert a larger attracting force to other points and influence their moving direction. Initially, all points have the same weight. At the end of the procedure, all points are classified into several different clusters according to the left points.

6. *LMS*: Multilateration using LLS or NLLS is vulnerable to attacks because of its non-robustness to "outliers". Due to the summation in the cost function shown in Eq. (2), a single outlier may ruin the estimation. Therefore, Li et al. (2005) propose to minimize the median of residue squares instead, based on the method introduced by (Rousseeuw and Leroy (1987). In this way a single outlier has little influence on the cost function, and won't bias the estimate considerably. Finding the exact solution of this non-linear optimization problem is computationally expensive. Thus, the authors suggest the following procedure for implementing an approximated solution as the robust LMS algorithm:

1. Set $n = 4$ as the appropriate subset size.
2. Set $M = \begin{cases} 20, & ifN > 6 \\ \binom{N}{n}, & otherwise \end{cases}$ as the appropriate total number of subsets.
3. Randomly draw M subsets of size n from the set of available anchors $\{(x_1, y_1), \ldots, (x_N, y_N)\}$. Estimate a position $(\hat{x}_0, \hat{y}_0)_j$ for each subset $j = 1, 2, \ldots, M$ using LLS and calculate the median of the estimation residuals r_{ij}^2 to each anchor $i = 1, 2, \ldots, N$.
4. Define $m = arg \min_j med_i \left\{ r_{ij}^2 \right\}$, then $(\hat{x}_0, \hat{y}_0)_m$ is the position estimate with the least median of all medians among all subsets.
5. Calculate the scale estimate $s_0 = 1.4826\left(1 + \frac{5}{N-2}\right)\sqrt{med_i r_{im}^2}$.
6. Assign a weight w_i to each anchor according to the formula $w_i = \begin{cases} 1, \left|\frac{r_i}{s_0}\right| \leq 2.5 \\ 0, otherwise \end{cases}$, whereas $r_i = \sqrt{(x_i - \hat{x}_0)^2 + (y_i - \hat{y}_0)^2} - d_i$ is the residue of the i-th anchor for the location estimate $(\hat{x}_0, \hat{y}_0)_m$.
7. Do LLS with weights $\{w_i\}$ and all anchors to compute the final position estimate $(\hat{x}_0, \hat{y}_0)$. This corresponds to executing LLS with only the anchors with a weight of $w_i = 1$.

The main idea of LMS is that at least one subset among all subsets contains only small or no measurement errors. Although smaller subsets increase the probability to have at least one good subset, $n = 4$ is chosen to reduce the chance that the samples are too close to each other to produce a numerically stable position estimate (Li et al. 2005).

4 Simulation

In this section we give a detailed analysis of the six localization algorithms introduced in Sect. 3. First, we give a quantitative analysis of the algorithms using a common error model for the distance measurement procedure. This way, we are able to compare our results with the results of other research papers. Second, we give an insight in the spatial error distribution by analyzing all algorithms with the LS^2 (Will et al. 2012) simulation engine. This simulator produces images of the error distribution by calculating the position error for every discrete point on the simulated area which easily shows the strengths and weaknesses of a given algorithm. Throughout the simulations we stick mostly to a grid layout of nine anchor nodes to be able to compare the results of the two approaches.

4.1 Quantitative Evaluation

We present simulation results that demonstrate the performance of the selected localization algorithms in different scenarios. We model each measured distance d_i between the unlocalized node and the anchor node i as,

$$d_i = \hat{d}_i + \epsilon_{LOS} + \epsilon_{NLOS} \quad (6)$$

where $\hat{d}_i$ is the real distance, which is contaminated by measuring errors and non-line of sight (NLOS) errors. The measuring error ϵ_{LOS} results from the measuring processes in a noisy channel and the NLOS error ϵ_{NLOS} derives from the blocking of the direct paths. For the sake of comparison, we model ϵ_{LOS} by a zero mean Gaussian distribution $N(0, \sigma)$ because this is done by the majority of the related research papers. The NLOS error ϵ_{NLOS} was simulated as an Exponential random variable with the parameter λ uniformly distributed, $\lambda \in U(0, b)$ where $b > 0$ is the maximum value of the uniform distribution. For each distance measurement a random value uniformly distributed between 0 (exclusive) and 1 (inclusive) is chosen and if smaller or equal than a predefined probability p, d_i gets increased by NLOS error. For direct line of sight distance measurements this probability is zero, thus $\epsilon_{NLOS} = 0$. The performance of the localization algorithms is given in terms of *mean absolute error* (MAE) which is the average of the difference between the real and estimated locations. For all of our simulations we have one unlocalized node which takes 100,000 random positions on a square area and executes each algorithm. The radio range is unlimited in our simulations, so the unlocalized node gets distance measurements to all anchor nodes regardless of its current location.

In our first simulation, we deploy 9 anchor nodes on a square area of increasing size. The side length of the area varies from 10 to 100 m. The anchor nodes are arranged in a grid of 3×3 nodes in order that they cover the whole area. The anchor setup can be seen in Fig. 1. There are only line of sight distance measurements with standard deviation $\sigma = 2.3$. Figure 2 shows the results of this simulation, where the vertical axis is the localization error and the horizontal axis is the side length of the square area. The performance of NLLS, LLS, LMS, and ICLA stays pretty much unaffected by an increased area size. The accuracy of ICLA even shows an improvement of 20 % until the side length reaches 60 m. The performance of AML and Min–Max decreases linearly as the side length grows, with Min–Max showing the worst behavior.

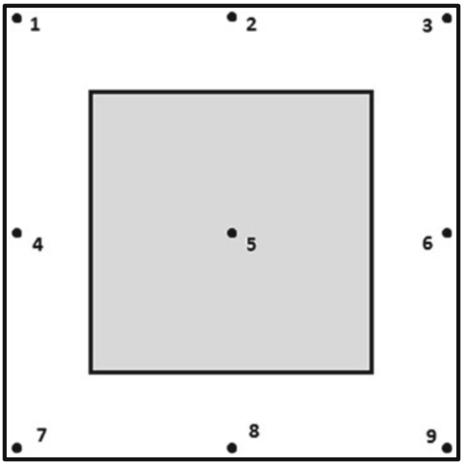

Fig. 1 3 × 3 Grid setup

In a second simulation, we deploy the 9 anchor nodes in the same way on a 100 × 100 m^2 area but continuously decrease the area the anchor nodes span. This can be seen in Fig. 1. At the start, the anchors cover the white square area. When reducing the covered area, the anchors would be deployed on the edges of the grey square area. In each step we reduce the covered area by 10 %. As a result of this, the unlocalized node will more and more take positions outside the grid because the anchors are not any longer the edges of the network. This is a reasonable test because it's not always possible to have an ideal anchor setup and the movement of mobile nodes is not always predictable in a real world deployment. Again, there are only line of sight distance measurements with $\sigma = 2.3$. Figure 3 shows the results of this simulation where the vertical axis is the localization error and the horizontal axis is the area coverage in percent in relation to the 100 × 100 m^2 area. In general, AML and especially Min–Max are affected most by the reduction of the covered area. NLLS, LLS, LMS, and ICLA stay relatively unaffected until the coverage ratio drops below a critical margin of 10 %, with NLLS showing the best performance all the time. Area coverage of 1 % also isn't a reasonable setup because the resulting grid only has a dimension of 10 × 10 m^2 with a distance of 45 m to the edges of the square area. However, area coverage of 30 % with a grid dimension of 54.8 × 54.8 m^2 and a distance of 22.6 m to the edges still sounds reasonable. In this scenario localization accuracy drops by 12.3 % (NLLS), 17.4 % (ICLA), 21.8 % (LMS), and 26 % (LLS) compared to the initial situation, whereas the accuracy of AML drops by 44.5 % and that of Min–Max by 206 %.

In the next set of simulations, we set the side length of the square area to 50 m and the area coverage to 70 % while sticking to the grid distribution of anchor nodes.

Figure 4 shows the result of a simulation where the line of sight measurement noise is increased constantly. This is done by increasing the standard deviation σ of the zero mean Gaussian measurement errors ϵ_{LOS}. All algorithms show a decreased performance in terms of localization accuracy if the measurement noise

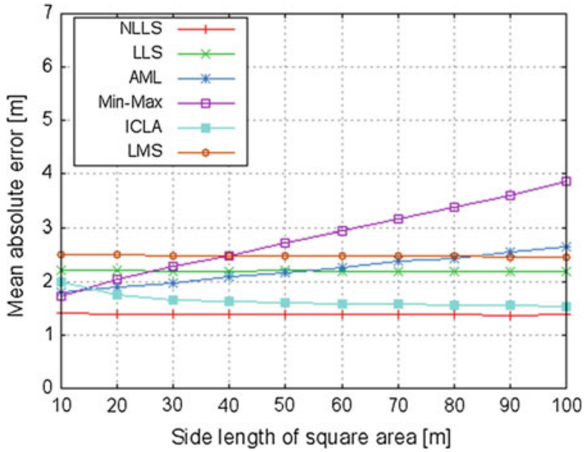

Fig. 2 Localization error to area size

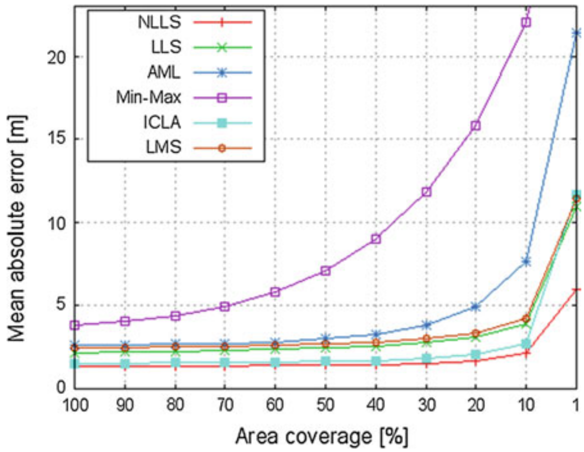

Fig. 3 Localization error to area coverage

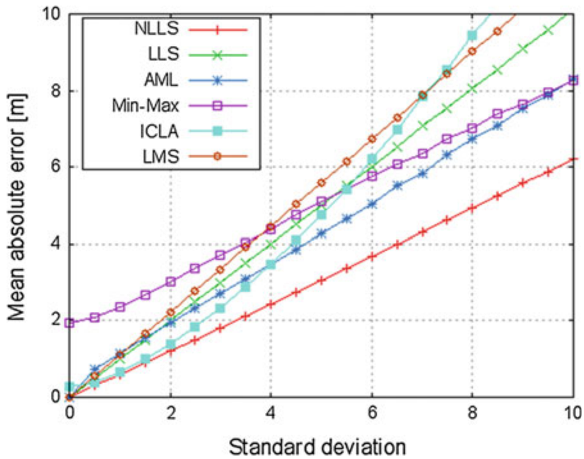

Fig. 4 Increasing measurement noise

is increased. The localization error of all algorithms except ICLA rises linearly. ICLA suffers most by an increased measurement noise while NLLS and Min–Max show the best overall performance. Although Min–Max doesn't start from the same level than the other algorithms it can even outperform AML in the end. When there is no measurement error, only ICLA and Min–Max don't produce very low estimation error. This is also expected since Min–Max does not produce an ideal solution of the equation system (by using bounding boxes) including anchor coordinates and distances to each of them. ICLA, on the other hand, occasionally clusters more intersection points than needed. This is the case when the unlocalized node is close to anchors and the resulting circles have small radii. As a result, there exist intersection points close to the intersection points of the ideal solution.

In our next simulation, we wanted to test the influence of NLOS errors to the chosen localization algorithms. Therefore, we set the line of sight error to $\sigma = 2.3$ and the upper bound of the uniform distribution for parameter λ to 3. In each simulation run, we set the probability p for having NLOS errors to a fixed value. Thus, the expected percentage value of non-line of sight distances is close to p. The maximum allowed distance estimation error was set to 30 m. In this way all estimation errors larger than 30 m are cut off and reassigned to 30 m. Figure 5 shows that the localization error of ICLA and Min–Max increases gradually with the increase of NLOS distances, which demonstrates good NLOS error tolerance. NLLS, LLS, and AML show large performance degradation in terms of localization accuracy. As expected, LMS can outperform LLS due to its attack resistance in case of large outliers. At 20 % probability of NLOS distances LMS starts to perform better than LLS. This observation even gets more obvious when looking at a simulation run whose results are displayed in Fig. 6. Here, the maximum allowed distance estimation error is increased in steps of 30 m and the probability of NLOS distances is kept fixed at 50 %. LLS and NLLS cannot withstand these large errors due to the summation in the cost function, whereas ICLA and Min–Max stay completely unaffected by larger errors. Even the performance of AML only slightly decreases and is better than LMS in the end.

In our last simulation, we reposition the anchors as seen in Fig. 7 and modify the amount of anchors to investigate its influence on the performance of the algorithms. In the first simulation run, we take anchor 1–3, in the second simulation run anchor 1–4 and so on. In this way, there are no collinear anchors and the covered area is always nearly at maximum. All other settings remain the same except that the probability of NLOS distances is set to 30 %. Figure 8 shows the results of this simulation where the vertical axis is the localization error and the horizontal axis is the anchor count. Except for AML whose estimation error increases temporarily when anchor count exceeds 5, the estimation error of the other algorithms decreases. LMS performs better than LLS when the anchor count exceeds 5 because only then can LMS build enough subsets of size 4 to filter out outliers. ICLA doesn't seem to work well with anchor counts below 5–6 but shows the overall highest performance gain of all algorithms and in the end outperforms even NLLS.

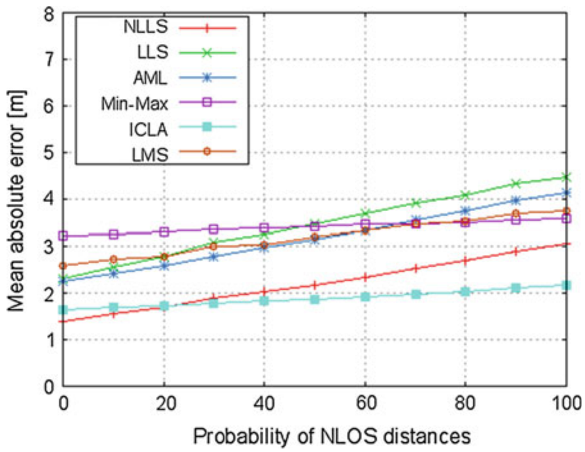

Fig. 5 Increasing the probability of NLOS distances

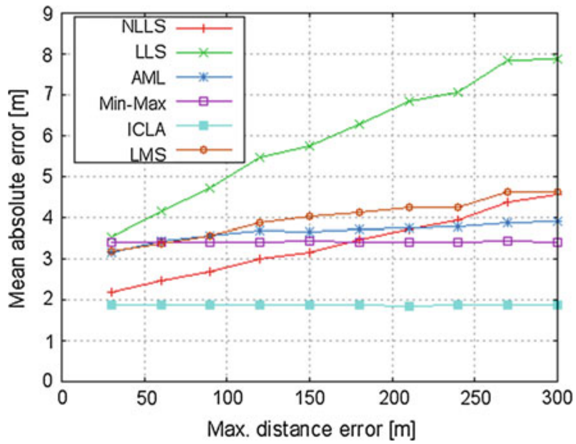

Fig. 6 Increasing the maximum allowed distance error

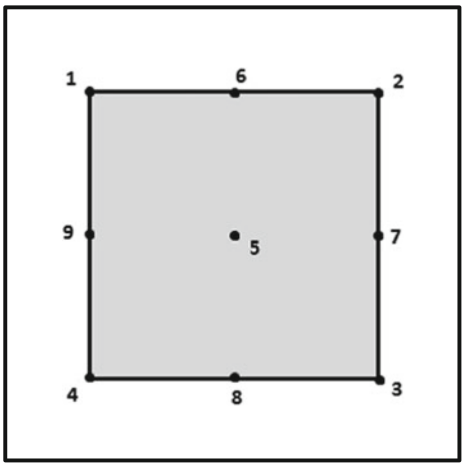

Fig. 7 Grid setup for anchor count simulation

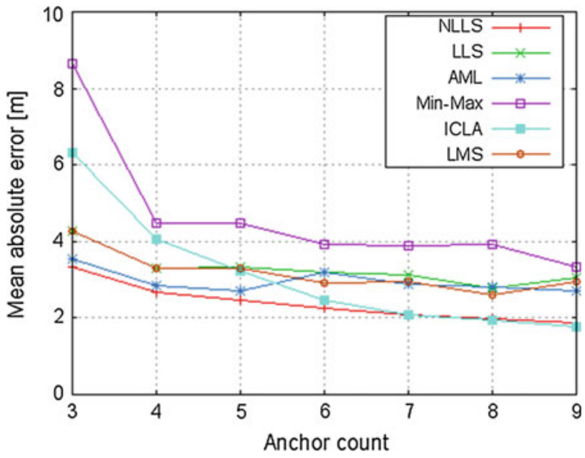

Fig. 8 Increasing the anchor count

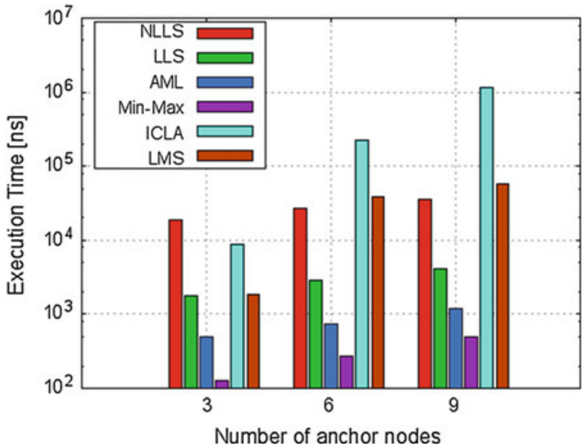

Fig. 9 Execution times of the six localization algorithms

Another important aspect when comparing localization algorithms is their computational complexity. Figure 9 shows the average execution times of the six algorithms needed for a single localization with three, six, and nine anchors in our simulation. Min–Max has the smallest execution time since it applies only simple arithmetic operations. The same holds for AML. The execution time of NLLS is much higher than that of LLS because of its iterative approach, whereas LLS uses a closed form solution. The execution time of LMS is around 14 times higher than that of LLS except when the anchor count is lower five because then LMS cannot build subsets of size four. The execution time of ICLA is extremely large compared to all other algorithms.

4.2 Spatial Evaluation

To evaluate the spatial distribution of the position error we executed every algorithm 1,000 times in the LS^2 simulation engine. LS^2 calculates the position error for every discrete point on the simulated area using an error model and an algorithm selected by the user. First, we simulated every algorithm with a uniform grid layout for the anchors. We chose nine anchors whose convex hull covers 4 % of the simulation area. The resulting images consist of up to three differently colored areas. The grey area indicates a position error between 100 and 500 % of the expected distance measurement error value; the darker the area, the higher is the error. The green area (if present) indicates a position error lower than the expected distance measurement error; the darker the area, the lower is the error. In the blue area the error is higher than 500 % of the position error and is cropped for better image contrast. The anchors are represented by the small red squares. We chose a uniformly distributed error with an expected value of 5 % of the playing field length for this simulation to minimize the effect of the error model and to maximize the effect of the geometrical constellation of the anchors and the influence of the algorithm. Other error models change the shapes very little but lower the contrast of the resulting images, so they are not as meaningful.

The green area is very important for cooperative localization strategies in WNs, because the position error stays in a reasonable range as long as the node remains in the green area. Otherwise the position error tends to grow much faster than expected.

In Fig. 10 we display the spatial distribution of the six algorithms in descending order of their average position error. As expected, Min–Max has the worst average error. But Min–Max performs much better than all other algorithms if the unlocalized node stays inside the convex hull of the anchors. If the node's position is more than the inter-anchor distance away from the convex hull, the error grows very fast. NLLS performs completely different. Its overall error distribution is nearly uniform but the weaker regions are inside the convex hull and not outside. This different behavior corroborates that statistical measures like mean error and standard deviation are less precise than analyzing the spatial distribution. LLS and LMS perform nearly similar with LLS having an overall better average result inside the convex hull in this setup. The quality of AML and ICLA is poor in every aspect in this setup. They have no real strengths and get weaker very fast with rising distance to the anchors. It is also remarkable that the spatial error distribution of some algorithms is not symmetric, although the anchors are set up symmetrically. LMS for example performs better in the lower right corner of the convex hull than in the other three corners. Only Min–Max and NLLS are nearly symmetric.

Especially the comparison between LLS and NLLS shows that LLS has its strengths and is useful in some scenarios even if NLLS performs much better in the average case. Looking only at this setup, the dynamic selection of algorithms (e.g. between Min–Max and NLLS) regarding a roughly estimated position would lead to better results.

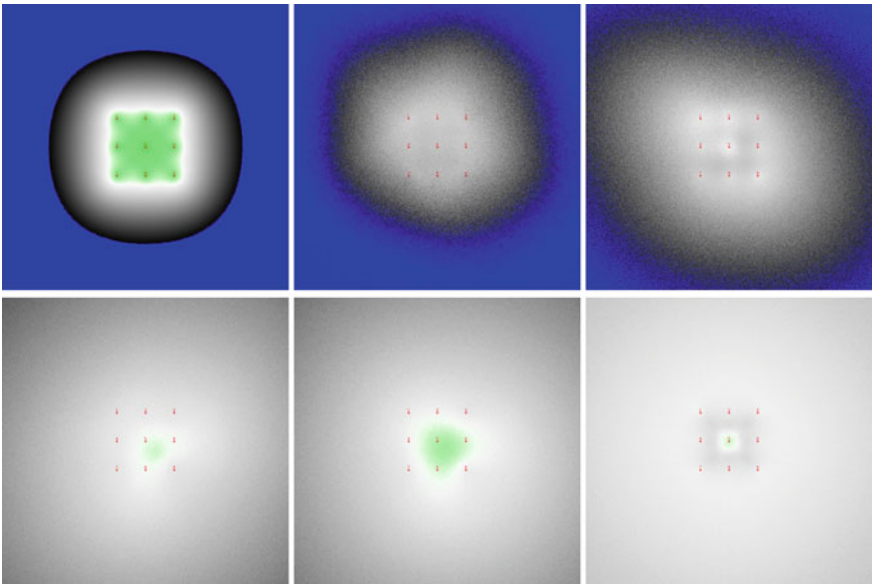

Fig. 10 The average spatial error distribution of the six simulated algorithms (1,000 simulation runs). The algorithms are from left to right: Min–Max (480 % average position error compared to expected distance error), ICLA (408 %), AML (340 %), LMS (202 %), LLS (188 %) and NLLS (138 %)

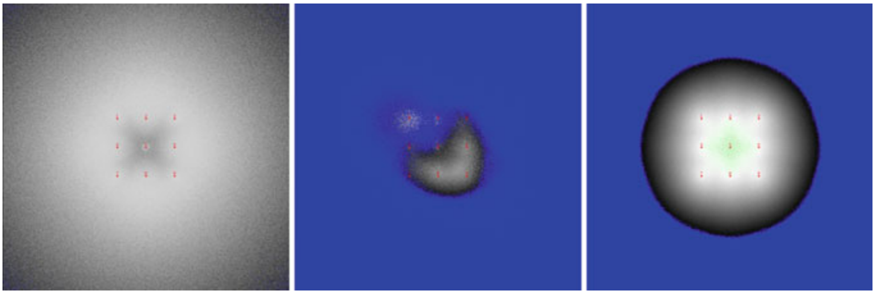

Fig. 11 Worst case results for NLLS, AML, and Min–Max (1,000 simulation runs)

The different spatial distributions of the position error of the six algorithms shows that statistical methods like the Cramér-Rao Bound, that do not take the geometrical characteristics of the algorithms into account, are often misleading or not very helpful.

For some applications where you have to guarantee an upper bound of the position error, e.g. in rescue scenarios, the worst case of the spatial distribution is more meaningful than the average case. In Fig. 11 we show the highest position error for every discrete location out of the 1,000 simulation runs. NLLS shows its weaknesses inside the convex hull more clearly, but in contrast to the average results, it looks strictly symmetric. AMLs worst case distribution looks completely

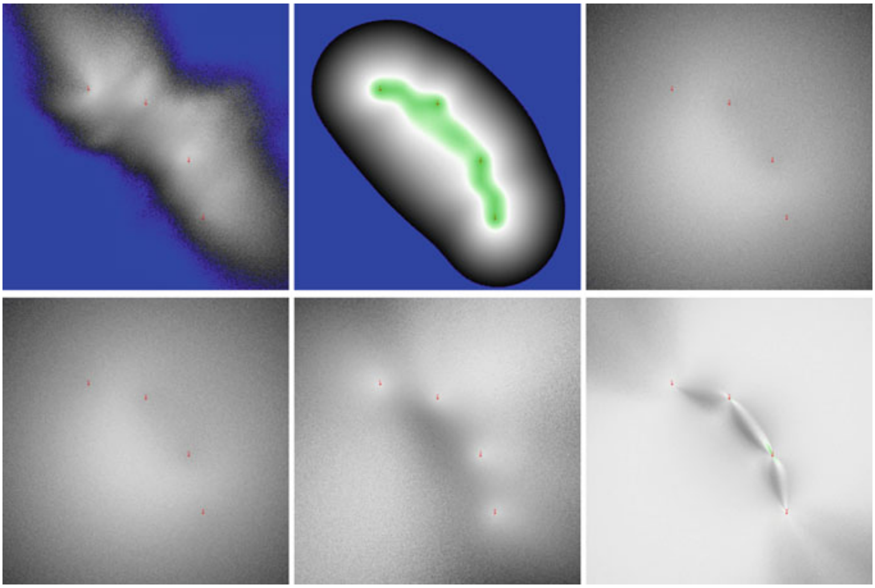

Fig. 12 The average spatial error distribution of the six simulated algorithms (1,000 simulation runs) with 4 anchors. The algorithms are from left to right: ICLA (406 %), Min–Max (382 %), LMS (262 %), LLS (261 %), AML (220 %) and NLLS (138 %)

different to the average case distribution. The lower right half of the convex hull was one of the weaker regions in Fig. 10 and is the best region in Fig. 11. Again, AMLs performance is very poor in this setup compared to the other algorithms. Min–Max again is the best algorithm if the unlocalized node stays inside the convex hull of the anchor nodes and the worst case distribution is linear weakened compared to the average one.

For the next simulation run, we lowered the number of anchors to four and chose a different layout, where the four anchors are not placed optimal but nearly collinear. The resulting spatial distribution of the position error in Fig. 12 has changed little. NLLS is weaker inside the convex hull and stronger outside, but still remains very homogenous. Min–Max remains very good between the anchors and quickly gets worse with increasing distance to the anchors. Min–Max has still the lowest error for all algorithms inside the convex hull. LMS and LLS perform nearly identically. They remain on a good average level and do not seem to suffer very much from the reduced anchor count. The only outlier is AML, which is the only algorithm of the six that performs better with fewer anchors in a worse layout. We conclude that AML has some design weaknesses and should be optimized to perform better with more anchors, or at least should only use a subset of the given anchors. In its original paper, AML is mainly simulated in a setup with a maximum of four anchors, so their conclusion that AML performs very well seems reasonable only under these limited conditions. ICLA once again is weak under these conditions. This contradicts somewhat to the findings in its original

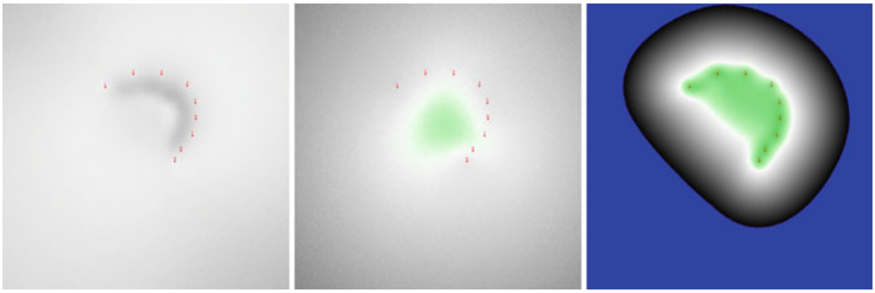

Fig. 13 The average spatial error distribution of three simulated algorithms (1,000 simulation runs) with 9 anchors. The algorithms are from left to right: NLLS (130 %), LLS (160 %) and Min–Max (360 %)

publication where ICLA always showed half the error of Min–Max and also to the previous subsection where ICLA showed better performance. An explanation can be seen in Fig. 4. Because the expected measurement error was much higher in the simulations using LS^2 than the other ones, the accuracy of ICLA experienced a much larger degradation. This is of particular importance since, as previously mentioned, ICLA suffers the most from an increased measurement noise.

For the last simulation we placed 9 anchors on a half circle. The results of this simulation can be seen in Fig. 13. The most interesting observation for this constellation is that the size of the green area is significantly bigger for the algorithms with high average errors. This leads to a new perspective in comparing these algorithms, especially for tracking applications where the current position can roughly be estimated. In the case shown in Fig. 13 one could implement a simple algorithm which switches between NLLS and Min–Max depending on the estimated node position.

This observation is also useful for a general comparison and evaluation of localization algorithms. Concentrating only on the average position error as an evaluation metric could lead to wrong conclusions if the spatial distribution is disregarded. The very different spatial distributions of ranging errors for a given scenario also implies that the CRB, which does not consider the algorithm itself, can give only a very vague estimation of the spatial distribution of the position error. For example, Min–Max has a worse average position error, but performs better in real world indoor deployments because the inter-anchor distance is normally low and the node can only move inside the hull of the anchors that are usually mounted to walls. This behaviour can be predicted from the spatial distribution.

5 Experimental Results

In order to measure the effectiveness of the six algorithms with real sensor network data and to be able to compare the results with the executed simulations, we recorded the data of a series of different test runs. The experiments were carried

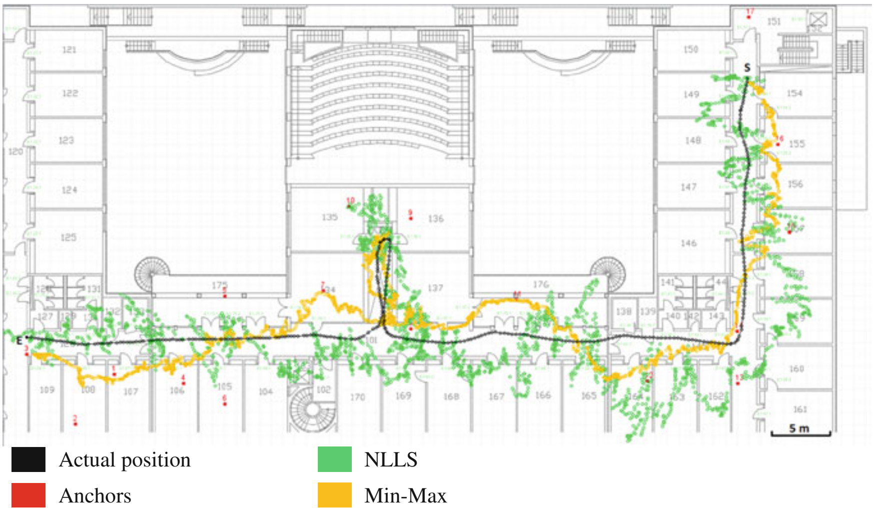

Fig. 14 Position estimates on the second floor of our Computer Science Department

out using a modified version of the Modular Sensor Board (MSB) A2 (Baar et al. 2008) node which is equipped with a Nanotron nanoPAN 5375 (Nanotron Technologies GmbH 2009) transceiver. This hardware enables the sensor nodes to measure inter-node ranges using time of flight (TOF) in the 2.4 GHz frequency band. The experiments took place on the second floor of our Computer Science Department during daytime.

Figure 14 shows one exemplary campaign of measurements following a route among offices, laboratories and with a few people walking around. For the reason of clarity, we plotted only the results of NLLS and Min–Max using a Kalman filter. The starting point is denoted by “S”, the endpoint is denoted by “E” and the total length of the path was about 100 m.

In each run, we used 17 anchors which were deployed throughout the building. Most of the anchors were placed in office rooms with doors closed. Only a small fraction of nodes was placed on the hallway, in case of Fig. 14, there were four nodes. Ground truth was measured with the aid of a robot system developed at our Department using a Microsoft Kinect. This reference system provides about 10 cm positioning accuracy. The robot also carried the unlocalized node and followed a predefined path with a predefined speed. We used the maximum movement speed of the robot, which is 0.5 m/s. In total, we performed over 5,300 localizations when adding up all test runs. The nanoPAN achieves ranging precision of around 2.85 m in average and the RMSE is 4.32 m. However, the ranging error can be as large as 20 m. We even encountered measurement errors up to 75 m in rare cases. Figure 15 shows the distribution of the distance measurement error using all anchor nodes and all runs.

The quantitative results of the six localization algorithms are shown in Table 2. The average anchor degree throughout all experiments was 7.48. As it can be seen, Min–Max outperforms the other algorithms in terms of localization accuracy with

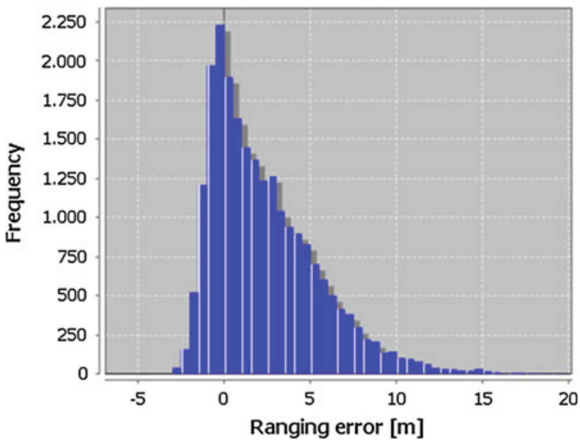

Fig. 15 Histogram of distance measurement error (all runs and anchors)

Table 2 Quantitative results for the localization task

ALGORITHM	MAE (m)	RMSE (m)	MAX (m)
NLLS	4.49	5.35	30.39
LLS	8.92	20.41	461.63
AML	4.96	5.96	36.76
Min–Max	2.05	2.42	15.39
ICLA	4.25	6.01	45.52
LMS	7.37	17.47	449.09

achieving an average error of 2.05 m. This is about twice as good as ICLA, the second best algorithm with an average error of 4.25 m. The good performance of Min–Max is not surprising because the inter-anchor distances were relative short (between 5 and 10 m) and the mobile node took mainly positions within the bounds of the network. As we know from Sect. 4 this is the optimal situation for Min–Max algorithm. This behavior can also be seen in Fig. 16 where the unfiltered estimated locations of Min–Max are displayed. For instance when looking at anchor 11 or 12, one can clearly see that the error is bounded by their coordinates.

The fact that the RMSE of NLLS, AML, and ICLA is only slightly larger than the RMSE of the distance measurements tells us that these algorithms performed well relative to the quality of the distance measurements available. The histograms of localization errors of all algorithms can be seen in Fig. 17 where the vertical axis is the absolute frequency and the horizontal axis is the localization error. LLS and therefore also LMS show poor performance compared to the other algorithms. Also the RMSE is much larger than that of the other algorithms. However, LMS can still achieve better localization accuracy than LLS as expected from our simulations.

Obviously, the position accuracy could be improved using some filtering techniques, such as Kalman or particle filters, but the aim of this chapter is to show and compare the performance of the used localization algorithms without using any of those filtering techniques.

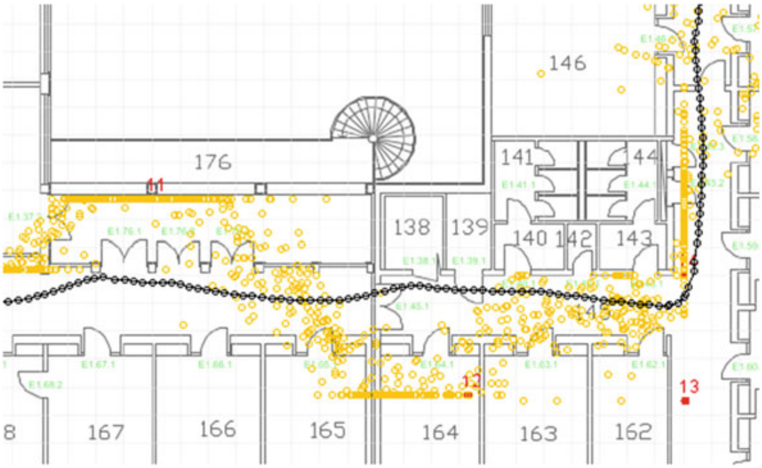

Fig. 16 Behavior of unfiltered Min–Max algorithm

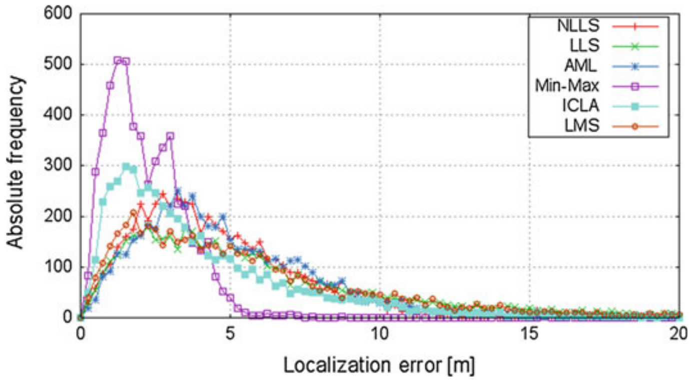

Fig. 17 Histograms of localization errors in a real environment, the second floor of our Computer Science Department

Summarizing the results of the simulations and experiments, it can be stated that NLLS shows the overall best performance no matter the area size and coverage ratio. Its spatial error distribution is very uniform which is proved by the simulations done in Sect. 4. It is also among the best algorithms of the real experiment. However, if the measurement noise is not that high, ICLAs performance is very close to that of NLLS. When the average anchor degree is greater than 5 and when operating in indoor environments where the percentage of NLOS distances is certainly higher than 30 % in most of the cases, ICLA outperforms the other localization schemes in terms of accuracy and shows a much better resistance to NLOS errors, even than NLLS. However, this advantage comes at the expense of increased calculation costs compared to all other algorithms.

Min–Max has the advantage of being computationally cheap and insensitive to errors, but it requires a good constellation of anchors; in particular, the desired localization error of Min–Max can be easily adjusted by placing the anchors at the edges of the network and having small inter-anchor distances. This fact is also stated by Savvides et al. (2002) and proved by Langendoen and Reijers (2003). AML works best when the number of used anchors lies between 4 and 5. This corresponds to the findings of Kuruoglu et al. (2009) and is the reason why they limit the number of used anchors to 4 when comparing AML with LLS and Min–Max. They identify the refinement phase of their algorithm as the reason for this behavior. Like Min–Max, AML also profits from a good constellation of anchors, although the impact is not as high as that of Min–Max. We could also prove that LLS performs better than LMS when the attack strength is low (less than 20 % NLOS distances), which is stated by Li et al. (2005). That's the reason why they implemented an efficient switched LLS-LMS localization scheme to overcome this situation. The desired design goal of being more robust against large distance measurement error due to non-line of sight signal propagation could be validated by our studies. Nevertheless, LMS cannot outperform NLLS unless the distance measurement error is abnormally high which shouldn't be the case even in indoor deployments.

6 Conclusion

We showed that the error distribution doesn't only depend on the error distribution of the measured distances, but also on the geometrical constellation between node and anchors and the characteristics of the algorithm. We presented results from both simulations and real experiments that corroborate our theory.

The NLLS algorithm is the best general purpose algorithm of the tested localization algorithms, because its spatial error distribution is very homogenous even if the anchor placement isn't optimal. ICLA, on the other hand, showed ambiguous behavior. While the algorithm performed weakly in the spatial error distribution analysis, the real experiments and other simulations showed opposite behavior. We discovered that ICLA measurement noise which should be adapted to omission is the reason for the poor performance in Sect. 4.2. If we know the error distribution of the distance measurement device and the operation environment (e.g. indoors), then ICLA provides a good alternative to NLLS. That ICLA should be adapted is also not mentioned in its original publication.

If the errors are large and the unlocalized node is in the convex hull of the anchors, Min–Max also is a good choice for localization. Especially in dense networks with small inter-anchor distances Min–Max outperforms all other algorithms as shown by the experiments in Sect. 5.

The optimal solution for the localization task would be to use a selection algorithm which is capable of analyzing the current situation at each point in time and then applying the ideal method for achieving the lowest positioning error possible.

Future work should address the development of an algorithm that is optimized for geometric constellations typically found in real world deployments. For indoor environments an algorithm should focus on low inter-anchor distances and the performance inside the convex hull of the anchors. For cooperative localization algorithms one should try to achieve a very homogeneous error distribution with position errors lower than the average distance error. To develop such algorithms or an adaptive combination of several algorithms, it would be helpful to get simple estimation for the expected quality of the current anchor setup with the current algorithm.

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Using the Magnetic Field for Indoor Localisation on a Mobile Phone

Andreas Bilke and Jürgen Sieck

Abstract Many people have difficulties getting their bearings when entering an unknown building. However, this problem can be solved by localisation and navigation on a mobile phone. This chapter presents a locating system which is based on recognising geomagnetic field disturbances and ambient light. A particle filter is applied to the locating problem. It is used to fuse together the data of both sensors and track the mobile phone. The prototypic implementation of locating takes place on an Android tablet. Different aspects of the particle filter are evaluated regarding their influence on the accuracy of locating. The tests took place in an office building. In the course of these tests an arithmetic mean locating error of 4 m was achieved.

Keywords Indoor localisation · Particle filter · Magnetic field · Ambient light

1 Introduction

A precondition of indoor navigation and localisation is the provision of various applications. Finding an office room in an unknown building is one of these. Most of the common techniques for outdoor localisation, like GPS, are not accessible in buildings. Walls and other obstacles shield the signal and therefore it is not

A. Bilke (✉) · J. Sieck
INKA Research Group, Hochschule für Technik und Wirtschaft Berlin,
Wilhelminenhofstraße 75a, 12459 Berlin, Germany
e-mail: bilke@htw-berlin.de

J. Sieck
e-mail: j.sieck@htw-berlin.de

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possible to receive it indoors (Eissfeller et al. 2005). It is therefore necessary to provide other reliable approaches. Most of the state-of-the-art technologies are either too elaborate or of relatively low accuracy.

Many systems use Wi-Fi for localisation. One disadvantage of this approach is that the signal propagation in the 2.4 GHz band cannot be fully predicted. Magnetic fields, which are distorted in buildings, can, however, be used in fingerprinting techniques such as Wi-Fi.

In this chapter, an infrastructureless localisation system using magnetic field and light intensity fingerprints is described. The accuracy of this system is improved by using a particle filter.

1.1 Localisation Systems

Most of the localisation systems can be divided into the following methods (Hightower and Borriello 2001):

ToA/TDoA The methods of time of arrival and time difference of arrival use signal runtime between sender and multiple receivers. Knowing the runtime and the propagation speed, it is possible to calculate the distance between all nodes. Because of the fixed position of the receivers, the exact position of the sender can be determined using multilateration. Both methods need synchronised clocks to work properly. Special hardware is required, which cannot be used in the scenario described above.

AoA The angle of arrival method uses the angle of incidence at the receiver. Multiple receivers permit calculation of the site. This method also needs complex hardware like antenna arrays or movable antennas.

RSSI The received signal strength indicator uses the characteristic signal attenuation function of a specific technology to determine the current location of a node.

Fingerprint In addition to the direct calculation of distances between nodes, it is also possible to use a statistical approach for localisation. The fingerprint method consists of two phases. In the off-line phase, characteristic signals, such as Wi-Fi signal strength, are measured and stored in a data base together with the location of their appearance. Later, in the on-line phase, these signals are measured again. The pattern is searched for in all previously recorded data base entries. The best matching entry is then used as the location of the mobile system.

Looking at the literature, most systems for localising objects are RSSI or fingerprint based. These theoretical approaches can be applied to different technologies. A Wi-Fi infrastructure is already available in many office buildings, therefore it is often used for localisation since no additional infrastructure is needed. Using a Wi-Fi RSSI system, it is possible to reach a median accuracy of 4.3 m (Bahl and Padmanabhan 2000). One disadvantage of this system is the foreseeability of the signal damping. Damping through walls or water affect the signal propagation and therefore the accuracy. The fingerprint approach does not need such a model and can achieve a better accuracy. However, the fingerprint approach is affected by environmental changes in buildings. If, for example, a piece of furniture is moved in a room, the signal characteristics change. Therefore the fingerprint data base has to be regularly updated.

The possibility of using magnetic field for localisation has been examined in different chapters. There are two different approaches. One of them creates an artificial field. A magnetic field sensor can detect the direction of the sender. This approach is similar to the AoA method. Since then, this approach has only been tested on small areas. However, the costs of this are high (Blankenbach et al. 2011).

The second approach utilises the earth's magnetic field. One example is a compass to locate mobile robots. The compass is used to estimate the robots' direction. However, the geomagnetic field is distorted in buildings because of steel girders or other obstructions. This leads to an adulterated measurement and, in addition, to a localisation error. This effect is described by Haverinen and Kemppainen (2009) and Storms et al. (2010); a fingerprint map of the specific magnetic disturbance being collected. However, this approach was only tested in a corridor and not on a complete floor.

1.2 Scope of the Work

In this chapter, we describe how the magnetic field fingerprint approach can be applied to larger areas such as floors in an office building. The increasing distribution of smart phones with numerous sensors allows them to be used for indoor localisation.

This chapter also examines whether the light-intensity sensor in mobile phones can also be used. Using the light has the disadvantage of irregularity. It varies in the course of the day or due to changes in the weather. To examine the general possibility of localising with such a sensor, the light situation in the following experiments are regarded as static. Static light situations occur, for example, in museums; therefore it is worth the attempt to investigate this issue.

To improve accuracy, a filter is applied to the system. The Kalman filter is often used, but because of the corresponding light sensor, it is not possible to apply it in this scenario. The predicted system-state of a Kalman filter has to be one position together with a Gaussian-distributed measurement mistake. Using light sources, it is not possible to apply it with this restriction. It is normal that a system-state using this sensor is not unique. However, this happens, for example, on a long facade of windows. As all the places on this facade have the same light intensity, a unique location cannot be determined. In contrast, a particle filter is able to handle such states. Therefore a particle filter is applied to this localisation problem.

Literature provides different extensions to the particle filter. One extension uses a map of the building to suppress invalid particle movements (Wang et al. 2007b). Different extensions are evaluated concerning their influence on the accuracy of localisation.

2 Particle Filter

The particle filter, initially developed by Gordon et al. (1993), is a recursive bayes filter for estimating a system-state using measurements. If the filter is applied to a localisation problem, the system-state is a position in space. The actual position cannot be determined exactly in most cases. The goal of the filter is to contribute a probability density function which describes the position of a device. This function is represented by particles. They consist of a state and a nonnegative weight. A high weight means it contributes more to the function and hence more to the estimated position. The set of particles is defined by:

$$\chi = \{\langle x_i, w_i \rangle \,|i = 1, \ldots, N\}$$

In which x_i is the state of a particle and w_i the corresponding weight.

The filter consists of two essential steps. In the motion model, the particles discover the state space using a transition function and, in the measurement model, the particle positions are evaluated and new weights are assigned on the basis of the measurements.

2.1 *Motion Model*

During the motion model, all particles discover the state space. The transition between states is described by means of a mathematical model. It is also possible to use inertial sensors for this model (Wang et al. 2007a). Using inertial sensors, a step and direction detection can be realised. Within these parameters, the particles can be moved through the state space.

This chapter uses a Gaussian randomised model (Bruce and Gordon 2004; Widyawan 2010). The motion parameters are extracted from random numbers.

The new speed of a particle is described with:

$$v_t \Big| = \mathcal{N}(v_{t-1}, \sigma_v), \; v_t = \begin{cases} v_t, & 0 \le v_t \le Max_{v_t} \\ |v_t|, & v_t \le 0 \\ Max_{v_t}, & v_t > Max_{v_t} \end{cases}$$
$$\sigma_v = \min(Max_{\Delta t})$$

The expected value is the speed of the last particle step. The standard deviation is the time difference between the occurrence of two measurements. An increasing time difference leads to an increasing probability of changing the speed in contrast to the last one. Variable Max_{v_t} describes the maximum speed of a particle. It is set to 10 ms^{-1}, since this is approximately the maximum speed a human being can walk (Widyawan 2010). $Max_{\Delta t}$ is the maximum time difference between measurements. It is set to 3 s.

The direction of a particle is based on its speed. The assumption is that a direction change is less probable if the speed is high and vice versa. If a person moves around a corner, one's speed is mostly slow. The following formula describes this process:

$$\alpha_t = \mathcal{N}(\alpha_{t-1}, \sigma_\alpha)$$

$$\sigma_\alpha = 0.4\pi - \arctan\left(\frac{\sqrt{v_{t-1}}}{2}\right)$$

Both variables are afterwards used to move the particle:

$$x_{i,t} = \begin{pmatrix} p^x_{i,t} \\ p^y_{i,t} \end{pmatrix} = \begin{pmatrix} p^x_{i,t-1} + v_{i,t}\cos(\alpha_{i,t})\Delta t \\ p^y_{i,t-1} + v_{i,t}\sin(\alpha_{i,t})\Delta t \end{pmatrix}$$

2.2 Measurement Model

The measurement model is used to evaluate the particle state. In this step, the particle weight is updated on the basis of the new measurements. The particle state always corresponds to a fingerprint position since a fingerprint approach is used. For each particle the nearest fingerprint will be searched for. Afterwards, the measured-data vector is compared to the data stored from the fingerprint. The comparison of both vectors is realised through a similarity function. This chapter evaluates three similarity functions regarding their impact on the accuracy. These functions are the Gaussian distance, cosine similarity and a probability-based function.

The vector measured corresponds to a point in the measurement space. The Euclidean distance describes the direct connection between both points. It is defined through:

$$d(\bar{x}, \bar{y}) = \|\bar{x} - \bar{y}\| = \sqrt{\sum_{i=1}^{N}(x_i - y_i)^2}$$

The cosine similarity, often used in the field of information retrieval, calculates the angle between both vectors. The measured magnetic-field vector points to the earth's magnetic north pole. The direction is distorted in buildings. In this case, the cosine similarity may be used to recognise the specific refraction. It is defined by:

$$d(\bar{x}, \bar{y}) = \frac{\bar{x} \cdot \bar{y}}{\|\bar{x}\|\|\bar{y}\|}$$

The probability approach, based on a Gaussian function, is able to consider measurement noise. To use this function, the measurement noise has to be determined in advance for the relevant sensor device. Later on, it will be used as the standard deviation parameter in the following function:

$$d(\bar{x}, \bar{y}) = \prod_{i=1}^{N} \frac{1}{\sigma\sqrt{2\pi}} exp\left(-\frac{(x_i - y_i)^2}{2\sigma^2}\right)$$

Using the Gaussian function, a particle weight, w_i can directly be derived. For each dimension of the measured vector, the previously-described function is applied. The total weight is the product sum of all dimensions. With the other similarity functions, only a similarity order can be computed. With the formula:

$$P(z_t|x_t) = 0.5^{i_t}$$

a probability can be constructed from the ordered set. i_t is the position of the fingerprint in the ordered list after applying the similarity function to all fingerprint values.

The magnetic field, measured on the mobile device, is always related to the device coordinate system. In the operating phase it is not possible to ensure a consistent alignment of the device. The measured vector must be transformed into a world-coordinate system. The Android operating system, which is used on the test device, can transform the locally-adjusted vector into a global-coordinate system. Unfortunately, the transformation occurs through the magnetic-field sensor. This leads to an error because of the distorted magnetic field. In a test scenario, it was discovered that, despite the transformation, the vector varies if the sensor is turned in different directions. To overcome this problem, the magnetic field was stored for each direction per fingerprint within the off-line phase. Later, during the on-line phase, the direction was determined again and only the correct data-vector for the corresponding direction was used to compare all fingerprints.

Another enhancement of the measurement model was introduced in by Evennou and Marx (2006). Map data can be used, if available, to control the particle movement. If a particle is moved through a wall during this phase, its weight can be set to zero. This additional step can be described with:

$$w_{i,t} = \begin{cases} 0, & wallcrossed \\ P\left(z_t \middle| x_{i,t}\right), & otherwise \end{cases}$$

2.3 Resampling

The first versions of the particle filter have one common problem. If the filter evolves through multiple iterations, it is unavoidable that the particle set degenerates. Some particles gets a very high weight while the rest contribute almost nothing to the probability density function. To overcome this, an additional resampling step was introduced (Ristic et al. 2004). The dominant particles are split into several particles with low weights, and the particles with the lowest weight were removed from the set. There are different resampling algorithms; however, in this chapter, the algorithm from Widyawan (2010) was implemented.

2.4 State Prediction

The state of a particle is related to a position of a fingerprint. To compute the estimated system-state, the most probable fingerprint has to be determined. For each fingerprint, all particles which are near to it have to be detected. The weights of these particles are added together—the estimated position is then the fingerprint with the highest total particle sum.

3 Tests

The previously-described particle filter, based on magnetic field and light intensity fingerprints, was evaluated on its performance regarding localisation accuracy. Therefore, five test runs took place in an office building. The particle filter used had several configuration possibilities which were evaluated according to their impact on the accuracy.

3.1 Environment

The total area of the test floor was 300 m^2 with eight rooms in total. About five fingerprints were recorded in each room. The complete floor, consisted of 52 fingerprints and half of the floor 27. The distance between two fingerprints were approximately 2 m. If a localisation error occured, the minimum error was therefore approximately this distance. During the test runs, an arbitrary route through the rooms was taken. A Motorola Xoom tablet computer was used as a test device.

3.2 Simulation of the Localisation

The reviewed configuration options used: the walls within the measurement model took into consideration the direction, different sensors, the similarity function and the number of particles to approximate the probability density function. In total there were 144 different configurations—it was therefore impossible to make a specific test run for each configuration. Instead, all measurement data was stored in a file for later analysis in the previously-mentioned test run. On some randomly selected points, the real location of the device was also additionally stored. An additional simulation software was written to review the behaviour of the particle filter under different configurations. The stored measurement data was used for this step. At each iteration of the filter, the result was an estimated system-state which was compared to the real position from the test run.

This simulation software makes it possible to obtain a mean error for each configuration. The root mean square error (RMSE) was used to compare the results. On the basis of the mean error, the best configuration of the particle filter was determined for this scenario.

The RMSE is defined by

$$\text{RMSE} = \sqrt{\frac{1}{2}\sum_{i=1}^{N}\|p_i^r - p_i^e\|^2}$$

where N is the number of the recorded real positions. p_i^r is the actual position and p_i^e the estimated position. In the following sections, the different algorithm aspects are evaluated regarding their influence on the system performance.

3.3 Wall Aspect

To compare the different algorithm aspects, box-plots where choosen. Each box, including the atennas, contains all measurement errors of the described simulation. The boxes contain 50 % of the data, the thick line in the middle being the median.

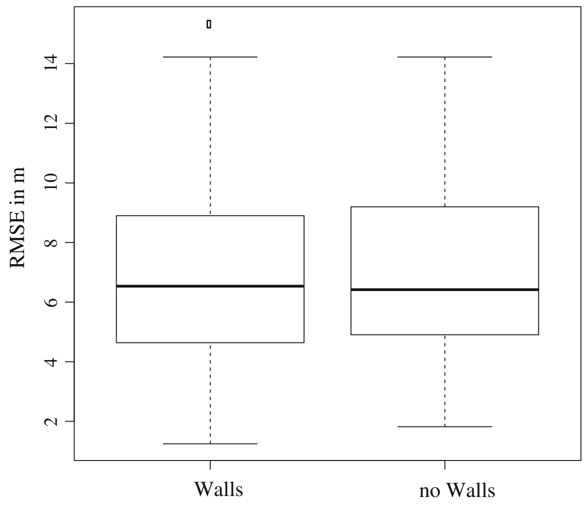
Using the wall aspect, it was determined if map information in the measurement model can suppress invalid particle movements. In Fig. 1, a box-plot is shown which compares the error of all configurations according to the wall aspect. It can be seen that the median of both boxes is very similar (6.53 and 6.41 m).

During the test runs, it was discovered that the filter misjudged the position more often if the wall aspect was used. When the filter recognised the device in an incorrect room, it was more difficult to get the correct position later if wall aspect was used. The particles become devalued if they cross a wall, therefore the filter cannot estimate the correct position when new measurement data arrives—the particles are caught in the room. This algorithm feature is proposed in many chapters to improve the system accuracy. However, while using magnetic fields, it was shown that better results are not achieved with this extension.

3.4 Direction

If the direction was taken into consideration within the measurement model, the median error was 6.43 m; without the observation, it was 6.54 m. At first, better results were assumed by using the direction for selecting the more appropriate fingerprint vector. However, when testing it was concluded that this extension has no measurable effect on the accuracy.

Fig. 1 Error distribution by using the wall aspect in the measurement model



3.5 Vector Similarity Functions

A similarity function has to be used to search for the more similar fingerprint within the data base. Within the test, run three different functions were evaluated. In Fig. 2, the results regarding used function are shown. Using the Euclidean distance, the lowest average error was reached. The Gaussian function, which was assumed to perform better when it comes to noise measurement, leads to the highest error.

3.6 Used Sensors

This chapter evaluates two different sensors for using the fingerprint approach. If only the light intensity sensor was used, an average error of 7.5 m was reached. The magnetic field sensor itself had an error of 6.37 m. If both sensors were combined, the error was 5.93 m (see Fig. 3). Since the used sensors are mostly available in modern mobile devices, they can be used to improve the accuracy without additional hardware.

3.7 Number of Particles

It has been theoreticly proved that an ∞ number of particles approximates the density function best, which leads to the lowest average positioning error (Ristic et al. 2004). However, with an increasing number of particles, the computation

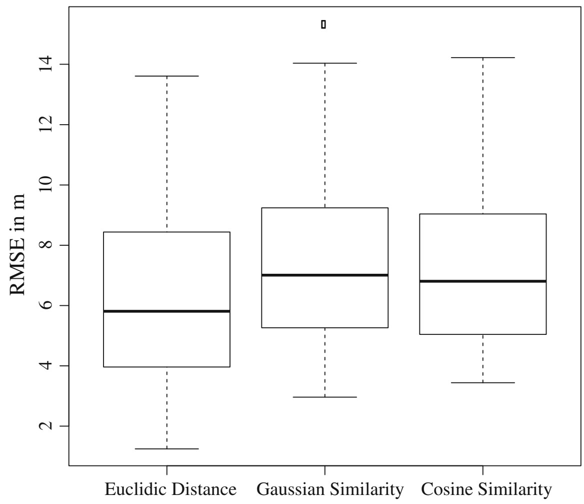


Fig. 2 Error distribution by using different similarity functions

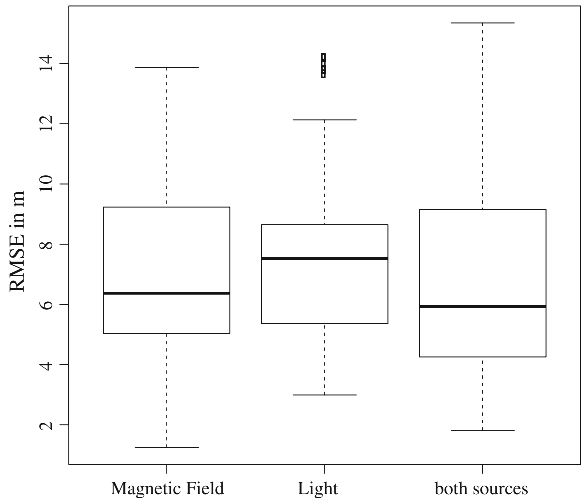


Fig. 3 Error distribution by using different sensors

time for iteration increases as well. A trade-off between error and computation time has to be found. In this chapter. the minimum number of particles which are needed for the scenario is determined.

It was discovered that the minimum number of particles for one floor is about 200. In contrast, other chapters proposed a minimum of 500 particles (Widyawan 2010; Haverinen and Kemppainen 2009). With more particles, the average error was not decreased, so it was not worth investing more computation time on it.

3.8 Best Algorithm Configuration

After comparing different algorithm aspects, it was possible to select the optimal configuration which lead to the lowest error. The configuration did not use the wall aspect, the usage of direction did not matter, the Euclidean distance performed best, the combination of both sensors achieved the best result and only 200 particles were needed to approximate the density function.

Using this configuration, Table 1 was created. The arithmetic mean was 4.1 m. In addition, a cumulative density function could be created (see Fig. 4). This shows the best configuration in comparison to a poor configuration.

The table shows that the average error increases if the used size of the floor also increases. The uniqueness of the fingerprints decreases if more fingerprints in the data set are used. The fingerprint approach using magnetic fields is based on the distorted field within buildings. If the area increases, it might be possible that a typical field disturbance is repeated, which leads to a poorer performance when searching for the best matching fingerprint in the data base.

Beside the total size of the floor, the structure of the individual rooms must be considered. During the tests, it was discovered that small rooms are more suitable for using magnetic field fingerprints. Narrow corridors also show a better performance. This leads to the assumption that steel girders and power cables have, in terms of distance, an influence on the field.

3.9 Comparison to Other Systems

As previously noted, there are several systems for indoor localisation. This section compares other systems with the one in this chapter. Other papers are cited only where the used scenario is comparable to this one.

The different papers are cited in Table 2. There are systems with a Wi-Fi propagation model approach (Bahl and Padmanabhan 2000), fingerprint based systems (Au 2010; Honkavirta et al. 2009; Gansemer et al. 2010; Widyawan 2010), magnetic field based systems (Haverinen and Kemppainen 2009), RFID landmark (Bergemann and Sieck 2011) and also hybrid approaches (Conaire et al. 2008; Evennou and Marx 2006; Chen et al. 2005).

It can be observed that all fingerprint approaches, regardless of their chosen approach, get better results. One disadvantage of the Wi-Fi approach is that it is

Table 1 Statistic value of the localisation error

Test run	RMSE (m)	Median (m)	Arith. mean (m)	Maximum (m)
Compl. floor	8.37	3.72	5.88	22.60
Half floor	3.53	0.00	2.01	14.15
Total result	6.59	1.90	4.09	22.60

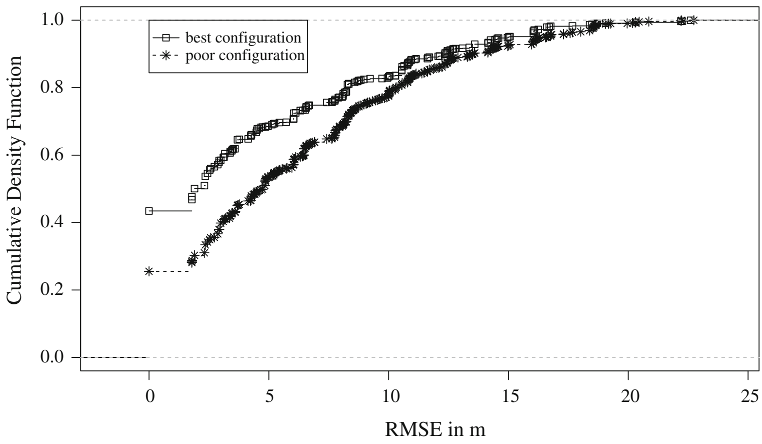


Fig. 4 Cumulative probability for different algorithm configurations

Table 2 Statistic values of the position error in other chapters

Chapter	Type	RMSE (m)	Median (m)	AM (m)
(Bahl and Padmanabhan 2000, p. 783)	WP	–	4.3	–
(Bergemann and Sieck 2011, p. 405)	RF	–	–	2.0
(Au 2010, p. 94)	WF	1.92	–	1.67
(Chen et al. 2005, p. 119)	HB	–	–	2.13
(Honkavirta et al. 2009, p. 250)	WF	5.5	3.8	4.5
(Evennou and Marx 2006, p. 173)	HB	–	–	1.53
(Conaire et al. 2008, p. 4)	HB	–	–	2.00
(Gansemer et al. 2010, p. 5)	WF	–	–	1.80
(Haverinen and Kemppainen 2009, p. 3146)	MF	–	–	3.43
(Widyawan 2010, p. 85)	WF	–	–	1.98

AM is arithmetic mean. Localisation types are WP (Wi-Fi propagation model), WF (Wi-Fi fingerprint), MF (magnetic field), RF (RFID landmark) and HB (hybrids approaches)

not infrastructure-less. It also suffers from signal changes which occur if furniture is moved in rooms or people obstruct the Wi-Fi signal. The magnetic field approach by (Haverinen and Kemppainen 2009) was only tested on a corridor.

4 Conclusion and Further Work

This chapter describes an infrastructure-less indoor-positioning system which uses magnetic field and light intensity fingerprints. The tests took place in an office environment. To improve the accuracy, a particle filter was applied to the system. In a test run, an arithmetic mean error of 4.1 m was reached.

Different extensions of the filter for improving the accuracy were reviewed. Multiple similarity functions for the fingerprint system were evaluated regarding their impact on the accuracy.

In later experiments, it has to be determined if a changing environment (e.g. moved furniture) has an influence on the magnetic fingerprints. Different kinds of rooms should also be investigated concerning their suitability for the described method.

With an increased area, the overall accuracy decreased. Further work on this system can improve it in two different ways.

The decreasing accuracy results from the lack of unique fingerprints. If the area gets bigger, the latter may overlap. One reason is that the sensor used has a noise measurement. In further research, this noise may be reduced by filtering the incoming signals with, e.g. a Kalman-filter.

Another approach may be to use the advantage of the existing magnetic field. This field is mostly distorted in buildings. It is possible to use this without any further installations. Instead of having the fingerprints close together, a combination of fingerprints and inertial sensors may be developed. The movement of a device will then be tracked by inertial sensors, and the estimation of position improved by fingerprints at strategic positions such as doors.

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Part III
Wayfinding/Navigation (Indoor/Outdoor) and Smart Mobile Phone Navigation and LBS Technologies

Indoor Route Planning with Volunteered Geographic Information on a (Mobile) Web-Based Platform

Marcus Goetz and Alexander Zipf

Abstract Route planning services for a priori route planning on computers or on-demand planning on mobile devices are omnipresent, not only for vehicles but also for bicyclists or pedestrians. Furthermore, public or commercial buildings such as hospitals, hotels or shopping malls are getting bigger and their inner complexity increases. Additionally, most of the time of our lives is spent indoors, apparently quite often in unknown and foreign buildings. Consequently, the need for mature indoor route planning applications emerged and both academia and economy are now trying to adapt well known outdoor routing services to complex indoor spaces. Contrary to the outdoors, where typically commercial data providers or professional surveyors capture spatial data, it is unlikely that commercial institutes are able to capture indoor information on a large-scale. In the last couple of years, Volunteered Geographic Information (VGI) or crowdsourced geodata has increasingly gained attractiveness and the manifoldness and quality of such data has already been demonstrated in different (outdoor) applications. Trying to gain traction in the emerging field of indoor applications, OpenStreetMap (OSM) as one of the most popular VGI communities aims at taking the lead in capturing information about indoor spaces. Trying to satisfy the demand for indoor services, this chapter presents an extensive application for indoor environments. By providing indoor maps and route planning services with indoor OSM data, the here conducted work on the one hand demonstrates the possibilities arising from VGI and on the other hand provides a mature indoor application. In particular, the developed application can be used for a priori route planning at home on a

M. Goetz (✉) · A. Zipf
GIScience Group, Institute of Geography, University of Heidelberg, Berliner Straße 48, Heidelberg 69120, Germany
e-mail: m.goetz@uni-heidelberg.de

A. Zipf
e-mail: zipf@uni-heidelberg.de

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personal computer as well as for on-demand route planning on a mobile device. A prototypical implementation for BlackBerry smartphones is also presented, whereas the application, due to its design and technology, can be easily ported to other mobile platforms such as Android smartphones, iPhones or iPads.

Keywords Crowdsourced geodata · Indoor routing · Indoor route planning · OpenStreetMap · Volunteered geographic information

1 Introduction

Urban built environments are continuously growing regarding building size as well as interior complexity. Especially public or commercial buildings such as hotels, airports, shopping malls or universities, are becoming bigger and bigger. Some examples are the Burj Khalif in Dubai with more than 800 m height, the Venetian Resort in Las Vegas with more than 7,000 rooms, Terminal 3 at the airport of Dubai with approximately 1.5 million m^2 floor space, the Mall of America with more than 520 shops, or the Warren G. Magnuson Sciences Building of the University of Washington in Seattle with more than 533,000 square meter floor space. Additionally, a recent study of the American Physical Society APS (2008) describes that the average North American spends about 90 % of his or her life in indoor environments and it seems likely that similar figures can be accounted for people living in megacities like Hong Kong or other developed countries like Germany or France. Although this 90 % also includes the time for sleep or leisure time at home, it can be still stated that people spend a lot of their time indoors, whereby often foreign and unknown buildings are involved (Winter 2012). Considering those above mentioned facts there is an increasing need for indoor Location Based Services (LBS), such as maps or routing services (Goetz and Zipf 2010), and there is also an increasing attention on indoors in science (Jensen et al. 2011). Additionally, global companies also started to extend their outdoor map applications to indoors, such as Google (2011), NAVTEQ (Privat 2011; Navteq 2011) or Bing (2011). Those newly developed indoor applications are typically based on proprietary and commercial data sources, which are on the one hand limited regarding usage possibilities and on the other hand often expensive to obtain. Additionally, for the authors of this chapter it seems unlikely that commercial data providers will be able to capture indoor information on such large scales as they are doing for outdoors, which leads to the question of how to satisfy the demand for indoor information. Also, Winter (2012) emphasizes that there is indeed a huge demand for information about indoors, but that there is also a lack of knowledge of how to satisfy this demand.

For the authors of this chapter, one possibility for solving this issue and satisfying the demand for indoor spatial information lies in volunteered geographic information (VGI) or crowdsourced geodata. These terms describe a continuous trend of billions of humans acting as remote sensors (Goodchild 2007) which collaboratively collect geodata. Such VGI communities normally aim for some distinct goal (e.g., collecting geo-referenced images, creating a huge world database etc.), but they all provide the collected data in a Web 2.0 Internet community platform at no charge. Essentially, everybody can download, use and enhance the data. One of the most prominent and popular examples of VGI is the OpenStreetMap (OSM) community. Within OSM, community members contribute both real spatial geometries as well as additional (semantic) information about distinct spatial features. Considering both quantity and quality, it has already been demonstrated that OSM is able to compete against commercially collected geodata (Zielstra and Zipf 2010; Haklay 2010; Neis et al. 2012). Trying to gain traction in collecting indoor information and to benefit from the (already proven) power of OpenStreetMap, researches developed a very detailed and powerful *IndoorOSM* mapping proposal (OSM 2012b), originating from research about the requirements on crowdsourcing indoor information (Goetz and Zipf 2011a). Different routing applications, such as OpenRouteService (Neis and Zipf 2008) or Mapquest (2012), have already demonstrated that pure OSM data can be used for the provision of routing applications. However, these are typically restricted to the OSM road network which includes vehicle roads as well as pedestrian paths. Essentially, routing pedestrians over a plaza (a polygon) is not directly feasible and is typically not integrated in the aforementioned route planning applications. That is, although OSM can be used for outdoor routing, it yet needs to be proven that it is also possible to provide indoor routing functionality in a detailed map application.

The main contribution of the conducted research is the development of a web-based application which on the one hand provides an overview about a distinct building and on the other hand allows for the planning of user-definable routes inside the corresponding building. That is, by using the application, users can plan routes through the building prior to their trips. Additionally, enabling the user to plan routes on-demand, that is when actually visiting the corresponding building, a distinct mobile application has been designed and implemented on a *RIM BlackBerry* device as a proof-of-concept. Both applications, the web-based browser app and the native mobile app, are based on World Wide Web Consortium (W3C) standards, such as Hypertext Markup Language (HTML), JavaScript or Cascading Style Sheets (CSS), and Open Geospatial Consortium (OGC) standards such as Web Map Services (WMS). That is, although the prototypical mobile app has been developed for *BlackBerry*, it can be easily ported to other platforms such as *Android* smartphones, *iPhones* or *iPads*. In contrast to existing indoor route planning applications, the here presented approach and its components (i.e., the map and routing service) are purely based on VGI from OSM. In doing this, it will be demonstrated that OSM can potentially serve as a good alternative (or additional) data source for the provision of indoor LBS. The route computation is based on the Dijkstra algorithm (Dijkstra 1959). The aim of this chapter can be summarized into three points: (1) to demonstrate the manifoldness and power of crowdsourced indoor geodata, (2) to present a web-based map and routing service for a priori trip planning on personal computers and (3) to describe the development of a native mobile route planning application for mobile devices.

The rest of this chapter is organized as follows: after this brief introduction, the next section summarizes existing indoor applications of both academia and economy. Thereafter the *IndoorOSM* mapping schema for OpenStreetMap is described, forming a base for the developed applications. The next section then describes the undertaken preprocessing steps as well as the system architecture of the developed services. Thereafter, both the web-based client as well as the mobile app client is described in more detail. The last section then concludes the undertaken work and additionally provides insights on future work.

2 Related Work

Within the last years, indoor maps and route planning services have gained an increasing interest in both research and economy. Quite early, Abowd et al. (1997) presented the Cyberguide system: one of the first approaches towards indoor navigation systems. It combines outdoors with indoors and aims at providing seamless navigation for tourists. A similar system, namely MARS, has been presented two years afterwards (Höllerer et al. 1999).

A combined indoor and outdoor navigation system has been developed by and for the École Polytechnique Fédérale de Lausanne (EPFL) by Gilliéron and Bertrand (2003). The system provides a web-based interface for navigation inside building or between several buildings. The system provides a two-dimensional bird's perspective. A floor selector enables the user to interactively select a distinct floor level, thus the complete map is changed to the desired floor level. The application is web-based, thus consumable on nearly every personal computer with a browser installed and an Internet connection, as well as on some mobile devices. However, considering the special requirements of mobile devices, they do not provide a distinct mobile app. As a data source, official architectural Computer Aided Design (CAD) plans has been utilized. Since *"the data are derived from CAD files, the implementation of navigation functions is very limited"* (Gilliéron and Bertrand 2003).

Aiming at a user-oriented development of a nomadic exhibition guide for trade fair visitors, Schmidt-Belz and Hermann (2004) presented the SAiMotion project. On the one hand the system provides functionality for route planning at home and on the other hand also a mobile guidance for being on-site is integrated. Similar systems for exhibitions visitors are presented by Krüger et al. (2004) and Pateli et al. (2005).

Another prototypical system is described in Meijers et al. (2005). For model storage the authors propose a Geo-DMBS for 3D Building models, i.e. a database system which handles different models (geometry, topology and graph) in one system, so different requirements can be satisfied. As a prototypical system the authors utilized Oracle Spatial 10 g and the building of the Aerospace Faculty of TU Delft (13 floors) as test building.

Kargl et al. (2007) presented an indoor navigation system, namely iNAV, serving as a proof-of-concept for the location framework with localization services called COMPASS (Kargl and Bernauer 2005; Kargl et al. 2006). The system provides route planning capabilities via a Java-based client. Due to massive communication with multiple web services, an Internet connection is required on the corresponding device. According to Kargl et al. (2007), this is also the reason why the prototypical implementation has a lack of performance. A similar approach with a client–server architecture based on PHP[1] web services and KML[2] models is described by Hijazi and Ehlers (2009). Further work on service infrastructures is available in Mäs et al. (2006). Moreover, Pfaff (2007) also present a PDA-based approach, Rehrl et al. (2005) are working on smartphone navigation and Raad (2009) presents a solution for the *iPhone*.

Inoue et al. (2008) aim at providing a ubiquitous information service inside commercial and office buildings. The system includes a two-dimensional visualization of the current location as well as of different routes to a distinct target on a mobile device. It furthermore provides a floor switcher, thus the user can display a distinct building floor plan. Similar prototypical approaches are presented in Huang et al. (2009).

In Papataxiarhis et al. (2008) the development of MNISIKLIS is described. The system tries to support several types of users, because it aims at the provision of universal indoor LBS for any user requirement. It offers several functionalities such as routing, localization or Point-of-Interest (POI) search to the user. However, the route planning functionality of MNISIKLIS is very limited, because route computation between different floors is not feasible (Karimi and Ghafourian 2010), which makes the system useless for multi-level indoor route planning. With CoINS, another similar indoor navigation framework is presented (Lyardet et al. 2006; Lyardet et al. 2008).

Ruppel and Gschwandtner (2009) present a navigation guide which is based on precompiled routes and navigation instructions. That is, *"routes can be computed efficiently in O(1) on the device and the only infrastructure that is required are the barcodes which can be easily printed and installed at walls or already existing signs in the building"* (Ruppel and Gschwandtner 2009). That is, the solution is easy to install, very cost-effective and requires little maintenance efforts. It also offers different kinds of route instructions, e.g. a simple textual instruction with additional arrow (Fig. 1a) or a detailed map overview (Fig. 1b) within the mobile application.

Besides the above mentioned research-motivated indoor routing systems, also some global companies started to develop and promote web-based indoor maps,

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[1] Hypertext Preprocessor, a programming language for dynamic web applications.

[2] Keyhole Markup Language, a proprietary XML-based markup language for Geodata which has been developed by Google.

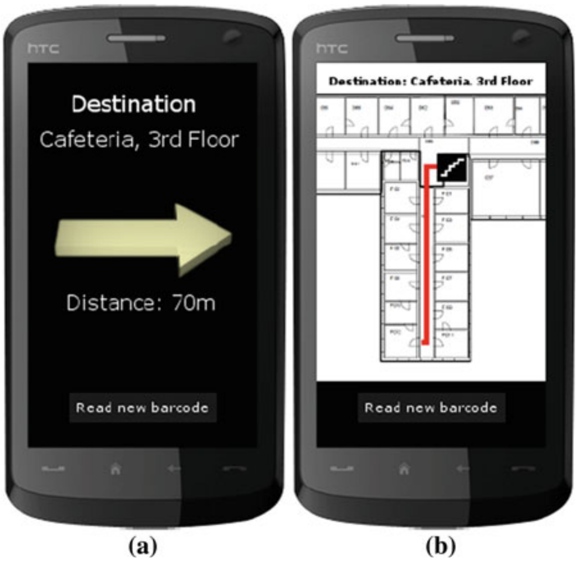

Fig. 1 Simple navigation instruction (**a**) and map overview (**b**) [both from Ruppel and Gschwandtner (2009)]

for example Google Indoor Maps (Google 2011), NAVTEQ Destination Map (Privat 2011; Navteq 2011), or Bing Maps Venue maps (Bing 2011).

The area of indoor maps and indoor routing is typically closely related to indoor localization techniques. However, this research field is out of scope of the here presented work. Nevertheless, an extensive and detailed overview about different positioning methods is provided by Liu et al. (2007).

As a conclusion of this brief review, it can be stated that there are already different approaches and solutions for indoor maps as well indoor route planning available, and both research and economy are continuously working on more advanced solutions. However, many existing solutions rely on proprietary technology or additional software, such as Java. That is, users have to install additional software prior to their indoor investigations, thus current services are not ubiquitously accessible and usable. Also, many approaches lack the consideration of using the service on common mobile devices, such as tablets or smartphones. Furthermore, all of the existing—without exception—solutions utilize proprietary data. A very early approach towards OSM-based indoor route planning applications has been presented by Hubel (2011). However, the application lacks visualization of different parts of a building floor, such as rooms or staircases. Essentially, corridors are not represented as dedicated polygons, but as the remainder of the building and its interior rooms. That is, the system does neither visualize real walls (a simple line is used for visualization) nor areas which are not traversable (e.g., holes in galleries). Although Hubel (2011) discuss the importance of smart phones, a dedicated mobile app is not presented. Except the latter mentioned approach, the above mentioned approaches use official or private architectural plans which are—in general—not publically available or have to be bought with typically high costs. Nevertheless, using OSM has couple of advantages. As stated, there are quite a lot of different data formats for indoor information. However, these are typically not related or referenced to each other. That is, combining or integrating them requires a lot of (manual) work. Furthermore, most of the data formats (such as pure building footprints or CAD plans) are typically not geo-referenced. That is, when developing a combined indoor/outdoor route planning application, extensive pre-processing is required. In contrast, OSM provides a seamless integration of indoor information into the outdoor environment. Furthermore, the OSM mapping schema (see also next section)—although promoted as an open community—can be regarded as some kind of global standard within the community. That is, when developing an indoor routing application for a building in e.g. Germany, the same application can be easily adapted to an appropriate building in Spain. That is, the contributors do not necessarily have to be able to develop an application themselves, but can rely on other application developers and ask them to simply extend their applications.

3 Collaborative Mapping of (Indoor) Spatial Information with OpenStreetMap

Within the last decade, due to the large-scale availability of low-cost GPS-enabled devices such as cameras and smartphones, and the increasing importance of geo-referenced data, an enormous potential of collaboratively collected and open geodata arised. By combining the idea of user-generated content (UGC), as already well-known from Wikipedia, and the need for spatial data, both laymen and professionals collect geo-referenced content of different types, such as geo-referenced Flickr photos or map data (e.g., Wikimapia[3]), in an open Internet community platform.

One of the most popular and most diverse sources for VGI is the OpenStreetMap community, aiming at the creation of a free global database of various types of geodata. Common for the Web 2.0, everybody can contribute, alter and optimize the data in OSM. Very briefly described, the community members contribute two different types of data: (1) two-dimensional map features and (2) additional (semantic) information. Very simple map features can be mapped with single geo-referenced *nodes*, and various nodes can be combined into so called *ways* for mapping lineal or polygonal geometries. More complex map features such as polygons with holes or complex relations between different OSM map features can be mapped with *relations*.

For adding additional (semantic) information, OSM contributors are able to tag map features. This is realized with an open key-value pair methodology, whereby the key describes some kind of information or characteristic (e.g., *natural*, *highway* etc.) and the value refines this information even further (e.g., *forest*,

[3] www.wikimapia.org.

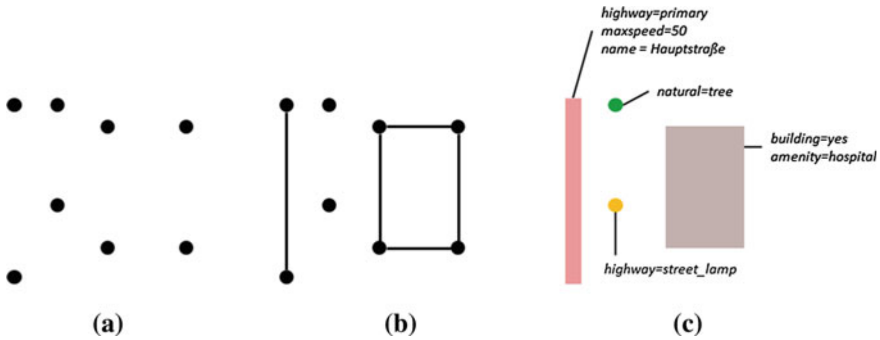

Fig. 2 Geo-tagged *nodes* in OSM (**a**), several *ways* consisting of *nodes* (**b**) and tagged map features (**c**)

residential etc.). There are some community-wide accepted tags and best-practices which are listed at Tagwatch (2012), but in general user can add any kind of key or value. The relationship between nodes, ways and the tagging methodology is additionally depicted in Fig. 2. Within OSM, the provided geometries and attributes are based on personal knowledge, personal GPS measurements, official data imports or aerial imagery tracing (e.g., Bing aerial imagery).

Trying to take the lead in the emerging area of indoor information, several community members are trying to push the community towards indoor mapping activities. Due to missing GPS signals inside buildings, users have to use different kinds of data sources or devices for their mapping, ranging from step counters, over photos of publically accessible evacuation plans, up to distinct mapping apps, for example for *Android* (Rosser et al. 2012). Regarding the mapping schema itself, there is currently no community agreed standard schema; however, couple of mapping proposals are available, ranging from very basic point information for indoors up to detailed indoor mapping proposals—an overview is available on the OSM Wiki Indoor page (OSM 2012a), but the documentation varies heavily. One of the most promising and most mature mapping proposals is the *IndoorOSM* mapping proposal (OSM 2012c). *IndoorOSM* originated from research on the demands and requirements of crowdsourced indoor geodata (Goetz and Zipf 2011a), thus scientifically motivated, reasoned and justified. It is also documented in great detail (OSM 2012c). In contrast to the other mapping proposals, *IndoorOSM* explicitly represents corridors as polygons. By doing this, walls can be properly represented. Furthermore, holes or obstacles (e.g., struts or galleries) can be easily integrated, whereas other tagging proposals cannot represent such (common) features. In the other tagging proposals, corridors are represented as a simple line (in most cases the centerline of the corridor), which has several disadvantages: At first, in some (complex) corridors, a centerline cannot be easily defined. Additionally, a room *A* which connects a corridor with a different room *B* can be either a real navigation target (the user wants to go to room *A*) or a corridor (the user wants to go to room *B*). In such a case it is unclear whether to map room A as a corridor (thus a line) or a room (a polygon). That is, by geometrically distinguishing between corridors and rooms, the actual mapping becomes more complex and unclear for an indoor contributor. In contrast, since *IndoorOSM* does not geometrically distinguish between the functionality of a building part (e.g., room, corridor, staircase etc.), the mapping becomes much easier for the contributor. Furthermore, mapping corridors as polygons also reduces the risk for topology errors in the graph, because the contributors do not have to care about the connectivity of the graph. In contrast, when explicitly mapping corridors as a graph, there is always a potential risk that graph elements are not really connected with each other. A disadvantage of mapping corridors as polygons is that this data cannot directly be integrated into existing outdoor routing applications (which are typically based on *ways* in OSM). Nevertheless, for combining outdoors with indoors there are two possibilities (when using *IndoorOSM* data). On the one hand, the generated indoor routing graph can be added to the outdoor routing graph. On the other hand, a combined system can simply incorporate several routing queries for the outdoor and the indoor. That is, instead of requesting one route from room *A* in building 1 to room *B* in building 2, a combined application could query an indoor route from room *A* to the entrance of building 1, an outdoor route from building 1 to building 2, and an indoor route from the entrance of building 2 to room *B*.

The *IndoorOSM* model is based on the assumption of a hierarchical structure of a building, thus one building consists of several levels (floor) which again contain several building parts such as rooms or corridors. Additionally, several levels can be vertically connected through vertical connectors, for example stairways, elevators, escalators etc., with each other. In OSM, a building is basically described as a *relation* (the main-relation) with additional (general) building information, such as address or name, attached to it. All building levels are also OSM *relations*, whereby each of them is designated as relation-member of the main-relation. The level-relations themselves then contain the various building parts, which are typically mapped as closed *ways* (*IndoorOSM* aims at mapping all building parts as polygons). Doors are furthermore mapped as *nodes*, whereby the location of the node represents the center of the door. Besides this textual description of *IndoorOSM*, Fig. 3 additionally depicts the basic principles. Due to space limitations, the mapping schema cannot be discussed in more detail here, but more information is available in Goetz and Zipf (2011a) and on the *IndoorOSM* Wiki page (OSM 2012c).

4 Generating and Providing Indoor Information

To allow for the generation and provision of the indoor map as well as the routing functionality, various data processing steps are required. This section aims at two things: first, the general system architecture and utilized technologies are

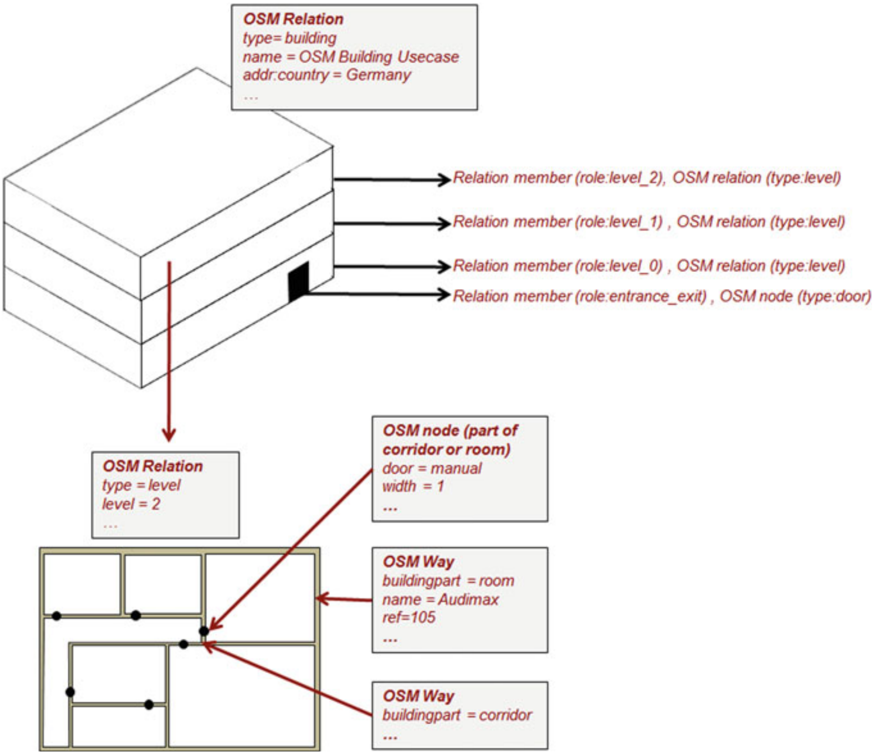

Fig. 3 The basic principles of the *IndoorOSM* mapping proposal

described. Afterwards the different preprocessing steps are described in more detail in the proceeding sub-section.

4.1 The Indoor Routing Service

The system architecture for the indoor map and route planning service consists of two parts: the service side and the client side (Fig. 4). On the service side, there is basically a database system which serves as a data container. It has been decided to use a PostgreSQL[4] database with PostGIS[5] extension, because both are open source and well proven for geographic applications. The database contains on the one hand raw *IndoorOSM* data and on the other hand pre-processed map features as well as a automatically generated *Weighted Indoor Routing Graph* (Goetz and

[4] www.postgresql.org.

[5] postgis.refractions.net.

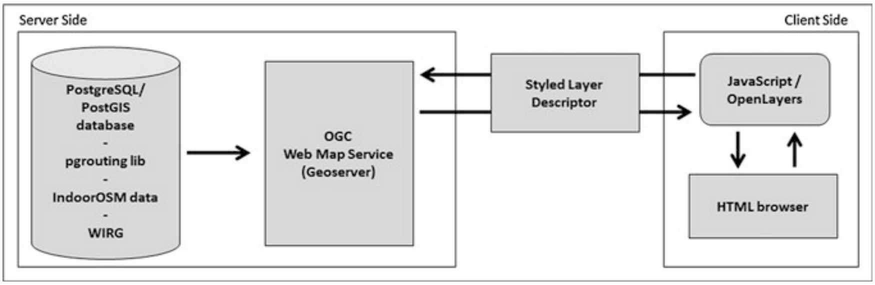

Fig. 4 System architecture of the indoor map and route planning service

Zipf 2011b) for the route planning functionality. For more information on the performed pre-processing steps, please refer to the next sub-section.

Being able to render the indoor maps and routes on different devices and platforms as well as utilizing them also in other (commercial) GIS software, the data of the database is provided through a standardized OGC WMS. By utilizing international standards it can be guaranteed that the data cannot only be used for one specific purpose, but also in other contexts and GIS applications. For the here presented work, the open source software Geoserver,[6] which can be connected directly to the database, is utilized as a WMS. Another OGC standard, the Styled Layer Descriptor (SLD), is furthermore utilized for styling and coloring the different map feature when requested by the client.

On the client side, the data of the WMS can be basically visualized from any GIS application. Aiming at a web-based solution, the here described client consists of a HTML front-end and different JavaScript functions. For rendering the data of the WMS, the OpenLayers[7] framework is utilized. For more details on the developed client applications (for both personal computers and mobile devices) please refer to the next main-section.

4.2 Preprocessing

For the provision and visualization of detailed indoor maps and routes via the WMS in combination with SLD, the raw *IndoorOSM* data needs to be pre-processed prior to publication. This processing can be performed inside the database, similar to the methodology described by Goetz et al. (2012). For *IndoorOSM*, the procedure is basically as follows:

The processing algorithm gathers all relations in OSM which represent a building, thus which are tagged with *type* = *building*. Thereafter, all building parts

[6] www.geoserver.org.

[7] www.openlayers.org.

of the corresponding level are retrieved by sequentially scanning all the relation-members of the building-relations. By utilizing the PostGIS function ST_*Make-Polygon*, a polygonal geometry for each building part (rooms, corridors etc.) is generated and stored in a database table (namely *indoor_elements*). Additionally, the corresponding level number, such as 0, 1, −1 etc., as well as the type of the building part (OSM key *buildingpart*) and its name (OSM key *name* or *ref*) are also stored with the geometry in the same table. That way, the WMS can easily filter indoor map features according to its level and/or type, as well as providing additional naming information, for example for labeling purposes. Furthermore, all doors are extracted from the *IndoorOSM* data and stored in another database table (namely indoor_*doors*) as a point-geometry together with the corresponding level number of the door as well as the involved room name. This will allow that the WMS can provide map features for the doors.

For applying shortest path algorithms on the indoor data, a comprehensive routing graph for the interior structure of the building is required. Following the formal definition of a *Weighted Indoor Routing Graph* (*WIRG*) (Goetz and Zipf 2011b), such a graph contains all doors of the building, represented as a node in the graph. Furthermore, corridors are represented with a centerline approach, thus additional graph nodes are added to the middle of a corridor and connected with each other through edges. For rooms with more than one door, all doors are connected pairwise with each other. Vertical connections, such as elevators or stairways, are also connected in the graph. Therefore the doors or openings of the corresponding connector are represented as nodes which are connected via an edge. Optionally, intermediate nodes can be added for representing turns on a stairway. It has been decided to use the *WIRG* definition, because it allows length-optimal indoor routing and requires less graph elements than other graph definitions (Goetz and Zipf 2011b).

Regarding the available data of *IndoorOSM*, such a *WIRG* can be generated automatically based upon OSM. All building doors are explicitly mapped as OSM-nodes, thus they can be directly utilized for the *WIRG*. Since the original definition of the *WIRG* considers a three-dimensional environment, and for avoiding congruent geometries, such as two congruent doors on different levels, a z-value needs to be defined for each door. Since the aim of this chapter is the development of a 2D application, there is no need for real z-values, thus one straight-forward solution is to populate the z-value according to the level number. This procedure is rather coarse, but it is enough for the sake of this chapter (2D) and it avoids congruent geometries. By computing the centerline of each corridor inside the building and adding vertical edges from the corresponding corridor doors to the centerline, it is furthermore possible to represent indoor corridors within the *WIRG*. The door-nodes are already added to the *WIRG*, thus only the nodes and edges for the centerline need to be added. As described beforehand, the z-values of the corresponding nodes are populated with the level number. For elevators, the elevator doors are also already included in the *WIRG*, thus those simply need to be connected via edges. Being able to map elevators which do not have entrances on

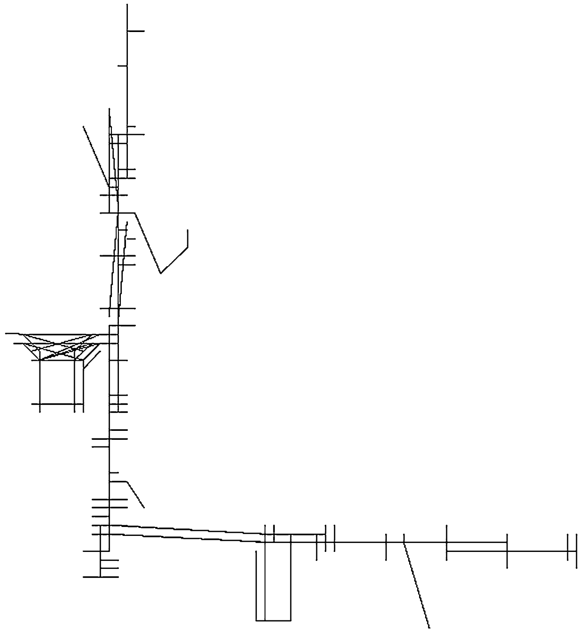

Fig. 5 Exemplary *Weighted Indoor Routing Graph* based on *IndoorOSM*

all levels, for example an elevator from the ground level to 5th and 6th floor, the *IndoorOSM* mapping schema proposes the key *connector:ids*.

Utilizing this key, it is possible to semantically describe such a vertical connection. Furthermore, this information can be utilized for adding the required edges to the *WIRG*. Other vertical connectors such as ramps or escalators can be added to the *WIRG* accordingly. For stairways the before described procedure is also suitable (utilizing the OSM keys *connector:ids*, *buildingpart:verticalpassage* etc.); however, for a more realistic representation, intermediate nodes, such as for representing intermediate turns of the stairway, could be added. This can, similar as for corridors, also be realized by computing the centerline and connecting its ends with the stairway openings or doors. The complete *WIRG* from a bird's perspective for an exemplary building with 4 floors (which serves as an example through the whole chapter) is depicted in Fig. 5. After generating the *WIRG*, it is stored in the database in the table *indoor_wirg*. For applying the shortest path algorithm Dijkstra inside the database by utilizing the open-source C++ library *pgrouting,*[8] this table is tailored to the requirements of the routing engine and contains link IDs, source and target node of the corresponding edge, the coordinates and the weight of the edge (basically the length).

For increasing the performance of the route planning, all possible routes are pre-computed and stored in the database. Therefore, all possible nodes of the graph (basically all doors, as well as key points in halls or corridors) are gathered and all

[8] www.pgrouting.org.

routes for possible node pairs are computed. For each route, the individual edge geometries are computed and stored in another database table (namely *indoor_shorest_paths*). Being able to identify the route segments, each table entry also contains the corresponding route start and target node. Furthermore, for each edge also the corresponding level, that is the building level where this individual edge is located at, is also stored. For vertical connector edges, the level of the start point is defined as the edge level. Essentially, the level information for individual edges can be utilized for requesting route parts for individual levels from the WMS. For data amount reduction purposes, identical routes are furthermore identified and pruned. The pre-computation of the routes does indeed require processing time; however, it allows a fast route planning and provision of any arbitrary route through the building within O(1).

5 Consuming Indoor Information

To allow for the consumption of the indoor information and using the route planning capabilities, a graphical user interface is required. Within the here conducted work, two different user interfaces have been developed: on the one hand a web-based user interface for a priori route planning at home and on the other hand a native mobile application for on-demand route planning on-site. The former application is described in the sub-section below, whereas the latter application is described in the second sub-section.

5.1 A Priori Route Planning on Personal Computers

For a priori route planning and building investigation, an indoor map application has been developed (Fig. 6). It provides a two-dimensional overview of one distinct building floor, whereas levels can be changed by using the level selector on the right-hand side. The map features panning and zooming functionality, thus the user can investigate the building in great detail. The map itself visualizes the polygons of the different building parts (rooms, corridors, staircases etc.), whereas different colors highlight the different functions of the polygons. Additionally when zooming in, doors and labels (room names) are also visualized for providing a more detailed overview about the selected floor. Additionally, the application features route planning capabilities, so it is possible to compute route through the building for arbitrary room pairs and especially for rooms on different levels. A pre-defined list (automatically generated) is available below the map, so the user can define the desired start point and target point. This also eases the selection of the desired points, because typos and spelling errors, while defining the points, are avoided.

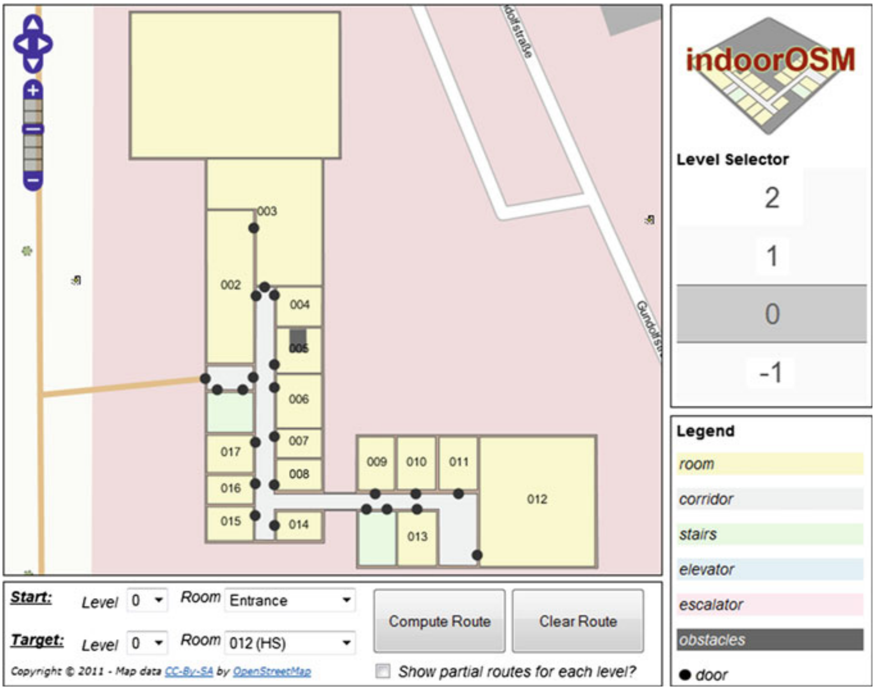

Fig. 6 Indoor map and route planning web application with level selector and zoom

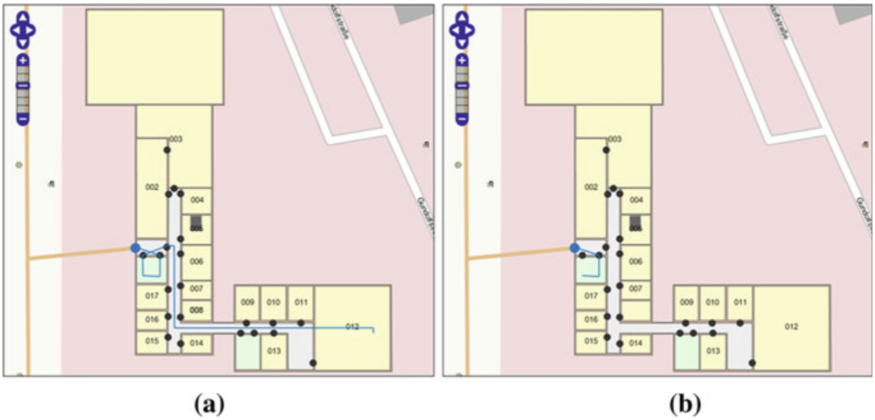

Fig. 7 Indoor route visualization of a multi-level route from the ground floor to the first floor in *complete mode* (**a**) and *partial mode* (**b**)

When actually computing a route, a user can decide between two different visualization modes: on the one hand, the complete route can be visualized (Fig. 7a), which provides a brief overview but lacks visualization for multi-level routes. On the other hand, the user can also request a partial route visualization for each individual floor, thus only those route parts of the currently selected building level are visualized (Fig. 7b). While switching the level in the map, the route visualization also switches to the desired level. Within the map, a blue dot indicates the selected start point of the route, whereas a blue cross depicts the aimed target.

Regarding the utilized technologies, the web-based application utilizes W3C standards such as HTML, CSS and JavaScript. The map rendering is realized with the OpenSource JavaScript framework OpenLayers.[9] The map container incorporates an OSM base layer for the outer environment as well as one map layer for the different levels and one for the routes. The latter two are dynamically styled with SLD, whereas the required parts are filtered accordingly, so for example when switching the building level the SLD automatically filters the map feature according to their level number, or when computing a route the SLD automatically filters the route-layer according to the desired start and target point of the route. Due to the utilized technology, the indoor map and route planning can be used on ordinary computers and essentially no additional software or plugins need to be installed. The only requirement is an Internet connection and a browser (preferably one of the latest).

5.2 *On-Demand Route Planning on Mobile Devices*

Quite often, users are not able to perform their route planning activities prior to a trip, such as in the case of a short-dated appointment, or they are not willing to print the computed routes and carry them with them. In such cases it is much more convenient to perform the route planning on-demand, thus when actually being on-site. With the wide-spread availability of advanced mobile devices such as smartphones or tablets and the coverage of mobile networks, it is no problem at all to consume applications without the need of actually being in front of a computer. Basically, the beforehand described web-based application can also be accessed and utilized on a mobile device by entering the service URL in a web-browser. However, the web-based application is not tailored to mobile devices and their specialties, such as restricted screen sizes, resolutions or different user interaction (for example using touch events rather than mouse clicks), thus the user experience is not satisfying. That is, a native application for different mobile devices is advantageous.

Within the here presented work, a prototypical native app for *RIM BlackBerry* devices has been developed. It is based on the web-based application for desktop computers which has been described in the previous section, thus it provides the same functionalities. The user interface however, is tailored to mobile devices,

[9] www.openlayers.org.

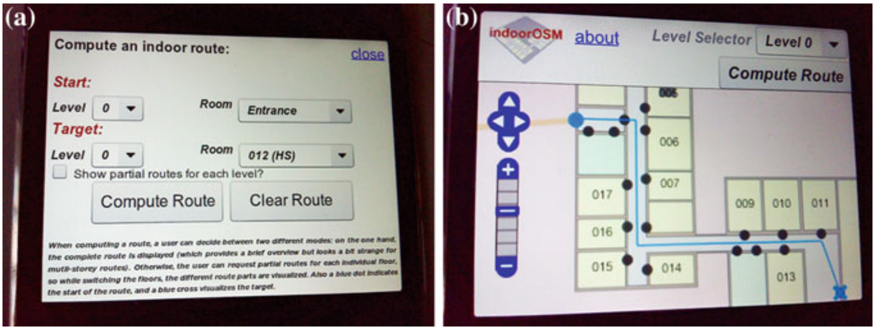

Fig. 8 Native mobile app on a *BlackBerry* device: Route computation interface (**a**) and route visualization map (**b**)

thus different elements are organized differentially. The route computation dialog for example is visualized in a separate window (Fig. 8a) and the main page with the map is designed in that way that most of the screen is utilized for the actual map (Fig. 8b). Since it is a native app, users can install and de-install the application on their mobile device, thus they do not have to utilize a web-browser. The application perfectly functions with the available user interaction methodologies (i.e., keyboard and touch-screen).

Basically, the native app is also based on HTML, JavaScript and CSS, whereas the *Phonegap*[10] framework is utilized for creating the actual native app. The advantage of this deployment way is that the native app only has to be created once and then can be easily deployed on different mobile platforms. That is, the here presented prototype can be ported easily on *Android* devices, *iPhones*, *iPads* and other mobile platforms. Additionally, the app can be easily provided in the corresponding platform app stores, such as *iTunes* or *BlackBerry App World*, which allows an easy distribution of the application as well as the well-known installation and de-installation mechanisms for the mobile users. That is, due to the deployment framework, it is possible to deploy native mobile apps on various platforms by simply using one programming language. In contrast, a real natively developed application, such as Java for Android or C++ for iPhones, would require much more work.

6 Conclusion and Future Work

Indoor LBS such as indoor maps or routing service are gaining an increasing interest, not only by academia and research but also by the economy. Contrary to existing approaches, the here conducted work utilized free and open geodata

10 www.phonegap.com

collected by volunteers. That is, the work benefits from crowd intelligence and no expensive data licenses are required. By utilizing W3C and OGC standards, the developed web-application is browser- and platform-independent. Additionally, native mobile apps for different platforms can be deployed very easily. That is, both a priori route planning at home as well as on-demand route planning on-site is feasible. All routes between arbitrary source and target rooms are pre-computed, allowing the provision of an arbitrary route within O(1). However, when developing such a system, the individual trade-of between costs for the pre-computation of routes vs. the latency when requesting a route on-the-fly (without pre-computation), need to be considered for an individual decision. Nevertheless, computing the route on-the-fly bears to potential of integrating the latest information, such as closed doors or elevators which are out of order. It has been demonstrated that *IndoorOSM* can serve as a data source for indoor route planning applications on desktop computers as well as on mobile devices.

To conclude it can be said that it is possible to provide rich web-based LBS for indoor spaces by purely using VGI from OSM, thus to transfer well-known services, such as route planning or map visualization, to indoor environments with no (low) costs. Although the here presented application is based on OSM data, it could also be easily extended or adapted to other kinds of crowdsourced indoor information—if they become available—such as specific indoor mapping communities. The only requirement is that those future communities provide data which is suitable for the extraction of 2D floor plans with doors, because this information is required for the graph generation and the map visualization.

Since users are often confronted with several foreign buildings, such as visitors of a foreign university, combined indoor and outdoor routing as well as routing between different buildings is required. By incorporating this scenario in the developed application, queries like *What is the best route between lecture room 001 in building A and the Mensa in building B* will be possible. Additionally, the development of indoor spatial searches for various POIs, such as *Where is the nearest restroom* or *Where is the next cash point*, are desirable as well as other LBS. The consideration of access restrictions and different states for doors also needs to be considered in both the *IndoorOSM* mapping proposal and the presented application. Additionally, the applicability of the *IndoorOSM*-based routing graph for complex analysis, such as emergency evacuation simulations, will be proven in future research. Also, for the development of more appealing and easy to understand routing instructions, work on route communication for indoor environments is important.

It is also essential to promote and demonstrate the possibilities of crowdsourced indoor information within OSM, because this will lead to more available buildings with indoor information, representing an additional motivation for the contributors to map even more indoor spaces. One step towards this is the development of a global and regularly updated OSM map combining outdoor and indoor spaces.

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Indoor and Outdoor Mobile Navigation by Using a Combination of Floor Plans and Street Maps

Jussi Nikander, Juha Järvi, Muhammad Usman and Kirsi Virrantaus

Abstract Positioning and map technology integrated to smart mobile devices allows the users to locate themselves and find routes between locations. Such route finding typically works only outdoors due to reliance on the GPS system and lack of indoor map data. This work introduces a prototype for combined indoor and outdoor mobile navigation system for a university campus. An important part of the prototype implementation is the conversion of CAD floor plans to GIS data that can be used together with existing outdoor maps for locating and for finding shortest routes between locations. This work describes a semi-automatic conversion process that produces indoor map data, which is combined with OpenStreetMap and Bing map data for route finding and displaying a hybrid map. The prototype application, which uses this data, has been implemented on the iPad. The prototype uses GPS for outdoor positioning and QR codes for indoor positioning. The work is currently in process, and future prospects of the prototype are discussed.

Keywords Positioning · Mobile navigation · Data conversion

J. Nikander (✉) · J. Järvi · M. Usman · K. Virrantaus
Department of Real Estate, Planning and Geoinformatics,
Aalto University School of Engineering, Espoo, Finland
e-mail: Jussi.Nikander@aalto.fi

J. Järvi
e-mail: Juha.Jarvi@aalto.fi

M. Usman
e-mail: Muhammad.Usman@aalto.fi

K. Virrantaus
e-mail: Kirsi.Virrantaus@aalto.fi

J. M. Krisp (ed.), *Progress in Location-Based Services*,
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1 Introduction

Integrated positioning technology is a regular part of all smart mobile devices. Users are capable of locating themselves and they can also get information about directions. However, such route finding services typically only work when the user is outside of buildings and in a relatively open place. There are two main causes for this limitation. First, the position technology used by the mobile device is usually the GPS system, which does not work inside buildings. Second, the map software used for navigation does not contain data about indoor layout structures. Thus, in order to enable indoor navigation on a mobile device, the user requires an application specific for the location, and there must also be an indoor navigation infrastructure present. Furthermore, this application should either be compatible with, or included in an outdoor navigation application, in order to integrate the indoor navigation with other navigation aids included on the mobile device.

There are many cases where a navigation application capable of combining indoor and outdoor navigation would be useful. In this research, our example is a university campus, which is a large complex consisting of numerous buildings. Finding the correct location is often a complicated task in such a large area, especially for people such as new students or visiting lecturers, who are unfamiliar with the place. Sometimes, however, even a member of the university staff can become lost in the large campus area. For example, they may need to go to a building that they have never visited before, or they may feel lost in case of renovation or other construction work during which access is limited. Thus, in a campus environment there is a need for a navigation application that can tell the user both where a building they are going to is, and how to navigate inside the building.

In this chapter we introduce our work on a campus navigation system for the Aalto University Otaniemi campus area. Our goal was to create a mobile application that combines indoor and outdoor positioning with maps and route finding together with location-aware calendar functionality. The work is currently on prototype stage and works only on the Apple iPad. The prototype includes a map of the campus, floor plans for the main building, and a route finding function. There is also a location-aware calendar in the prototype. The user can mark meetings they need to attend to the calendar, and add the location of each meeting on the map. They can then find the fastest route from their current location to the calendar location using route finding. The research challenges of this work are especially on solving the indoor navigation problem, and on solving the routing problem inside the buildings, including the required data pre-processing work, as well as designing an easy to use interface for the application.

1.1 Positioning Technology

In outdoor positioning, the GPS satellite navigation system has been the de facto standard for decades. Nowadays, most mobile devices employ an enhanced version of the system, the A-GPS, for positioning. For the average user, one big problem with the GPS system is that it cannot be used indoors, since the satellite signal is blocked by buildings. Furthermore, the positional accuracy of the GPS system is approximately 6 m, which is typically insufficient for indoor navigation. The user might also have problems in densely built areas where there are a large number of tall buildings (Stook 2011). There have been attempts to overcome such problems by, for example, using ground-based transmitters called pseudolites to boost the GPS signal (Wang 2002; Ning et al. 2004). However, employing such systems in real-world situations has proven to be difficult (Rizos et al. 2011). These days there are also alternatives for the GPS being developed. The Russian GLONASS system is already fully operational while the European Galileo and the Chinese COMPASS are yet to offer service.

Indoor positioning is, by nature, local and covers a certain building or buildings. This is in contrast to satellite-based outdoor positioning systems, which cover the whole planet. There are numerous different technologies available for indoor positioning (Liu et al. 2007; Gu et al. 2009). One option for indoor positioning is to use the radio signals of wireless LAN infrastructure (Li et al. 2006), or dedicated transmitters (Rizos et al. 2011). Other options include the ultrasonic-based Cricket Location Support System (Priyantha et al. 2000) and the Active Bat System (Harter et al. 1999). In the Cricket system a mobile device listens to a number of beacons spread through the building, and calculates its location from the strength of these signals. In Active Bat, a transmitter is attached to the user, and the user's location is calculated by a number of receivers that listen for the ultrasonic signals. Perhaps the largest advantage of using ultrasound is the high degree of positional accuracy achieved. Ultrasound system can have an accuracy measured in centimeters, while still having sufficient range inside a building (Lau et al. 2004).

Indoor positioning can also be calculated using the RFID technology (Ting et al. 2011). In such an application, RFID scanners are mounted through the building, and each user is given an RFID tag. User location can then be calculated by the scanners. The main problem with RFIDs is the short range of RFID tags, which makes it hard to maintain knowledge of the position of the user. If passive RFID tags, which have no internal power source, are used, the range is just a few meters. Definitely the cheapest and easiest method to deploy is, however, QR codes (Ruppel and Gschwandtner 2009). Such a location system can be deployed without having to buy any sort of infrastructure. The users can then locate themselves by taking a picture of a QR code on their mobile device. The problem with such an arrangement is, of course, the fact that the user needs to actively participate in the positioning process. Despite this, QR codes make a very good initial prototyping environment because of their very low cost and ease of deployment. Another option is NFC tags,[1] for which support on modern phones is becoming available, and the devides have a very low cost. They have a short detection range, but so does a realistically sized QR code, which can be identified from a camera phone image in normal indoor corridor lighting conditions.

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[1] http://kimtag.com/s/nfc_tags.

1.2 Existing Indoor Navigation Applications

During the last few years several indoor positioning and navigation systems of various quality and functionality have been implemented. For example, the Version 6.0 of Google Maps for mobile devices, announced in November 2011, includes indoor navigation (McClendon 2012). As of this writing, the service contains numerous indoor locations, mainly in the United States and Japan. For university campuses, at least two combined indoor and outdoor navigation systems currently exist: The CampusGuiden system of Norwegian University of Science and Technology (CampusGuiden 2012), and the EPFL Map service of Lausanne Technical University (EPFL Map 2012).

There are also indoor navigation research efforts that are aimed to help the blind (Hub et al. 2003; Metha et al. 2011) or guide autonomous robots (Luimula et al. 2010). In such research, the focus is different from indoor navigation systems, which are aimed at the general public. A navigation system for blind assumes that no visual information is available by the user. The system typically includes many more tasks than merely finding their current position or the route to another location. It can help in, for example, the detection and identification of obstacles and objects. On the other hand, the navigation of a robot aims for managing the open space for some specific tasks, like work in a factory hall, or vacuum cleaning a room, thus also the pre-assumptions vary.

2 Materials and Methods

The work described in this chapter consists of constructive research: we have implemented and tested a prototype application for mobile indoor navigation. The research effort described here consists of an initial survey of available data, methods and tools, followed by the design and implementation of the prototype system.

For outdoor positioning and navigation, there are numerous spatial data sets available that can be used for research purposes free of charge. Some cover the whole globe, like Google Maps[2] and OpenStreetMap (OSM),[3] while others cover smaller areas. For this research, we selected OSM as the outdoor map, since it is freely available and contains both background map and data required for outdoors route finding. Furthermore, it is easy to link the OSM routing data to indoor route finding functionality. We also used other freely available maps, such as the Bing maps, in the project. Bing, unlike OSM, contains satellite images in addition to a map view.

[2] http://maps.google.com/.

[3] http://www.openstreetmap.org/.

For the generation of indoor maps, we managed to acquire the university floor plans in CAD format. In order to combine this data with the outdoor map, we developed a semi-automatic method for converting the existing floor plans to geographic data format, which can be used both for route finding and viewed on the map display. For indoor positioning, we selected QR codes because of the low cost, ease of installation, and the fact that they do not require any physical infrastructure to work.

We selected Apple iPad as the platform for the prototype implementation. Before the project, we had some prior experience with the iPad, and thus it was an obvious candidate. Furthermore, the screen of the iPad is large compared to smartphones, which is advantageous during the prototyping stage since we have more room to work with. Thus, there is no need to focus that much effort in designing a user interface that takes as little space on the screen as possible. Furthermore, the iPad contains all functionality required for the platform in this project: ability to use GPS, existing outdoors map application, and QR code reader. We used the PhoneGap toolkit,[4] which allows programming the iPad using web development techniques, to quickly develop the prototype. This accelerated development speed much but introduced some performance issues with map scrolling.

2.1 Prototype Development

The largest challenge we faced in the prototype development was the conversion of CAD floor plans to a format that could be used by the prototype application. For this, the floor plans need to be converted to the geographic coordinate system used by the map application and turned into a data format the application can read. The route data needs to be added to the floor plans in a format that can be used for calculating the shortest route, and integrated with the existing outdoors routing data. Optimally, this process should be automated as much as possible, since it can be a very long and time-consuming task. The process described here is a semi-automatic solution, which uses common desktop tools and free software in the conversion process, instead of potentially expensive commercial solutions.

After being processed into a format used by the map application, the floor plan data was used both in the background map, and for route finding. On the background map the data makes it possible for the users to position themselves and navigate inside a building. When combined with outdoor route finding included in OSM, the data makes it possible for the user to get routes inside the campus area. The screen shot seen in Fig. 1 shows the map view of the prototype. The indoor map of the university main building is overlaid over a Bing map satellite view. The shortest route between two points inside the main building is shown using a red polyline in the Figure.

4 http://phonegap.com/.

Fig. 1 View of the prototype application that contains both indoor and outdoor map, and a shortest route

2.2 Map Generation and Presentation

The map generation process for indoor navigation in this prototype involves both manual and automated work. Figure 2 presents the data processing model used in this work. The floor plans are obtained in CAD format and require a number of processing phases in order to be turned into an indoor map.

Our floor plans contained several data layers representing different types of indoor data features. For navigation purposes the relevant ones were walls, windows, doors, stairs and room labels. The main problem when combining them with GIS data was that the original data is conceptually just a line drawing. Rooms were not explicitly present in the CAD data, but instead were delimited by lines drawn in the wall, the window and the door layers. Gaps were present in walls where there were windows and doors, and several rooms often shared a single wall.

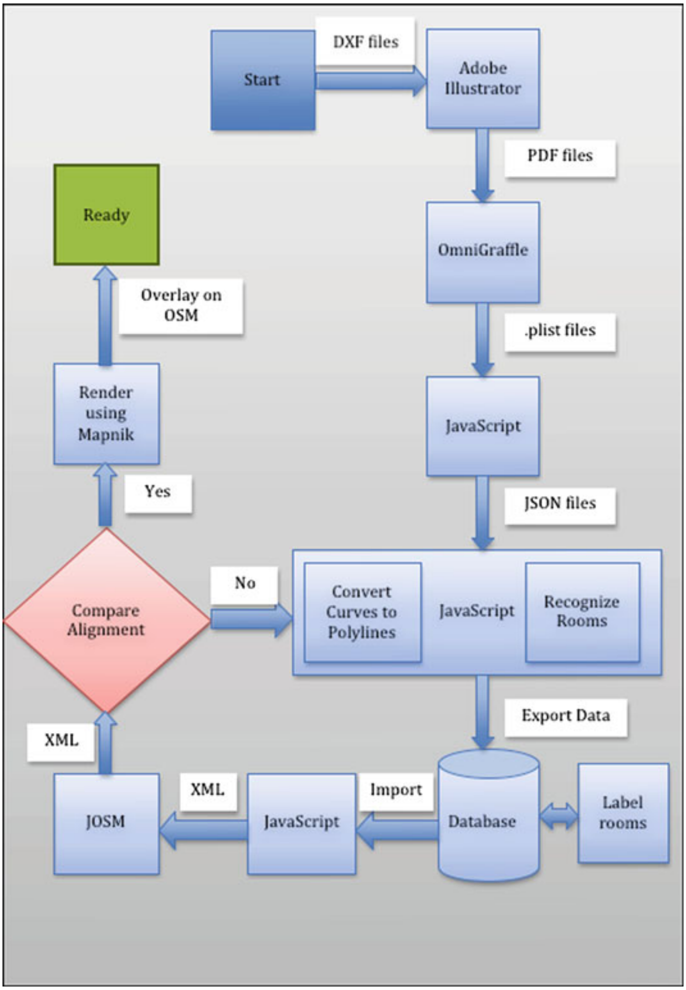

Fig. 2 Data preparation process

Room labels were simply text associated to a point near the center of the room. The first step was to form correctly labeled room polygons for GIS use.

The process starts by opening the CAD floor plans in Adobe Illustrator. This retains the mapping between the data and the physical units, although it scales meters to millimeters to work in the desktop publishing context supported by the program. Different layers, such as walls and windows, were renamed from numeric codes to textual descriptions for easier handling. Areas with different purposes and access patterns such as inaccessible areas, rooms, and corridors were colored with predefined colors, which can be automatically recognized in further processing. During the filling, all layers except walls, windows, and doors were hidden. Thus, while each individual layer contained gaps, their combined representation did not.

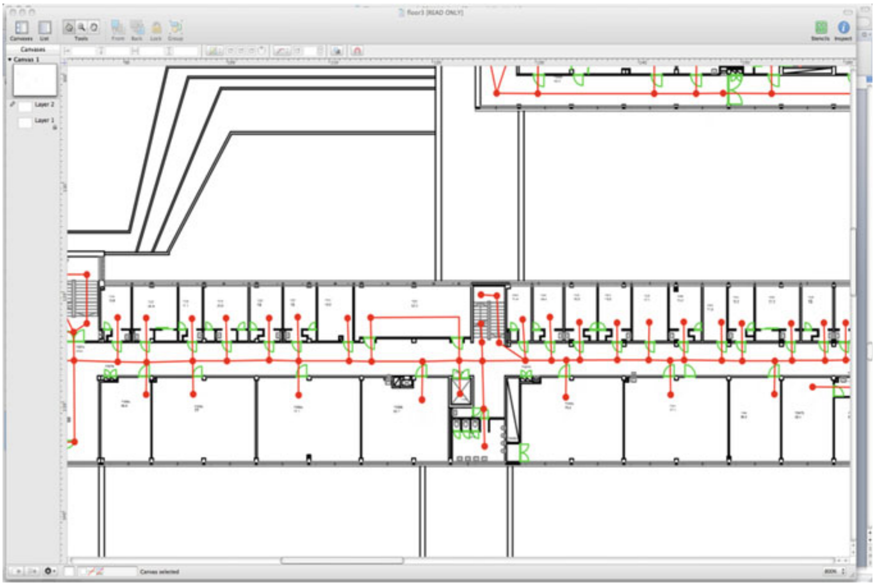

Fig. 3 2D graph generation process in omnigraffle

The software was able to create a polygon based on the appearance of empty space between lines with a single click, allowing quick manual coloring of rooms, corridors, inaccessible spaces, and courtyards, based on shape and door placement.

The resulting data was saved in Portable Desktop Format (PDF) and imported in OmniGraffle. There we manually generated the graph of accessible paths for indoor navigation, shown in Fig. 3. First, points were added in locations important for navigation such as corners, end points of staircases, and both sides of all doors. The points were then connected with undirected lines. OmniGraffle was chosen because it allows for easy conversion of the desktop publishing file format into an XML file, while retaining all necessary metadata. This made it easier for us to automate parts of the process. OmniGraffle internally uses a graph representation of the data. Lines are connected to navigation points, and all lines connected to a point change shape when the point is moved. The connection graph can also be retrieved from the output file.

The floor plans were saved in OmniGraffle's native XML-based PList (property list) format and automatically converted into JavaScript Object Notation (JSON). The files were then loaded into JavaScript programs directly as program code containing data. Using JavaScript, navigation points and their connections were extracted for route finding purposes.

In order to correctly label rooms and transfer the room labels to navigation points inside the rooms, the room polygons were transferred into an SQL database called SpatiaLite, which has GIS extensions. Doors in the original data were represented by Bézier curves, which are not handled by the GIS tools available to us. Thus, we converted the curved parts still present in the room polygon outlines into polylines using DeCasteljau's algorithm. After this, each room label point could be associated to the room it belonged to, and the label text could be transferred into the room polygon's metadata using a single SQL query. Navigation points inside rooms were then labeled according to the room around them using a similar query. Room color was used to mark points belonging to rooms, corridors, or elevators. Different classes of features, along with their respective labels, were determined automatically by using JavaScript. The floor plans now contained the attribute data required for visualizing them on a map, and for using them in route finding.

2.3 Data Presentation

After features had been labeled and stored in the database, the data was fetched from the database and given as input to a JavaScript program. The program converted the data files into an XML format, which was now ready to be visualized on top of OSM in Java Open Street Map (JOSM). However, before the floor plan data could be used on the map, it had to be aligned with the background map. Thus, each building needed to be given correct geographical coordinates. This involves determining the correct coordinates, scale and the correct angle compared to the rest of the map. In this work, we calculated the location and alignment of each building manually. Floor plans were set in the correct coordinates, and the difference between the angle of the floor plans and the angle of the same feature on the background map was calculated. If required, this process could be repeated iteratively until correct alignment was reached.

2.4 Floor Plan Overlay on Top of Background Map

After the floor plan and the background map were perfectly aligned, the data was combined with all other OSM files representing the same floor in the other buildings. The combined data was then imported to Mapnik, which split the map into 256×256 pixel sized tiles using spherical Mercator projection.

Figure 1 shows an example view, where the university main building has been aligned and rendered over a background map. In the figure, Bing map aerial view is used as the background.

2.5 Route Planning

The same script used to output OpenStreetMap XML format maps was also used to output a JSON file with navigation points, links between them, and all relevant metadata. This data was then manually combined with the outdoor navigation graph provided by OSM. The combination was done by connecting the relevant nodes of the indoor and outdoor graphs. In order to calculate the shortest path, the application could then locate the user and the goal location given, and find the graph node closest to each. These were used as the start and goal location. Indoors, QR codes were used for finding the current location of the user, while GPS was used outdoors.

The application calculates the shortest path between the current location and the target location using Dijkstra's algorithm. An example of a shortest path generated by the application is shown in Fig. 1. For calculating the shortest distance between two points, simple Euclidean distance is used.

3 The Application

The application described here was implemented for the iPad platform. We decided to use iPad for the prototype since it is mobile, has relatively large screen, contains the functionality required for the application, and because we had prior experience with the platform. The application currently has three main functionalities: it contains a combined map of indoor and outdoor locations can be used to find the shortest route between locations, and has a calendar that can be used to schedule appointments at given locations.

3.1 User Interface

The prototype has a simple, interactive user interface. The application has two main screens: a map screen, and a calendar screen. In the map screen, the user can view the map, and the locations of the calendar appointments, and create shortest routes; on the calendar screen they can manage their appointments.

3.2 The Map Screen

The maps screen of the application is shown in Figs. 1 and 4. Figure 1 shows a building floor plan over the background map and a shortest path inside the building. Figure 4 shows information about an appointment on the map. The map screen uses either OSM or Bing map as the background map. The user can change between the two map services as desired. The initial view of the background map is zoomed to Otaniemi campus, which is the test area of the application.

The map view has standard interactive map features of zoom and pan. For buildings with multiple floors, the user can switch between the different levels using a drop-down menu. They can request shortest path for from a start to a goal

Fig. 4 Information about the scheduled events

location, and select which calendar appointments are shown on the map view. Possible selections are the current, or next appointment, all appointments for today, appointments for the week, or all appointments.

3.3 The Calendar Screen

The calendar screen for the application is shown in Fig. 5. The calendar screen has standard calendar features of appointment management, and showing appointments using month, week, or day views. The appointments scheduled in the application's calendar are synchronized with the map screen, and each appointment in the calendar can be seen on the map as a marker, as shown in Fig. 4.

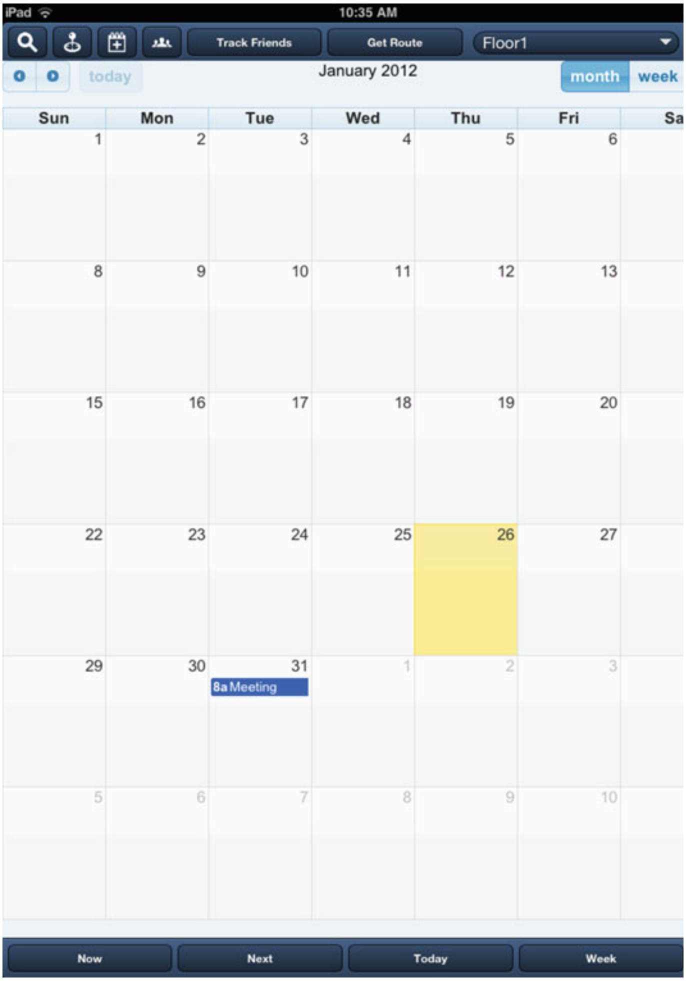

Fig. 5 Calendar screen in the application

Currently, on the calendar screen, the user can select the location of an appointment from a pre-defined list of locations. This makes it possible for the user to locate an appointment without having to use the map screen. The location of an appointment can also be selected from the map, or be left undefined.

3.4 Positioning

For prototyping the indoor positioning, we wanted to use cheap, off-the-shelf components, which require no infrastructure. QR codes offered such functionality, and thus we adopted QR code positioning for indoors. Outdoors, iPad can use GPS for positioning. In order to position themselves using QR codes, the users needs to take a picture of the QR code using their mobile device and use QR code reader software to decipher the information given by the code. In the case of location codes, each QR code carries information about the location it is in.

4 Discussion

By far, the largest challenge in this work was the process needed to convert the floor plans to a format that could be included to the map. Most existing floor plans lack a lot of information that is needed in order to use the data for navigation purposes, such as geographic coordinates or polygon topology. Due to this quite a lot of work must be done before the data is in a usable format.

A general outline of the data transformation process is shown in Fig. 6. The work starts with the filtering of unnecessary data from the input CAD and turning the remaining data into a polygon network consisting of rooms and corridors. After this, a graph that describes the connectivity between different polygons in the network is created and combined with the polygon data. Labes are added, and the data is scaled to and aligned with an existing geographic map. Finally, the combined map is turned into a raster picture, which is tiled and thus ready to be used in a map application.

Our current data conversion process, described in Sect. 3, is a working outline that could be optimized in many ways. We are especially interested in trying to automate the process as much as possible, since there are several phases, which require tendious manual work. For example, the creation of the polygon network, the graph, and the labeling, are parts where at least partial automation could be used. The workload could also be reduced with other refinements to the process, such as using several reference points for fitting the buildings with the map instead of one point and angle.

It is unlikely that the whole process can be automated. The CAD data we have lacks a lot information that would be required for simple, fully automated conversion. This is likely to be true for any CAD data. And, since we cannot know beforehand the exact details of the input, it is hard to create a completely automated process. Automation could, however, be used speed up the process by removing a large amounts of simple, repetitive work. Especially the creation of the rooms and corridors, their categorization, and the creation of the graph for route finding contain a large amount of probably unnecessary manual work.

A phase that might be hard to totally automate is the association a floor plan with the corresponding map location. Unless there is matching building metadata both in the input and the background map, this is likely to be a hard problem.

An advantage of the current conversion process is its rather low-cost. We use mainly freely available tools with OmniGraffle and Adobe Illustrator being the only commercial solutions used in the current process. Both are likely to have freely available alternatives that would work for our purposes.

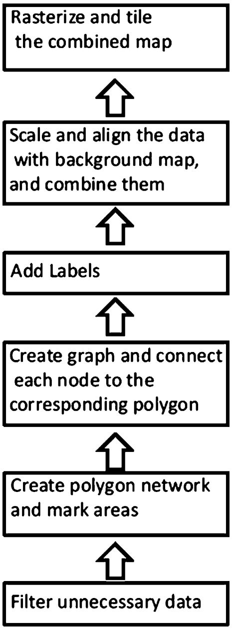

Fig. 6 Generalization of the data conversion process

4.1 Positioning

We wanted that the users do not have to carry tags or other such special equipment aside from their mobile device. Thus, since QR codes do not require any sort of infrastructure, are cheap, easy to install, and are widely supported by modern mobile devices, they were a natural choice for prototype indoor location system. However, since QR codes require the user to find the code plate and take a picture of it with the QR code reader software before they can position themselves, QR codes are not an attractive choice for a real system.

A production system needs to be such that the mobile device can locate itself automatically. In a real situation, the users are likely to become frustrated if they need to be an active part of the positioning process. That, in turn, would lead to less people using the system. The CampusGuiden system, for example, uses WLAN for positioning (CampusGuiden 2012). For comparison, the EPFL map apparently has no positioning technology associated with it. Unfortunately, the CampusGuiden indoor positioning has approximately 5–10 m positional accuracy, which we think is insufficient for indoor use; with a 10 m error in position, a receiver could position itself in a completely wrong room, or in a location that should not be accessible. Thus, we are interested in more accurate positioning systems, which can reliably establish which room the receiver is in. QR codes can offer accurate positioning due to the requirement of having a line-of-sight on the code. Bluetooth, or some WLAN-based indoor positioning solutions offer positioning up to an accuracy of a few meters (Liu et al. 2007). Such solutions could be used as a basis for the final product.

Of course, it is not necessary to use positioning in a navigation system as demonstrated by the EPFL Map; the user can still ask the system for directions without locating themselves. In a university environment, this might not be a huge problem, since each room has a unique, clearly visible code number associated with it. Thus, if the system knows all the room codes, it could be used to find the user location without positioning technology. However, in other places such manual location finding might not be possible. Furthermore, such system would always be more cumbersome than automatic positioning.

4.2 Indoor Route Planning

University buildings can sometimes be labyrinthine affairs, where routes between locations are non-intuitive. The third floor of the main building at Aalto University is an example: the floor is separated into two unconnected areas. Thus, the shortest route between some of the rooms in the third floor goes through the second floor, and the most commonly used stairs to the third floor do not reach all rooms on the floor. This means that people sometimes need to follow complex, non-intuitive routes in order to reach their goal.

The complexity of the route is important because people prefer to follow simple routes (Papataxiarhis et al. 2009). Thus, if the shortest route is considered complex, for example due to many turns, the user might prefer to be given a simpler route. This problem is not covered in this prototype. Theoretically, the problem could be solved by assigning weights to the edges of the routing graph. The weights could be assigned according to the travel time, or according to the comfort level derived from the user's preferences (Dudas et al. 2009).

5 Future Work

The application introduced in this work is currently in prototype phase, and there are many possible paths of future work. The inclusion of more floor plans, wider range of supported mobile platforms, and a better indoor positioning system are obvious engineering improvements. Currently, the only type of indoor positioning that has any sort of infrastructure available at the campus area is positioning based on wireless LAN signals. However, we do not know if the campus area has sufficiently dense WLAN base station infrastructure for indoor positioning. Thus, alternative solutions may be required.

An area of the work that requires a lot of development is the process of producing indoor maps and route graphs out of the CAD format floor plans. The current process requires a lot of manual work, and is thus laborious to use and susceptible to errors. For example, we have noted that routing graphs created by different people have large differences between them. Developing an algorithm to automate the process of extracting the map and the routing graph is thus an important goal. Furthermore, the current routing graph contains only node distances as edge weights. In the future, it would be interesting to investigate how the complexity of the paths can be affected by edge weights.

We are also very interested in adding social networking aspects to our prototype. From the very beginning of the project we have planned on including functionality where a user could see the current locations of their friends with the system. Thus, the users could, for example, use this functionality to find an ad-hoc meeting location without having to be in constant direct communication.

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Augmented Maps with Route Sketches

Padraig Corcoran, Peter Mooney, Michela Bertolotto and Basel Magableh

Abstract This article proposes a novel representation for route descriptions called an Augmented Route Sketch Map (ARSM). In this representation a route is composed of a sketch map drawn over a detailed base-map. The base-map has the effect of augmenting ones knowledge and in turn reduces the complexity of accurately representing and interpreting a route. This is demonstrated through a set of user trials. The proposed ARSM representation also facilitates the automatic parsing of route descriptions and in turn the transformation to other representations such as a turn-by-turn instructions.

Keywords Route description · Sketch map

1 Introduction

Providing a route description to an individual with limited or no knowledge of the area in question is an activity most perform regularly in many different contexts. The oldest and most common of these is providing a route description which will take an individual to a desired destination. However, with the advent of social media this activity has gained significant popularity in many other contexts. For example, sites such as mapmyrun.com offer the facility for its members to share running routes. Route descriptions may contain many forms of information. Turn-by-turn

P. Corcoran (✉) · M. Bertolotto · B. Magableh
School of Computer Science and Informatics, University College Dublin, Dublin, Ireland
e-mail: padraig.corcoran@ucd.ie

P. Mooney
Department of Computer Science, National University of Ireland Maynooth, Maynooth, Ireland

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instructions provide very detailed information regarding the route in question and are commonly used in automotive navigation systems. They correspond to instructions such as “turn left at the next junction, go straight through the following junction, turn right at the following junction”. It is generally accepted that, although effective, such instructions do not coincide with the way humans intuitively describe routes (Ziegler et al. 2011). This is attributed to the fact that human route descriptions commonly contain landmark information where landmarks are defined as cognitively salient, prominent features in the environment (Duckham et al. 2010). An example of such a route description is the following “continue straight until you see a large church on your right, turn left at the following junction”. However, in some environments, such as suburbs, landmarks may not be available or difficult to extract automatically (Westphal and Renz 2011). Destination descriptions do not provide information relating to the route explicitly but instead describe the route destination. They correspond to instructions such as “opposite the Stillorgan shopping centre”. Destination descriptions have the potential to be of a shorter length than route descriptions based on turn-by-turn instructions or landmarks. However, they assume the individual using the description has prior knowledge of the environment which may not always be the case.

There exists many means of representing a route description. These include text, linguistic, map, sketch, tactile and augmented-reality based representations (Rehrl et al. 2010). The most suitable representation used is in some cases context dependent. For example in the context of motorist navigation a linguistic representation is suitable because it does not distract the user’s visual attention from the road. In this article we focus on sketch based representations of route descriptions. The most common form of sketch based representation is known as a Route Sketch Map (RSM) and involves drawing a sketch on a blank white background. We propose a novel type of sketch based representation, entitled an Augmented Route Sketch Map (ARSM), which overcomes a number of limitations associated with existing approaches to generating route descriptions. This approach is based on a fundamental concept of constraining a sketch by drawing it over a detailed base-map and in turn augmenting the knowledge of both the individuals who create and use it.

The layout of this article is as follows. In Sect. 2 we review existing sketch based representations of route descriptions. Section 3 describes the proposed ARSM representation. In Sect. 4 we present an evaluation of this approach through user trials. Section 5 describes results which demonstrate that the use of ARSMs reduces the complexity of transforming a route description to other representations. Finally in Sect. 6 we draw conclusion and present some possible future research directions.

2 Route Sketch Maps

A seminal study by Tversky and Lee (1999) of 29 RSMs demonstrated that each contained the information necessary to complete the navigation task in question. It was also found that linguistic and sketch representations exhibited the same underlying structure and semantics and therefore a conversion between representation should be possible. Skubic et al. (2004) subsequently proposed a method for converting a sketch representation to a linguistic representation. Kopf et al. (2010) proposed a method for converting a map based representation to a sketch based representation. Igarashi et al. (1998) and Hagedorn and Dollner (2008) proposed methods for sketching paths in a virtual 3D environments. Sketch based representations of route descriptions have also been used many times in the context of robot navigation (Chronis and Skubic 2003; Shah et al. 2012).

The popularity of RSMs can be attributed to a number of factors. Tversky (2002) demonstrated that, when compared to a linguistic representation, sketch based representations generally contain a greater amount of the spatial information necessary to perform the navigation task at hand. Sketches are an external representation which complements human memory (Tversky 2002) . Therefore, unlike linguistic representations (Tom and Tversky 2012), they do not need to be remember. Sketches also complement information processing (Tversky 2002). They facilitate the user to perform processes such as spatial chunking which can be defined as the grouping of navigation instructions (Klippel et al. 2003).

Despite their popularity RSMs exhibit a number of limitations which we will now discuss. Generating an accurate RSM requires accurate knowledge of each part of the route in question where this knowledge can be represented in a number of different ways. Consider the map in Fig. 1a, which is an accurate representation of an urban area, where an individual wishes to draw a RSM representing the route from the green circle to the red circle along the blue dashed line. The most difficult and important part of the route to represent accurately in a RSM is the right turn. Next consider the corresponding RSM in Fig 1b where the start and end of the route are represented using the symbols *S* and *E* respectively. In this sketch the right turn is represented correctly in terms of the number of prior right turns (4 in this case). Therefore this sketch map contains accurate knowledge of the right turn in question represented in terms of the number of prior right turns. An alternative means of representing the right turn accurately, if the number of prior right turns is unknown, is in terms of distance along the road. Such a RSM would contain accurate knowledge of the right turn in question represented in terms of distance from a location. Accurate knowledge of the turn could also be represented accurately in terms of a landmark at the turn or the name of the street which is turned onto. It is evident from this discussion that representing the right turn correctly requires accurate knowledge of that part of the route. An individual with less than accurate knowledge would not know the correct number of prior right turns or distance along the road. They may also not know the name of individual street or know of a landmark at the turn if one actually exists. In the study of Tversky and Lee (1999) the authors asked individuals who “answered affirmatively” that they knew the route to a particular restaurant to draw a corresponding RSM. This suggests that all RSMs in the study were drawn by individuals who had accurate knowledge of the route in question.

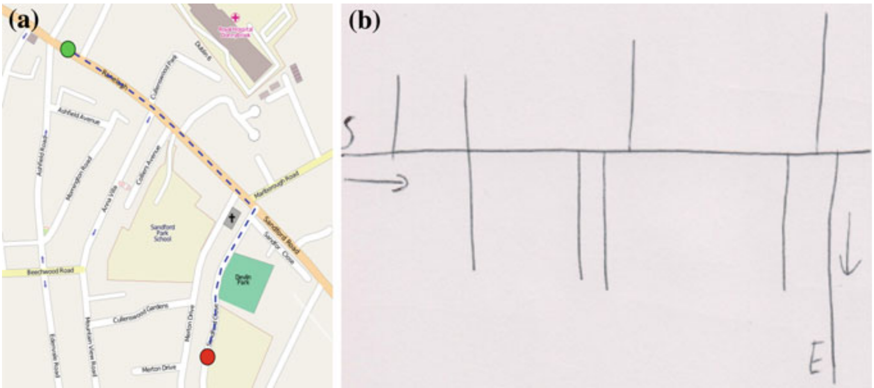

Fig. 1 A route shown on OpenStreetMap is displayed in (**a**). A corresponding route sketch map is displayed in (**b**). Map data (c) OpenStreetMap contributors, CC-BY-SA

Other limitations of RSMs are that they are time consuming to draw and their quality is affected by individual drawing ability (Bell and Archibald 2011). Also the individual for which the route sketch map is intended may have prior knowledge of some parts of the route in question. In such a situation an optimal RSM will contain low levels of detail in areas for which users have prior knowledge and high levels of detail elsewhere (Ziegler et al. 2011; Richter et al. 2008). Finally in some situations it may be necessary to parse and convert the RSM to an alternative representation such as a linguistic description for use in car navigation. However the automatic parsing of an RMS is extremely challenging (Broelemann 2011; Chipofya et al. 2011).

To mitigate the above limitations the following strategies are generally employed. In most cases RSMs are only drawn for routes of short distance. For example in the study of Tversky and Lee (1999) the RSMs corresponded to a route from a university to a local restaurant for which the corresponding route was short and contained only three turns. Another strategy commonly used is to draw a RSM corresponding to a route which is not necessarily the best route, for example in terms of distance, but can be accurately represented by a sketch map due to its low complexity (Haque et al. 2007; Westphal and Renz 2011).

In the following section we propose a novel sketch based representation of route descriptions which is based on a fundamental concept of constraining a sketch by drawing it over a detailed base-map. de Silva and Aizawa (2010) proposed a method for drawing a route on a map although the purpose of this method was to retrieve a video along the path and not to specify a route description. Many web based routing services such as Google Maps and OpenRouteService provide a method for generating a route drawn over a map. However, these methods do not allow the user to draw the route and they may only specify the route to a limited degree through adding way-points.

3 Augmented Route Sketch Maps

To overcome a number of limitations associated with existing approaches to generating route descriptions we propose a novel type of sketch based representation entitled an Augmented Route Sketch Map (ARSM). An ARSM is created using the following steps which are performed by the individual whose task is to provide the route description. Firstly given a map of large geographical scale the individual selects the region in this map containing the route in question. We refer to the selected map region as the base-map. This map should contain a detailed road network along with addition information such as street names and local features. For example consider again the example from Sect. 1 where the goal is to represent the route from green to red circles along the blue dashed line represented in Fig. 1a. In this situation one would select a base-map such as that displayed in Fig. 2a. Given a suitable base-map the individual creates a corresponding sketch map, which is drawn over the base-map, as follows. The individual sketches a directed line or arrow over the base-map along the route path. For example in the context of specifying the route in Fig. 1a the individual would sketch a directed line over the base-map in Fig. 2a similar to that represented by the blue directed line in Fig. 2b. The user may also annotate the route in any way they please. For example in Fig. 2b the individual has drawn a circle around a feature in the base-map corresponding to a church in order to indicate that this is a landmark. If a feature is not present in the base-map the individual may add it to the sketch map. Together the base-map and sketch map constitute the ARSM. The sketch map is drawn with a high degree of transparency to ensure it does not occlude important information in the base-map.

The proposed approach to the creation of sketch based representation offers many advantages over the traditional RSM. We now describe these in some detail.

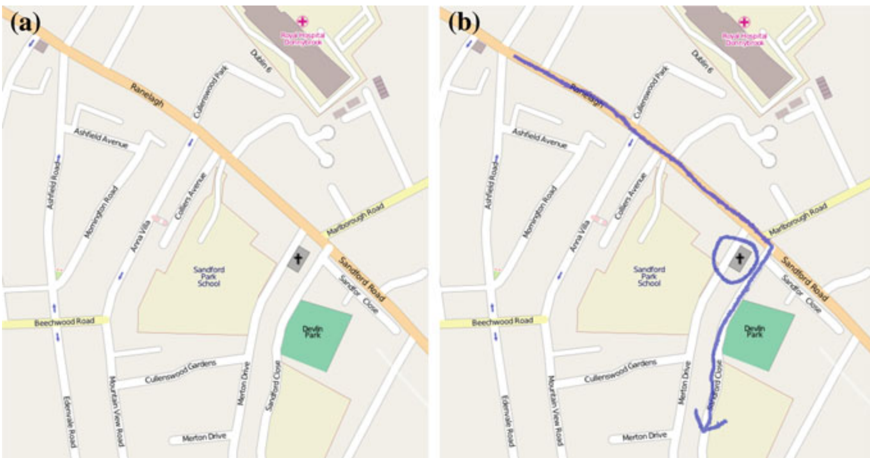

Fig. 2 The selected base-map and corresponding sketch map are displayed in (**a**) and (**b**) receptively. Map data (c) OpenStreetMap contributors, CC-BY-SA

The proposed approach generally does not require the individual providing the route description to have accurate knowledge of every part of the route in question. If accurate knowledge regarding a particular part of the route is unknown it may possibly be inferred through spatial reasoning which is a function of the base-map and knowledge relating to other parts of the route. As such, the base-map allows the individual to augment their less than complete route knowledge. Consider again the example in Fig. 2 where an individual wishes to accurately represent a right turn. If the correct number of right turns prior to the turn in question is unknown this information may be inferred in a number of ways. For example if the individual knows that the following part of the proposed route passes by the area known as *Devlin Park* (represented by a green polygon in Fig. 2a) they can infer the correct turn. Alternatively if they know that the turn in question is directly after the church represented in the scene, despite the fact that this feature may not be a suitable landmark, they again can infer the correct turn.

The base-map also allows an individual attempting to navigate with an ARSM the ability to augment the information contained in the sketch map where necessary. This in turn offers a number of benefits. Consider the situation where an individual is attempting to navigate using the ARSM in Fig. 2b. If they have taken a right turn but are unsure if it is in fact the correct turn they may reject the hypothesis that it is correct if a park does not appear on their left a short distance later. This is despite the fact that the individual who created the ARSM may not have explicitly represented this feature in the sketch map. Other forms of information which may be drawn from the base-map to facilitate navigation are distances, compass directions and street names. The ability to augment route information where necessary allows one to obtain a route description of varying levels of detail (Richter et al. 2008; Ziegler et al. 2011). In locations where one has little prior knowledge, a detailed description is necessary and can be inferred. While in locations where one has significant prior knowledge there is no requirement to infer additional information. The above process of drawing additional information from a base-map is similar to the task orienteers perform when planning a route between locations (known as *controls*) on an orienteering map (Eccles et al. 2002). Orienteering maps differ from ARSMs due to the fact that they only specify *controls* and not a route between them.

Another advantage offered by ARSMs over traditional sketch based representations is that they facilitate the transformation to other route description representations. This is achieved through performing matching between the proposed route in the sketch map and the street network in the base-map. This fact will be demonstrated in Sect. 5.

4 Evaluation

In this section we present an evaluation of the proposed ARSM representation relative to the traditional RSM representation. As discussed in the introduction to this paper the use of route descriptions can occur in many contexts. In this section we evaluate the ARSM in the context of long distance runners providing and interpreting running route descriptions. Currently the most popular medium for runners to share routes is GPS traces using sites such as mapmyrun.com. A long distance runner can run anything between 10 and 30 km on a daily basis for training purposes. This offers the opportunity to evaluate the use of ARSMs for routes of such lengths. The evaluation consisted of a series of user trials where each trail contained two parts. The aim of the first and second parts of the trials were to evaluate the effectiveness of an ARSM as a medium for creating and interpreting a route description respectively.

In the first part of each trial an individual with knowledge of the area in question was asked to create a RSM of a route which they ran recently. Once completed the concept of an ARSM and their construction was explained to the individual. They were subsequently asked to create an ARSM corresponding to the route previously represented. In the second part of each trial the RSM and ARSM were used by two separate individuals with little knowledge of the area in an attempt to navigate the route in question. As is standard practice both forms of route maps were created in the presence of these individuals. This allowed the individual creating the route sketch map to explain the reasoning behind their actions.

To facilitate the above evaluation we created a software implementation for capturing an ARSM. When creating an ARSM the individual first pans and zooms the base-map in order to locate the region containing the route they wish to represent. Next they create the sketch map by sketching over the base-map. All results were printed on A4 white sheets of paper. These sheets were then used by the individuals who wished to navigate the route in question. The city of Dublin was used as the study area and the data used was taken from OpenStreetMap. The OpenStreetMap data for Dublin city is generally regarded as being of a high quality and rich in detail. RSMs were captured by sketching on an A4 white sheet of paper using a black pen.

In total seven trials were performed. All participants in the user trials were experienced male runners recruited from a local athletics club who regularly compete in long distance races including the marathon. All based maps used in the trials were taken from OpenStreetMap (www.openstreetmap.org). In the following two subsections we present results and analysis corresponding to both parts of the trials.

4.1 Route Representation

Examining the corresponding pairs of RSM and ARSM route descriptions demonstrated a number of advantages offered by the ARSM which we will now discuss in turn. In all cases the time required to create a RSM was significantly greater than that required to create the corresponding ARSM. For example consider Figs. 3 and 4 which display a RSM and ARSM pair corresponding to an individual trail. The total length of the route represented in Fig. 4 is 10.1 km. The time

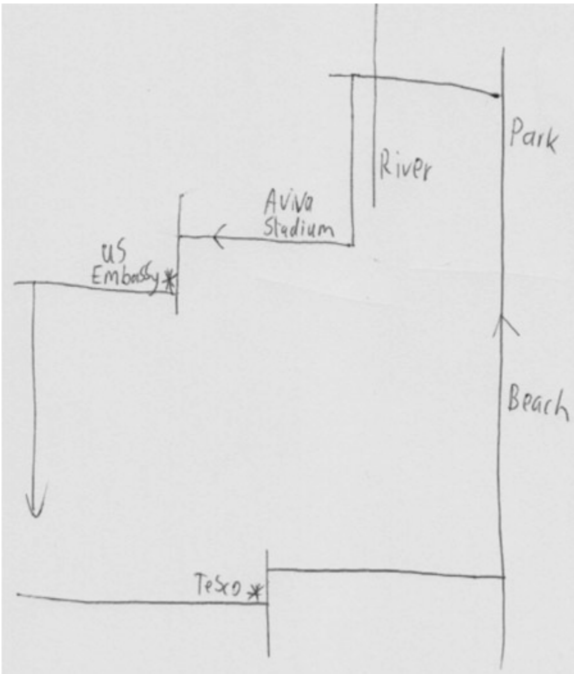

Fig. 3 The RSM for an individual user trial

required to create these route maps was 165 and 55 s respectively. Over all trials the average time required to create a RSM and ARSM was 162 and 70 s respectively. This saving in time offered by the ARSM can be attributed to a number of factors. Firstly in all cases creating the ARSM required a lesser amount of detail to be drawn. This included simply underlining or circling a feature in the base-map in order to represent a landmark in the ARSM. For example in top centre of Fig. 4 the text "Aviva Stadium" in the base-map is circled to indicate a landmark. While in the corresponding RSM the name of the landmark is written in full. This feature was exhibited in all trials. In some situations a landmark which required representation in the ARSM was not represented in the base-map. In all such cases the individual annotated the ARSM in order to include this information. For example in the left centre of Fig. 3 the ARSM is annotated to include a landmark corresponding to the Embassy of the United States. A number of individuals in the trials commented that creating the ARSM did not require them to attempt to recollect as much information regarding the route. This point is a direct consequence of the base-map augmenting the individuals knowledge.

Examining the set of RSMs generated indicated that in 5 of the 7 trials they were not sufficient. That is, each map contained some ambiguity with respect to the route in question. For example consider the top right of the RSM in Fig. 3 which contains a left turn. By examining the corresponding base-map in Fig. 4 we can see that there are a number of left turns in this area. Despite this fact the individual who created the map did not use a street name, landmark or any other strategy to distinguish the

Fig. 4 The ARSM for an individual user trial. Map data (c) OpenStreetMap contributors, CC-BY-SA

correct turn from others. By their nature of being drawn on an accurate base-map, the ARSMs did not contain any such ambiguities. The above point regarding the issue of route ambiguity will be discussed further in the next section.

Another point which was evident from comparing the set of corresponding RSM and ARSM representations was that a number depicted slightly different routes. For example consider again the RSM and ARSM of Figs. 3 and 4 respectively. The RSM contains only a single left turn after the Embassy of the United States landmark. On the hand the ARSM contains a number of left and right turns after this landmark. This property of representing a less complex route in the RSM was exhibited in 2 of the 7 trials. Upon questioning all the corresponding individuals stated that they felt they could not represent the desired route using a RSM due to a lack of knowledge of the route and therefore represented a less complex route instead.

4.2 Route Interpretation

In 2 of the 7 trials performed using a RSM the individuals stated that they became lost and were forced to retract their path to the beginning. In a further 2 of these trials the individuals stated that they became lost for a short period but later rejoined the specified route. For example one individual became lost at the location corresponding to the top right of the RSM in Fig. 3 due to ambiguity regarding the correct left turn. However, this individual later rejoined the specified route at the Aviva stadium landmark.

In all trials performed using an ARSM the individuals stated that they followed the specified route correctly without becoming lost. They also stated that they drew significant information from the base-map and that this was necessary in order for them to follow the route correctly. Four individuals stated that this information included street names. Four individuals stated that it include distance and street angles. While two individual stated that it included the street class.

Tversky and Lee (1999) demonstrated a RSM to be effective when the route in question is of a short distance and the individual creating the map has intimate knowledge of it. However, it is evident from the results presented in this section and the previous that if both these criteria are not met the RSM representation is not effective. However, these results demonstrate that the ARSM representation overcomes these limitations.

5 Representation Conversion

As discussed in Sect. 2 the ability to convert between different representations of the same route description has many applications. However, the automatic converting of many representations, such as a RSM, is extremely challenging (Broelemann 2011; Chipofya et al. 2011). In this section we demonstrate that in the context of converting an ARSM to an alternative representation this challenge can be simplified through the application of existing map matching techniques. Map matching is a process by which an inaccurate route, typically a GPS trace, is registered with a street network (White et al. 2000). Due to the fact that an ARSM is created by drawing over a base-map containing a road network, the route in question may be registered to this road network by applying map matching. To demonstrate this we implemented a popular map matching technique know as the *weak Fréchet distance* (Brakatsoulas et al. 2005). Figure 5 displayed the result of applying this method to the route specified by the ARSM of Fig. 4. Visual

Fig. 5 The red line represents the result of applying map matching to the route in Fig. 4. Map data (c) OpenStreetMap contributors, CC-BY-SA

inspection verifies that this is an accurate registration to the street network. We evaluated the *weak Fréchet distance* using all ARSM routes generated in the user trials of Sect. 4. In all cases an accurate registration was achieved. In some cases is straight forward to convert a route which is registered to a street network to different a representation. This is the case when converting to a set of turn-by-turn instructions (Lou et al. 2009). In fact this type of conversion is performed by most commercial automotive navigation systems. This demonstrates that by being drawn over a base-map the proposed ARSM facilitates the transformation to other representations.

6 Conclusions

Sketch based representations are a popular medium for route descriptions. The seminal work of Tversky and Lee (1999) demonstrated traditional sketch representations drawn on a blank sheet of paper to be effective when the route in question is of a short distance and the individual creating the map has intimate knowledge of it. In this article we demonstrated that when these criteria are not met this representation is no longer effective. We have presented a new sketch based representation for route descriptions known as an *Augmented Route Sketch Map* (ARSM). A series of user trials were performed in order to evaluate this representation. They demonstrate that the use of a base-map in the ARSM augments ones knowledge and simplifies the tasks of route representation and interpretation. This facilitates the generation of suitable route descriptions even when the criteria above are not met.

In future work we plan to present a more in-depth and detailed evaluation of the proposed ARSM methodology. Due to the fact that an ARSM is a novel form of route representation it offers many other exciting opportunities of further research. These include the potential of applying map generalisation techniques to the map once the route in question has been determined through map matching (Agrawala and Stolte 2000). This would allow the reduction of information irrelevant to the individual attempting to navigate such as streets not travelled. On the other hand it would also allow the enhancement of relevant route information such as street names. Another possibility for future research would be the introduction of route consistency checks. This would include checks such as ensuring the route does not travel the incorrect direction along a one-way street. In this paper all ARSM have been created using base maps taken from OpenStreetMap. Evaluating the impact of different base maps represents another possible research direction.

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High Precision 3D Indoor Routing on Reduced Visibility Graphs

Horst Steuer

Abstract Indoor navigation is becoming a most wanted application especially on the background of the wide availability of powerful personal mobile devices and new methods for indoor positioning. Existing approaches do seldom incorporate that people can move freely through e.g. big halls and are not constrained to specific lanes as vehicles are on road networks. Thereby these approaches can only approximate shortest paths and cannot benefit from possible highly accurate indoor positioning methods. In this chapter we show how the concept of visibility graphs can be applied to indoor routing and how it results in highly accurate shortest paths. We demonstrate how any accurate position can be incorporated in the automatically constructed graph. Furthermore we show how the knowledge that different levels of a building are usually sparsely interconnected can be used to speed up the well-known shortest path algorithm A* by introducing a new heuristic. In experiments we show that our approach needs 29 % less run-time than a standard A*-algorithm.

Keywords Indoor routing · Visibility graph · Heuristic · Shortest path

1 Introduction

Navigation in outdoor environments is probably the most used application of geodata in the end-user market, especially since the upcoming of satellite navigation systems. With the ever growing demand of navigation solutions a big

H. Steuer (✉)
Fachgebiet Geoinformationssysteme, Technische Universität München, Arcisstraße 21, 80333 Munich, Germany
e-mail: steuer@tum.de

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diversity of products emerged on the market: from hardware to software, expanding automotive navigation to bicycle as well as pedestrian navigation. Accompanying these developments is an ever growing demand for map data: at first only roads needed to be mapped, later bicycle tracks and pedestrian paths were required as well.

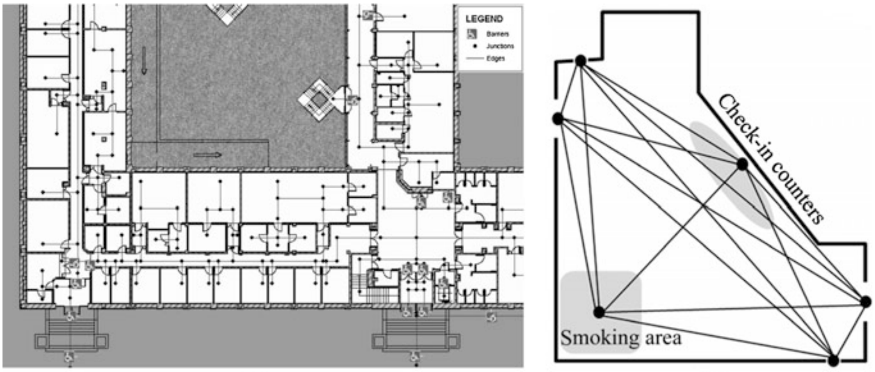
With the development of indoor positioning methods and further establishment of mobile devices like smart phones the demand for new indoor navigation methods arises. Indoor navigation can be especially helpful in unclear, public buildings like airports, train stations or malls.

The task of (indoor) navigation for humans can be divided in several essential sub-tasks:

- Data acquisition, the first step, is the process of generating the necessary map and localization data for all of the following tasks. This can be done either by traditional geodetic methods, by building on existing plans or by using volunteered geographical information like Open Street Map (Haklay and Weber 2008).
- Localization is the process of determining the (start-)location by manual or automatic means. The user can give his/her position by addressing it or the navigation system can determine its own position by means of different sensors like GPS or Wi-Fi-positioning (Evennue and Marx 2006). Localization is a necessary step before the subsequent ones, but can also be repeated during the process later.
- Addressing is necessary for enabling the user to specify his or her destination. This can for example be a point in a coordinate system, a specific room number or the exit of a building.
- Routing is the process of computing an optimal path in regard to some optimality criteria. Usually a length optimal path is sought for but there also exist several requests where a safe path for handicapped people is sought (Karimi and Ghafourian 2010).
- Visualizing the optimal path has to be done in the most useful way for the user. This can be done by visualization in a map (e.g. Hagedorn et al. 2009) or as a set of commands which can be presented visually or acoustically (May et al. 2003).

In this chapter we will focus especially on the routing sub-task. Historically, routing is based on graphs since road networks can easily be described as sets of nodes and edges. Another reason why graph based solutions are so popular is that there exist well-known algorithms like Dijkstra's algorithm (Dijkstra 1959) or A* (Hart et al. 1968) which can compute shortest paths on any given graph with edge weights. Since these graph-based shortest path algorithms can guarantee to find shortest paths, the problem of defining an algorithm to find shortest paths in indoor environments is reduced to generating a useful graph.

In pedestrian navigation one has to observe that pedestrians usually are not constrained to straight paths like cars but can move freely in huge places or big halls. A static graph design which represents every possible pedestrian movement would induce the number of nodes and edges to grow to infinity, and is therefore infeasible.



(a) (b)

Fig. 1 Examples of graph structures which discretize the available moving navigable space (**a**) an office building where each room is represented by a single node in the graph, corridors and halls are represented by more nodes (Ariza-Villaverde et al. 2010) (**b**) an airport entrance hall with two zones of interest (Goetz and Zipf 2011). Since in both examples only a few points are used as nodes of the graph it is obvious that the given graphs cannot lead to exact shortest paths and can lead to discretization errors when using a self-localization technique

One popular approach to solve this problem is to focus on the topology of rooms and build a graph to represent this topology. In Fig. 1 you can see examples of this approach.

Figure 1a shows a floor of a bureau building where each bureau is represented by one node. Each of these nodes is connected to the corridor by an edge. As can be seen, it is not enough to generate a single node for the corridor but there have to be quite a few nodes in order to compute a useful path. The advantage of this approach is that it results in a relatively small graph. Because of the low number of nodes a shortest path can be computed in very fast run time and the resulting path can be easily described by simple commands like “Move 10 m straight ahead, Turn left, Enter Room 101”. Furthermore the addressing sub-task part becomes trivial since for each point of interest an extra node can be added. The disadvantage of this approach is that the space of possible movement is reduced/discretized to these few nodes. Thereby it is not guaranteed to find a geometrically shortest path.

As can be seen in Fig. 1b this becomes even more relevant in less constricted places like an airport entrance hall. Additionally the self-localization poses a problem: The (automatically) determined position has to be projected onto these nodes and the error in initial positioning has to be communicated to the user.

1.1 Contribution

In this chapter we present a different approach to generate a dynamic graph automatically from a floor plan. This approach originates in the field of robotics but has not yet been applied to human indoor navigation to our knowledge. In the next section we describe the structure of the floor plans we need as an input to this approach. In the section "Construction of a Graph" we describe the automatic generation of a so called visibility graph. Using Dijkstra's algorithm and A* with a standard and a custom heuristic we perform several experiments which we present in section "Applying the Dijkstra and A* Algorithms" before we give a conclusion in the last section.

2 Description of Indoor Environments

In the following, we will assume that a single floor of every indoor environment can be modelled or at least be approximated by a polygon with holes. The outer walls of the building, including touching inner walls, make up the outer border of the polygon, while walls which do not touch the outer perimeter and any other obstacle are modelled as holes of this polygon (see Fig. 2). For simplicity reasons we assume that each floor is completely flat, meaning there are no steps or ramps on this floor. Non-flat floors would have to be modelled as a set of more floors in this approach.

Assuming that a human being can approach an obstacle only up to 30 cm measured from his/her barycentre we can add a buffer operation to these polygons. In doing so we also close gaps between obstacles which are too small to walk trough. As a result we obtain a polygon which describes the navigable- or moving space of a person.

In order to connect the different floors of a multi-level building we do not model steps and elevators geometrically but add special nodes to the graph. Especially for the elevators this is a valid approach, since these often have a relatively narrow entrance zone.

3 Construction of a Graph

Given a one-floor polygonal environment we described in the last section we adopt the principle of visibility graphs first introduced in Lozano-Peréz and Wesley (1979). The property of every shortest path in such an environment is "that it is composed of straight lines joining the origin and the destination via a possibly empty sequence of vertices of obstacles" (Lozano-Peréz and Wesley 1979). If we interpret the outside of the polygon as obstacle the visibility graph G(V, E) is defined by a set V of all vertices of all obstacles (inner holes and outer perimeter) and a set of edges E. Each edge e = (v1, v2) of E (v1, v2 element of V) is connected by a straight line which lies completely inside the polygon and does not cross an obstacle. As edge weights we use the euclidean length |(v1, v2)| of the edge.

We can reduce the number of edges in E by removing those which would intersect an obstacle when elongated by an ε (see Fig. 3). This graph G is

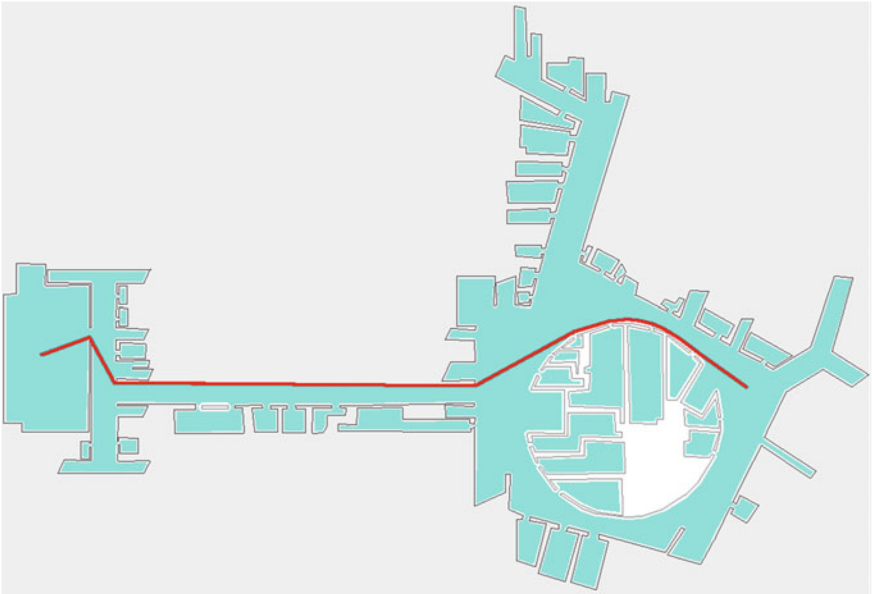


Fig. 2 Floor plan of a mall: the navigable space is described by the *cyan* polygon which we obtained by buffering the input polygon (*grey lines*). Obstacles are modelled as holes in the polygon. The *red line* is an example shortest path computed by the presented algorithm. Note that start and end positions can be at arbitrary positions inside the navigable space

universally useful for the computation of any shortest path in a given environment. Since it does not need to be changed, we call it the static part of the graph. Figure 4a and b show a simple example of such a polygonal environment and the resulting reduced visibility graph (Latombe 1991).

In order to compute a shortest path we add a start vertex s and a goal vertex g to V, as well as edges e = (s, v) and e = (g, v) respectively, where v is an element of V such that e does not leave the polygon or crosses an obstacle. Furthermore we do not need to consider edges as described in Fig. 3. Since these edges have to be established for every shortest path computation anew we call it the dynamic part of the graph. Figure 4c shows an example for these dynamic edges. Using such a graph consisting of a static and a dynamic part we can apply well-known shortest path algorithms as we will describe in detail in the next chapter to obtain a shortest path (see also Fig. 4d). The division of the graph into a static and a dynamic part makes the construction of the graph run-time efficient.

The concept of visibility graphs has several advantages over the space discretizing graphs described in the first section:

- An exact geometrically shortest path can be computed.
- An exact position (e.g. measured by some self-localization system) can be integrated directly into the graph without loss of accuracy due to discretization.

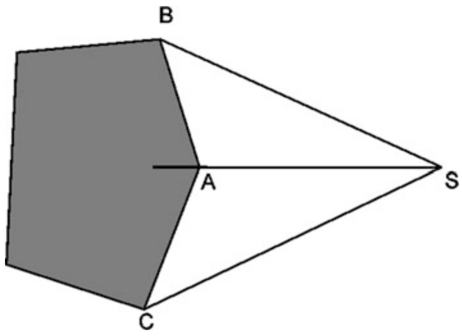


Fig. 3 Reduction of the visibility graph: (S, A) intersects an obstacle when elongated by an ε. Any path starting at S and passing the obstacle has to use either B or C. A path using (S, A) cannot be a shortest path because of the *triangle* inequality: $|(S, A)| + |(A, B)| > |(S, B)|$ and analogously for C. Therefore the edge (S, A) is not needed for the computation of a shortest path and can be removed from the graph

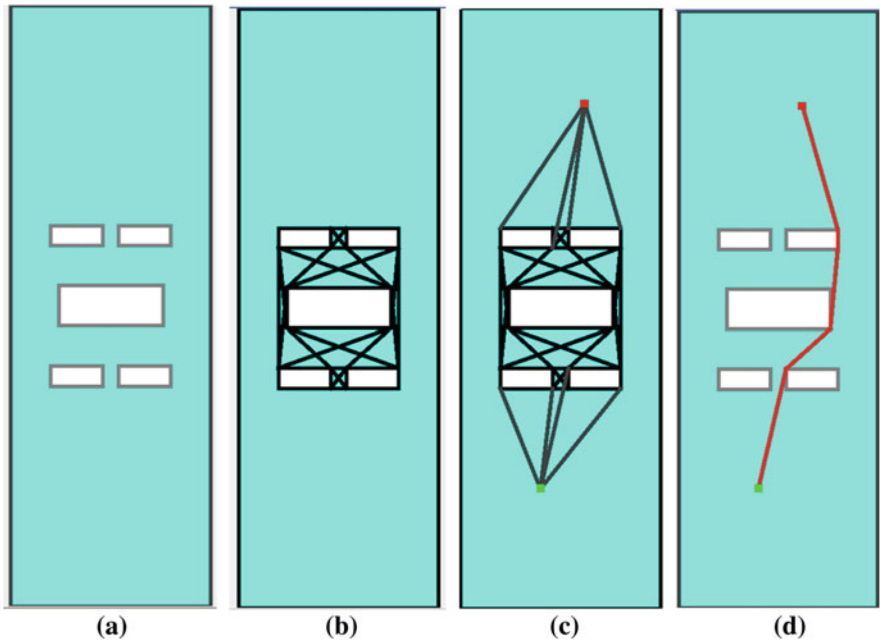


Fig. 4 Computing a shortest path with visibility graph: **a** a room with five obstacles, **b** the resulting reduced visibility graph, **c** adding vertices and edges dynamically to the graph for start and goal positions, **d** the resulting shortest path

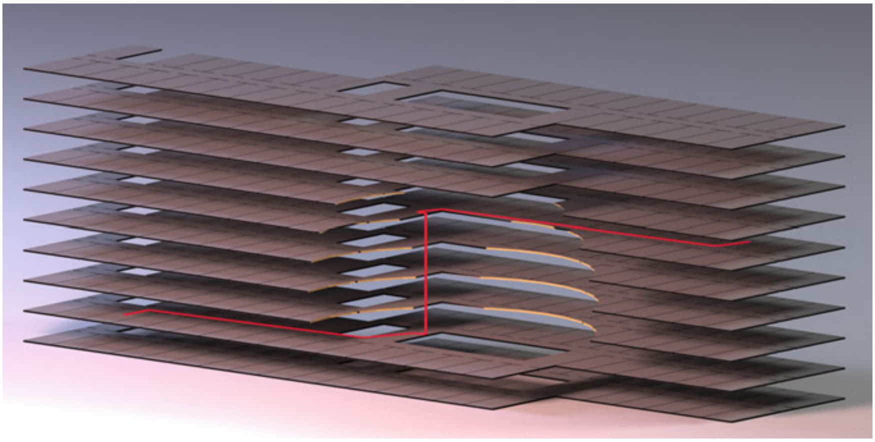


Fig. 5 A 10-story building. The different floors are connected by four *centrally* located elevators and two staircases in the *middle* part and on the *left* side, respectively. The *red line* shows a shortest path using an elevator

4 Shortest Paths with Customized A*

The probably most famous shortest path algorithm is the algorithm given in (Dijkstra 1959). The algorithm works by managing two sets of nodes: the visited and the unvisited nodes. Initially the visited set consists only of the start node while all other nodes are part of the unvisited set. Then one node n is chosen out of the nodes of the unvisited set which is adjacent to a node of the visited set and has a minimum distance d(n) to the start node (adjacent means the node is connected to another node by an edge). This distance is computed by adding the length of the edge which connects the node to one node n_v of the visited set to the distance this node n_v has to the start node.

$$f_{Dijkstra}(n) := d(n) := d(n_{predecessor}) + e(n_{predecessor}, n) \rightarrow min \qquad (1)$$

Repeating the last steps until the goal node is added to the visited set yields the shortest path.

In other words the algorithm of Dijkstra expands the set of visited nodes successively in all directions until the goal node is found. In Hart et al. (1968) the A* algorithm was introduced, which can be seen as an extension of Dijkstra's algorithm. They suggest to add a heuristic h(n) which steers the expansion of the set of visited nodes into the direction of the goal node. Hence, A* chooses the node of the unvisited set which is adjacent to a node of the visited set and where the sum of the shortest distance to the start node and the approximated distance to the goal node is minimal.

$$f_{A*}(n) := d(n) + h(n) \rightarrow min \qquad (2)$$

These two algorithms introduced by Dijkstra and by Hart et al. can both guarantee to find a shortest path in a weighted graph like the one we constructed in the last section (without negative edge weights). A* additionally needs an admissible heuristic h(n) as input, which estimates the distance of a node n to the goal node. A heuristic is admissible if it does not overestimate the distance to the goal node. In order to be implemented in a run time efficient way the heuristic also has to be monotonic, meaning that for every two adjacent nodes n_1 and n_2 the following in equation is fulfilled:

$$h(n_1) \leq h(n_2) + e(n_1, n_2) \tag{3}$$

The probably most often used heuristic in graphs which represent topologies in a euclidean space is the euclidean distance.

$$\begin{aligned} h_e(n) &:= dist(n, goal) \\ &= \sqrt{(n.x - goal.x)^2 + (n.y - goal.y)^2 + (n.z - goal.z)^2} \end{aligned} \tag{4}$$

In the visibility graph described above, where edge weights are set to the euclidean distance of the two nodes, in Eq. (3) can be written as

$$dist(n_1, goal) \leq dist(n_2, goal) + dist(n_1, n_2) \tag{5}$$

which is a variant of the triangle inequality and therefore the heuristic h_e is admissible.

Another admissible heuristic is

$$h_0(n) = 0. \tag{6}$$

Using this heuristic h_0 f_{A*} is reduced to $f_{Dijkstra}$ and the A*-algorithm behaves like Dijkstra's algorithm.

In Fig. 6 you can see a behaviour for the three-dimensional case. Here A* still outperforms the algorithm by Dijkstra in regard to the number of expanded nodes but expands many nodes on the floors between the start and goal node. This happens because the heuristic h_e does not differentiate between the three axes of the coordinate system. A* tries to approach the goal node on every floor.

4.1 Customized A*

We optimize the behaviour of A* by using our knowledge on the graph's structure. We know that there are relatively many nodes and edges on each floor but that these floors are only sparsely interconnected. Therefore on reaching steps or an elevator we would like the algorithm to prioritize a vertical movement over a horizontal one: We achieve this by using a different heuristic:

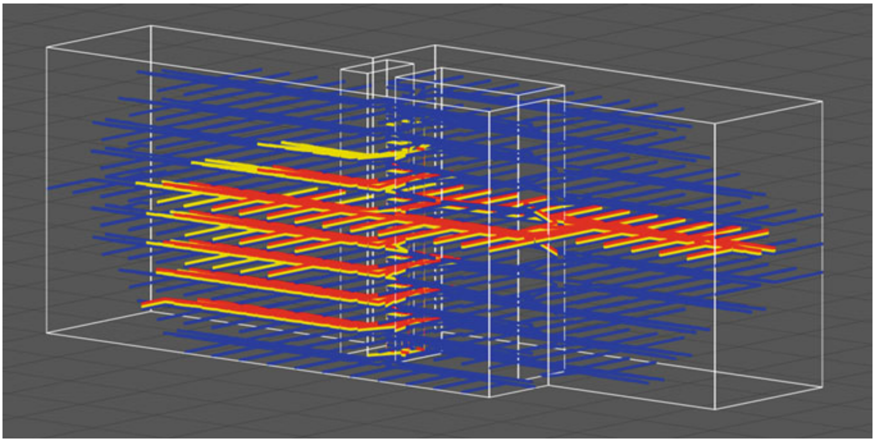


Fig. 6 Three sets of visited nodes: Dijkstra's algorithm (*blue*), A* using the standard heuristic h_e (*yellow*) and A* using the proposed heuristic $h_{3D\_building}$ specialized for routing in 3D buildings. We are visualizing the edges leading to the visited nodes instead of the nodes itself because of clearer visibility

$$h_{3D\_building}(n) := \sqrt{w * ((n.x - goal.x)^2 + (n.y - goal.y)^2) + (n.z - goal.z)^2} \tag{7}$$

with a weight w out of [0,1]. Experiments showed that 0.5 is a valid choice of w in our test case. Using this heuristic the vertical distance gets a greater weight. In Fig. 6 you can see a resulting set of expanded nodes (red). A* using our heuristic $h_{3D\_building}$ outperforms both Dijkstra's algorithm as well as A* using the standard heuristic h_e.

4.2 Experiments

In order to do a more extensive test we chose 100 pairs of points in our 10-story test building (see Fig. 5) at random and computed the shortest path with all three algorithmic options on this set of points. We made sure, that none of these randomly chosen points lies outside of the building so we have no outliers. The test was done on an Athlon 64 X2 system with 2.21 GHz. The graph consists of 3,832 nodes and 11,886 edges. All three algorithmic options find the same path for each of the point pairs.

Table 1 shows that on average A* using our heuristic h_3D_building needs 29 % less run-time than A* using the heuristic h_e and 77 % less run-time than Dijkstra's algorithm.

Table 1 Accumulated computation times and numbers of expanded nodes of 100 shortest paths between randomly chosen points of the 10-story building depicted in Fig. 5

	Dijkstra	A*	A*-3D_building
Time	192 s	63 s	45 s
Expanded nodes	94,950	29,975	25,921

The runtime includes the generation of the dynamic parts of the graph and the shortest path computation itself

5 Conclusion

We showed that using the concept of visibility graphs can improve indoor navigation without requiring excessive amounts of run-time. Based on the assumption that each floor is modelled as a polygon we showed how highly accurate shortest paths can be computed using completely arbitrary positions for start and goal nodes. To achieve this we adopted the concept of reduced visibility graphs which are automatically constructed from polygonal floor plans. Furthermore, we introduced a new heuristic which enables A* to favour vertical over horizontal movement, leading to 29 % less run-time.

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Travel-Mode Classification for Optimizing Vehicular Travel Route Planning

Lijuan Zhang, Sagi Dalyot and Monika Sester

Abstract Navigating and travelling between destinations with the help of Geographic Information Systems route planning is a very common task carried out by millions of commuters daily. The route is mostly based on geocoding of the addresses given by the traveller based on static road network into digital-map positions, and thus the creation of path and directions needed to be taken. Today's navigation data sets rarely contain information about parking lots, related to building entrances, and walking paths. This is especially relevant for large building complexes (hospitals, industrial buildings, city halls, universities). A fine-tuned route tailored for the driver requirement, e.g., park the car close-by to destination, is required in such cases to save time and frustration. The idea of this chapter is to extract this information from the navigational behaviour of users, which is accessible via an analysis of GPS traces; analysis of car commuters in relation to their point of departure and destination by analysing the walking path they took from—and to—their parked car in relation to a specific address. A classification scheme of GPS-traces is suggested, which enables to classify robustly different travel modes that compose a single GPS trace. By ascribing the classified vehicular car trace, which is accompanied by a walking path to/from the car, to a specific address, it is made feasible to extract the required ascribed data: parking places corresponding to that address. This additional data can later be added to the road network navigation maps used by the route planning scheme to enable the construction of a more fine-tuned optimal and reliable route that will prevent subsequent detours.

Keywords Data mining · Classification · GPS · Route planner · Optimization

L. Zhang (✉) · S. Dalyot · M. Sester
Institut für Kartographie und Geoinformatik (IKG), Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany
e-mail: Lijuan.Zhang@ikg.uni-hannover.de

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1 Introduction

Nowadays, vehicle drivers use commercial route planners via electronic maps to guide them from their point of departure to destination: from finding an office to planning cross-country excursions. The routes given by mass-use route planning systems, such as Yahoo! Maps, Google Maps, to name a few, are commonly constructed and based usually on static data derived from the use of road networks existing in geospatial libraries and databases. Most algorithms that rely on such road networks are usually based on designed cost-function schema—or a mix of such functions—associated with the network 'edges'; most commonly used ones are travel time, distance, scenic value, etc., which together construct the 'most optimal' route. Relying solely on the road network yields that not all available data regarding neighbouring attributes, for example parking lots or means of access, are taken into consideration when the route is being constructed. Moreover, the destination point, which is normally an address, is being geocoded into a single position, e.g., coordinate, on the digital-map. A driver who is unfamiliar with the area and uses a vehicle to get to that destination address will usually require a car parking, which adds some ambiguity since this might not exist or be accessed directly from the destination address; thus, a detour to the assigned route is unavoidable. Consequently, an alternate route that is the optimal one for the driver's needs might have been constructed in case the driver's destination was the parking place affiliated with his specific destination address that he wishes to get to. Figure 1 depicts such an example, in which a fine-tuned route (right image) that directs the driver from point of departure (denoted as *A* in green bubble) to the affiliated parking place (brown circle) of his desired address (denoted as green arrow) is shorter by 400 m than the optimal preliminary route constructed (left image). A detour to find the affiliated parking (denoted as red arrow) will cost the driver in this case to drive an additional distance of 1,100 m. These translate to a fine-tuned solution that will evidently save the driver, who is unfamiliar with that area, time and unnecessary frustration.

GPS-data today are often collected through mobile handheld devices. As a result, roads, paths and routable traces derived by GPS measurements are collected straightforwardly by pedestrians, vehicular commuters, bicycle riders, and more. The assumption is that every GPS-trace stores some unique and relevant characteristics that are dependent on a specific travel-mode resultant by the road-type it was acquired on. A single such trace is usually composed from several sub-traces; each corresponding to a different travel-mode. Based on this assumption, a GPS-trace composed of vehicular driving data accompanied by walking paths before and/or after points to a route where parking took place; parking that apparently is essential to get to a specific address or location. By being able to classify correctly such trace should deliver the data that is required to construct the optimal route planning, and hence update the existing navigation map with this significant and valuable data.

This research proposes a classification scheme of GPS-traces, which enables to classify robustly different travel modes that compose a single GPS trace.

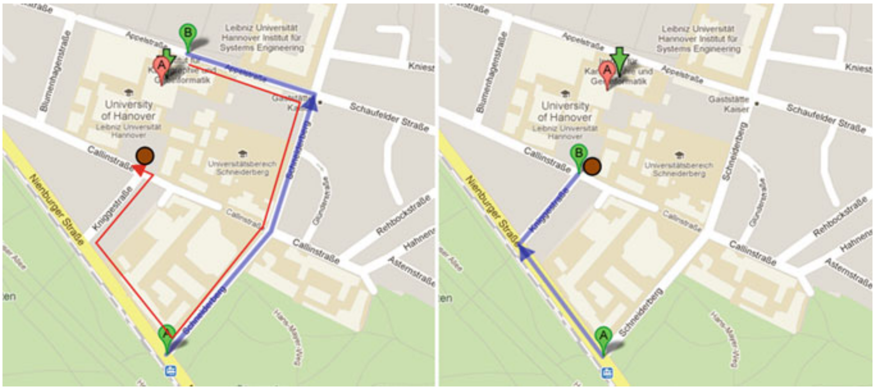


Fig. 1 An example showing different planned routes using Google maps (*left*): directly to the address (*denoted as green arrow*), and to the address's affiliated parking place (*brown circle*), yielding a route that is 400 m shorter (*right*). *Red arrow* (*left*) depicts the additional 1,100 m required in the first route to get to the parking place (*source* http://maps.google.com/)

By ascribing the classified vehicular car trace, which is accompanied by a walking path to/from the car, to a specific address (building), it is made feasible to extract the required ascribed data: parking places corresponding to a specific address. This additional data is added to the route planning scheme enabling to extract a more fine-tuned optimal route.

2 Related Work

Since data in road networks is usually static, path construction is mostly based to some extent of pre-computations, which are stored and re-used for acceleration reasons. Classical static algorithms might suggest the Dijkstra's Algorithm (Dijkstra 1959), which maintains an array of tentative distances for all nodes exist in the road network. As shown by Delling et al. (2009), though most algorithms used today will aim to guarantee (to some extent) that indeed the shortest route (path) is found, the commercial route planning systems usually settle for an approximate result. This usually happens due to the fact that these systems neglect certain data as being unimportant for certain preference issues, thus moving away from the optimal solution.

Due to increase in mobile navigation systems, as car navigation and the use of smartphones equipped with GPS, dynamization is integrated into the route planner: traffic jams and such can also be incorporated (for example: Biagioni et al. 2011). This also yields the use of Multi-Criteria Routing (for example: Li et al. 2011; Nadi and Delavar 2011), which states that the fastest or shortest route in the analysed network is often not the 'best' one—since other criteria are to be taken into account. For example: price—or in this chapter's case—time spent for finding a parking spot. This also yields Multimodal Routing constraints (walking to and from) that might also have a significant influence and criteria on the optimal route chosen. Jariyasunant et al. (2010) had suggested a real-time route planner system to predict shortest path between any points—while relying on static maps only—together with incorporating third-party information. It also integrated to the analysis user-defined data that considered the travel mode in different regions of the path to achieve close to optimal routing. Axhausen et al. (2003) attempted to construct route planning scheme that is based solely on a vast number of GPS traces collected; still, no attempt was carried to try and classify the different traces—assuming all where only vehicular ones—in order to produce a fine-tuned optimal route tailored for a specific need, for example: means of transportation. Adapting such scenarios is perhaps one of the main challenges in near future.

Since GPS observations alone supply only with geometric and temporal data, specific data-mining methods have to be applied in order to extract the required information of travel-mode type classification. Most approaches include two steps in such process: a segmentation of the trajectory into a series of single travel-mode; and, assigning a specific travel-mode to all segments exist in the series. A basic assumption is usually made (Chung and Shalaby 2007; Zheng et al. 2008) that walking is necessary when a mode-change occurs, e.g., change point-based segmentation method. Segmentation of such usually relies on small or no position change accompanied by low speed value and time-length of segments. Though usually found to be accurate, the research proposed here suggests using additional characterization values and parameters, such as heading and single travel-mode pattern-classifiers, thus introducing more robust and non-ambiguous segmentation to a given GPS-trajectory. This is a key-element here, since we look here for vehicular travel modes accompanied by walking (specifically: from/to car).

As for classification, most of the existing methods compare some known preliminary travel-mode related measures, e.g., rule-based values, to empirically determined values. Most commonly used values are derived from the speed and acceleration of a segment (single travel-mode), such as maximum and mean speed (Bohte and Maat 2009; Oliveira et al. 2006). Still, it was shown that these approaches might present ambiguous-classification, thus yield errors and lack the flexibility to examine properly change in pattern and uncertainty of the travel-mode. Also, the thresholds depend on a specific study-area and supplementary data, making them not generic to be implemented for all environments and test-data. To overcome the uncertainty and ambiguity existing in the data, the use of fuzzy logics as a replacement for the empirically determined values is also suggested for classification. The speed and acceleration measures are related as fuzzy sets, while fuzzy membership patterns are structured to enable travel-mode classifiers via linguistic rules (Tsui and Shalaby 2006; Schüssler and Axhausen 2008). Although these researches show an improvement in robustness of classification, the determination of bounds for each linguistic rules associated with each measure, such as fast speed and long travel, was found to be depended on subjective experience exist in the travel-logs. A Decision Tree is also used (for example: Reddy et al. 2008), where the authors present its superiority to other approaches commonly used. Still, some perquisites in the classification process were considered (grouping several different travel mode classes to a single one) together with training data that was relatively small. In past research we had presented a first version of segmentation and multi-stage classification approach dividing it to two supplementary stages. The first stage used a fuzzy-logic classification for identifying walking, cycling and vehicular travel-modes. The second stage entailed the classification of the vehicular travel-mode class using Support Vector Machines (SVMs) schema into car, train, tram, and bus travel-modes. Adopting that scheme showed promising and qualitative classification results of all six different travel-modes. In this chapter, this is explained in more detail with additional examples, while data extracted (classified) is used for the determination of important locations in the network, namely parking lots and access paths to buildings.

3 Segmentation and Classification Methodology

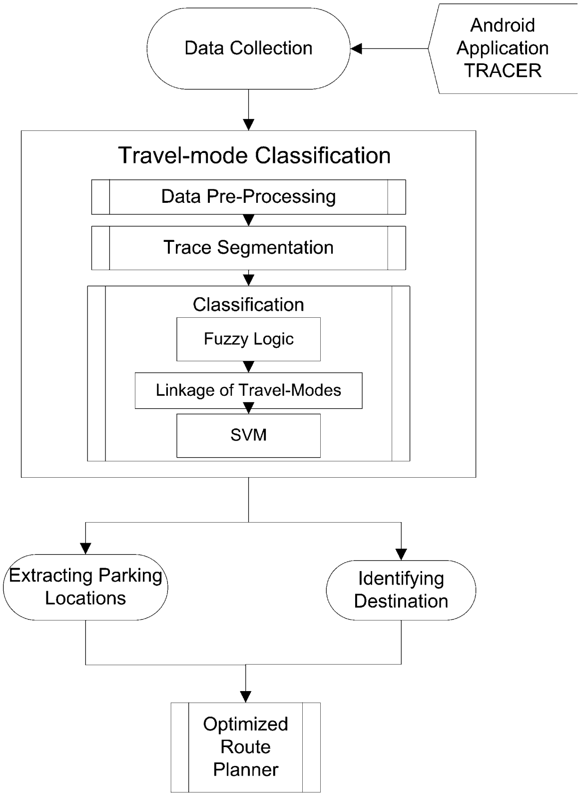
Classifying correctly car and walk travel modes is the main emphasize given here; by doing so, the added data required to fine-tune the GPS routes and make them optimal is made feasible. Since the research carried here try to simulate the natural way of commuters in their everyday all available data is collected and classified. Work schema of the proposed methodology is presented in the diagram, depicted in Fig. 2.

3.1 Data Collection

GPS traces involved with vehicular car routes in the urban region of Hanover City were collected using android-based handheld mobile devices (smartphones). These devices, which are equipped with GPS for collection of positions, used a designated application for data collection that was developed specifically for this research. To evaluate the reliability of the approach presented here, travel-modes are recorded also by the application as reference—together with the collection of the traces' positions. Emphasis was given to simulate the natural way of commuters in their everyday life during data collection without applying any special concerns or restrictions.

Since the reliability and consistency of the travel-mode classification process is a primer key in this approach, training data with supplementary information is required. The Android-based application, which was programmed in Java, collects GPS data and reference travel-mode tagging specified by the data-collection user. The Graphical User Interface (GUI) of the TRACER, depicted in Fig. 3, presents specific and easy-to-use functions. These functions include: a toggle button for starting and stopping data acquisition (left); and, a button enabling the user to

Fig. 2 Proposed methodology workflow diagram



select (and modify) the current travel-mode (right). The user can choose from six different travel-modes, which were chosen to simulate all travel-modes commonly exercised: Walk, Bike, Car, Bus, Train, and Tram. Though this chapter addresses two specific travel-modes: Car and Walk; still, emphasis was given to verify all travel-modes are enabled and collected, and 'used' during the classification process.

Since the data acquisition is supposed to be a passive procedure, the TRACER application provides with a notification system that requires the user attention on specific predefined events. The notification system utilizes all modes of user notifications provided by modern smartphones, e.g., visual, sound and haptical. If required by the user, a checkbox labelled "silent" allows the user to choose not to be notified by certain predefined events. The idea is that the application will not irritate the user as much as possible, so the data-collection will be a smooth and almost 'transparent' process to the user. Still, certain notifications are used here, while their common goal is to obtain the user's current travel-mode, which is vital for the handling of the training data.

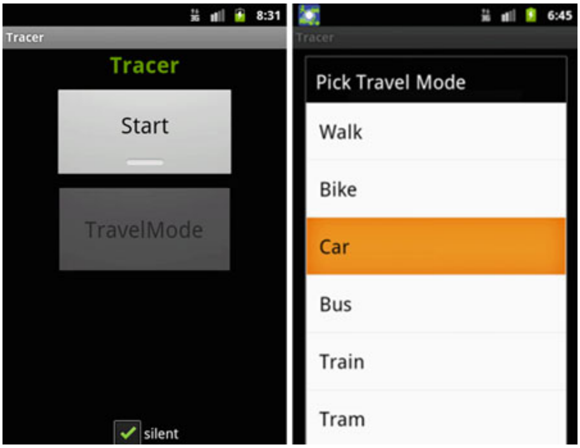


Fig. 3 TRACER GUI: main view (*left*); and, travel-mode selection (*right*)

The TRACER application implements the following events:

- Constant travel-mode update: this event forces the user to update the current travel-mode every 10 min. This is implemented to prevent the user from forgetting to do so, i.e., did not change travel-mode whilst travel-mode had changed.
- GPS-signal loss: this event is triggered only after gaining back of GPS-signal, which was lost for more than 20 s (tunnel, non-coverage area, etc.). This event also prevents cases where travel-mode had changed while no GPS-signal was available.
- Speed inconsistency: this event is triggered when there seems to be speed anomalies in respect to the travel-mode assigned by the user. Thus, speed limits, which are based on some coarse preliminary knowledge, for walking and cycling travel-modes for more than 10 consecutive seconds are implemented. Since thresholds used are coarse, as such they are only a type of warning enforcing and travel-mode change during the data collection process.

3.2 *Data Pre-Processing*

The positional accuracy of mobile handheld GPS signal in normal conditions can reach several meters (Wolf 2006). Still, it is quite common that the positional accuracy is even worse, in cases where there is a lack of sufficient satellites coverage, equipment that is not being ideally positioned (this is common with the use of GPS in smartphones), signal that is being reflected by tall buildings, bad weather—to name a few. The errors are reflected directly on the position of the acquired GPS data. Moreover, since travelling attributes are the key-features for enabling reliable travel-mode classification, positional errors are projected directly on such attributes, such as speed and acceleration. Thus, preliminary reduction of error affects before the calculation of attributes and parameters is implemented. The use of smoothing method to reduce speed errors by averaging its neighbourhood is introduced. The range of the smoothing is five travel-epochs, or seconds under common conditions. Heading smoothing was not implemented here, because heading is not a continuous phenomenon by nature, thus smoothing might remove its characteristic and degrade its reliability as a travel-mode parameter that is required on latter stages of classification.

3.3 Traces Segmentation

Since the relations between both car and walk travel-modes are mandatory to achieve the approach addressed here, it is only logical that a GPS trace is not derived from a single travel-mode; instead, it is composed of several different travel-modes: walking to the car, driving to work and parking the car, and walking from the car to the office (for example). Thus, before any classification can be implemented, a division of the single GPS trace into segments of (still unknown) individual travel-modes has to be implemented. These different segments are categorized and characterized as sub-traces. A definition is made, which states that a sub-trace is composed of a single travel-movement segment that is separated (divided) by two stops. A stop can be a temporal pause in movement (no change in position over time), but also a change in travel-mode (e.g., change point-based segmentation method). Figure 4 (top) depicts an example of stops, which consist of a sequence of observations—black segments—that have very low speed and very small distance changes that on the same time are not classified and defined as a walk. Thus, identifying stops and consequently filtering-out the stops-data before actual classification takes place is important (calculating travel-modes parameters should avoid using stop-data, otherwise modifying these parameters and weakening the reliability of the classification process).

Most researches trying to identify change point-based segmentation commonly use values associated with stops—namely small distance changes per-time and low speed value. This research proposes the use of magnitude in heading change; this parameter was found to be vital for a robust identification of stops. Figure 4 (bottom) depict the idea behind this, where stops are always accompanied with large magnitude values in heading changes (in black), which cannot be explained by realistic movement changes (as the ones in blue or red, for example, which correspond to specific travel-modes). The reason of the existence of these accompanied large values is the result when no change in position occurs, i.e., stops or low speed values, thus large and random magnitude values in heading changes exist due to relatively small change in position. This can be interpreted as heading change noise, which expresses a very limited change in position over time.

The following thresholds are used in this research to form the sub-traces segmentation existing in a single GPS-trace: (All values given below are in respect to

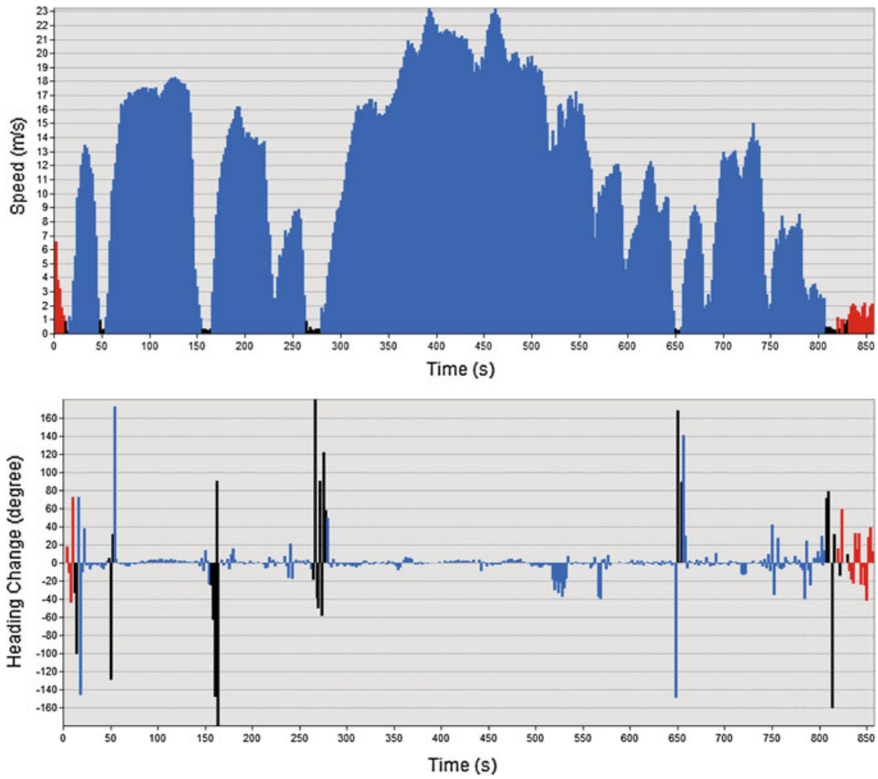


Fig. 4 Speed derived from a GPS-trace representing approximately 15 min of travelling divided into different individual segments in blue (*walk is in red*), and identified stops in *black* (*top*); corresponding heading changes magnitude (*bottom*), showing high correspondence exist between stops (*in black*) having high heading change values

the 1 s time-stamp of the GPS-traces locations collected in this research; modifying these values should be considered when other time-stamp values are used).

- Variation in position: cases where distance change for 5 consecutive seconds is less than 5 m are identified as stop.
- Speed values: cases where for 5 consecutive seconds speed value is less than 0.5 m/s are identified as stop.
- Magnitude in heading change: cases where heading change value for 5 consecutive seconds is larger than 100 decimal degrees are identified as stop.

The algorithm workflow is as follows:

- From the first observation point on, in case accumulative distance from that observation point to the fifth consecutive observation point neighbour is less than 5 m—break the trace from that point; go to step 2.

- Check all points existing in this 5-points segment: if speed is smaller than 0.5 m/s and/or change of heading magnitude is larger than 100°—check next point. Else—break the trace from that point and go to step 1. If no break occurs—go to step 3.
- Assign the sixth point (in regard to the first observation point examined) as the beginning point—go to step 1.
- Stop when reaching the end of the trace.

3.4 Segments Travel-Mode Identification

Classification is applied to the separate segments identified earlier, which together compose a single GPS-trace. This is finalized by linking of neighbouring segments that have been classified with the same travel-mode to form a sub-trace. It was found that the characteristics of walk and bicycle travel-modes are prominently different from all other travel-modes, categorized here as vehicular class. Additionally, a classification all four vehicular, namely car, bus, tram and train, which is based solely on the segments, might result in an ambiguous results. This is due to the fact that the divided segments might present similar characteristics (parameters values), while the characteristics of the whole sub-trace of a specific travel-mode are not utilized. For example, buses and cars are specifically different on the fact that buses have regular stops and cars do not. Still, by examining a single segment only might show otherwise.

As a result, adopting a multi-stage method is required: on the first stage, pedestrian and bicycle travel-modes are differentiated from motorized vehicles based on specific characterizations and specification of their segments. On the second stage, segments are linked up to form sub-traces, and consecutively car, bus, tram and train travel-modes are classified based on the specific characterizations and specification of the sub-traces. Still, the proposed idea behind this research is concerned mainly with car travel-modes associated with walking travel modes to/from the car, thus the first stage should satisfy this requirement. Nonetheless, the second stage is presented in short here, which is required where validating that the travel-mode classified is indeed of a car is required.

First stage classification, which is derived from two main parameters associated with travel modes, is employed based on fuzzy logic classification scheme:

- Speed related characteristics are very important for identifying travel-modes, mainly in this stage. Four principal parameters are used here, namely: mean speed, maximum speed, mean acceleration, and maximum acceleration. These are calculated for each individual segment of the trace. To achieve more reliable parameters and reduce classification errors and bias that might exist when using one observation alone for each segment, the parameters of maximum speed and maximum acceleration are calculated based on the average values of the largest five (5) values exist in the segment.

- Heading related parameters, namely mean and maximum heading magnitude changes, are also employed. The heading change is calculated in a way that it is in the range of (−180°, 180°) decimal degrees. When calculating mean heading changes all values are transferred to positive because the magnitude alone—and not the sign—is of importance. As shown earlier in Fig. 4, while maximum heading change corresponds to stops, walking always show a large magnitude value for the average heading changes, thus making this parameter very useful for this stage classification.

Figure 5 depicts three of the classifiers, namely mean speed, maximum speed and mean heading changes, used in the fuzzy logic classification stage. Wide enough ranges for the three classifiers are used to include all possible segments into consideration whilst avoiding making wrong classification. As stated earlier, additional classifiers are used to validate correct travel-mode separation and classification. From Fig. 5 it is clear that there are some overlay areas for the parameters used, between: stop and walk, walk and bicycle, and bicycle and motorized vehicles. Taking all three under consideration, a minority of segments will fall into these overlay areas simultaneously. Solving these ambiguities yielded extra parameters to be incorporated into the fuzzy logic classification process:

- Stop and walk overlay area: maximum heading change is introduced. Since stops are always accompanied with high magnitude values of heading change, it was found that in case this value for a specific segment is larger than 80 decimal degrees, the entire segment can be classified as a stop (and not walk).
- Walk and bicycle overlay area: the use of second order polynomial is performed, where the polynomial is fitted to the segments speed pattern. The coefficients (a,

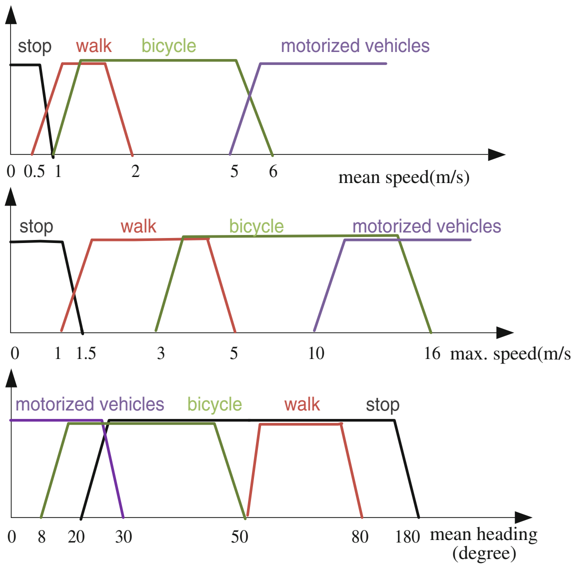


Fig. 5 Fuzzy logic classification: value range used for different travel-modes—mean speed (*top*), maximum speed (*middle*), and, mean heading changes (*bottom*)

b, and c) of the best fitting polynomial are used, where it was found that walking usually show a constant value of the second coefficient (b)—as opposed to bicycle, which is noisier.

- Bicycle and motorized vehicles overlay area: the use of maximum acceleration is introduced. It was found that when bicycle travels with a relatively high speed (mean speed >5 m/s) it is accompanied with high value of acceleration (maximum acceleration >4 m/s^2)—as opposed to motorized vehicles, which will usually show a smaller maximum acceleration value when travelling at these speeds.

3.5 Sub-Traces Construction: Linkage of Travel-Modes

Neighbouring segments with the same travel-mode are linked up to form sub-traces, which are assigned a travel-mode of walk, bicycle or motorized vehicle. The segments are checked with specific predefined rules to ensure they are not incorrectly classified before joined to a sub-trace. For example, a vehicular segment, which has a relatively low speed (parking process, for example), may be wrongly identified as bicycle. However, if this segment's neighbouring segments both are classified as vehicular segment travel-mode, and since it is not possible to transfer directly from bicycle to car, for instance, without stop or walk, the travel-mode is corrected and re-classified accordingly.

In order to correct the possibly wrongly classified segments, rules are applied during the linking procedure according to the basic travel knowledge:

- A travel-mode should exceed the period of 120 s—the use 120 s is designed to eliminate sub-traces that are too short and thus have no significance on the sub-trace, or are wrongly classified.
- Stop duration between two neighbouring segments of one sub-trace should be less than 120 s—if the stop duration is longer than 120 s then the trace should be treated as two individual sub-traces.
- No direct transformation from bicycle to any of the motorized vehicle class is possible—unless at least 120 s of walking or stop took place. The time duration threshold of 120 s is used to avoid linking two different modes together. This linkage rule is of major importance here, since it helps in identifying walk travel modes accompanied with car travel mode, and perhaps more importantly, avoids the classification of bicycle travel mode that come before/after a car travel mode.

3.6 SVM Classification

Since this research is aimed at classifying car and walk travel-modes only, the first stage facilitates this. To assure the classification of car travel-mode (and not public bus or train, which is normally accompanied with walking, for example), the use of the supervised learning method SVM is employed, aimed at classifying the different motorized vehicles (that includes car, bus, tram and train). SVMs are a popular machine learning method used in recent years for classification and other learning tasks. This method projects the parameters to a high–or infinite–dimensional space and constructs a hyperplane, which can be used for classification (Smola and Schölkopf 1998). The SVM produces a model based on a set of training data (attributes together with target values), and then uses this model to predict the target value of the test data with attributes only to find the solution for the optimization problem. A kernel function is used; in this case a Gaussian Radial Basis Function (RBF) that is suitable for cases where the relation between class and attributes is simultaneously nonlinear and linear (Hsu et al. 2003).

SVM classification is based solely on the constructed sub-traces of the already-classified motorized vehicles. The entire sub-trace is treated as a single object, and the attributes of each sub-trace are presumed to describe the characteristics of a unique travel-mode. An assumption is made (for a more reliable classification of cars) stating that bus, tram and train travel-modes should present regular stops, which are longer than those of car; this together with similar travel duration between two consecutive stops. Additional parameterization of travelling characterization—11 parameters in total—is used as attributes in the SVM implementation:

- Mean and standard deviation of maximum speed
- Mean and standard deviation of average speed
- Mean and standard deviation of acceleration
- Mean and standard deviation of average acceleration
- Mean and standard deviation of travelling duration
- Ratio of stop duration in respect to travelling duration.

Each segment within an individual sub-trace is used for the calculation of the aforementioned attributes. The attributes are scaled before applying SVMs to range (0, 1). Both the corresponding attributes of training and testing data are scaled in the same way. The main advantage of doing so is avoiding the attributes in greater value ranges dominating those in smaller numeric ranges, together with benefit of reducing calculation complexities.

4 Travel Route Plan Optimization

4.1 Extracting Parking Locations

After classification of all GPS-traces is finalized, all traces composed of car accompanied by walking travel-modes are analysed for the proposed optimization route planning process. First, all change points are identified where travel-modes are altered from car to walking—or vice versa. These locations refers and points to the desired information about parking lots related to building entrances. Also, these locations refer to starting/ending point of walking paths taken by the driver that are located nearby the point of departure—or destination. Consequently, these locations will have to be associated to specific addresses in their vicinity to be associated as their parking lots.

4.2 Identifying Destination

Since the positional accuracy of the GPS is at least several meters (and worse in build-up areas), and GPS multipath signal errors and signal-loss is common in the vicinity and inside of buildings, identifying correctly the building in which the walking started/ended in is important. This stage is achieved by performing a buffering process around building features in the close vicinity of the start and end points locations identified earlier. A building feature buffer that contains in its spatial extent (intersect) the first/last walking signal acquired in the trace, or some walking trace-segments, is assumed to be associated to that trace; hence, destination address can be identified. An example of this process is depicted in Fig. 6. Since parking lots are mostly situated in the vicinity of large building complexes (hospitals, industrial buildings, and such), the assumption is that if several building buffers contain the same walking positions, all can be attributed to the same parking lot position since it probably serves all these buildings. Buffer size used is derived from the positional accuracy of the building features (existing in the given database), but also from the positional certainty of the GPS signals acquired during the walking trace. Since build-up areas is of poor positional certainty, this value should be considered based on some knowledge of the errors at hand. In the examples analysed in the next chapter, buffer size used had the magnitude of 10 m, which was found to be sufficient.

5 Experimental Results

5.1 Classification

Evaluating the reliability and certainty of the classification methodology is carried out. This is an important assessment to verify that indeed when all the collected observations are processed, only those GPS-traces that are relevant to the fine-tuning process, namely car traces accompanied by walk, are identified correctly. 149 GPS-traces were collected in the study-area of Hannover City. Almost all traces are composed of two or more travel-modes. Table 1 depicts the fuzzy-logic classification results, showing high statistical classification certainty of close to 100 % for all classified travel-modes. When compared to the available reference

Fig. 6 Building buffer containing walking travel modes to/from car parking place: car traces are represented in *blue*, walk traces are represented in *red*

Table 1 Fuzzy-logic classification results

Travel-mode	Total	Correct	Statistical classification certainty (%)
Walk	47	44	94
Bicycle	19	18	95
Motorized vehicle	170	165	97

data (TRACER tags) the most common erroneously classification is walk-stop; this usually occurs when walking presents very low speed together with rapid stops.

Table 2 depicts the SVM classification results after comparing all observations to the available reference data (TRACER tags). Perhaps the most significant figure in this table is depicted in the upper row, showing 98 % certainty for car travel-modes that are correctly classified; this is very important to the scope of this research since these traces are later used for the optimization process. Analyzing the error matrix received for the SVMs classification showed that no other type of vehicular travel mode was classified as car, which also strengthens the assurance of this classification process.

Table 2 SVMs classification results

Travel-mode	Training data	Testing data	Correct	Statistical classification certainty (%)
Car	49	50	49	98
Bus	11	10	8	91
Tram	19	9	7	78
Train	4	2	2	100
Total	83	71	66	93

5.2 Identifying Parking Lots and Entrances

Since all GPS-traces are classified automatically and with high statistical certainty, the final stage in which the route plan is being optimized can take place. All traces composed of car accompanied by walking travel-modes are identified, so the extraction of parking locations and the identification of buildings/addresses can take place. An example is depicted in Fig. 6, which shows a building buffer polygon containing traces of walking travel-modes (in red) emerging from car travel modes (in blue). It is visible that the 10 m building buffer covers in its extent all walking traces leading to/from it. Since this building has two entrances, some walking traces lead to its north entrance associated to the east parking lot, while the other lead to its south entrance associated to the south parking lot. Consequently, both parking lot positions are associated to this building. Also, it is visible that other building in the vicinity will also be associated to one (or both) parking lots extracted here.

Figure 7 depicts a scenario of the proposed route optimization: blue traces represent car travel-mode and red traces represent walking travel-mode (right). The left image depicts the default route plan produced via Google Maps, while the right image depicts the route which would be taken if the parking lot was available in the data set, which is devised by knowing the digital-map position (coordinates) the car should get to in order to park. The position of the parking place is the one that was associated with the walking route—represented by the red traces. This scenario shows that the optimized route is much shorter—approximately 800 m. Not only that the route is shorter, thus saving driving time, the driver will most probably save some time and frustration in finding this specific parking place.

Figure 8 depicts two additional scenarios, in which by knowing the parking place associated with the desired address the driver is directed to a different but more appropriate and optimized location. By doing so, the driver is not directed straight to the address, represented by a pink buffer in both images. In this way, the system is able to automatically detect the most appropriate locations for parking spaces related to certain addresses. This information is revealed from the behaviour of users.

These examples amplify the argument presented in this research: by including the knowledge regarding parking places in the vicinity of building and facilities addresses into the navigation maps and databases, it is possible to construct a more

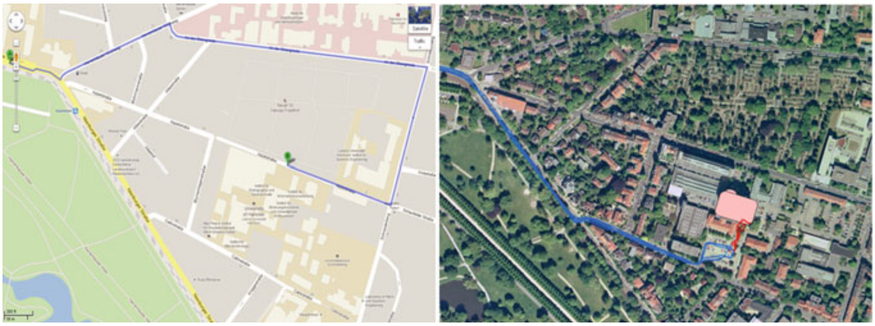


Fig. 7 Route planning scenario: 'off-the-shelf' Google maps route (*left*) (*source* http://maps.google.com/), and optimized route proposed in this research, showing precise classification and extraction of parking place associated with desired address

Fig. 8 Optimized route planning scenarios showing precise classification and extraction of parking place associated with desired address avoiding detour and loss of valuable time: car trace in *blue*, walking trace in *red*, destination in *pink polygon*

fine-tuned route that answers the user requirements; the closest location where he or she can park the car in order to get to the desired address. This is done automatically and with high certainty and positional reliability.

6 Conclusions and Discussion

Routing techniques using static road networks have made tremendous progress in the last few years, mainly in the speed-up domain where fast query response time is critical. Still, answering also requirements derived from multi-criteria optimization for specific users is under constant development. This chapter presents a working frame that facilitates a more fine-tuned, optimised and fully-automatic route planner that answers specific user demands. In this case, giving driving instruction to a parking place associated with the desired address (destination). This modified route planner makes use of an automatic detection and classification travel-modes working schema of GPS-traces, which are acquired today straightforwardly by travellers. Segments of GPS-traces and sub-traces comprised of an individual travel-mode are found with very high certainty, reliability, and efficiency. Preliminary tests and examples presented in the chapter are promising, showing good results in producing routes that are usually shorter, but perhaps more important—tailored to the problem at hand. Thus proving technical feasibility as well as having positive effects on the drivers travelling these routes.

Future work will involve the analysis and verification of the presented process on larger datasets, while integrating the extracted knowledge with navigation maps of road networks that are used for real-time route planning. It will also involve the adaptation of the proposed classification methodology to other multi-criteria scenarios, such as adding bicycle path to the route planner. As the appropriate parking locations associated with an address are automatically derived from the users' behaviour, it is also possible to reveal temporal properties, e.g., that the best parking place varies over the day: in the morning there might be enough parking lots in front of a building, whereas in the afternoon a nearby alternative parking lot may be the most appropriate one to use. Also, our first approach for identifying the entrances is rather straightforward using buffer threshold; future work will entail the use of clustering approaches. These are issues of future research we plan to deal with.

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Taxonomy of Navigation for First Responders

Zhiyong Wang and Sisi Zlatanova

Abstract Navigation services are gaining much importance for all kind of human activities ranging from tourist navigation to support of rescue teams in disaster management. With the frequent natural disasters occurring in recent years, emergency navigation for first responders poses a set of serious challenges for researchers in the navigation field. The chapter introduces a taxonomy of navigation among obstacles, categorizes navigation cases on basis of type and multiplicity of first responders, destinations, and obstacles, and reviews related research. This review reveals limitations in current navigation research and challenges that have not been explored yet. We also briefly present our approach using agent-based technology, real measurements and web technologies for the development and implementation of navigation systems that aim at navigating first responders among both static and moving obstacles. Finally, we conclude by providing views on further investigations and developments.

Keywords Taxonomy · Navigation · First responders

1 Introduction

Advances in geographic positioning technologies and the popularity of communication methods such as Internet and ad hoc network have fueled widespread adoption of Location-based services (LBS) in many everyday situations, especially in emergency response scenarios. LBS applications have shown the potential to be

Z. Wang (✉) · S. Zlatanova
OTB Research Institute for the Built Environment, TU delft, Jaffalaan 9, 2628BX Delft, The Netherlands
e-mail: Z.Wang-1@tudelft.nl

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a valuable addition in disaster management (DM), providing a variety of services that facilitate rapid response (Togt et al. 2005). Typical examples of these services are location and navigation. Disaster managers must be able to keep track of their locations. Location information of moving objects such as first responders can be obtained through various outdoor and indoor localization technologies like GPS, wireless local area network (WLAN), radio frequency identification (RFID) and ultrasound range sensors (Khoury and Kamat 2009; Girard et al. 2011; Li and Becerik-Gerber 2011). The frequent changes of large amount of location information demand an efficient management of moving objects which have been intensively studied by many researchers (Sistla et al. 1997; Wolfson et al. 1998; De Almeida and Güting 2005; Meratnia 2005). Besides, rescue teams must be able to be re-routed around dangerous areas to reach safety quickly if conditions change. How to assist users in navigation has been the focus of considerable research effort over the past decades, but some problems still need to be addressed.

Although over the years researchers have put much effort into utilization of location information for navigation purpose, navigation for first responders brings forwards requirements of a higher level, e.g., the coordination among first responders, the incorporation of the obstacles information and the development of corresponding algorithms to deal with these information, all of which are not met by existing navigation developments. Many commercial navigation systems (e.g., Tom–Tom, Mio, Garmin) are designed and developed to provide personalized routing services, and some of them are even able to incorporate information about traffic congestions and suggest alternative routes. However, these systems do not take into account specific emergency response requirements, which result in poor performance in response to disasters. The navigation service provided by existing emergency support systems (Johnson 2008; Parker et al. 2008) are capable of finding the shortest route to a certain location, taking the damages of the infrastructure into account, but lack consideration of real-time information of disasters, which brings serious limitations when applying these systems to disasters that affect road network dynamically. For instance, in response to a real contaminant plume, the emergency response units should not be guided right through the toxic plume by their route planners. This kind of changing plumes can be considered as moving obstacles with changing location and shape that cause temporary blocks of road segments. Although some navigation algorithms have been developed for avoiding moving obstacles, they have not been implemented in the software for emergency response yet due to their insufficiencies. In addition to that, most traditional navigation systems are dedicated to routing for only one response unit with a pair of starting and ending points. But in many emergency situations, response units need to cooperate and perform tasks together. They not only need to obtain individual routes but also take into consideration other units in the area. For example, in the case of emergency medical service, there is a need for a better organization within the hospitals concerning the deployment of paramedics, availability of medical supplies, transportation, and equipments. Ambulances have to deliver several patients to different destinations which can either be static or dynamic in some situations.

This work represents the first step of an approach to support emergency navigation among obstacles for first responders. Our main focus is to propose path-finding methods taking into account both static and moving multiple obstacles. This chapter presents a taxonomy of navigation cases and a set of analysis related to optimal navigation for mobile rescue units. Although prior studies have paid little attention to the emergency navigation among obstacles, various similar studies have been conducted in the field of mobile robot navigation and different kinds of approaches to assist path finding among static/moving obstacles have been proposed (Bowling and Veloso 1999; Zu et al. 2004; Kunwar et al. 2006; Belkhouche et al. 2007; Undeger and Polat 2010), which provide potential opportunities for developing navigation-related solutions for disaster management.

The organization of the chapter is as follows. Firstly, we introduce a taxonomy of navigation for first responders and present selected criteria for our taxonomy. In the following sections, we divide all navigation cases into two broad categories according to the characteristic of obstacles: static obstacles and moving obstacles. Then we briefly review related publications that fit in each case. After that, we present our approach to the problem of navigating first responders among moving obstacles and describe the architecture of our proposed navigation system. Finally, we conclude this chapter and present views on future directions.

2 Taxonomy of Navigation with Obstacles

A number of researchers have addressed issues related to navigation. Advances in various areas such as engineering, computer science, applied mathematics, etc. provide significantly rich solutions to navigation related issues, although their focus and applications can differ considerably. Similar research on robotic navigation considering static/moving obstacles have been considerably investigated for path planning for robots (Bowling and Veloso 1999; Yang et al. 2006; Belkhouche et al. 2007; Li et al. 2009; Undeger and Polat 2010; Ni and Yang 2011). Research results from these work could benefit the research on navigation for first responders in some aspects. For example, Kulich et al. (2004) make use of ant colony algorithms to assign moving objects to multiple target locations. Yang et al. (2006) proposes some methods for finding a suitable collision-free path. However, little attention has been paid to the routing problem for multiple first responders in the context of obstacles caused by disasters. Most path finding algorithms that are designed for solving obstacle-avoiding problems deal with only one moving object given a pair of starting and end points (Mitchell et al. 1992; Mitchell 1993; Kapoor et al. 1997; Li and Klette 2006; Visser 2009; Nedkov and Zlatanova 2011).

Furthermore, the related work on robot navigation mostly focuses on path planning in free space, but does not take into consideration constrains of the real road network. Besides, the considered obstacles are often stationary, which can not reflect the dynamics of physical phenomena (flood, plume, fire, etc.) that cause disasters. (Mitchell et al. 1992; Mitchell 1993; Van Bemmelen et al. 1993; Kapoor et al. 1997; Li and Klette 2006; Nedkov and Zlatanova 2011). Since the status of the road network varies with the disasters over time, it is necessary to take into consideration the moving obstacles in the path finding process. Moreover, the first responders work in groups and cooperate with each other to achieve the common goal (e.g., searching for the survivors within an area affected by disasters), the coordination between their paths should also be considered.

In order to understand navigation cases in disasters, we need to categorize them and break them down into their lower-level classes. More importantly, by introducing a comprehensive review of categories, we can gain a greater understanding of characteristics and differences of these cases and study them separately. This taxonomy also encourages the design of new techniques by taking advantage of achievements in relevant fields. In previous navigation research, Zlatanova and Baharin (2008) present a taxonomy of navigation, trying to structure this field into different categories. Nevertheless, this classification does not take into account the obstacles. The aim of this work is to explore possible navigation scenarios in disasters by constructing this taxonomy.

Instead of a strict classification (which is very difficult to provide), we offer some broad keywords and phrases that characterize some classes of these cases. We assume that: (1) We deal with moving objects (e.g., responders), but they start moving at a given time and from given positions (2) We have multiple obstacles, i.e., if the routing works well to avoid many obstacles, it should be able to deal with the environment with one obstacle as well. Following these assumptions, we have identified the following criteria and distinguish the cases in the form of a quadruple:

$$X = \langle X_1, X_2, X_3, X_4 \rangle$$

where

- $X_1 \in \{o, m\}$ is the number of responders (one or many)
- $X_2 \in \{O, M\}$ represents the number of destinations (One or Many)
- $X_3 \in \{S, D\}$ is the type of destinations (Static or Dynamic)
- $X_4 \in \{s, m\}$ corresponds to the type of obstacles (static or moving)

For example, one case denoted by $\langle o, M, D, m \rangle$ means one moving object has to be routed to many dynamic destinations, avoiding many moving obstacles.

We offer an overview of work that fits to each case and illustrate its potential application to emergency response. We do not claim that this taxonomy is explicit, since further refinements can be performed if adding more criteria, e.g., the obstacle can change its shape or not; the movement of the obstacle can be a priori known or not; the obstacle can have either distinct boundaries or fuzzy shape due to the nature of disasters. However, most current navigation cases fit into our taxonomy.

3 Navigation Cases with Static Obstacles

In the following section, we mainly consider the navigation problems that deal with static obstacles.

3.1 One Moving Object has to be Routed to One Static Destination, Avoiding Many Static Obstacles $\langle o, O, S, s \rangle$

This is a typical example of the rescue operation when a large-scale disaster occurs. The rescue team has to be routed through an affected area of which some segments are not passable. This case has been well studied in computational geometry, which is to compute an optimal obstacle-avoiding path in a geometric context. The most basic form of the problem is: Given a collection of obstacles, find a Euclidean shortest obstacle-avoiding path between two given points. By considering several parameters that define the problem, a broader collection of problems has been defined and investigated, and accordingly various algorithms have been proposed (Li and Klette 2006; Mitchell et al. 1992; Mitchell 1993; Kapoor et al. 1997). The case for real road network is also studied. Schmitz et al. (2008) present an example of utilizing OpenStreetMap (http://www.openstreetmap.org) data for the disaster management operation. A web-based route service called OpenRouteService (http://openroute-service.org) is developed to provide route planning services taking blocked areas or streets into account. For similar purpose, Nedkov and Zlatanova (2011) propose a method for performing shortest path calculations taking constraints and obstacles into account. The A* path-finding algorithm is used to guide Google's Directions Service around obstacles (see Fig. 1).

3.2 One Moving Object has to be Routed to Many Static Destinations, Avoiding Many Static Obstacles $\langle o, M, S, s \rangle$

This situation may occur when a rescue unit has to visit multiple emergency locations within an affected area. For example, a fleet of rescue trucks is sent to deliver relief goods to several affected locations after a strong earthquake. The information of severely damaged transportation infrastructure is essential in the routing for this emergency response service. This problem can be addressed as a variant of the traveling salesman problem (TSP), the goal of which is to plan a trip with least cost in an environment with obstacles. Faigl (2011) proposes two self-organizing map (SOM) algorithms for the TSP which are examined in the multi-goal path planning problem motivated by inspection planning in the polygonal domain that contains obstacles. The first is Somhom's algorithm, and the second is the Co-adaptive net. The authors improve the algorithms using modifications of

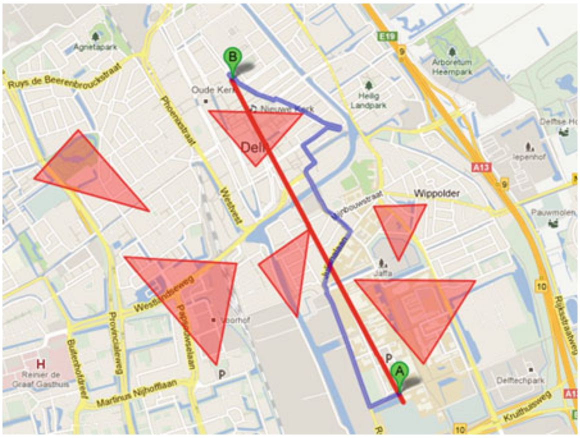


Fig. 1 Calculated route result (from Nedkov and Zlatanova 2011)

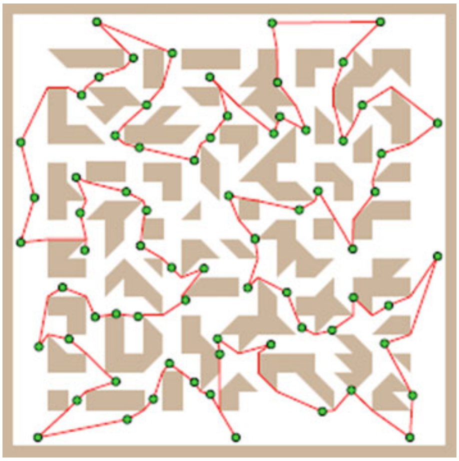


Fig. 2 Selected solutions found by the modified Somhom's algorithm, the small disks represent cities (from Faigl 2011)

recent adaptation rules and by new proposed improvements, which significantly reduce the required computational time. One of selected solutions found by the modified Somhom's algorithm is presented in Fig. 2.

3.3 Many Moving Objects have to be Routed to One Static Destination, Avoiding Many Static Obstacles $\langle m, O, S, s \rangle$

This situation often takes place after the occurrence of disasters. A classical example is that several fire trucks have to be routed to a fire location through a road network damaged by earthquake or flood. This problem can be split into sub-problems by navigating moving objects separately, which can be addressed by approaches proposed for $\langle o, O, S, s \rangle$. We can also extend this problem by

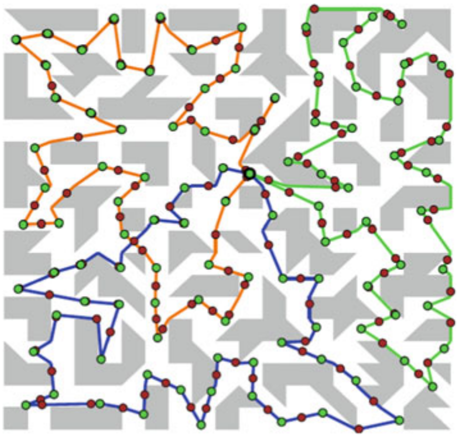


Fig. 3 The best solution found for 3 agents in the map with 100 cities, obstacles are in grey (from Kulich et al. 2004)

considering moving objects as moving obstacles. In this extended case, each moving object takes into account other moving objects in its path planning to avoid potential collisions. This extended problem can be re-formulated into the problem that arises in the case $\langle m, O, S, m \rangle$.

3.4 Many Moving Objects have to be Routed to Many Static Destinations, Avoiding Many Static Obstacles $\langle m, M, S, s \rangle$

This is the case that often takes place when major disasters strike. Several rescue teams are dispatched to perform tasks in different places or to transport a large amount of materials to the disaster areas. Substantial efforts have been made to provide the optimal set of routes for fleets of relief vehicles. The difficulty of this problem arises when obstacles are taken into consideration. Intelligent algorithms with improvements provide a promising approach to overcome this difficulty. Kulich et al. (2004) apply three soft computing techniques—ant colony optimization, genetic algorithms, and neural networks to rescue operation planning that can be restated as the multiple traveling salesmen problem (MTSP): given N cities and A agents, find an optimal tour for each agent so that every city is visited exactly once. It improves the selected techniques by introducing suitable heuristics and applies the implemented solutions in large areas with obstacles (see Fig. 3).

3.5 One Moving Object has to be Navigated to One Dynamic Destination, Avoiding Many Static Obstacles $\langle o, O, D, s \rangle$

The situation appears when one responder pursues one victim moving in a road network, parts of which are damaged and not accessible. This also happens in the

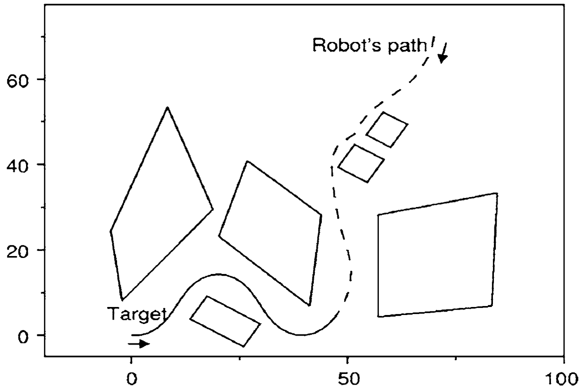


Fig. 4 Robot's navigation toward a goal moving in a sinusoidal motion in the presence of obstacles (from Belkhouche et al. 2007)

free space of a building in which corridors can be blocked by collapsed ceilings or floors. Some researchers have been working on robot navigation in free space. Belkhouche et al. (2007) present a method for robot navigation toward a moving object in presence of static obstacles. The proposed method integrates two navigation modes, parallel navigation mode which is to design a control strategy for the robot in order to reach the moving target, and obstacle-avoidance mode which is to avoid local obstacles. Figure 4 shows that the navigation strategies help robot to successfully reach the moving target under some conditions.

3.6 Many Moving Objects have to be Routed to One Dynamic Destination, Avoiding Many Static Obstacles $\langle m, O, D, s\rangle$

This may occur if many first responders have to be routed through a transportation infrastructure ravaged by disasters to meet somewhere to exchange equipment or transfer the wounded. The responders have to pursue a meeting point that changes with traffic conditions, which needs effective coordination between them, or police cars need to stop a criminal trying to escape. This problem can be seen as an extension of the well-known Pursuit-Evasion (PE) problem with obstacles. Undeger and Polat (2010) address the problem of multi-agent pursuit in an environment full of obstacles. They propose an algorithm called Multi-Agent Real-Time Pursuit (MAPS) for multiple predators to capture a moving prey (see Fig. 5). MAPS employs two coordination strategies, blocking escape directions (BES) and using alternative proposals (UAL), to help the predators waylay the prey in possible escape directions.

3.7 One Moving Object has to be Navigated to Many Dynamic Destinations, Avoiding Many Static Obstacles $\langle o, M, D, s\rangle$

$\langle o, M, D, s\rangle$ happens when a response unit is sent to rescue multiple victims that fleet using traffic facilities hit by natural disasters. In this situation, the response unit

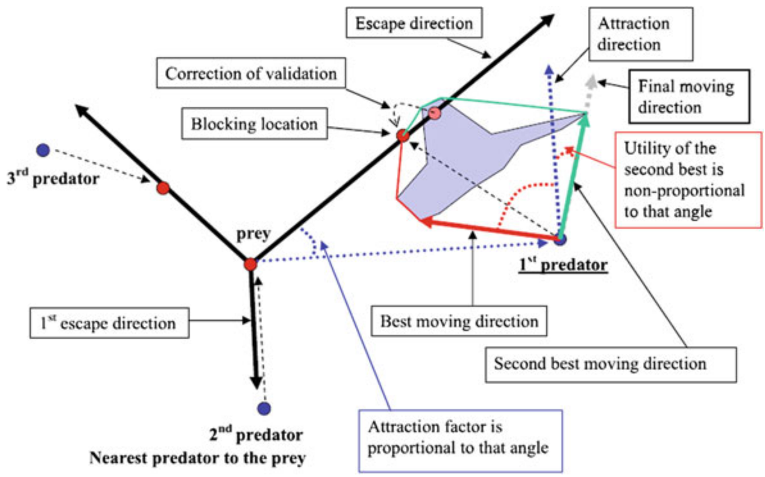


Fig. 5 A complete sample illustrating the entire process of MAPS (from Undeger and Polat 2010)

can be considered as an interceptor and has to be navigated to pursue many targets whose positions change with the change of conditions. This problem has also been studied in robot navigation and a method proposed by Kunwar et al. (2006) for pursuing multi targets taking into account the environment with static and/or moving obstacles will be described in the case $\langle o, M, D, m\rangle$ (see next section).

3.8 Many Moving Objects have to be Routed to Many Dynamic Destinations, Avoiding Many Static Obstacles $\langle m, M, D, s\rangle$

The situation becomes more complex when several responders starting from different positions have to meet at a series of dynamic locations to perform their tasks, avoiding static obstacles. Three basic problems have to be taken into account: (1) path planning; (2) coordination that helps reach the meeting points efficiently; (3) obstacles avoidance. Similar problems in robot navigation have been investigated by Ni and Yang (2011). They propose an approach based on a bioinspired neural network for the real-time cooperative hunting by multi-robots, where the obstacles are linked with different shapes. The bioinspired neural network is used for cooperative pursuing by the multi-robot team. Simulation results demonstrate that the proposed approach can deal with the situations of multiple evaders and can dynamically change the pursuing alliances to guarantee that all the evaders can be caught efficiently.

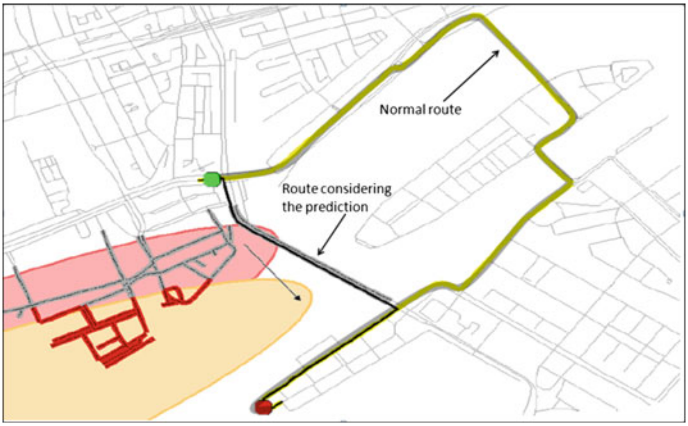


Fig. 6 Route considering the prediction versus normal route (adapted from Visser 2009)

4 Navigation Cases with Moving Obstacles

Based on the literature reviewed, navigation cases with moving obstacles are presented in the following way:

4.1 *One Moving Object has to be Routed to One Static Destination, Avoiding Many Moving Obstacles* $\langle o, O, S, m\rangle$

This may happen when one first responder has to go through an area affected by many moving obstacles (e.g., plume) simultaneously. In this case, the prediction of moving obstacles should be incorporated into the route determination process. Visser (2009) proposes a path-finding approach that takes into account changes in the road network and predictions of future situations. The Dijkstra algorithm is extended to incorporate the routing with predictions of plume movement and bridge openings and closings, and to decide whether it is better to wait or take an alternative route. An example of routing with predictions for one moving obstacle is shown in Fig. 6.

4.2 *Many Moving Objects have to be Routed to One Static Destination, Avoiding Many Moving Obstacles* $\langle m, O, S, m\rangle$

A typical example of this situation is guiding a certain amount of fire trucks to one emergency location. The system should not only compute the routes for all

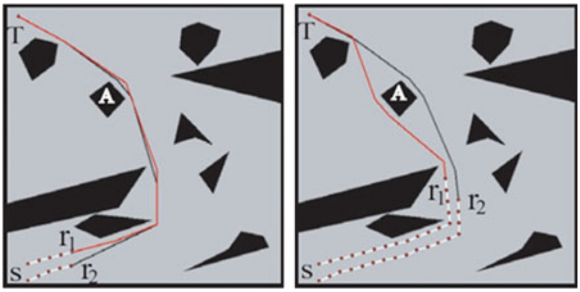


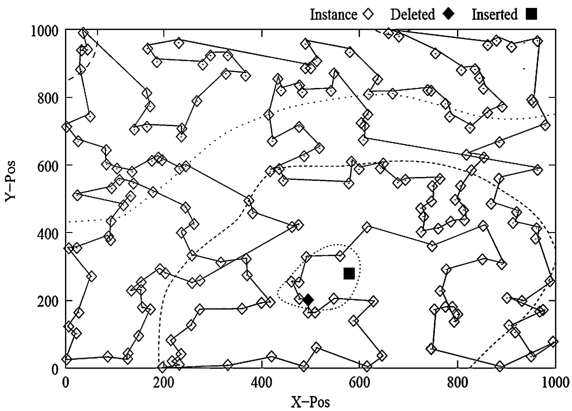
Fig. 7 Path planning for 2 robots with the same target (from Yang et al. 2006)

trucks but also coordinate their paths to avoid traffic congestions or possible collisions by considering other moving objects as obstacles. Some researchers in robotics have been doing research on this topic. Yang et al. (2006) propose a knowledge based genetic algorithm (GA) for on-line path planning of multiple mobile robots in dynamic environments. The proposed GA uses a unique problem representation method to represent the environments with complex obstacle layouts and obstacles can be of arbitrary shapes. An evaluation method is developed specially for accurately detecting collisions among robot paths and obstacles, and assigns costs that are effective for the proposed algorithm. Figure 7 shows the simulation results of path planning for two mobile robots with the same target.

4.3 One Moving Object has to be Routed to Many Static Destinations, Avoiding Many Moving Obstacles $\langle o, M, S, m \rangle$

One classical example is navigating a rescue team to search several places within an area struck by disasters. The navigation system must be able to plan a trip connecting these locations in the dynamic environment, which can be addressed as a dynamic version of TSP. An ant colony optimization (ACO) approach for this dynamic TSP is proposed by Guntsch et al. (2001) to provide a good solution whose quality is averaged over time. A certain amount of cities are deleted or inserted at different frequencies. As shown in Fig. 8, one city is inserted and one city is deleted. The changes of cities could be caused by the moving obstacles in the environment. The authors investigate three different strategies, i.e., Restart-Strategy, η-Strategy and τ-Strategy, for pheromone modification in reaction to changes of the problem instance. They also extend these strategies by combining some of them and proposing a heuristic for keeping a modified elitist ant. The results show their approach can find better solutions for a variety of problem classes than the pure strategies.

Fig. 8 TSP test instance with best solution (from Guntsch et al. 2001)



4.4 Many Moving Objects have to be Routed to Many Static Destinations, Avoiding Many Moving Obstacles $\langle m, M, S, m \rangle$

This navigation problem can be considered as a generalization of TSP, where more than one salesman is allowed to be used in the solution and many moving obstacles exist in the environment. It has practical application in disaster management when disasters (e.g., fire, plume) occur and rescue groups are sent to multiple places to alert or rescue local citizens. The problem is characterized by a dynamical environment and coordination between rescue groups. Li et al. (2009) propose an approach for a multi-robot path-planning problem with the same characteristics. Multiple robots have to coordinate in the workspace while avoiding moving obstacles. A neural-network-based intelligent planner is designed for the coordination of multiagent systems (MASs). The landscape activities of the neural network represent the dynamics of the workspace included with moving obstacles. Simulation results demonstrate the capability of the proposed approach in planning the paths in presence of moving obstacles.

4.5 One Moving Object has to be Navigated to One Dynamic Destination, Avoiding Many Moving Obstacles $\langle o, O, D, m \rangle$

This case $\langle o, O, D, m \rangle$ is similar to the case $\langle o, O, D, s \rangle$. The only difference is that rescuers work in an area with dangerous moving obstacles, which poses a new challenge for researchers. Masehian and Katebi (2007) present a method for generating collision-free near-optimal paths for mobile robots pursuing a moving target amidst both dynamic and static obstacles. They introduce a new concept called Directive Circle (DC) which can prevent the robot from being trapped in deadlocks or local minima. The speeds of dynamic obstacles are calculated online, which requires sufficient robot's sensors in terms of the number and coverage.

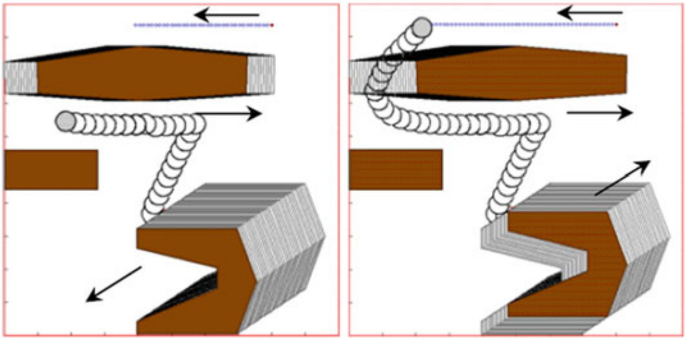


Fig. 9 Collision-free trajectories of robot that pursuits a moving target in an environment with one static and two moving obstacles (from Masehian and Katebi 2007)

As shown in Fig. 9, the proposed method is capable of coping with static and moving obstacles.

4.6 Many Moving Objects have to be Routed to One Dynamic Destination, Avoiding Many Moving Obstacles $\langle o, O, D, m \rangle$

Such situation could occur when many response units have to meet at a certain point which can change with the dynamic situation. The moving obstacles can either be disasters (e.g., plume, fire) or crowds. This is also a variant of the PE problem, where multiple pursuers (responders) must coordinate their moves to jointly capture the evader avoiding moving obstacles. Similarly, in a multi-robot game, robots in a robotic team have to achieve a specific goal avoiding other opponent robots which can be viewed as obstacles. Bowling and Veloso (1999) introduce a motion control algorithm, which allows a team of general differential-driven robots to accurately reach a moving target point in an environment with multiple moving obstacles.

4.7 One Moving Object has to be Navigated to Many Dynamic Destinations, Avoiding Many Moving Obstacles $\langle o, M, D, m \rangle$

This is similar to the aforementioned situation $\langle o, M, D, s \rangle$, but the considered environment is more complex including multiple moving obstacles. As mentioned above, a novel method for the interception of moving targets in the presence of static and/or mobile obstacles is proposed by Kunwar et al. (2006). The proposed method provides simultaneous positional interception and velocity matching of the target moving in a dynamic environment with obstacles. An acceleration command for the autonomous robot (i.e., interceptor) is computed from a rendezvous-guidance technique that considers the kinematic and dynamic limitations of the interceptor, which can be extended to the application of intercepting a set of multiple targets.

4.8 Many Moving Objects have to be Routed to Many Dynamic Destinations, Avoiding Many Moving Obstacles $\langle m, M, D, m \rangle$

This is the most complex case. The responder vehicles have to go through an area affected by several moving obstacles to meet at some dynamic points. This problem may be reduced to a path-planning problem with equal number of vehicles and targets which could be addressed by the algorithm proposed by Zu et al. (2004). They investigate path planning for multi-vehicle multi-target pursuit (MVMTP) and propose a global cost function (GCF) for an optimal one-vehicle-one-target-pair appointment. Each appointed pair uses artificial potential (AP)-guided evolutionary algorithm (EA) to search the path that allows the vehicle to catch the target at a specified criterion while avoiding moving obstacles.

5 Discussion

In this taxonomy, we concentrate on the navigation cases that involve one/many moving objects, one/many static/dynamic destinations and many static/moving obstacles. Table 1 shows a summary of the taxonomy of navigation cases. Many of the cases listed in the table have been investigated by previous studies. In the table, we list 3 aspects of interest, which are separately assigned to one column of the table. The column with the heading "Problem Type" gives the type of the navigation problem: shortest path problem (SPP), pursuit-evasion (PE) problem and traveling salesman problem (TSP). The next column with the heading "Environment Type" indicates whether any investigation has been conducted on the case corresponding to each listed environment type. The last column with the heading "Application Domain" tells if any relevant research on each navigation case have been studied in the concrete application domain. A tick ($\surd$) denotes that it is under investigation, while a cross (x) denotes no investigation is found and a dot (•) means uncertain. As indicated in Table 1, there are 4 navigation cases where typical shortest path routing is applicable. Totally 8 navigation cases associated with dynamic one/more destinations can be seen as generalizations of the PE problem and have been intensively applied in robotics. The other 4 cases with multiple static destinations can be considered as extended TSP problems. Although there are many methods developed for routing with obstacles, most of them are proposed in the mobile robot navigation domain and only a few approaches can be

Table 1 Summary table of navigation taxonomy

	Navigation case	Problem type	Environment type		Application domain	
			Road network	Free space	Emergency response	Robotics
Navigation cases with static obstacles	$\langle o, O, S, s\rangle$	SPP	√	√	√	√
	$\langle o, M, S, s\rangle$	TSP	x	√	x	•
	$\langle m, O, S, s\rangle$	SPP	x	•	x	•
	$\langle m, M, S, s\rangle$	TSP	x	√	√	•
	$\langle o, O, D, s\rangle$	PE	x	√	x	√
	$\langle m, O, D, s\rangle$	PE	x	√	x	√
	$\langle o, M, D, s\rangle$	PE	x	√	x	√
	$\langle m, M, D, s\rangle$	PE	x	√	x	√
Navigation cases with moving obstacles	$\langle o, O, S, m\rangle$	SPP	√	√	√	√
	$\langle m, O, S, s\rangle$	SPP	x	√	x	√
	$\langle o, M, S, m\rangle$	TSP	x	•	x	•
	$\langle m, M, S, m\rangle$	TSP	x	√	x	√
	$\langle o, O, D, m\rangle$	PE	x	√	x	√
	$\langle m, O, D, m\rangle$	PE	x	√	x	√
	$\langle o, M, D, m\rangle$	PE	x	√	x	√
	$\langle m, M, D, m\rangle$	PE	x	√	x	√

applied to obstacle-avoiding routing for emergency response. All in all, we present 16 cases there, but, to the best of our knowledge, only two of these cases, i.e., $\langle o, O, S, s\rangle$, $\langle o, O, S, m\rangle$ have been studied with consideration of constraints of road network by previous research. The remaining cases should be further investigated and there are many open issues that still need to be explored in navigating first responders in the road network with obstacles.

6 Proposed Approach

In our study, we focus on navigation among moving obstacles for multiple first responders. These are the eight cases in the second half of Table 1. We believe the approaches for moving obstacles can be also applied to the problem with static obstacle by setting the moving obstacles' velocity to zero. Furthermore, most emergency responses take place in the outdoor environment, which require navigation services working in real road networks. Currently, our work is limited to the cases including only static destinations. Since navigation problems with both static destinations and static obstacles can be converted to well-known transportation problems by adapting the transportation cost, our research will concentrate on the routing in the road network with static destinations and moving obstacles, and will adapt existing routing algorithms for obstacle-avoidance purposes. As shown in Table 1, with respect to the cases with only one target location (i.e.,

$\langle o, O, S, m \rangle$ $\langle m, O, S, m \rangle$), shortest path algorithms with modifications have been proposed and can be applied to find optimal or near- optimal routes. Therefore we are going to investigate the other two cases, i.e., $\langle o, M, S, m \rangle$ and $\langle m, M, S, m \rangle$. These problems can be seen as various extensions of the TSP. Although previous research (Guntsch et al. 2001; Li et al. 2009) on the same topics existed, they lack consideration of the road network and simulation with real-time measurements, which limit the application of their methods in the navigation aid for first responders. To address these two aspects, we intend to integrate various algorithms with web mapping technologies and agent-based modelling and simulation, which will be corrected with real-time data via sensors and the web. We believe that the agent-based simulation system can facilitate emergency navigation in at least two aspects: (1) the simulation itself has the ability to predict "future" situations with the "current" states as input, serving as a tool for achieving situation awareness; (2) the agent-based simulation could help responders evaluate the routing plan and modify it if necessary. As traditional simulation models based on rigid input parameters, which make little usage of real-time data, fail to reflect the real disaster behaviors and reduce their ability of predictions, we will explore the way to update simulation systems by means of real-time measurements and information to make it capable of adapting itself dynamically to the constant changes of environment conditions. Such capabilities promise more accurate analysis and prediction, and more reliable outcomes that we can use for real-time emergency navigation support. The real-time information can be obtained by sensor measurements (GPS tracking of emergency responders, pollution sensors, filed measurements) or by crowd-sourcing. The advent of the web mapping technologies facilitates the dissemination of data to responders. Building the system on top of these web mapping technologies enable the response community to easily and quickly share their emergency plans and to work collaboratively.

Figure 10 illustrates the intended prototype system, which consists of several components: data collection, data management, agent-based simulation model and visualization of simulation results. Real-time information with respect to disasters and real-time position data about the moving objects (i.e., first responders) will be structured to drive and update the simulation model. The agent-based simulation model will be connected to the disaster model updated with real-time data. The disaster is visualized in the form of one or more moving polygons crossing a certain road network (see Fig. 11). First responders will be modeled as mobile agents who can use heuristics algorithms to computes the routes. A database is used for data management and to store the geo-information of the network, the information of mobile agents (the routes, current position, starting point, end point, the status, etc.) and the real-time data. 2D/3D GIS data (e.g., OpenStreetMap) will be used to model the spatial environment, especially the road network, and to obtain details about the objects within the environment. The simulation output data will be displayed to users through web application technologies.

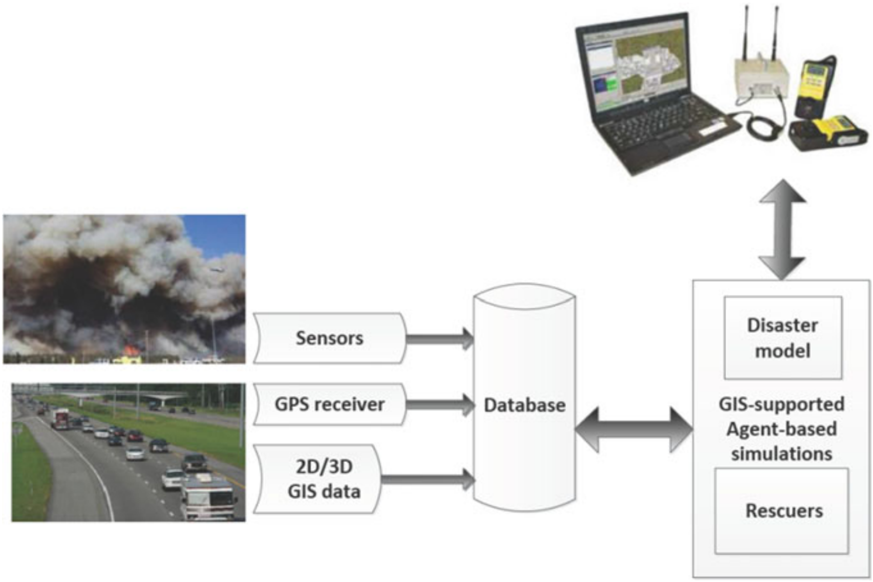


Fig. 10 The architecture of the prototype system

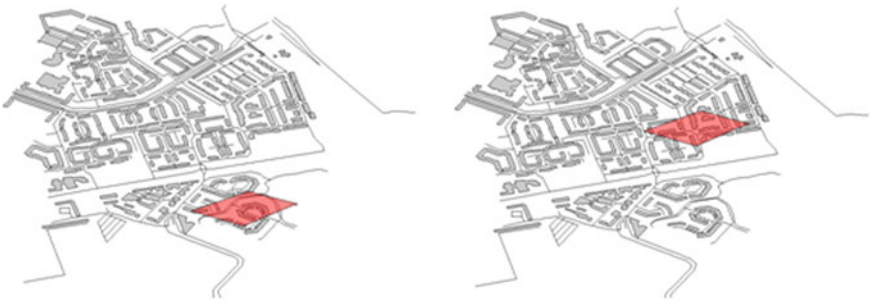


Fig. 11 Snapshot of disaster simulation

7 Summary and Outlook

This chapter concentrates on navigation aids for first responders among obstacles. We provide a taxonomy of navigation broadly classifying the cases with obstacles and briefly describing existing approaches proposed in various domains for navigating moving objects in the environment populated by a set of static or moving obstacles. We also present a system architecture within which the obstacle-avoiding routing algorithms can be designed, implemented and tested through simulations. The main components of the proposed system architecture are agent-based modelling simulation and sensor measurements delivered via web-based technologies. Such an approach will also allow evaluating computed navigation results.

In spite of the long history of routing and navigation, research on navigation for first responders is largely in its beginnings. Compared to its counterpart in robotics where a rich set of navigation approaches has been developed to deal with obstacles, many issues of obstacle-avoiding routing in road network are open for further investigation. The focus of this research is on navigating multiple responders to multiple static destinations avoiding multiple moving obstacles. Various aspects need to be investigated: communications between the agents to enrich the situational awareness, strategies for avoiding obstacles (choose a longer way or wait for the obstacle to move), strategies for completing tasks, etc. In the near future, we will concentrate on the development of obstacle-avoiding routing algorithms. To support the routing process, different data models will be considered and extended to represent the first responders, disasters and spatial information.

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Part IV
Interactions, User Studies and Evaluations

App-Free Zone: Paper Maps as Alternative to Electronic Indoor Navigation Aids and Their Empirical Evaluation with Large User Bases

Alexandra Lorenz, Cornelia Thierbach, Nina Baur and Thomas H. Kolbe

Abstract Nowadays, mobile devices are widely used as navigation aids, e.g., for car navigation. Their greatest advantage is the ability of automatic position tracking. In indoor environments, this feature is often not available, since indoor localization techniques are not ready for the mass-market yet. What remains is a small display with limited space for route visualizations. In contrast, the variable size of paper allows for the representation of additional context information as a means for spatial understanding and orientation in space, rendering it a valuable alternative presentation medium for indoor navigation aids. Independent of the medium used, provided visualizations must meet specific cartographic requirements like clarity, comprehensibility, and expedience. Within a co-operation between geoinformation science and sociology, we develop and investigate cartographic methods for effective route guidance in indoor environments. Our evaluation base comes from user studies conducted with more than 3,000 visitors, of both genders and aged between 4 and 78 years. These user studies were collected during the "Long Nights of Science" in Berlin in 2009, 2010, 2011, and 2012. We used paper as the presentation medium for our experiments, not only for practical reasons but also because we want to confront our participants with a solution which does not align to the current trend. Within this article we put special focus on media characteristics and users' media preferences. Therefore, we

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A. Lorenz (✉) · T. H. Kolbe
Department of Geodesy and Geoinformation Science, Technische Universität Berlin, Straße des 17. Juni 135 10623 Berlin, Germany
e-mail: alexandra.lorenz@tu-berlin.de

C. Thierbach · N. Baur
Department of Sociology, Technische Universität Berlin, Fraunhoferstr. 33–36
10587 Berlin, Germany

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asked our participants about their opinion on the provided paper maps in contrast to mobile solutions. Based on their answers, we could derive media characteristics relevant from a user's perspective, as well as the affinities of different user groups. One astonishing outcome was that 11–15 year-old teenagers indicate a much higher tendency towards paper maps than towards smartphone apps.

Keywords Indoor navigation · Map design · Paper map · Social experiment

1 Introduction

Nowadays, mobile devices as navigation aids enjoy great popularity, especially for car navigation. With complete GPS coverage outdoors, the current position can be determined with an accuracy down to a few meters, which is sufficient for car tracking. Reading the map is not meant to be a main task during car driving and travelling at high velocities inevitably requires coarser graphics to reduce stimulus. Therefore, the underlying map typically consists of not much more than the street network plus information about the course of the route. The graph structure of the street network forms the basis for route calculations, which are executed on-the-fly.

The situation is more complex in a pedestrian scenario. Space accessible by pedestrians rarely follows such simple structures. Consequently, pure geometric hints like turn-by-turn instructions or distance values are less useful for pedestrian guidance. What pedestrians need are semantic references, which serve as linking objects between a map and the real world. According to May et al. (2003), landmarks are by far the most popular and effective type of information for pedestrian guidance. Information density of navigation maps for pedestrians is considerably higher than that of higher-velocity applications because of higher perception capacity. Pedestrians want to be informed not only about their current position but also about their surroundings. In outdoor environments one can refer to a broad geographic data base, comprising all object types relevant for pedestrian navigation available in various levels of generalization. In combination with available positioning technology, dynamic approaches may be implemented like video and panorama based virtual environments (Kolbe 2003) or augmented reality as user interface in a mobile computing application (Reitmayr and Schmalstieg 2003).

When it comes to indoor map design, things get even more complicated, since we have to leave the two-dimensional plane. Inside buildings, we usually move between several floors. As basic data for indoor applications, one may rely on existing floor plans, but as the name "plans" already suggests, they typically represent a detailed, non-generalized, CAD-like copy of the floor's architecture. Figure 1 shows a commented example. From a cartographic perspective, such plans are as inappropriate for user guidance as cadastral records in outdoor environments. Another source for indoor geometries along with their thematic

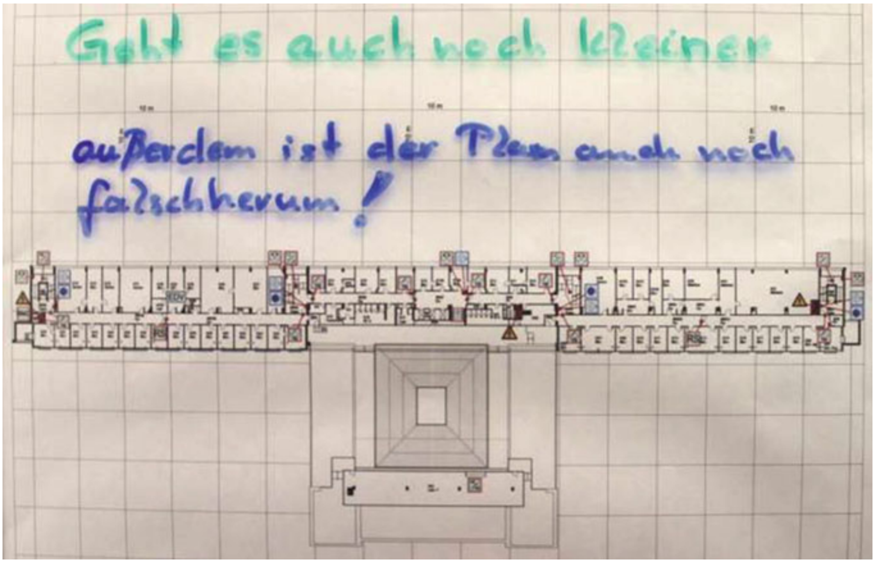


Fig. 1 Floor plan mounted within the main building of TU Berlin (real size approx. 20 × 30 cm). The comments translate to: "why not printing it even smaller?" (*top*), "the plan is upside-down!" (*bottom*)

meaning are virtual 3D building models following standards like IFC (ISO 2005) or CityGML (Gröger et al. 2008).

Existing data sources allow for the storage of building data, which may only be used as a basis for the creation of indoor navigation maps, since they are not meant to fulfill cartographic requirements themselves. Consequently, issues in the design of existing building data are often mentioned or even criticized. Still, most existing approaches fall back to the available (pseudo-) cartographic material like aforementioned floor plans and superimpose them with additional route information. A rare alternative is the concept of indoor tubes (Nossum 2011), which visualizes accessible building parts in the same fashion as we are used to from subway maps. Unfortunately, *design guidelines* are not widely available. They are mostly byproducts of user studies (e.g., Puikkonen et al. 2009; May et al. 2003; Vinson 1999) and therefore do not allow for the formulation of comprehensive catalogues of design recommendations.

In order to evaluate different design aspects, we have conducted annual user studies since 2009. We have the chance to use the "Lange Nacht der Wissenschaften" ("Long Nights of Science"; LNDW[1]) as a framework for our experiment, which frees us up from a lot of organizational effort. At the same time it provides us with up to 1,100 participants per year, allowing for detailed examinations of the influence of various user characteristic parameters (e.g., cultural background, age,

[1] LNDW, Lange Nacht der Wissenschaften. http://www.lndw.tu-berlin.de/

education, personal abilities, interests, familiarity with the study area) and context issues (e.g., route complexity, abstraction of the map, influence of other participants). Statistical analyses and results are published in (Lorenz and Thierbach 2012; Thierbach 2011; Lorenz et al. 2010).

This article shifts the focus from map design variations, towards using paper as a presentation medium for indoor navigation aids. The sheer size of our user base prevents the use of mobile devices as presentation medium. So we dare to go against the current trend with using paper as the output medium for the resulting maps. In this article, we analyse the opinions on the use of this medium among our user base and identify reasons for users preferring paper over mobile devices and vice versa.

2 Paper Versus Mobile Devices

Both, paper and mobile devices have their advantages and disadvantages regarding their suitability as presentation medium for personal indoor navigation maps. In the following we will present two comparative literature analyses which later on will be opposed with results from our survey. One obvious drawback of mobile devices, which is always stressed, is their typically very small sized device displays. They "have not been particularly designed for map applications. Hence, the maps had to adjust to the conditions of the device that has been designed to be preferably compact" (Pauschert et al. 2011). We will refer to several studies, which have demonstrated that small displays negatively influence the user's orientation and spatial understanding. The reason for this lies in the strong segmentation of space, caused by the big ratio between screen size and displayed area. "Despite advances in small-screen cartography, the limitations due to size and display technology will remain for the foreseeable future. Interactivity can be a key benefit but a large percentage of user actions is typically concerned with control interaction to address the limitations of the devices used" (Paelke and Sester 2010). The insertion of the current location, using positioning methods, helps with this. Through automatic user tracking, orientation becomes easier and users may find their way without full awareness of their environment. Unfortunately, positioning methods are not as ubiquitous for indoor environments as they are for outdoor environments. We will outline the state of the art of indoor positioning methods and their implementation in mobile navigation aids at the end of this section.

2.1 Comparative Analyses of Presentation Media for Navigation Maps

Pauschert et al. (2011) compare paper maps and electronic devices. For their analysis, they refer to the concept of affordances, which goes back to the

Table 1 Affordances of paper maps and electronic devices (Pauschert et al. 2011)

Affordances of paper maps, guides	Affordances of electronic devices
Flick through several pages (guide)	Access larger amounts of information
Read across several documents at once	Access and display multimedia content
Make annotations on the document	Modify documents and create new ones
Get an overview of an area of interest (map)	Get additional information linked to a document
Grasp, fold the map	Use computational resources for services like navigation, route guiding
Work collaboratively on one document	Remote communication with other users
Source of static information	Access dynamic information
Independent, easily accessible	Dependant on battery power, network connection, familiarity of the user with the technology

ecological psychologist Gibson (1979). Contrary to objective media characteristics, affordances of media express their subjective relation to people, i.e., what they can use them for. Table 1 shows several affordances of paper maps and compares them to the affordances of electronic mobile devices.

Paelke and Sester (2010) compare paper maps and maps on electronic handheld mobile devices, analysing general features, content presentation, as well as use and interaction properties (Table 2). Several aspects are rated for both media, underlining their complementary strengths and weaknesses.

2.2 Impact of Display Size

Several studies examined the impact of display size on way-finding behavior and spatial knowledge acquisition. Dillemuth (2009) tested 80 undergraduate students, aged between 17 and 41. They had to solve navigation tasks with the help of scrollable maps of a fictitious town with different extents. Those participants viewing the full extent of the map had the advantage of direct perception, whilst participants with the small-window conditions had to rely on mental representations held in memory. For the estimation of relative distances and relative directions, the crucial point seems to be whether all landmarks necessary for orientation are located within a single view. If they are not, zooming to a smaller scale could be beneficial, but this might introduce new issues concerning the estimation of absolute distances. Another serious insight is the mismatch of confidence and accuracy regarding relative distances and relative direction estimates. Participants are often unaware of their incorrect judgements, which could lead to wrong

Table 2 Comparison of paper maps and maps on electronic handheld devices (Paelke and Sester 2010)

		Paper Maps	Hand-held eMaps
Features	size	small to large, foldable, flexible	small, fixed
	power consumption	none	significant; endurance hours to days
	weight	low	wide range; typically several 100g's
	price	low	high
	reliability	very high	limited
Content	resolution (spatial)	very high	low
	resolution (temporal)	very limited (static depictions)	potentially high (animation)
	flexibility of content	no adaptation, difficult update	easy if supported by software
	content dimensions	fixed, limited	flexible, potentially unlimited
	coverage	fixed	potentially unlimited
	level-of-detail	fixed, typically high (use specific)	lower due to display resolution, flexible
Use and interaction	readability	very high	lower
	information access	mostly push; serendipitous discovery common	mostly pull; often lack of overview for discoveries if not explicitly supported
	use, interaction	well known interaction with paper; but learned map skills required	special mechanisms, devices specific, only tasks supported by the software
	accessibility	high, but no support for visual impaired	lower, but special mechanisms for target groups can be implemented in software
	flexibility of use / adaptation to other uses	very easy, common	only if supported by the implementation, typically limited
	annotation	simple with pens, post-its etc.	only if supported by the software
	query, search	only pre-designed indices	full support possible in software
	integration of GPS	none	full support possible in software
	multi-user interaction	very easy, common	difficult due to device size

decisions in a real world navigation scenario. Correlating the results of spatial ability tests with general performance in all navigation tasks, suggests that people with good spatial abilities even perform well with small-window conditions, whereas people with lower abilities do not and therefore may benefit from efficiently designed maps. Gartner and Hiller (2008) tested 30 persons who had to find a route and solve navigation tasks with the help of either a paper map or a small display mobile device with scrolling and panning functionality. Evaluation results show that paper map users performed better in all navigation tasks, including the estimation of absolute directions, topological understanding expressed by sketch maps, and spatial action, i.e., find the way back to a prior destination. Ishikawa et al. (2008) came up with similar results when they tested 66 college students, aged 18–28, in a slightly modified scenario. Using GPS-based navigation systems, paper maps, or direct experience, participants had to follow six routes and solve navigation tasks at the end of each route. Results for the estimation of absolute directions and topological understanding, confirm the strength of bigger displays, primarily their potential in displaying large amounts of context information. Another interesting issue mentioned by Ishikawa et al. (2008) is the interference between local focus of attention, in the case of a small display size, and global processing of spatial information, which is required for getting oriented in space by interrelating the surrounding space, the user, and the map.

2.3 State of the Art Indoor Positioning Methods and Their Implementation in Mobile Navigation Aids

In short, indoor positioning methods are not yet ready for the mass-market (Wirola et al. 2010). Suitable methods need an acceptable level of accuracy, along with availability indoors and low installation and maintenance costs. Unfortunately, existing families of positioning methods only partially fulfill these requirements. Satellite based methods are very cost-effective since satellite positioning systems like GPS are globally available and can be received and interpreted by almost every modern smartphone. But there is one considerable drawback in that GPS signals are shielded by building walls resulting in low positioning accuracy indoors. Cellular network based methods also have accuracy challenges, since positions may be determined with an accuracy of around 20 m (UMTS). WiFi and short range methods require new infrastructure in terms of tags, beacons, or markers as well as corresponding radios or cameras. This allows for higher positioning accuracy, but also implies higher costs. For that reason, such methods are only affordable within small-scale realizations.

Such small-scale realizations differ in terms of positioning technology, kind of representation, user adaptation, and interactivity. Often they are hybrid (outdoor and indoor) systems, relying on GPS outdoors and sensor techniques like WLAN or Bluetooth indoors (e.g., Krüger et al. 2004; Rehrl et al. 2007). For better results, different sensor techniques may be combined like in the NAVIO project (Gartner et al. 2004), where WLAN is combined with other wireless techniques like Bluetooth or ZigBee. In contrast, the following approaches use alternative positioning and/or presentation solutions. Müller et al. (2006) propose an approach where a mobile phone is used as a magic lens which is swept over existing georeferenced floor plans. This allows for position verification without the necessity to track the user and forms the basis for augmenting the route on the camera image of the floor plan. Hide and Botterill (2010) developed a system integrating measurements from a foot-mounted IMU with position and orientation updates from computer vision techniques. It can be applied indoors and outdoors, providing position accuracies better than 10 m (typically 1–5 m). Another concept, which has only been tested outdoors so far, but could (in a slightly adapted version) also be deployed indoors, is the Rotating Compass. This is an advanced kind of signage which individually indicates the direction to a specific destination (Rukzio et al. 2009). Becker et al. (2009) provide a conceptual framework for indoor navigation introducing a multilayer space model for the representation of both topographic and sensor space. Nagel et al. (2010) proposed formal requirements for an indoor navigation standard which the multilayer space model meets. Such a standard should support different navigation contexts which are constituted by three main factors: the mode of locomotion of the moving subject or object, the logical context representing pre-knowledge or navigation constraints, which result from various application domains, and the localization infrastructure used. For the modelling of indoor environments, a navigation standard should be compatible to existing 3D building models and employ a hierarchical aggregation concept for the grouping of spaces.

A lot of research efforts are dedicated to indoor navigation using mobile devices and automatic positioning. Nevertheless, we must not loose sight of conventional paper maps for indoor navigation. If they were designed adequately, they could be a valuable alternative, because not everyone appreciates the use of mobile devices for navigation tasks.

3 User Tests

In order to evaluate different design aspects, we have conducted annual user studies since 2009, within a collaboration between geoinformation science and sociology. This allows us to bundle experience and know-how in cartographic methods and social research. The user studies take the form of a social field experiment (factorial design without control group) conducted with visitors of the LNDW at the Technische Universität Berlin's main building. Due to its complex architectural structure, consisting of two components with different floor heights and an intricate system of staircases, the university's main building is well suited for the purpose of developing and testing design guidelines for indoor navigation maps. Most user studies in this domain are typically conducted with a small number of participants with similar age and social background, such as students. In contrast, a total of more than 3,000 persons participated in our experiments, to date. In 2011 (the date for which all results presented in this paper are based upon), 1,140 persons aged between 4 and 78 years had tested our maps, 54 % of which were male and 46 % female.

We applied a mixed-method research design with both qualitative and quantitative data. In order to grasp familiarity with the test location, orientation behavior, prior experience, and personal characteristics, participants were asked to answer an a priori survey before being assigned a map/route. The experiment itself was organized as a race, so that two parties (single persons or groups) compete against each other, one using the Eastern route and one the Western route (see Fig. 2). Both routes start in front of the main auditorium, within the entrance area of the main building of TU Berlin, and lead to the Geodätenstand, a geodetic laboratory on the roof of the building. Participants have to ascend seven floors using four to five different staircases, but no elevators. Along the route, they pass seven critical decision points. The average walking time for people who are not familiar with the route is about 10 min. The simpler, but longer Eastern route is characterized by fewer turns, one long corridor without visual cues, and fewer changeovers between building parts. In contrast, the more complex, but shorter Western route, features much more changeovers, route parts within and outside the building and a more winding route, complicating route visualization. After having arrived at the (same) destination, participants were asked to answer an a posteriori survey and open-ended questions in order to assess the participants' navigational approach, their motivation for participation, as well as their experience with the route and especially with the provided map. In addition, we conducted a focused ethnography (Knoblauch 2005) along the route, i.e., coworkers observed the participants (Lamnek 2005) during navigation in order to see how they oriented within the building. This gives us the opportunity to get to know and analyze unexpected effects during the navigation task, as for example group dynamics and reasons for delays, for outstanding quick runs, or for leaving the recommended route (Thierbach 2011).

The maps are based on existing floor plans, which are generalized for the final representation scale. This involves the selection of relevant architectural structures, geometric simplification, exaggeration of important details, as well as amalgamation of building parts according to their function. For the purpose of navigation, we decided to only distinguish indoor hallways, rooms, outdoor paths, and roof areas, with each colored appropriately. For each floor, we cut out the relevant parts of the produced maps and arranged them accordingly. Stairs and pillars were inserted and connecting elements were added as means for orientation.

In addition, we systematically varied map design aspects for each route. The active, controlled variation of map design variables in the social experiment gives us the chance of systematically analyzing their suitability with respect to specific user groups and context settings. In 2011, we developed eight maps, focusing on two map design issues: representational perspectives (2D and 3D) and different types of landmark representation (natural versus artificial landmarks represented as symbols along the Western route and natural landmarks represented as symbols versus text along the Eastern route). Figure 2 visualizes one of the maps tested in 2011, showing an oblique view (referred to as 3D) of the Western route including natural and artificial landmarks. In this context, natural landmarks are distinctive objects that one can find in the building, e.g., fire extinguishers, garbage cans, or restrooms. Artificial landmarks are not naturally there, but have to be placed artificially. We chose zodiac signs as artificial landmarks and installed them along the Western route at difficult parts and decision points where no natural landmark supports navigation.

4 Results

In 2011, we tested navigational success based on representational perspective as well as different types and amounts of integrated landmarks. Our data shows that generally 3D maps perform better as they strongly enhance spatial understanding. However, a surprising detail was that, for the representation of vertical structures, 2D maps are almost as good as 3D maps, if additional textual information like navigation hints and floor numbers are included. Landmarks are only regarded as being helpful if the connection between landmark and route is obvious. In our survey, both statements receive similar amounts of positive user feedback, implying that the alignments seem to be well done, are understood by users, and

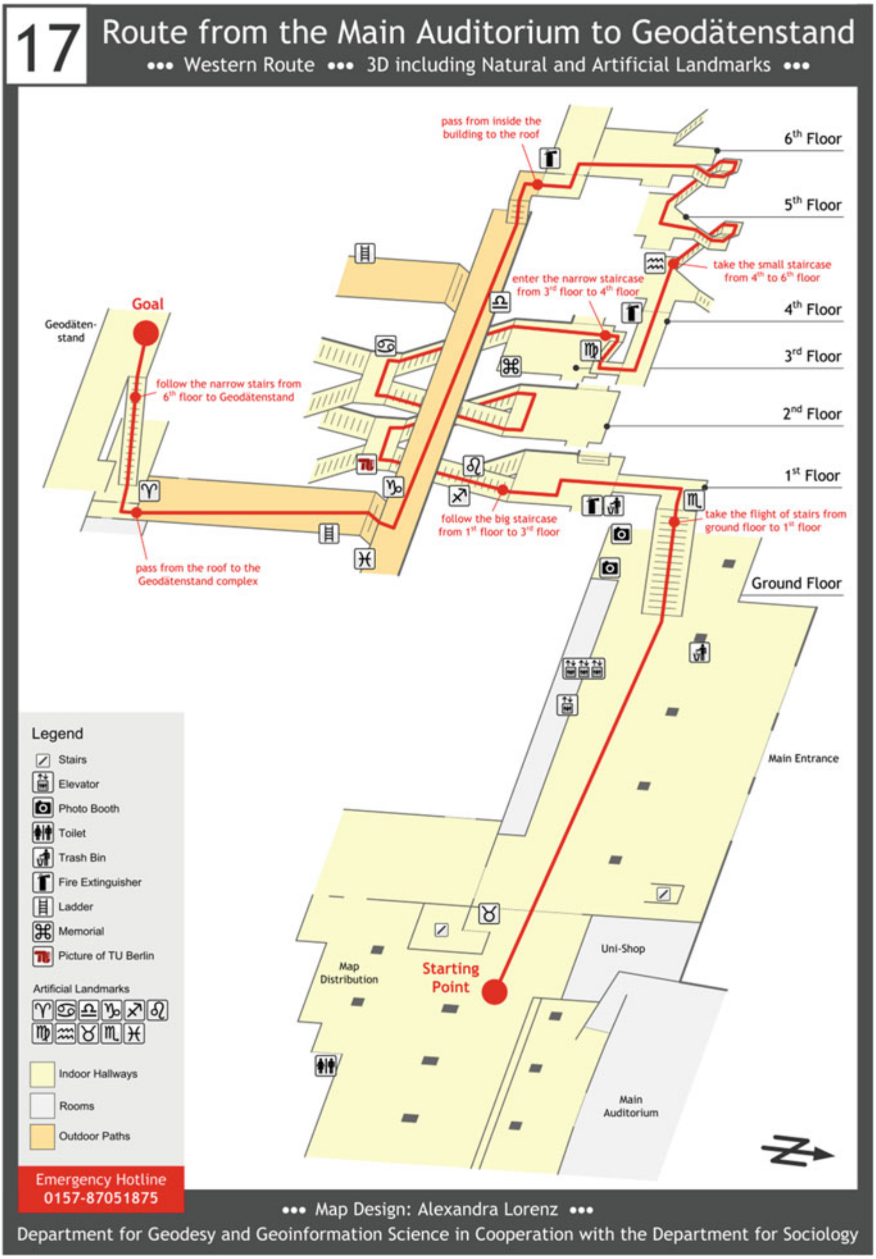


Fig. 2 Sample map: western 3D route including natural and artificial landmarks. All maps tested within our user studies can be accessed online at: http://www.gis.tu-berlin.de/menue/projekte/laufende_projekte/das_entwirrte_labyrinth/

are seen as being very helpful. The importance of landmarks for navigation maps is confirmed by the fact that both benefit and alignment of landmarks strongly correlate with overall users' satisfaction.

In order to relate users' map satisfaction with different aspects like user characteristics, route complexity, and map design, we conducted a series of analyses of variance (ANOVA; Baur 2012). The results show that although often humorously stressed, gender and age are not significant indicators of users' likely satisfaction with maps. The properties of the route are much more important, explaining 5.6 % of users' satisfaction with maps, whereas map design issues like variation of landmark representation and representational perspective are of utmost importance, as they explain 29.2 % of differences in user satisfaction with maps. More details regarding the evaluation of the results from our user studies can be found in Lorenz and Thierbach (2012), Thierbach (2011) Lorenz et al. (2010).

4.1 Media Preferences: Who Prefers Paper Maps Over Apps?

Within this chapter, we concentrate on our findings on users' preferences for different presentation media. In order to get a feel for the public opinion on this topic, we inserted the following question into the 2011 a posteriori questionnaire: "You used a printed map for this experiment. If you had the choice, would you prefer to use such a printed map or a mobile phone app?" Our participants are surprisingly decisive on this issue: 54 % prefer paper maps, only 19 % prefer electronic solutions, and 27 % do not show any preference.

An insight from sociology is that very often, there are typical patterns in social preferences and actions. This means that we expect that different types of people prefer different types of media. In order to assess who prefers printed paper maps over apps, we conducted a series of multiple linear regression analyses (see Table 3; Fromm 2010). First, bivariate analyses show the correlation (Pearson's r) between single variables/factors and media preference. Factors in this context are sets of variables with similar response tendencies, formed on the basis of a factor analysis. Models 1–4 investigate different categories of variables, which might influence people's affinity for paper maps or apps: sociodemographics, media experience, other experience helping orientation, and orientation praxis. They form the basis for the complete and the final model, which explain all or the most important variables/factors respectively. The regression coefficients (Beta) express the expected change of media preference in relation to single variable changes. Variables are only relevant if they have a low significance value (Sig.), which defines the linear relation between variable and media preference. S.E. describes the standard error of variables in the linear regression. Finally, R-Square measures the ratio of the explained variance for the applied models.

Model 1 shows that sociodemographic variables (gender and age) together explain about 5 % of the differences between respondents. In the case of women, we observed a strong tendency towards paper maps (61 % paper map, 16 %

Table 3 Who prefers paper maps over apps? Results of a multiple linear regression analysis (Fromm 2010) explaining the relation between sets of different independent variables (models 1–6) and users' media preference

	presentation medium	ratio	sub categories	n° of entries	analogies to Pauschert et al.'s affordances of paper maps and electronic devices	analagies to Paelke & Sester's comparison of paper maps and maps on electronic devices
smartphones / mobile devices	paper map	10%	no or seldom usage of mobile phone	9		
			only for phone calls	1		
			not app capable	39		
	app/ e-map	8%	always available	11		
user characteristics	paper map	27%	familarity with paper maps	31	familarity of the user with the technology (switched)	well known interaction with paper, but learned map skills required
			advanced age	6		
			old fashioned	13		
			anti-smartphone	19		
			affinity for paper	38		
	app/ e-map	11%	familarity with apps/e-maps	3		
			modern	5		
			pro-smartphone	3		
			affinity for technology	4		
presentation medium	paper map	32%	always ready to use	37	easily accessible; independent of battery power and network connection (switched)	no power consumption; high accessibility; very high reliability
			customizable, foldable	6	make annotations on the document; grasp and fold the map	simple annotation with pens, post-its etc.; foldable
	app/ e-map	8%	all-in-one solution	4	remote communication with other users; access larger amounts of information	
			eco-friendly	7		
usability	paper map	7%	usability	20		flexible; adaptable to other uses
			free adjustment of map orientation	8		
	app/ e-map	30%	usability	37		
			automatic adjustment of map orientation	4		
graphics	paper map	40%	big display size	60		flexible size
			readability, comprehensibility	20		very high display resolution and readability
			overview	80	get an overview of an area of interest	typically high level-of-detail
	app/e-map	15%	compact display size	8		
			readability	4		
			overview	9		flexible; flexible level-of-detail; potentially unlimited content dimensions and coverage
(no) interaction	paper map	5%	no undesirable dynamics	21	source of static information	information access mostly by pull
			multi-user interaction	0	work collaboratively on one document	very easy multi-user interaction
	app/e-map	14%	desirable dynamics	13	access dynamic information	information access mostly by push; potentially high temporal resolution
			adaptiveness, additional information	4	get additional information linked to a document; access and display multimedia content	easy adaptation if supported by software; full support of search & query possible
			additional functionality	2		special mechanisms for target groups can be implemented
routing capability	app/e-map	13%	tracking of user location display of course direction	17		full support of GPS possible in software
			route calculation	1	use computational resources for services like navigation; route guiding	

For this analysis, the sample size reduces to 613, since not all participants responded to all relevant questions (variables/factors)

Data Base LNDW Survey 2011. n = 613. *Significance Levels* + α = 0.1; * α = 0.05; ** α = 0.01; *** α = 0.001

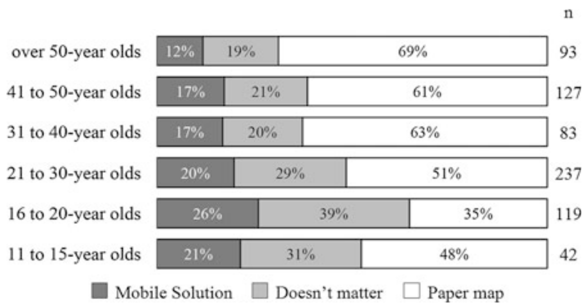
electronic solution), whereas men's preference for paper maps is not as clear (47 % paper map, 22 % electronic solution). The main reason for this gender difference seems to be that men have a stronger affinity for technology and other practices relevant for orientation. This means that we suspect that women who have an affinity for technology and are good at orientating themselves, are more similar to men in their media preferences than to other women. Our data suggest that this is true, as gender differences become insignificant when controlling for orientation practices and prior experience with technology relevant for orientation (Model 5).

Another factor which significantly affects preferences for presentation media is age. Figure 3 gives an overview of the preferences of different age groups. As presumed, with increasing age users' affinity for paper maps gets stronger. Older people even indicate their age as a reason for their paper preference, e.g., "I'm 59 years old and prefer to orientate myself on paper maps." or "I'm old school". However, not only adults strongly tend towards paper maps. Within the group of 11–15 year-olds, only 21 % prefer electronic maps. This may be due to smartphones not frequently being used by persons within this age group. The peak for electronic maps is reached within the age group of 16–20 year-olds, but still here, paper maps are preferred. In contrast to gender, age remains significant when controlling for other variables.

People are prone to habits. Therefore, they might simply prefer media that they are used to, as this is more convenient. In fact, our data shows that *prior media experience* (Model 2) is the single most important factor for media preference, explaining 13 % of the variance between respondents. Not surprisingly, people who currently often use paper maps prefer using paper maps in the future, while a large number of people who often use maps on the internet, GPS, and other electronic maps would prefer an app. All these effects remain significant when controlling for other variables. Interestingly, frequently using floor plans or engineering drawings privately or professionally (which would be the case for engineers and cartographers) does not influence media preference.

Whilst prior media experience influences the specific experience a user has with different types of maps, users might also gain general experience in orientation itself. In turn, good orientation skills might include knowledge on how to orient best in a practical way and which media to use best for orientation tasks. Model 3

Fig. 3 Preferences for a presentation medium (by age)



shows that these *other experiences potentially relevant for orientation* do have an effect, although it is small, explaining 3 % of the variance between respondents. However, the effect is not much smaller than that of sociodemographics. The first thing we tested, is how people typically are moving around in space on an everyday basis. We found that some people tend to use cars, while others tend to walk or use public transport. However, neither seems to be relevant for preference of a specific media type. Furthermore, we examined people who are forced to orientate themselves in new environments very often: They travel a lot to new cities or countries, go often to airports and to buildings unknown to them (such as houses, shopping malls, cinemas, hospitals, or government buildings). As a front-seat passenger, they often help the driver of a car finding her way by reading road signs and maps and by giving directions. Those people typically prefer apps. Very likely this has to do with the fact that apps provide the functionality of automatic localisation using GPS, as this effect looses significance when controlling for other variables. Finally, we observed gaming practices: Some people do not play at all, whilst others love playing games such as strategy games, logic games, various kinds of role plays, shooting games, outdoor orienteering games, and second life. While almost no person plays *all* these games, typically people have a tendency towards playing several or none. This seems to be important for media preference, as people who play a lot of games strongly prefer apps—regardless of other experiences.

Knowing how to orient themselves and how to use maps does not automatically mean that people apply that knowledge or rely on it. In fact, one of the things we found in our ethnography was that most people prefer to walk in groups—they strongly rely on others for finding their way. However, actual *orientation praxis* (Model 4) explains only 2 % of variance and thus only has a small effect on media preference. Again, there are typical patterns in how people orient themselves. While some people are very self-reliable, other people have a strong tendency to use external help (regardless, if they have a map or not): Whenever they visit someone they have never visited before, they let someone describe the way orally before they leave or ask for a written description of the way. On the way, they use the step-by-step written description and ask other people for help. During our experiment, they additionally used other maps (e.g., escape plans and floor plans) and like that sometimes found other ways to the goal than the one described on our maps. In tendency, these people had more problems than others in spatially visualizing the whole route and did not use the landmark information in the maps. Nevertheless, these orientation habits do not affect media preference at all.

Regardless of how much external help people use, there are map-readers and followers: Some people believe that they are very good at orientating themselves and reading maps. They very often use classical printed road maps, town maps, floor plans, and/or engineering drawings, but also maps on the internet. This reflects in their orientation practices: Whenever they visit someone they have never visited before, they look at a map (e.g. a traditional paper map or a map on the internet) before they leave. On the way, they make use of the full range of possibilities for orientating themselves: They use maps, road signs, buildings, other landmarks, and finally rely on their spatial sense. In contrast, other people find it more convenient to let others do the orientation work: Whenever they visit someone, they have never visited before, someone else tries to find out how to get there before and during the trip—they only walk along. This pattern is important when analyzing media preference, as map-readers, i.e., people who always read maps themselves and typically do the actual orientation work, would prefer paper maps.

Our *final model* (Model 6) compiles all factors tested that are significant when controlling for other variables. As can be seen, older people and people experienced in using paper maps and people using maps themselves (in contrast to relying on other people) prefer paper maps. Only people playing games a lot, frequently using maps on the internet, GPS and other electronic maps would prefer apps. These six factors together explain 16 % of variance between respondents.

4.2 Why do People Prefer Specific Media?

Our quantitative analysis gives us insights into *who* prefers which medium. In order to get deeper insights on *why* people prefer specific media, we analyzed the reasons given by participants, provided as free text in the questionnaire. Since we did not suggest any response categories, this method resembles a brainstorming, allowing for a broad range of answers, but giving only rough estimates of de facto percentages. The resulting aspects (see Table 4) are impulsive ideas to which the user presumably attaches particular importance.

The classification of answers results in seven main categories: smartphones/ mobile devices, user characteristics, presentation medium, usability, graphics, (no) interaction, and routing capabilities. According to user responses, all categories split into several aspects regarding paper maps and app/e-maps. In order to visualize the relevance of different categories and aspects, we inserted percentual values for all main categories as well as the amount of entries for individual aspects. e.g., 40 % in case of paper map graphics means that 40 % of all paper map supporters mentioned graphic issues like big display size, readability, comprehensibility, or overview as one reason for their affinity. Since each user might have mentioned more than one aspect, the total number of entries is not equal to the total number of participants, just like ratios for one presentation medium (paper map or app/e-map) do not sum up to 100 %. Comparing user support, we can state that paper maps score highly with their graphics, but also regarding user characteristics. They show minor advantages when it comes to the characteristics of the presentation medium as well as the necessity of mobile devices capable of displaying apps/e-maps. Mobile devices exhibit good usability and routing capabilities. Furthermore, they surpass paper maps regarding possible interaction.

As already mentioned, we compared findings from literature, namely the two comparative analyses of presentation media, with results from our survey. For this purpose, we tried to draw parallels between the three investigations. Accordingly,

Table 4 Reasons for preferring a specific presentation medium based on results from our survey and parallels to comparative analyses from literature (Pauschert et al. 2011; Paelke and Sester 2010)

	presen-tation medium	ratio	sub categories	n° of entries	analogies to Pauschert et al.'s affordances of paper maps and electronic devices	analagies to Paelke & Sester's comparison of paper maps and maps on electronic devices
smartphones / mobile devices	paper map	10%	no or seldom usage of mobile phone	9		
			only for phone calls	1		
			not app capable	39		
	app/ e-map	8%	always available	11		
user characteristics	paper map	27%	familarity with paper maps	31	familarity of the user with the technology (switched)	well known interaction with paper, but learned map skills required
			advanced age	6		
			old fashioned	13		
			anti-smartphone	19		
			affinity for paper	38		
	app/ e-map	11%	familarity with apps/e-maps	3		
			modern	5		
			pro-smartphone	3		
			affinity for technology	4		
presentation medium	paper map	32%	always ready to use	37	easily accessible; independent of battery power and network connection (switched)	no power consumption; high accessibility; very high reliability
			customizable, foldable	6	make annotations on the docu-ment; grasp and fold the map	simple annotation with pens, post-its etc.; foldable
	app/ e-map	8%	all-in-one solution	4	remote communication with other users; access larger amounts of information	
			eco-friendly	7		
usability	paper map	7%	usability	20		flexible; adaptable to other uses
			free adjustment of map orientation	8		
	app/ e-map	30%	usability	37		
			automatic adjustment of map orientation	4		
graphics	paper map	40%	big display size	60		flexible size
			readability, comprehensibility	20		very high display resolution and readability
			overview	80	get an overview of an area of interest	typically high level-of-detail
	app/e-map	15%	compact display size	8		
			readability	4		
			overview	9		flexible; flexible level-of-detail; potentially unlimited content dimensions and coverage
(no) interaction	paper map	5%	no undesirable dynamics	21	source of static information	information access mostly by pull
			multi-user interaction	0	work collaboratively on one document	very easy multi-user interaction
	app/e-map	14%	desirable dynamics	13	access dynamic information	information access mostly by push; potentially high temporal resolution
			adaptiveness, additional information	4	get additional information linked to a document; access and display multimedia content	easy adaptation if supported by software; full support of search & query possible
			additional functionality	2		special mechanisms for target groups can be implemented
routing capability	app/e-map	13%	tracking of user location display of course direction	17		full support of GPS possible in software
			route calculation	1	use computational resources for services like navigation; route guiding	

aspects from Pauschert et al. (2011)'s affordances as well as Paelke and Sester (2010)'s comparison are added to Table 4: aspects which match with user entries from our survey are inserted into the respective row; new aspects are assigned one of the main categories and provided with a new row, e.g., multi-user interaction is added as an additional aspect of the category (no) interaction. We ignored three affordances listed in Table 1 (Flick through several pages [guides], Read across several documents at once, Modify documents and create new ones) since they did not fit into our user case of a single-sheet paper map and an app respectively. The comparison in Table 2 considers aspects in terms of both media, underlining their contrasting nature. We picked out only beneficial ratings, i.e., typically each aspect is taken up for one presentation medium.

Table 4 also reveals various aspects mentioned by our participants, which have not been investigated by Pauschert et al. (2011) or Paelke and Sester (2010). Above all, this concerns the usage of smartphones/mobile devices, user characteristics (except for familiarity) and many usability aspects. In detail, we detected the following very beneficial aspects of paper maps: no necessity of a mobile phone capable of apps, many people just like paper maps (because of being a bit old fashioned, detesting smartphones in general, or having an affinity for paper), paper has no breakdowns, and interactions like zooming and panning are not necessary for coarse orientation. Comments like "I'm a boyscout. We do not always have to use technology.", "I hate iPhones and apps. Old is just as good!", "The haptics of a paper map are sexy.", "Technology often leads to even more irritations.", and "I feel uncomfortable with digital maps if they change during navigation." support these advantages. Furthermore, we found the following positive aspects of mobile devices: many participants are equipped with a smartphone anyway and are eager to use it, mobile devices are eco-friendly (no paper is wasted for throwaway maps) and show good usability (they are easy to use, good to handle, or practical). Some users even like their compact display size. Again, various comments underline the benefits: "I've got my mobile with me anyway—other paper stuff often gets lost!", "No idea, paper maps are too complicated.", and "There is no room for an A4 map within my pockets.". In order to refine our estimates for user preferences, we are going to introduce multiple-choice response categories within 2012's questionnaire.

5 Conclusions

Within this chapter we concentrated on our findings regarding users' preferences on different presentation media. Based on a series of multiple linear regression analyses, we assessed who prefers printed paper maps over apps. Expecting that different types of people prefer different types of media, we investigated the influence of the sociodemographic variable, prior media experience, other experiences potentially relevant for orientation, and orientation praxis on participants' media preferences. Our analyses show that women have a slightly stronger tendency towards paper maps than men. Additionally, all age groups prefer paper maps with stronger affinity as age increases. The peak for electronic maps is reached within the group of 16–20 year-olds, but still here, paper maps are preferred. From all factors, prior media experience is the single most important one, explaining 13 % of variance between media preferences of respondents. The reason might be that people are prone to habits and therefore simply prefer media that they are used to. Interestingly, frequent usage of floor plans and engineering drawings does not influence media preference at all. Other experiences possibly relevant for orientation such as being forced to orient oneself and playing a lot of games have a small influence on media preference. The effect of actual orientation praxis is very small, with only people who always read maps themselves having a significant tendency towards paper maps.

In order to get deeper insights into why people prefer specific media, we analyzed reasons participants provided for their media preferences. They could be classified into: usage of smartphones/mobile devices, user characteristics, presentation medium, usability, graphics, (no) interaction, and routing capabilities. Paper maps score highly with their graphics, but also regarding user characteristics, while mobile devices exhibit good usability and routing capabilities. We drew parallels between the findings of our survey and existing comparative analyses on this topic, revealing some new aspects only mentioned by our participants. They include beneficial aspects of paper maps, i.e., no necessity for a mobile phone capable of supporting apps, an affinity for paper, and no breakdowns, as well as advantages of mobile devices, i.e., various usability facets. In summary, paper maps and mobile devices support different user needs: Whereas the size and presentational perspective of paper maps allows for a better overview and therefore better spatial understanding of the environment, mobile devices may interactively accompany the user along a route, facilitating position verification and map alignment.

Our investigations are based on navigation experiments carried out within a cooperation between geoinformation science and sociology. The large number of participants allows for statistically significant statements. Although visitors of the LNDW might not include people from all social backgrounds, we can make the assumption that our sample is quite representative of the total population. Experience acquired during the past three years has shown that paper maps constitute a serious alternative to mobile devices as navigation aids for indoor environments. Provided that map design follows cartographic principles, they are most suitable for guiding a user to a desired destination. As importantly, people just like paper maps. This was not clear to us when we started our experiments. Initially, we took the decision to use paper maps simply because of pragmatic reasons. Only later, positive user feedback confirmed our choice. In the future, one of the biggest challenges will be to find out which indoor configurations influence user needs regarding map design. This will support the automatic derivation of optimal maps for individual routes which will also be beneficial for LBS using apps.

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Zooming In–Zooming Out Hierarchies in Place Descriptions

Daniela Richter, Maria Vasardani, Lesley Stirlng, Kai-Florian Richter and Stephan Winter

Abstract Hierarchical place descriptions are a common means for people to communicate about place. Within them hierarchically ordered elements are linked by explicit or implicit relationships. This study analyses place descriptions collected in a mobile game, investigating hierarchies based on a classification of spatial granularity. The main findings show a dominance of hierarchical structures in place descriptions, but also a considerable number of deviations. Deviations are explained by principles other than spatial granularity, such as the presence of salient features and other construction principles. We conclude the need for and significance of more flexible models of hierarchies in the interaction with users of location-based services.

Keywords Place descriptions · Hierarchies · Granularity · Salience

D. Richter (✉)
Institute of Photogrammetry and Remote Sensing, Karlsruhe Institute of Technology, Karlsruhe, Germany
e-mail: daniela.richter@kit.edu

D. Richter · M. Vasardani ·
K.-F. Richter · S. Winter
Department of Infrastructure Engineering, The University of Melbourne, Melbourne, Australia
e-mail: mvasardani@unimelb.edu.au

K.-F. Richter
e-mail: krichter@unimelb.edu.au

S. Winter
e-mail: winter@unimelb.edu.au

L. Stirlng
School of Languages and Linguistics, The University of Melbourne, Melbourne, Australia
e-mail: lesleyfs@unimelb.edu.au

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1 Introduction

Verbal place descriptions—descriptions answering a where question about a thing or event—typically have a hierarchical structure (Shanon 1979). The hierarchical structure can appear as zooming in (e.g., 'in the park, at the pond') or as zooming out (e.g., 'in Parkville, Victoria') (Plumert et al. 2001). A hierarchical structure of verbal descriptions reflects the hierarchic organization of spatial knowledge in the mind (Hirtle and Jonides 1985), which, in turn, is based on the individual's acquisition of this knowledge through direct and indirect interaction with the environment. Thus, while place descriptions are broadly observed and accepted as being hierarchical, one can expect a high degree of variability in their construction from spatial knowledge. This variability requires flexible interpretation mechanisms in location-based services.

This chapter focuses on human place descriptions. It will identify the major building principles of hierarchical structures in these place descriptions, which will progress their automatic interpretation. Our hypothesis is that:

1. The dominance of hierarchical structures in human place descriptions can be verified in a large corpus of place descriptions.
2. Hierarchical structures are not organized purely by spatial granularity; deviations from spatial hierarchies will reveal other hierarchical systems, for example, based on the cognitive principles of salience or prominence.[1]

The chapter will systematically study a large corpus of human place descriptions collected in a mobile game called *Tell-Us-Where* (Winter et al. 2011). The corpus can be analyzed to learn about the general classification principles of place descriptions. Spatial granularity is one of the classification criteria. Applying it in the present study, we will identify whether such descriptions are hierarchical by granularity, or whether other organizational principles were used. Hierarchical structures can only emerge if at least two spatial references are present. Thus, in this chapter only such place descriptions will be considered. It will be interesting to see how the hierarchical systems of spatial granularity and salience are linked, whether there are preferences for one of them, and whether they can occur independently.

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[1] *Salience* refers to outstanding perceptual or semantic properties of a feature, while *prominence* refers to the degree of shared knowledge about a feature in a community. While the two terms are not synonymous it can be expected that salient features over time also become prominent. In this chapter no strict distinction is needed; mostly, the term salience will be used. For example, the Eiffel Tower is a salient feature because of its unique pyramid-shaped, metal skeleton construction that is very different from the rest of the buildings in Paris. However, it has also become one of France's most prominent (or well-known) features, and certainly a feature that is associated with Paris. Therefore, it can be used as an anchor point of place descriptions in the city of Paris. However, it has also become one of France's most prominent (or well-known) features, and certainly a feature that is associated with Paris. Therefore, it can be used as an anchor-point of place descriptions in the city of Paris.

Hierarchical structures (on whatever principle) have mainly two roles: one is anchoring the location of a thing or event to known places or anchor points ('[I'm in] a café near the library'), and the other is disambiguating the places referred to ('[I'm in] the café near the library'). Anchor point locations are presumed to be cognitively salient cues in the environment referring to a person's individual cognitive map, and thus are known at least by one single person (Couclelis et al. 1987).

The functions of anchoring and disambiguating place are critical for communication success, and this motivates the strong expectation expressed in the hypothesis. However, we also detect different structures, especially answers involving egocentric locomotion ('heading to…'), or listener-centric route descriptions ('to find me, you…'). We will also discuss these deviations from the expressed expectation. We expect to shed some light on the current perceptions of the hierarchical structure of spatial knowledge and to confirm the need for some flexibility in the implemented mechanisms, rather than adherence to absolute rules that may not be able to accommodate the context of different place descriptions. The results will be relevant for understanding and generating human spatial language, facilitating human computer interaction and the creation of intelligent systems.

The remainder of the chapter is as follows: Sect. 2 introduces prior work; Sect. 3 discusses the theoretical framework for the analysis. Section 4 details the analyzed corpus and the classification schema. Sections 5 and 6 present and discuss the results of the analysis.

2 Literature Review

Spatial mental representations are acquired through direct and indirect interaction with the environment (Ishikawa and Montello 2006; Siegel and White 1975) and help people communicate about space. Verbal place descriptions, as one such communication means, reflect cognitive organization principles of spatial knowledge. From a linguistic perspective, place descriptions are referring expressions (Dale et al. 2005) to locations of objects. Gestalt theory suggests that with a focus on the object they form the figure, and references to (the locations of) other features are taken from the ground (the environment). Talmy (1983) specifies that the figure object typically is more movable, is smaller, is conceived as geometrically simpler, is more salient, or is more recent on the scene. The ground object acts as a reference object with known spatial characteristics, is more permanently located, is larger, has greater geometric complexity, is less salient, or is earlier on the scene. Some of these observations directly correlate with the expectation that place descriptions must be hierarchically structured (e.g., smaller–larger), but not all of them (e.g., salience).

Schegloff (1972) points out the large variety of a place's 'correct' location formulations (place descriptions in the sense of this chapter). In a given context, references are selected using the principles of relevance and appropriateness. A more developed model of relevance in conversation is provided by Grice: conversational participants behave in accordance with an assumed in principle agreement to be co-operative (Grice 1975). In particular, they adhere to a relevance principle, which claims that the recipient in a specific communication context will interpret the expression according to this context, in order to maximize the efficiency of actions. Usually, people select the most relevant referents from a possible set of referents. These conversation principles are relevant to the rest of the chapter. They are, for example, cited in the context of generating hierarchically organized place descriptions (Kelleher and Kruijff 2006; Tomko and Winter 2009) to select first, intermediate and final place references in an incremental manner.

The mental organization of spatial knowledge is based on an individual's acquisition of this knowledge. It is formed by landmarks and routes (Siegel and White 1975), and distorted by preferential reasoning through anchor points (Couclelis et al. 1987; Sadalla et al. 1980), i.e., asymmetric relationships caused by differences in salience, and hierarchical structures defined by partonomies (Hirtle and Jonides 1985; Stevens and Coupe 1978). If salience causes asymmetric relationships, it imposes an order, which is independent from partonomies. Measures for salience have been suggested (e.g. Raubal and Winter 2002; Sorrows and Hirtle 1999), but they are local measures, providing an order only in a given context. They do not lend themselves to building a global hierarchy.

Place descriptions inherit the hierarchical organization of spatial knowledge (Plumert et al. 2001; Shanon 1979). These hierarchical structures are employed to decrease the cognitive effort of storing and retrieving information, and to decrease ambiguity in spatial knowledge sharing (Taylor and Tversky 1992). However, dealing with (at least) two independent hierarchical organization principles it is not clear from the outset how these two principles harmonize or are applied together. Finally, while our hypothesis expects a monotonic zooming in or zooming out behaviour, route directions, for example, have been shown to vary in their hierarchic structures with trips that involve various modes of transport (Tenbrink and Winter 2009) or various levels of a hierarchical transportation network (Timpf et al. 1992).

3 Hierarchies in Place Descriptions

3.1 Defining Place Descriptions

A place description is a verbal description answering a where question. Language provides great flexibility in construction principles, to a large extent related to the communication context. A typical form to describe the location of X is:

[[(opt) subject verb] (opt) prepostition] NP

We expect the noun phrase (NP) to refer to a location, as in: 'Where are you?'—'[[I'm] in] Brunswick'. The locative noun phrase can be a simple noun (as in the example), a compound ('Melbourne Central Station'), or complex. If we agree that anchoring one's place to a known place, as in the simple place description, is not hierarchical as such, only complex forms can expose a hierarchical structure. Complex forms can be nested (as in postal addresses) or independent sequences (as in ternary relationships). Prepositions may be explicit (as in the example) or implicit (as in postal addresses).

Research has provided formal models for qualitative spatial relations, distinguishing topological relations, absolute and relative direction relations, and distance relations. However, prepositional phrases (PPs) in language may be ambiguous in their classification. For example, 'at' can appear as a topological descriptor of *in* ('I am at school'), *touching* ('arriving at the school'), or a distance descriptor of *near* ('at the intersection'). These and more ambiguities can often be resolved only from context.

3.2 Identifying Hierarchical Structures in Place Descriptions

Studies identifying a zooming in or zooming out hierarchical behaviour of place descriptions focus solely on an organization by spatial granularity. Many of these hierarchies exist and all are formed by part of relationships. These spatial hierarchies are reflected in cognitive representations and reasoning (Stevens and Coupe 1978); it is reasonable to expect them to be reflected in language as well. An example is postal addresses: a street is part of a city, which is part of a state, which is part of a country.

Algorithm 1: Mechanical procedure to identify hierarchical structures in place descriptions.
Data: A complex place description.
Result: Hierarchical structure of the place description.

1 Identify the locative noun phrases in a place description.
2 To each noun phrase, apply a classification schema identifying the level of spatial granularity.
3 Construct a list of granularity levels in the place description, in order of noun phrase appearance.

We suggest a mechanistic procedure to identify hierarchical structures in place descriptions as laid out-in Algorithm 1. Applying this algorithm, a complex place description can expose one of the following hierarchy patterns:

- *Strictly hierarchical*: place descriptions showing a strictly monotonically increasing or decreasing behaviour towards the spatial hierarchy. The sequence of granularity levels is either zooming in or zooming out; no duplicates of the same levels occur.

- *Partially hierarchical*: place descriptions showing a monotonically increasing or decreasing behaviour. Duplicates of the same levels occur.
- *Flat*: place descriptions that show constant behaviour towards the spatial hierarchy; at the same time monotonically increasing and decreasing (no zooming in or out). They form a special type of partially hierarchical descriptions.
- *Unordered*: non-monotonic place descriptions.

Compound locative NPs may challenge the classification schema. For example, 'Flemington Racecourse' is a compound and a proper geographic name. Classifying this compound at one level of the spatial hierarchy (as granularity level street in this case) can be defended, but it can also be split up into two locative NPs, 'Flemington' (a suburb, district level) and 'Racecourse' (street level). If both NPs were classified according to their individual spatial granularity, the compound would be treated as a complex place description and accordingly as strictly hierarchical. For the purposes of this chapter compounds are treated as single names without limiting generality.

Only the strictly or partially hierarchical patterns from the above four patterns would satisfy the first part of the hypothesis. However, place descriptions with flat or unordered patterns may illuminate other hierarchy structures and need further investigation, in accordance with the second part of the hypothesis.

3.3 Adding Other Cognitive Patterns to the Study

Exceptions to the spatial hierarchical structure of place descriptions may reveal other hierarchy structures in the construction of human place descriptions. Design patterns to be discovered in flat or unordered descriptions may apply to spatially hierarchical place descriptions as well, but this is not considered further.

Place descriptions (either simple or complex), which anchor one's place to a known place, reflect a hierarchical order by cognitive salience that may be independent of spatial hierarchies. For example, 'the building opposite the library' is spatially flat (two buildings), but one NP is known, the other is not (or less) known. More drastically, the spatial hierarchy can be inversed, as in 'the place at Cleopatra's Needle', which links an unnamed place to a better known structure that is part of the place itself. Nevertheless, a correlation exists between spatial hierarchies and salience rankings. For example, 'Switzerland' is globally better known than 'Lake Zurich', or 'Küsnacht' on Lake Zurich.

Cognitive salience imposes an order, but in the absence of absolute comparison measures not a proper global hierarchy. While one might generally distinguish global, regional and local landmarks, or point-, line- and area-like landmarks (Hansen et al. 2006), this distinction describes a function of a reference to a geographic feature, which can change with context. Salience itself depends on the communication context, especially on the communication partners. Hence, when investigating flat and unordered place descriptions for hierarchical structures based on salience, applying Algorithm 1 is not revealing of such structures. Instead we apply a weaker Algorithm 2, which will reveal those flat and unordered place descriptions that are (strictly or partially) hierarchically ordered by salience rankings. Hierarchies by salience are based on the assumption that (personally or communally) more significant features anchor less important (less salient) ones, which again can be anchor points for features of lower significance, and so on. Properties to define such an order may be relational spatial (such as frequency of interaction), relational non-spatial (such as personal meaning) or by referring to intrinsic properties of objects, such as perceptual or symbolic salience (cf. Couclelis et al. 1987). Some examples to illustrate this are 'at the train station near my house' anchoring the train station (less salient) to a more salient feature 'my house' (more salient because of its significance to the person), or 'a café opposite to the big red building', where the 'big red building' (more salient by its visual properties) serves as an anchor point for 'the café'. Adding salience rankings to the interpretation tool set will provide further supporting evidence for our hypothesis.

Algorithm 2: Identification of salience ranking in place descriptions.
Data: The union set of all flat and unordered place descriptions.
Result: A set of all place descriptions that are hierarchic by salience.

```
forall flat and unordered place descriptions do
    Identify the salience rankings of component parts by a semantic, context-aware
    interpretation.
    Construct a ranking sequence in the place description.
```

Finally, a third algorithm is suggested for those unordered place descriptions that have not exposed hierarchal structures after applying Algorithms 1 and 2. The algorithm tests whether a place description classified by the mechanistic Algorithm 1 as unordered is semantically flat or hierarchic. Consider the example 'I'm in the café across the street from the library'. To Algorithm 1 it appears as unordered, switching from a building level to a street level and back to building level. But the string 'across the street' is not an independent PP. The sequence can only be read as 'across the street from the library' (an extension of 'from the library'). 'Street' is best viewed as part of a complex prepositional construction, not as an independent reference to a geographic feature. Algorithm 3 will remove spatial granularity levels in sequences produced by Algorithm 1 as a result of locative noun phrases that are part of a complex PP. Adding complex PPs to the interpretation tool set, we may find final supporting evidence for our hypothesis.

Algorithm 3: Semantic filtering of unordered place descriptions.
Data: A set of unordered place descriptions.
Result: A set of unordered place descriptions filtered for semantic hierarchy.

```
forall unordered place descriptions do
    Identify isolated violations of monotonic spatial granularity orders.
    if this occurrence is part of a dependent PP then
        remove it from sequence.
    if after all removals the place description is flat then
        re-apply Algorithm 2.
```

4 Data and Methods for Analysis

4.1 Corpus of Place Descriptions

In this chapter a subset of place descriptions collected through the mobile location-based game Tell-Us-Where (Winter et al. 2011) is analysed by means of a classification schema, and by manually applying the presented algorithms.

In Tell-Us-Where participants were encouraged to confirm their GPS self-localization on a smartphone-map and to submit a textual description of their location answering the question ‘tell us where you are’. Apart from these tasks and knowing they may win a gift voucher, no further context was specified. No further information about the location and knowledge of the recipient was collected. Participants could freely choose where, and also what to submit. The game was implemented as a web-browser based application to run platform-independent on various current smartphone operating systems. All place descriptions were stored server-side. Records were directly attributed with a record number, the latitude and longitude of the self-localization, the map zoom level of the self-localization confirmation, the date, and an indication whether the submitted place description won a voucher. Tell-Us-Where was promoted in Melbourne and beyond via social networks, the press, and the local radio. Within six months of running the game, 2,221 geocoded place descriptions were collected with a large variety of styles or assumed communication contexts—primarily of locations in and around Melbourne. Since there were no data acquired about the participants, information about age, gender or educational background are not available.

For the following analysis of hierarchic structures, a classification schema for the spatial granularity of each spatial cue is needed. We are using the schema presented in Table 1. The granularity of cues classifies seven different levels of spatial granularity, and place descriptions have further been labelled for spatial relations, such as qualitative and quantitative distances, relative or absolute orientation, and topology.

Table 1 Classification of granularity

Class	Description
Furniture	Location within a room, referring to furniture ('at my desk', 'in bed', 'on a bench'), small vehicles (bike) or natural features ('under a tree')
Room	Location within a building, or within parts belonging to it ('in my lab', 'hallway on the second floor', 'back yard') or medium vehicles (car, boat)
Building	Location of a building, e.g., street no, street corner, building name ('engineering dept', 'spencer street station', 'at work'), large vehicles (train, ferry)
Street	Institution, public space or street level, i.e., larger than building and/or vaguer boundaries than building. Included are infrastructure (railway, tramline, Ave, Ln, Boulevard, circuit, way, Cres, Pl.), public spaces (golf course, sports ground, school, university, cemetery, hospital, mall), natural features (port, bay, lake, hill, park, reserve, paddock)
District	Suburb, rural district or locality, post code areas ('carlton', 'South Melbourne'), categorical information ('central business district', 'downtown', 'city center')
City	Town or city level, and metropolitan areas ('Canberra', 'South of Melbourne', 'near geelong')
Country	Everything beyond city level. This includes highways, freeways ('black spur Hwy'), islands ('Phillip island'), national parks, rivers, states ('In Australia', 'WA somewhere')

Since place descriptions were manually classified, a random sample of 10 % of the corpus was independently classified a second time. An inter-annotator agreement of 95 % supports the robustness of the specification of the classification schema.

4.2 Spatial Hierarchic Structures

From the total of 2,221 place descriptions, a subset of 722 descriptions that contain at least two spatial cues were extracted to investigate granularity of elements, as well as the order and direction of order (zooming in or out) within hierarchic elements.

The classification of spatial cues in place descriptions requires abstraction and definition of granularity levels, especially for features that may be ambiguous or show great variations in size (e.g., rivers, parks or islands) compared to features that are more assessable (e.g., 'at home', 'in my car'). The classification schema establishes seven levels of granularity, namely *country, city, district, street, building, room,* and *furniture* (see Table 1 for specifications and examples). These levels reflect human perception of spatial scales (Montello 1993). And given the elements referred to in the Tell-Us-Where corpus, these levels proved to be most appropriate, even though the restriction to seven levels may ignore some potentially hierarchic structures (e.g. 'Victoria, Australia' are both categorized on level country). Elements beyond these levels were not observed.

The classification of cues according to spatial granularity captures the difference in levels as well as the difference in the number of mentioned cues. Spatial cues are assessed regardless of the spatial relationships involved, i.e. 'South of Melbourne' and 'near Geelong' will be classified as granularity level city. Partial features were reduced in granularity level. For example 'South Melbourne' is classified as district level, referring to the southern part of Melbourne. Similarly, 'end of Arnold Crt' would be reduced from street level to building level. Multitudes of objects (e.g., apartments) are classified as a coarser granularity level, i.e., whereas one single 'apartment' is classified as room level the plural form 'apartments' is classified as building level. The distinction between city and town (level city) and suburb, localities, township, and village (level district) was made according to VicNames.[2]

Place descriptions are strictly hierarchic, partially hierarchic, flat or unordered (Sect. 3.2). Strict and partial hierarchic place descriptions were classified to be either *zooming in* or *zooming out*. An example of a place description with zooming in order is 'little lonsdale street near the parliament house', since the coarser element 'little lonsdale street' (street level) is followed by the finer element 'parliament house' (building level). A zooming out example is 'behind kfc on swanston st', which zooms out from the finer element 'kfc' ('Kentucky Fried Chicken'; building level) to the coarser element 'swanston st' (street level). An unordered place description is 'In Bok Choi, the Chinese restaurant at federation square—top floor'. It starts with a zooming out from building level ('Chinese restaurant') to street level ('at federation square'), and then zooms into room level ('top floor') again.

After a first pass coding of descriptions according to spatial granularity, Algorithm 2 is applied to all descriptions that were identified as flat or unordered. This identifies a number of flat hierarchies to be semantically hierarchical. For example, the description 'diagonally opposite St. Francis church, at a tram stop' is according to spatial granularity flat (all spatial cues are at building level). However, the PP 'diagonally opposite St. Francis church' defines a wider area behind a landmark or anchor point ('St. Francis church'), while the PP 'at a tram stop' refines the exact position in this area. As a result, there is a semantic hierarchy identified in the spatially flat description that zooms in from the general area defined by a salient feature to the more specific location (or less salient feature) within it. For all remaining unordered descriptions, Algorithm 3 reveals certain patterns that allow for the categorization of these descriptions as semantically flat or hierarchic.

While in this chapter the algorithms were applied manually, it seems possible to automate the process in principle. Natural language processing allows extraction of information from text by means of named entity recognition. Using an open-source framework such as GATE (Cunningham 2002)[3] in combination with gazetteers for place name detection would enable an implementation of Algorithm 1. For the identification of salience rankings and semantic filtering of unordered

[2] http://services.land.vic.gov.au/vicnames/

[3] http://gate.ac.uk, implemented in Java

place descriptions (Algorithm 2 and 3) further parsing rules have to be established, to interpret complex descriptions and to assess salience based on context knowledge.

5 Results

Regarding the types of descriptions, the vast majority of place descriptions (91 %) contained location positions, 2 % route descriptions, and 9 % locomotions (the classes could overlap). In terms of granularity, 40 % of all spatial references were classified as street level, 30 % as building level, and 13 % as district level, with smaller percentages for the other levels.

Table 2 shows the frequency distribution of the number of different granularity levels within place descriptions, grouped by the different types of hierarchic order.

5.1 Hierarchic Place Descriptions

623 descriptions (86.3 %) contain different levels of granularity. The majority of these (514 descriptions) are hierarchic with a sequential order of different levels. 109 of the descriptions are unordered, and the remaining 99 place descriptions are flat. The hierarchic place descriptions were further distinguished as 386 (53.5 %) strictly hierarchic and 128 (17.7 %) partially hierarchic. Table 3 shows the distribution of strictly and partially hierarchic place descriptions for the respective directions of order, and with further subdivision into different description types.

5.2 Flat and Unordered Place Descriptions

Flat place descriptions that contain references on one level of granularity have been identified on building level (28 %), street level (68 %), district level (2 %), city level (1 %), and country level (3 %). Most flat place descriptions contain two spatial cues on building or street level (80 %) and 14 % contain three cues on these levels. The flat descriptions were examined for salience hierarchies by

Table 2 Frequency distribution of place descriptions

No. of levels	Strict. hierarchic	Part. hierarchic	Unordered	Total	(%)
1 = 'Flat'	–	–	–	99	(13.7)
2	336	82	49	467	(64.7)
3	39	23	36	98	(13.6)
4	9	19	19	47	(6.5)
5	2	4	3	9	(1.2)
6	–	–	2	2	(0.3)
Total	386	128	109	722	(100.0)

Table 3 Frequency distribution of hierarchic place descriptions according to the different directions of order

		Strict. hierarchic	Part. hierarchic	Total (%)
Zooming out		278	98	376 (52.1)
	Position	256	95	
	Locomotion	18	3	
	Route	2	–	
	Position + locom.	1	–	
	Position + route	1	–	
Zooming in		108	30	138 (19.1)
	Position	85	28	
	Locomotion	20	2	
	Route	1	–	
	Position + locom.	2	–	
Total		386 (53.5 %)	128 (17.7 %)	514 (71.2)

applying Algorithm 2. 17 cases were classified as locomotion descriptions and were not further analyzed (their construction principles are beyond the scope of this chapter). Nine cases are compound NPs treated as a proper geographic name (e.g., ‘Melbourne central shopping centre’), and thus were excluded from further analysis. In some flat descriptions, a hierarchical structure was implied by the preposition ‘in’ (e.g., ‘on the footpath in a little side street’). The preposition ‘in’ induces a hierarchical part of relation for the two spatial cues ‘footpath’ and ‘little side street’ that belong to the same granularity level street.

Algorithm 2’s results show that nearly half of the descriptions (47) contain references to a more salient feature. This acts as an anchoring element that indicates an (assumed) better known location, implying a salience hierarchy. The preposition ‘near’ also suggests a hierarchy in flat descriptions. In 13 cases, the feature following ‘near’ acts as a refining element (e.g., ‘frawley road near tennis courts’, where the PP ‘near tennis courts’ refines the location on ‘frawley road’), while in three cases the PP acts as a disambiguating feature (e.g., ‘tram stop near mayer’, where the PP ‘near mayer’ disambiguates the ‘tram stop’). In seven place descriptions other refining elements to specify a location within a wider area are used. The flat description ‘At the park where the eastern freeway bike path is’ zooms in from the general area of the park to the more specific part defined by the compound NP ‘eastern freeway bike path’.

The unordered place descriptions contain at least three different cues. 29 % of them contain exactly three cues, 28 % contain four cues, 15 % contain five cues, 10 % contain six cues, 12 % contain seven, eight, or nine cues, and 6 % contain ten or more cues. Although unordered place descriptions show a high number of spatial cues, 45 % use only two different levels of granularity (usually adjacent levels), 33 % use three levels, 17 % four, and 5 % use five or six levels (cf. Table 2). 39 % of the unordered descriptions start with zooming in and then zoom out again. Of these, 7 % continue with a zoom in, further 4 % with a zoom out, and 1 % with a zoom in. Thus, the latter 1 % have a zooming structure of in–out–

in–out–in. On the other hand, 61 % of the descriptions start with a zoom out followed by a zoom in. Therein are 26 % of the descriptions that continue to zoom out, further 14 % zoom in, 3 % that zoom out and 2 % zoom in (the latter have a structure of out-in–out–in–out–in).

Due to the small number of unordered place descriptions, correlations between different types of place descriptions are not significant. However, 75 % of locomotions start with zooming in, whereas 80 % of route directions start with zooming out. 37 % of location descriptions start with zooming in, 63 % with zooming out. Algorithm 3 identifies some of the zooming in–out patterns to be hierarchic.

6 Discussion

6.1 Hierarchies in Place Descriptions

The analysis of the Tell-Us-Where corpus clearly supports Hypothesis 1: a vast majority of place descriptions (86 %) refer to two or more geographic features on different levels of spatial granularity. More than two-thirds of them (71 %) exhibit either a strictly or partially hierarchical structure. At the same time, these numbers indicate that other mechanisms than simply differences in spatial granularity are at play as well, when people describe where they are.

These other mechanisms manifest themselves in the observed deviations from zooming in or zooming out structures, namely flat and unordered structures. Some of these deviations reveal hierarchical structures based on salience, which supports Hypothesis 2. Some deviations result from the chosen order of analysis (Algorithms 1–3). Hierarchies based on spatial granularity are identified first; salience is only considered for those descriptions not yet classified as hierarchic. This processing order is to some extent arbitrary, and ignores possible interplays between granularity and salience, which prohibits further analysis of preferences or links between the two. This is left for future work. Other deviations seem to be the consequence of not using static, locative place descriptions; some are artifacts resulting from how the classification schema defines granularity levels.

A significant number of the flat or unordered place descriptions are in fact hierarchic based on salience of features or on spatial relationships, as has been shown in Sect. 5.2. For example, consider the flat description ‘In Gopal’s restaurant, diagonally opposite of Melbourne City Hall’. Here, ‘Melbourne City Hall’ is the prominent landmark that defines an anchoring region; within it ‘Gopal’s restaurant’ defines a more exact location. In many other flat descriptions, use of similar prepositions (e.g., ‘in front of’, ‘behind’, ‘next to’) define a semantic or salience hierarchy. These prepositions anchor a place relative to other features in an environment, which are often seen to be more salient than the place itself. Some of the prepositions (e.g., ‘near’) may also be used to refine the location with respect to a larger region, as in ‘frawley road near tennis courts’.

The existence and number of unordered descriptions seems a surprising result, and contrary to what has previously been reported in the literature (Plumert et al. 2001). However, a closer examination of the grammatical, semantic and referential structure of these expressions, and of other potential ordering patterns such as salience of locations, motivates the apparent switching between granularity levels in many cases. A full description of the grammatical and semantic structure of the expressions is beyond the chapter's scope, but a few observations illustrate the kinds of patterns observed. For example, many of those descriptions involving three spatial cues turn out to have a two-part structure as locational descriptions. We observed three different kinds of such two-part structures:

1. General location (overall place, usually building or institution) + more specific location within it, OR
2. Location + salient reference point to help further identification, OR
3. Apposed location + alternative description of the same location (e.g., street address + name of the building).

As an example of the first pattern consider 'In the University of Melbourne in the building number 174 near to Grattan street from south'. This description goes from street level ('University of Melbourne' as institution) to building level ('in the building 174') to street level again ('near Grattan street from south'). If semantically interpreted, the description can be decomposed into two locational descriptions and classified as hierarchical, going from the first general location ('In the University of Melbourne') to the more specific location within it ('in the building number 174 near to Grattan street from south'). The description '483 swanston st. opposite public city bath' is an example of the second pattern, going from building level to street level to building level again. Semantically, the first spatial reference provides a location (the address '483 swanston st.', classified as building plus street level), followed by a PP that uses a more salient feature ('public city bath') to support identifying the location. In this case, the description can be considered as flat, comprising two locational descriptions of the same (building) level. An example of the third pattern is '570 Bourke Street, DSE building' that goes from building, to street, to building level. It can be considered as the composition of two alternative descriptions of the same place (address and building name) resulting in a conceptually flat description.

Locomotion descriptions and route directions are other observed deviations from static hierarchical place descriptions. Their detailed analysis is part of future work. Since the producers of locomotion descriptions are moving, an exact localization of their current place is not helpful. Rather, their final destination or the geographical feature they are travelling on is of interest, often expressed at coarser levels of granularity (city level, or highways classified as country level). If such a description also contains the mode of transportation ('in my car' classified as room level), descriptions become hierarchical with references to very different granularity levels because references to elements on the intermediate granularity levels are not relevant here—in fact, they would likely be confusing.

The way the experiment was designed the participants represented only a particular subset of the general population. Because the game was promoted through social networks in an academic environment, most likely the majority of participants were students. An investigation of place descriptions with respect to different groups of participants is certainly interesting. But such information on the participants was not captured by the game. This, however, could be considered in another implementation.

Also the participants were not told about a particular task or context of their task. It would be interesting to investigate if, for example, time-critical tasks in a mobile environment produce certain types of place descriptions. The corpus contains 120 place descriptions during locomotion (directed) and 136 involving activities (undirected) that could already be used for this purpose.

6.2 Implications for Location-Based Services

Place descriptions are an everyday means for people to describe their environment, to tell others where they are, to locate features in an environment, or to request information about an area. These place descriptions reflect human spatial memory (Hirtle and Jonides 1985; Siegel and White 1975). Their integration into location-based services that can interpret and produce such descriptions would greatly benefit the utility of these services and improve human–computer interaction in areas such as emergency response (locating callers), search (defining spatial search queries), and navigation services (understanding destination requests, providing concise instructions).

The analysis of the Tell-Us-Where corpus illustrates that Algorithms 1–3 would provide a useful first step in this direction. These algorithms have been applied manually for the analysis presented in this chapter. Many descriptions are indeed hierarchical based on spatial granularity, which can be captured in spatial data structures. However, a non-trivial subset of place descriptions requires a careful semantic interpretation, which is dependent on specific contexts. This is clearly much harder to perform automatically. Algorithms 2 and 3 provide means for this in principle, but need further, more detailed specification to be really applicable automatically. High quality computational syntactic and semantic parsing systems may take us some way further towards this goal. It also seems worthwhile to develop (qualitative) interpretation models for the spatial relations used in place descriptions. These relations often induce a hierarchical relationship that allows for interpreting the intended meaning. The models would need to be adaptable to different contexts, and need to provide both anchoring and refinement operations. Also, better models for capturing salience of geographical features (cf. Richter and Winter 2011; Tomko et al. 2008) are required to enable the identification of hierarchies beyond spatial granularity.

7 Conclusions

This chapter presents an analysis of a place description corpus collected through a mobile game. The context in the game was largely underspecified, allowing for the collection of a wide range of different descriptions. The aims of the chapter were to test the hypothesis that place descriptions are typically hierarchical in their structure, and to explain any observed deviations from such hierarchies. The hypothesis was found to be true with most of the place descriptions showing a spatially hierarchical structure of either zooming into or zooming out from the place of 'where people are.' Results also illustrate that people employ hierarchies of salience in addition to hierarchies of spatial granularity. The chapter suggests a sequence of three (high-level) algorithms for the interpretation of place descriptions. Implementing these algorithms would allow for automatically interpreting most of the collected place descriptions. However, several descriptions have been found to be context-dependent and requiring careful semantic analysis, which has implications for the inclusion of place descriptions in location-based services. Results are preliminary because the proposed algorithms are based on place descriptions given in English only. A general application of the algorithms will need further investigation of certain similarities in structures of place descriptions with respect to other languages and cultures.

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Understanding the Roles of Communities in Volunteered Geographic Information Projects

Peter Mooney and Padraig Corcoran

Abstract As a society we are now more connected than ever before. Citizens interact with each other and form virtual communities based on a common interest or being involved in certain cultural, political, intellectual, or other issues. Volunteered Geographic Information (VGI) is generated when citizens annotate content from social media and smart devices. OpenStreetMap is a famous example of a VGI project with a very large community of contributors. This chapter examines this community and investigates the types of contributors and interactions amongst members of OSM. Our results show that there are very small groups of individuals creating and editing over 85 % of all OSM objects in three case-study cities. Editing and contribution behaviour is mostly steady and consistent over time except during months where OSM 'mapping parties' occur or when freely available spatial data is bulk imported into OSM. The paper also provides results of analysis into the social interaction between contributors to OSM where we show that a very small number of contributors are actively editing and maintaining the data submitted by other contributors. This indicates that most contributors work exclusively on their own data and rarely edit the work of others. Overall this paper will be of interest to LBS practitioners considering using OSM as a source of spatial data for LBS applications.

P. Mooney (✉)
Department of Computer Science, National University of Ireland Maynooth (NUIM),
Co. Kildare, Ireland
e-mail: peter.mooney@nuim.ie; peter.mooney@tnuim.ie

P. Corcoran
School of Computer Science and Informatics, University College Dublin (UCD),
Dublin 4, Ireland

P. Mooney
Department of Computer Science, National University of Ireland Maynooth,
Maynooth, Ireland

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1 Introduction

In today's information society citizens are more connected to each other than at any other time in human history. The Internet, social media, and continued advances in smart device technology and telecommunications have had a profound affect on how citizens interact with each other. The Location-based Services (LBS) industry has grown exponentially in recent years based on these types of interactions. These factors have combined to see an unprecedented increase in the amount of user-generated content (UGC) created and made available on the Internet today. Text messaging, social media interactions, photos, video, blog entries, etc. are amongst the most popular forms of UGC. Recently, with the widespread availability of consumer GPS devices much of this UGC now contains spatial information (embedded geographical coordinates, locational information, etc.).

A special form of UGC is Volunteered Geographic Information (VGI). Overviews of VGI can be found in a number of recent papers (Dodge and Kitchin 2011; Goodchild 2008; Mooney et al. 2010). VGI can range from geographical coordinates automatically embedded in a digital photograph (Goodchild 2009) and made available in some online repository to more complex forms of spatial data such as annotated GPS tracks and trails (Mooney and Corcoran 2012; Neis et al. 2012). OpenStreetMap (OSM) is a famous example of VGI on the Internet and in recent years has been subject to analysis by many leading GIS researchers. Anyone can be a contributor to OSM and these contributors form a very large community of citizens collecting (and subsequently editing) spatial data. The OSM collaborative model is not dissimilar to that of Wikipedia where a large online community collaborates to collect knowledge and information to create an online encyclopedia.

This chapter focuses on examining the community of contributors in OSM using an analysis of the historical database of contributions to OSM for three major cities (Berlin, London, and Paris). The analysis in the chapter is based on providing answers to the following research questions. (1) Are the contributors to OSM in these cities actually interacting with each other in a collaborative manner to build the OSM databases for their city? (2) If there is collaboration then how do we quantify it and (3) what are the types of contributions members of OSM actually make? In their analysis of editing behaviour in Wikipedia Iba et al. (2010) recommend that analysis of collaborative knowledge projects should focus on the most prolific actors in these networks. Despite the potentially large size of collaboration networks they still process small world properties. Our analysis primarily focuses on the most frequent contributors to OSM in the three case-study cities.

The remainder of the chapter is organised as follows. Section 2 provides an overview of the related literature on Volunteered Geographic Information. Section 3 provides the experimental analysis of the OSM historical data for our three cities. Section 3.1 describes the spatial data and contributor characteristics of these study areas. Section 3.2 then moves to investigate the overall editing behaviour of contributors in the study areas by analysing way creation and editing on a monthly basis over the entire history period. In Sect. 3.3 we describe how a social network data structure is extracted and built from the OSM history data using edit interactions between contributors to infer linkages between contributors. Section 3.4 attempts to classify the edit interaction behaviour of high ranking contributors in each of the cities. In Sect. 3.5 edit interactions are used to build and describe a collaborative social network for OSM in the cities. Section 4 is the final section in the paper where the key outcomes and findings are discussed in a review of the paper. The paper closes with Sect. 4.2 and a discussion of some of the issues that provide scope for future work on this topic.

2 Review of Related Literature

Volunteered Geographic Information (VGI), the term coined by Goodchild in (2008), is the recent empowerment of citizens in the collaborative collection of geographic information. OpenStreetMap (OSM) is a collaborative project to create a free editable map database of the world as is probably the most well known example of VGI. There are few reports published in the literature regarding the extraction of social network characteristics directly from VGI. In OSM there are consultation and collaborative discussions on Wikis and mailing lists (Budhathoki et al. 2010) and at "mapping parties" but these are not very easily quantifiable. From a Location-based Services viewpoint VGI offers opportunities for access to a vast array of data and information about the environment around us. The quality of the VGI is a major obstacle towards its more widespread adoption in application areas such as LBS. Goodchild (2009) argues that very different mechanisms will be required to ensure the quality of data volunteered by amateurs. Despite the absence of clear methodologies or approaches to ensuring the quality of VGI Goodchild remarks that since 2007 "there are now literally hundreds of Web services that collect, compile, index and distribute VGI content" (Goodchild 2009). For this reason that we are interested in exploring the social processes that occur in the collection of VGI. Coleman et al. (2010) argue that by understanding the motivations of contributors to VGI and their social interactions one might be able to better understand the decisions made around the quality of contributions. "The crowd" as a metaphor signifies the power that can emerge from a mass of individuals converging to tackle a set of tasks. In the virtual realm, a crowd can be drawn together across a widely distributed set of actors for little cost in order to tackle very large challenges (Dodge and Kitchin 2011) such as mapping the transportation networks, utility networks, built environment, and green spaces of an entire urban metropolis. From a social viewpoint McLaren (2011) suggests that quality assurance could be directly provided by members of the local communities who take direct responsibility for authenticity of data in their area.

Quality analysis of VGI requires a broad multifaceted approach (Mooney and Corcoran 2012a, b). While this paper does not focus on the geometric and semantic quality of geographic objects in OSM we feel that understanding the characteristics of contributors who generate OSM data is an important aspect towards making decisions regarding the quality of OSM data. Many researchers (Haklay et al. 2010; Over et al. 2010; Girres and Touya 2010; Mooney and Corcoran 2012) have shown that when a large number of contributors work on OSM for a specific area this usually leads to better quality data and a stable, well maintained, OSM dataset for that area. Previous studies have focussed on relationships between the number/quantity of contributors in a given area without focussing on (1) who the contributors are or (2) what are the dynamics of the community within which these contributors are working. Wikipedia offers the closest comparison to OSM in terms of a large crowd working on a collaborative knowledge project. Iba et al. (2010) analyses editing patterns of Wikipedia contributors using a social network analysis. They identify the most creative Wikipedia editors among the few thousand contributors who make most of the edits from a pool of millions of active Wikipedia editors. They identify the key category prolific authors who start and build new articles of high quality. Feldstein (2011) carried out an analysis of how Wikipedia articles are created. Felstein comments that common wisdom has it that the Wikipedia has been created by "the crowd". He argues that this does not hold at the level of article creation and "at least not in the sense that a large swarm of Wikipedia editors descends upon a blank topic page and, when the dust settles, a fully formed Wikipedia article appears". Felstein's pilot study suggests that the article creation process, at least, seems to more closely mirror the traditional writer/editor process than it does the "crowd as writer-editor".

Overall we can see that the social processes governing the creation and maintenance of spatial data in VGI are not well understood yet. The role, influence, and work performed by "crowd" as a whole and individually have not been quantified. The next section of the paper provides the analysis of the OSM history data for the three case-study cities (London, Berlin, Paris).

3 Experimental Analysis

The OSM history for three cities (London, Berlin, and Paris) was extracted from the complete OSM history file (http://wiki.openstreetmap.org/wiki/Planet.osm/full). This file is generated every 2–3 months and made available from the OSM website. The OSM history is encoded in OSM-XML format. We used polygons for London, Berlin, and Paris based on the EU Nomenclature of Territorial Units for Statistics (NUTS) coding to OSMOSIS and extracted the three cities. The resulting OSM-XML was then processed and stored in a Postgresql PostGIS database. The complete history for the three cities was extracted from early 2006 until March 2012.

Table 1 A summary of the overall spatial and contributor characteristics extracted from the historical analysis of OSM for London, Berlin, and Paris

Statistic	London	Berlin	Paris
Area (km^2)	1,572	891	1,368
Total contributors	2,795	2,848	1,168
Unique ways	419,801	347,556	280,765
Total way edits	876,743	897,610	5,21,637
Contributors ≤10 edits	1,738 (63 %)	1,571 (55 %)	774 (67 %)
Contributors ≤20 edits	2,002 (72 %)	1,852 (65 %)	865 (74 %)
Contributors ≥200 edits	250 (8 %)	333 (11 %)	101 (8 %)
Top 10 (ways created)	194,511 (46 %)	155,495 (44 %)	218,888 (77 %)
Top 10 (total edits)	365,984 (41 %)	425,905 (47 %)	367,228 (70 %)
Top 250 (ways created)	404,135 (96 %)	319,708 (91 %)	279,452 (99 %)
Top 250 (total edits)	762,766 (87 %)	822,591 (91 %)	516,501 (98 %)
Ways (1 vers)	228,222 (54 %)	176,665 (50 %)	155,724 (55 %)
Ways (vers ≥5)	33,230	48,152	12,745

3.1 Characteristics of the Study Areas

In Table 1 we provide a summary of some of the key characteristics from the database of all edits to OSM in Berlin, London, and Paris. There are over 419,000 unique ways in London, almost 350,000 unique ways in Berlin, and almost 300,000 ways in Paris.

In Berlin and London there are over 800,000 edits to ways (polygons and polylines) whilst there are just over 500,000 edits to ways in Paris. The number of distinct contributors to OSM in Berlin and London is almost 3,000 whilst the number for Paris is just over 1,000. We ranked all of the contributors in each city by the number of distinct edits to ways which they performed. In the three cities this resulted in a long-tailed distribution of a small number of people performing a large number of edits. We used the threshold of the top 250 ranked contributors (benchmarked from the London dataset). The top 250 in London performed exactly 200 or more edits. The top 250 in London are responsible for 87 % of edits, 91 % of edits in Berlin, and 98 % of edits in Paris. Within this group of the top 250 the top 10 contributors have performed 41 % of all edits in London, 47 % of edits in Berlin, and 70 % of edits in Paris. At the opposite end of the ranking the number of contributors performing only a small number of edits (≤10) is substantial. In London 63 % of contributors perform ten or less edits whilst this figure is 55 % in Berlin and 67 % in Paris. Overall, it is apparent that in each city a relatively small number of contributors to OSM are bearing the responsibility of the vast majority of all editing work. Focussing on the creation of ways (essentially the first representation of a given polygon or polyline in the OSM database) the statistics are very interesting. In London and Berlin the top 10 ranked contributors are responsible for the creation of over 40 % of all ways in those cities and over 75 % for Paris. When we look at the top 250 contributors, in terms of way creation, they are responsible for 87, 91, and 99 % of all way creation in London, Berlin, and Paris respectively. This indicates that this group of contributors are of fundamental importance to OSM in these cities.

Each time a way is edited a new version is created in the OSM database. On initial viewing of Table 1 it might appear that all of the ways are being edited frequently. This is not the case. Over 50 % of all ways in the three cities are single version (ways are only created and never edited). These ways are created but are left untouched by their creator or other contributors. Edits can consist of modifications to geometry and/or editing of tagging and attribution contribution. Mooney and Corcoran 2012a, b) introduce the concept of 'heavily edited' OSM objects. Their analysis investigates the properties of those ways with $\geq$15 versions. In the table we see that a relatively small percentage of ways have 'high edit' characteristics. In this case we consider 'high edit' ways as those with $\geq$5 edits and at least two distinct contributors. We found that the threshold of $\geq$15 versions as outlined in Mooney and Corcoran 2012a, b) was too high and their analysis was performed on larger datasets. From this part of the analysis we can see a small subset of contributors performing the vast majority of editing work to OSM in the three cities.

3.2 Characteristics of Way Creation and Editing

In this section we will discuss the overall characteristics of the creation of new ways and the subsequent editing of existing ways in the three case-study cities. If one examines the current snapshot of OSM for any given area it is impossible to understand how the current map representation has evolved to it's current configuration.

In Fig. 1 we show a time series graph of total monthly edits and way creation in Paris over the entire period represented in the OSM history for the city. Up to the beginning of 2010 the pattern of collaborative mapping in Paris was one of low frequency way creation followed by slightly higher frequency editing. In the period of April 2010 to January 2012 the French National Cadastre dataset was imported into OSM. This resulted in thousands of way creations per-day and subsequent edits. OSM import rules mean that bulk imports such as this must be intelligently merged with existing data already in the OSM database. An editing campaign in late 2011 was instigated to fix some metadata/tagging problems with the import. In Fig. 2 we show a time series plot of the total monthly edits and way creation in Berlin. The London city time series is very similar. With the exception of a period of consecutive months in 2010 the amount of editing and maintenance of existing ways was greater than the monthly rate of way creation. There are two spikes in way creation in 2009 and 2011 most probably relating to smaller scale bulk imports—from ortho-photo tracing and the national post-code database. However the monthly rate of way creation is decreasing. This is to be expected as the number of 'new features' left for mapping diminishes rapidly. Berlin shows impressive and reasonably consistent total monthly rates for editing of existing

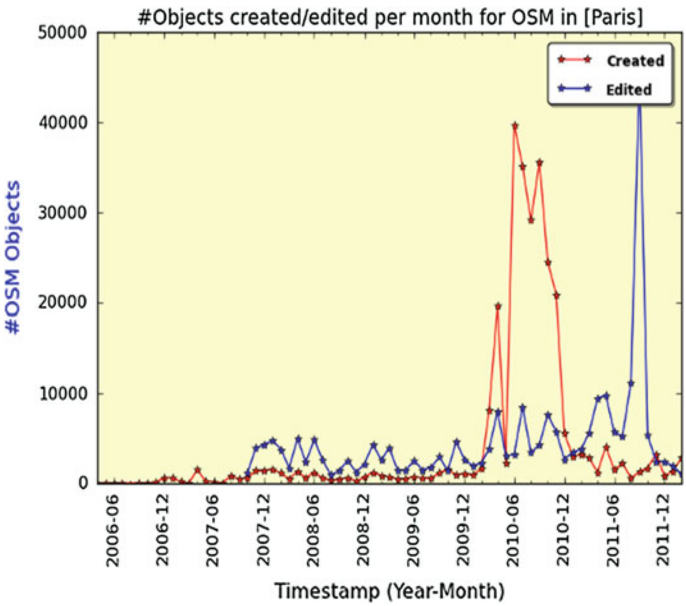

Fig. 1 A timeseries graph of total monthly edits and way (object) creation in Paris over the entire period of OSM history in the city

ways. This is very important as it can indicate that the OSM database for the city is being well maintained and kept up-to-date.

3.3 *Creating a Social Network Structure in OSM from Edit Interactions*

Usually, in social network analysis one infers linkages between nodes (actors, participants, etc.) by finding similarities in the characteristics of the nodes. If some measure of similarity is satisfied then there is a link or edge between those two nodes. For example in a Twitter conversation network there is a natural link between two Twitter users if they follow each other or retweet each other's tweets. In Flickr or Facebook networks linkages are most naturally between users who 'like' each other or are 'contacts' with others. A citation network can be considered as a specific form of a social network based on the citation patterns of academics. In Wikipedia where contributors collaborate to edit an article on a given subject a link is inferred if (1) two users edit the same article, (2) have conversation in the talk pages of the article wiki, or (3) edit each other's work on the chapter. In OSM it is not easy to build a social network data structure directly from the characteristics of contributors. Such information is not available for automated extraction. Contributors in OSM do not "follow" each other as in social

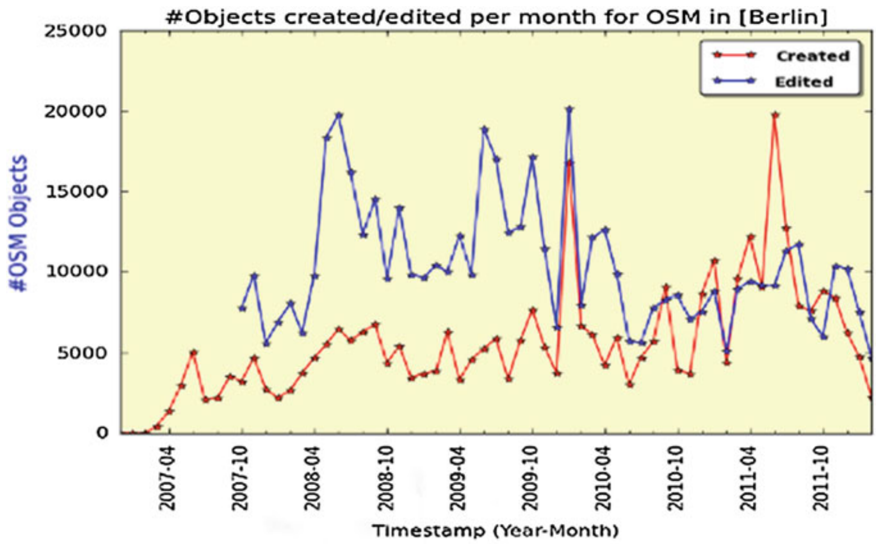

Fig. 2 A timeseries graph of total monthly edits and way (object) creation in Berlin over the entire period of OSM history in the city

networks such as Facebook. There are no explicit linking mechanisms between contributors in OSM expressed in any OSM datasets. Finally, unlike Wikipedia, there is no hierarchy in contribution to OSM. Some OSM contributors, after a long period of time contributing to OSM, become 'de-facto' moderators or administrators. However this does not bestow any special rights on them and any large scale changes or edits (deletions, reverts of potential vandalism, etc.) to the OSM database must be done with the consensus of the wider OSM community. In this analysis we infer a linkage between two contributors if they have *co-edited* a way.

We define co-editing as follows. The historical data for all of the contributions performed by a given contributor A are extracted from the database. Suppose a contributor A edits the work of contributor B on some way object O then $s(A, B, O) = 1$ where A creates the version of O labeled O_{t+1} where B created the version of O labeled O_t. Then O_t and O_{t+1} are consecutive versions of the same object O. We call this an Edit Interaction (EI). In the next section we use EI as a means of understanding the social network characteristics of the contributor network to OSM in the three case-study cities.

3.4 Edit Interaction Behaviour Amongst Contributors

We computed all of the EI for every contributor in the top 250 contributor list for each of the cities. The EI of the top 250 contributors for each of the three cities were summarised under four distinct classifications based on the types of edits

Table 2 Results of clustering and classification of edit interactions (EI) of the top 250 contributors to London, Berlin, and Paris

City	Only created	Geometry edits	Tagging only	Geometry and tagging	Unclassified
London	27	98	81	35	9
Berlin	18	68	28	120	16
Paris	13	90	37	101	9

performed namely: 'Only Created' where this contributor only created a way as an edit and performed no further editing. Inherent in the creation of a way is the association of tags with the first version of the way. Creation of a way is a special form of edit; 'Geometry Edit' is where a contributor potentially created a way but only performed geometry edits on that way. This also includes the case where s(A, B, 0) = 1 and A only edited or changed the geometry of O as created by B, '*Tagging only*' is where a contributor only performed edits on the tags associated with a way object, and finally 'Geometry and Tagging' is where the edits are both related to changes in the geometry of the way and the associated tagging metadata. The scores for these four classes are stored in an EI description vector for each contributor. We applied k-means clustering to this dataset with k = 4. Bayesian classification was used to assign contributors to a specific classification. We carried out a process of manual verification to ensure that the classification was as expected. In Table 2 we tabulate the results of the clustering and classification of the EI of the top 250 contributors for each city.

In Table 2 the majority of the unclassified contributors are at the lower end of the top 250 contributors ranking where their EI cannot be easily classified as belonging to one of the specific four classes. There are a number of interesting observations from the results in Table 2. London has the largest number of contributors who 'Only Create' ways and those contributors whose edits are predominantly 'Tagging Only'. It could be argued that 'Tagging Only' requires the least amount of work in terms of contribution effort. Berlin has the largest number of contributors (almost 50 % of the top 250 contributors) whose EI are predominantly 'Geometry and Tagging'. Berlin also has the largest number of contributors (28) whose EI are predominantly 'Tagging Only'. Paris appears to have top 250 contributors EI very similar to that of Berlin.

3.5 Social Network Characteristics of the Edit Interactions

Using the EI data from the previous section we built a social network graph for the top 250 contributors for the three cities. An edge exists between two contributors where contributor A creates the version of O labelled O_{t+1} where contributor B had created the version of O labelled O_t. Table 3 tabulates the summary of the social network characteristics of the Edit Interactions (EI) for the top 250 contributors to each of the three cities in our case study.

Table 3 The social network characteristics of the edit interactions (EI) for contributors in our three case study cities

Network characteristic	London	Berlin	Paris
Nodes (contributors)	1,788	1,986	1,054
Percentage of all contributors	64 %	70 %	90 %
Edges	15,765	16,483	9,763
Strongly connected components	1,541	1,762	836
Mean betweeness centrality	0.12	0.15	0.08
Mean eigenvalue centrality	0.08	0.11	0.07
Mean degree	8.817	9.12	6.38
Observations	12 nodes with BC > 0.45	16 nodes with BC > 0.51, 8 nodes with EC > 0.25	3 nodes with BC > 0.61

In Table 3 we show the results of three important social network characteristics. Firstly, Eigenvalue Centrality (EC) is very similar conceptually to Google Page Rank. The EC metric returns a value [0…1] for any node in the network. EC is somewhat recursive in its definition as high scores are given to nodes if they are connected to other nodes which are also themselves important in the network. In terms of social interaction the concept is such that a contributor's influence in the network is proportional to the total influence of the contributors to whom they are connected. Secondly, Betweeness Centrality (BC) is a measure of a node's centrality in a network. Suppose for a node X then the BC of X is equal to the number of shortest paths from all nodes to all other nodes that pass through X. BC is a useful measure of a node's importance to the network overall rather than simply a measure of it's connectivity. In terms of social networking the concept of BC is that if two contributors do not know each other but have share a contributor who edits both their work then it is very likely that they will be connected to each other soon and edit each other's work directly. Finally, we compute the number of strongly connected components in the network. A strongly connected component is a subgraph of a network where there is a path from every node in the subgraph to every other node in the subgraph. Strongly connected components have been shown to correspond to smaller, tightly knit, groups of nodes in a social network—for example a group of friends with common interest or working on a specific task/job. BC, EC, and strongly connected components are well known network statistics and consequently are available in most leading graph handling packages.

In the case of each EI social network in Table 3 the number of nodes is greater than 250. The EI interactions for the top 250 contributors are computed and contributors not in this subset are included because they have had their work edited by one of the top 250.

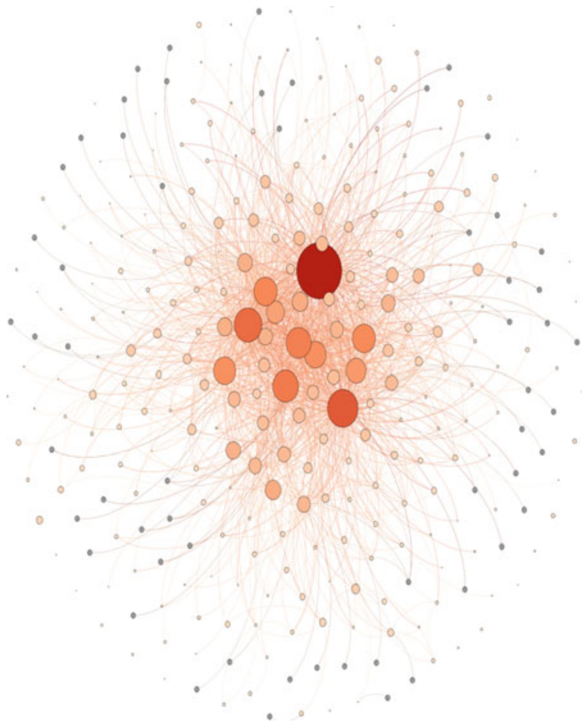

Fig. 3 The edit interactions social network for the top 250 contributors to openstreetmap in Berlin. For visualisation clarity the number of EI must be ≥ 10 for a graph edge to be visible on the graph. The nodes are weighted corresponding to their betweeness centrality (*blue low–red high*)

Figure 3 shows the social network graph of the EI for the top 250 contributors in Berlin. The size of the nodes are weighted by their betweeness centrality values (blue nodes have very low BC while red nodes have high BC). It is clearly evident that there are several very dominant contributors who are interacting with many other contributors in terms of EI. For visualisation purposes and to make the linkages between contributors with higher BC more apparent we have omitted edges in the network where the number of EI between two contributor nodes is less than 10.

4 Conclusions and Future Work

The analysis outlined in this chapter is based on working with the entire edit history of OSM for three cities. The type of retrospective analysis carried out would not be possible using only the current snapshot of OSM which is available in real-time for download. Overall there are strong indications that there is collaboration amongst the OSM community in the three cities studied. However it is difficult to ascertain at this moment if this collaboration is intentional or incidental. Is contributor A editing the work of contributor B through a process of mutual collaboration or are these edits performed without interaction between A and B?

This analysis shows that a small number of dedicated contributors are responsible for a very large amount of the total OSM work in these cities over the entire period of their history. In the remainder of this section we shall review the key outcomes and findings from our work.

4.1 Review of Key Findings

Table 1 provided an overview of the key characteristics of the three cities investigated in our case study. The information in Table 1 is only accessible through analysis of the history of the OSM project over a long period of time. London and Berlin are very similar for all of the characteristics discussed. Paris displays some different types of characteristics—a small contributor base in comparison to the other two cities but these contributors appear to carry out more work in total. However Paris has been the subject to a significant bulk import. The three cities have very similar results for: the overall percentage of ways with only a single version, the overall percentage of contributors with $\leq$10 edits performed, and the percentage of ways created by the top 250 ranked contributors. Figures 1 and 2 shows the total monthly edits and way creation for Paris and Berlin respectively. In particular Paris shows a dramatic way creation phase in 2010 which then changes to a sustained period of way editing in 2011 (as explained by the bulk import of data). Berlin, on the other hand, displays increases and decreases in the editing and way creation processes in periodic fashion. This shows two important characteristics of VGI for use in LBS applications and services. VGI, such as OSM, can undergo periods of sustained editing or maintenance while also experiencing periods where there is a large influx of newly created data. In the case of Berlin and London (figure not shown) total monthly way creation is decreasing overall. There are less 'new things to map' and the job for OSM contributors in cities such as these changes from 'white space filling on the map' to maintenance of the OSM database in terms of: updating metadata for features and changes in environmental geometry (demolished buildings, changes in road/street network geometry, etc.).

Table 2 shows that the principal contributors to all of the three cities are similar in terms of how they contribute and edit OSM. For Berlin and Paris there appears to be a preference for "geometry only" and "geometry and tagging" behaviours while in London there appears to be more focus from contributors on "way creation" and then subsequent "tagging" of ways. Table 3 provides a summary of the social network characteristics of the Edit Interactions of the top 250 contributors in the three cities. Visualisations of two of these characteristics are shown in Figs. 3 and 4. Crucially, this part of the analysis demonstrates that a small number of contributors (depicted by larger sized nodes in Figs. 3 and 4) are involved in collaborative editing work with a large number of other contributors. Their importance to the collaborative editing process in OSM is indicated by their high scores from the social network characteristics of BC and EC. BC is used to weight

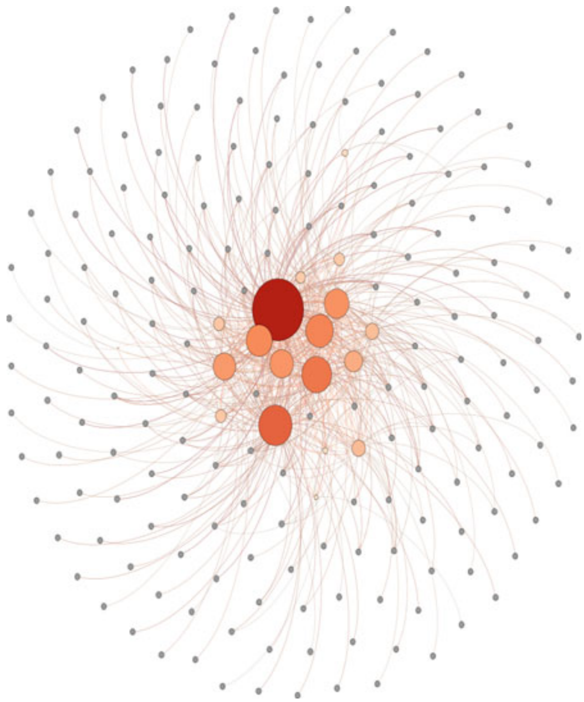

Fig. 4 The edit interactions social network for the top 20 contributors (from the top 250 contributors) in London. The social network shows that this special subset of contributors are heavily involved in the editing of ways created by other contributors. In this network G = (197,693)

nodes in Figs. 3 and 4 respectively. For the three cities over 64 % of the total number of contributors are involved, to some degree, in the collaborative process of map editing as inferred by the EI of the top 250 contributors. Berlin and London contain a large number of strongly connected components within this social network data structure. The mean BC and EC for the three cities is low which is expected given the high percentage of contributors performing a small number of edits.

4.2 Issues for Further Work

The results outlined in the paper have successfully provided insightful answers to the research questions outlined at the beginning of the paper. However, there are still a number of areas where further work is required. Automated inference of links (edges) based on commonalities in contributor profiles (for example: contributor A lives in the same part of Berlin as contributor B) or contributor A is "friends" with contributor B is not currently possible as these types of information are not made available in the OSM datasets. We intend to conduct a survey of OSM contributors in London to find biographical details which can be used to construct a social network data structure. The properties of these graphs could be compared to the graphs automatically generated from the OSM history.

We are currently undertaking research into extending our definition of co-edits to include a spatial component—that is contributors who co-edit ways in the same geographical area (council area, postcode, borough, etc.) are more likely to be linked. This could help us understand if local groups (strongly connected components or cliques) form when we weight co-edit linkages between contributors more heavily if they are spatially related. The influence of mapping parties (gatherings of small numbers of OSM contributors on a particular date to collaborative map an area) will be investigated in this analysis. We chose the top 250 ranked contributors as the threshold for analysis in this study. We feel that this is adequate for an analysis of this type for a city/urban area. As discussed earlier there are a very large percentage of contributors (just under 75 %) who perform a relatively small number of edits ($\leq$20). We feel that by considering a greater number of contributors from the overall ranking may not provide us with any additional insight into the collaboration amongst the OSM community for city/urban areas. As immediate future work we shall be updating our analysis for other cities/regions. Rather that analyse a fixed subset of the contributor population we shall use a relative subset (top 5 %, top 10 %, etc.) to ensure that the results are consistent across different OSM contributor bases.

Whilst the quality of the data generated by these contributors is beyond the scope of this study a longitudinal study could investigate the quality (geometric, semantic, spatio-temporal, etc.) of the OSM data as the social network characteristics of the contributor network changes. Girres and Toura (2010) and Haklay et al. (2010) amongst others have investigated and commented on the effects of increased numbers of contributors on overall data quality in OSM. However these studies were performed on a static snapshot of OSM rather than an analysis over a longer period of time.

Finally we see in Figs. 1 and 2 that there is an overall decrease in the map editing and creation in OSM in Paris and Berlin (and London). This is coupled with the information in Table 1 where we see a small number of contributors taking responsibility for a very large amount of work. Is this actually sustainable going forward. The sustainability of VGI projects such as OSM is a critical issue for LBS developers if they choose VGI as a source of spatial data. McLaren (2011) asks that “with so many crowd sourced sites contending for the attention of the citizen, will fatigue and lack of interest over time make citizen contributions a scarce resource?” Cuff et al. (2008) warn that “today’s exotic and disturbed data collection practices may appear banal 10 years hence”. They emphasis that to maintain citizen interest in urban sensing projects and VGI the user interface to applications and management systems are crucial. They comment that “if individuals are motivated to participate user interfaces are critical to both data collection and interpretation”. If it is too difficult or costly to contribute volunteered information people will simply avoid the hassle. While this is not directly a topic discussed in this paper the LBS community have a part to play in development of better or improved user-interfaces to allow even greater participation, using mobile devices, in the collection and maintenance of VGI.

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A Conceptual Model for Analyzing Contribution Patterns in the Context of VGI

Karl Rehrl, Simon Gröechenig, Hartwig Hochmair, Sven Leitinger, Renate Steinmann and Andreas Wagner

Abstract The chapter proposes a conceptual model as foundation for analyzing user contributions in the context of VGI. The conceptual model is based on a set of action and domain concepts, which are combined to a task-model describing typical tasks of volunteered geographic information contribution. As a proof-of-concept, the model is applied to two sample data sets that are extracted from the OpenStreetMap (OSM) change history. OSM data samples provide a proof-of-concept concerning the applicability of the model for crowd activity analysis. The resulting "contribution graph", which is a graph-like structure of linked editing actions, can be used as foundation for analyzing complex contribution patterns.

Keywords VGI · Crowd activity · Contribution analysis · Editing patterns · Conceptual model

K. Rehrl (✉) · S. Leitinger · R. Steinmann · A. Wagner
Salzburg Research, Jakob Haringer-Straße 5 5020 Salzburg, Austria
e-mail: karl.rehrl@salzburgresearch.at

S. Leitinger
e-mail: sven.leitinger@salzburgresearch.at

R. Steinmann
e-mail: renate.steinmann@salzburgresearch.at

A. Wagner
e-mail: andreas.wagner@salzburgresearch.at

S. Gröechenig
Carinthia University of Applied Science, Europastraße 4 9524 Villach, Austria
e-mail: simon.groechenig@edu.fh-kaernten.ac.at

H. Hochmair
Fort Lauderdale Research and Education Center, University of Florida,
3205 College Avenue, Fort Lauderdale, FL 33314–7799, USA
e-mail: hhhochmair@ufl.edu

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1 Introduction

The term Volunteered Geographic Information (VGI) denotes geographic information, which is collectively contributed by a heterogeneous crowd of voluntary people. Over the last years, VGI has gained increasing interest in the GI research community (Goodchild 2007). VGI is considered as a serious source for geographic information (Goodchild 2007; Kuhn 2007), even more triggering a change in information production while challenging science as well as businesses (Budhathoki et al. 2010). While most of the research methods from GI science could be applied to VGI as well (Kuhn 2007), new research strands such as VGI digital spatial data exchange, collaborative planning through VGI, or societal impacts of VGI (Elwood 2008) are opened. Budhathoki et al. (2010) propose a three-tiered conceptual framework for VGI, which provides a good reference frame for classifying VGI-related research. The framework is composed of the three arenas "Motivation", "Action and Interaction" and "Outcome". Most of the VGI-related research so far can be classified in one of the three arenas. Recent work addresses questions about the motivation of VGI contributors (Budhathoki et al. 2010; Coleman and Georgiadou 2009; Coleman 2010), different interaction patterns (Mooney and Corcoran 2012a) and the quality of the outcome (Neis et al. 2011). In addition to the three arenas, Budhathoki et al. detail the arenas with sub-arenas. For example, in the context of the arena "Action and Interaction" the conceptual framework defines the three sub-arenas "Structure", "Action", "Norms/Rules-in-use". The sub-arena "Norms/Rules-in-use" addresses rules within the community, e.g. what contributors of VGI projects should do or not do. "Structure" is the result of applying rules. "Action" addresses questions of how people actually contribute within the constraints of structure. While the proposed arenas and sub-arenas provide a good overall frame, more detailed conceptual models for analyzing one of the sub-arenas are still missing.

This work proposes such a conceptual frame for the sub-arena "*Action*", which subsumes all kinds of user interaction with the emphasis on information contribution. The remainder of the chapter is structured as follows: The next section introduces related work on editing actions in the context of VGI. The following section proposes a set of action and domain concepts as foundation of editing patterns. In the subsequent section action and domain concepts are combined to editing actions representing typical editing patterns. The section afterwards shows a proof-of-concept with sample data from the OpenStreetMap project, which is followed by conclusions and an outlook on future work.

2 Related Work

Currently there are two different research strands to analyze action and interaction in the context of VGI: One is a *user-centric strand* and the other is a *data-centric strand*. *User-centric* means that the analysis starts from the motivation of individual users (Budhathoki's "Motivation" arena) and their activities (Budhathoki's "Action & Interaction" arena) and generalizes contribution behavior over specific user groups. Typical research questions are "How do users contribute?", "Which roles can be attributed to users or user groups?" or "Is it possible to identify different interaction styles based on individual user contributions?". The other strand is a *data-centric* one, putting the collective outcome and not the individual user in focus ("Outcome" arena). Typical research questions are "Which features are in the dataset?"or "Which updates happened to a feature?" or "Which features are missing?". The main goal of this research strand is to identify feature-related activity patterns.

One of the newer approaches to investigate action and interaction in the context of VGI is to analyze editing histories of datasets. Some of the VGI projects store a complete history of all dataset updates, e.g. the most prominent VGI project OpenStreetMap (Haklay and Weber 2008), which could be used to analyze editing behavior of the crowd. But even without a complete change history crowd activity may be reconstructed with regular database snapshots. Over the last years, some authors have started to analyze crowd activity of VGI projects, specifically using the OpenStreetMap history dump. Recently, Mooney and Corcoran followed the *user-centric strand* with investigations on social interactions in the OSM London dataset (Mooney and Corcoran 2012a). Their research addressed the question whether editing profiles could be extracted from the contribution history. Haklay et al. (2009) tackled the question of how many users it takes to map an area well. Mooney and Corcoran (2012b) also followed the *data-centric strand*. The authors analyzed the distribution of users contributing to edits in heavily edited features in OpenStreetMap. The authors also proposed an algorithm to access the OpenStreetMap history dump (Mooney and Corcoran 2011).

van Exel et al. (2010) state that both strands are intertwined since data-centric editing patterns are closely related to user-centric ones (because any editing action is bound to a user). Nevertheless, the question of action in VGI projects is tackled from different perspectives and thus a conceptual model could help to integrate both strands.

3 Towards a Conceptual Model for Editing Actions in the Context of VGI

One of the first questions related to a conceptual model of user actions is: "What are typical user activities in the context of VGI?". Related work distinguishes at least four different action and interaction activities (Budhathoki et al. 2010; Ramm and Topf 2010): (1) *contributing geographic information* (e.g. creating and editing features), (2) *building community structures* (e.g. organizing mapping parties, operating mailing lists), (3) *working on norms and rules* (e.g. contributing to definitions in the OSM Wiki) and (4) *working on community tools* (e.g.

contributing to editors like JOSM). The last activity is not explicitly mentioned in related work, but is a necessity of VGI projects, too. Each of the identified user activities can be further detailed into concrete action and interaction patterns. For example, the user activity "*contributing geographic information*" can be further detailed in the following sub-activities: (1) *collecting information* (e.g. GPS traces, street names, speed limits), (2) *editing features* (e.g. drawing features, adding attributes, changing attributes and attribute values, deleting features) and (3) *submitting edits to the database*. Sub-activities are considered a good starting point for a conceptualization process. While sub-activities could be identified for any of the aforementioned activities, in this work we focus only on the activity "contributing geographic information". We assume that any activity related to geographic information contribution directly affects the dataset and thus can be derived from the change history. According to Guarino (1998), a conceptualization is "the formal structure of reality as perceived and organized by an agent, independently of the vocabulary used or the actual occurrence of a specific situation". In order to conceptualize user actions in the context of volunteered geographic information contribution, we have to conceptualize *actions* ("How do users contribute?") and *geographic information* ("What is the result of actions?").

3.1 Action Concepts

One of the approaches for conceptualizing user actions (task modeling) is to build on the conceptual frameworks of activity theory (Kuuttii 1996). The principle of activity theory is to define a "minimal meaningful context" for individual actions. Activity theory structures user activities with the following hierarchical layers:

Activity: A sequence of actions following a certain "motive". Typically an activity follows a certain strategy.
Action: A sequence of operations for reaching a certain "goal". Actions have a cognitive component.
Operation: The most granular level. Operations are atomic and represent "well-defined habitual routines".

As Kuhn (2001), states *activity* and *action layers* may contain several hierarchical sub-structures. Timpf (2001) proposes four different approaches for deriving geographic task-models: (1) task analysis, (2) information on past task-analyses, (3) analysis of GIS products and (4) applying knowledge from knowledge engineering. In our conceptualization we combine different approaches. We build on information from previous task-analyses (e.g. information from related work), we analyze typical tasks of VGI contributors (e.g. by means of self-experiments as well as community workshops) and we analyze tools, especially those available as open source in the context of OpenStreetMap. Building on these information sources we define the following VGI specific layers for structuring user activity:

VGI Activity: A sequence of consecutive actions (information contribution) by a *single volunteering user* or a *group of volunteering users*. Activities could be structured in different dimensions: (1) *by users* (all actions by one user or a group of users), (2) *by location* (all actions in a certain geographic region), (3) *by action type* (all actions belonging to the same or a similar type, e.g. create, edit, delete), (4) *by information category* (all actions contributing to the same information category, e.g. streets, land use, buildings) and (5) by *time*.
VGI Action: A sequence of consecutive operations by a *single volunteering user* within a timespan. A typical user action is a certain manipulation of a *single geographic feature*.
VGI Operation: An atomic operation on a *single geographic feature*, e.g. creating the geometry, modifying the geometry or adding an attribute.

3.1.1 A Basic Set of VGI Operations

If we assume that geographic information is stored in a database, the four basic operations for persistent data storage (CREATE, READ, UPDATE, DELETE, also called CRUD) are at the heart of any conceptual model (James 1983). Following these basic operations, any contribution to a VGI dataset by a volunteered user may be drilled down to one of the aforementioned operations: CREATE, UPDATE and DELETE (READ could also be considered as a concept, however, since it makes no changes to the dataset, it is not relevant for contributions). It is worth to mention that each operation has to be uniquely attached to a *single user* and a *timestamp*. The resulting conceptual model for VGI operations and their relationships to action and activity concepts is shown in Fig. 1. We further assume that the aforementioned database operations may be executed on different information items, depending on the geographic information domain. For example, if the operation CREATE is executed on a geographic feature, it could be detailed to the operation CREATE FEATURE. In order to further detail operations, a conceptual model for the geographic information domain has to be defined. We call the concepts representing information items "domain concepts". The conceptual model for action and activity layers is proposed in a later section, by combining action and domain concepts.

3.2 Domain Concepts

Domain concepts are considered as *conceptualizations of real-world phenomena in the geographic domain* (Mark et al. 2001). In related work serveral conceptualizations of geographic phenomena have been proposed (Goodchild 2010). Most of the current GIS are based on object-based conceptualizations of real-world phenomena (Câmara et al. 2009). One such commonly used model is the *OpenGIS Abstract Specification, Topic* 5: *Features* (Kottman and Reed 2009) specified by

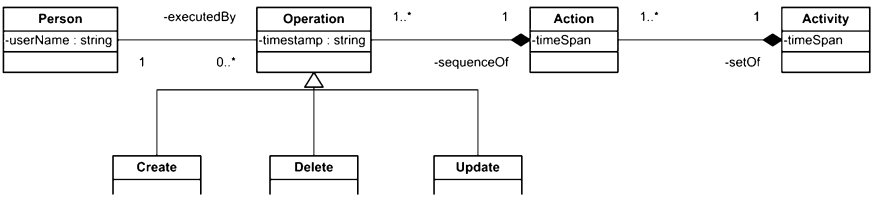

Fig. 1 Relationships between operation, action and activity concepts

the Open Geospatial Consortium (OGC). Instead of developing a new conceptual model, our approach builds on the OGC specification and adapts this specification to the requirements of VGI. The OGC specification introduces the concept of a *geographic feature* as representation of a geographic phenomenon. Each feature is composed of a *geometry*, which is bound to a *spatial reference system* and a *feature type*. A *feature type* defines a set of attributes which is used to describe the feature. Features have a flat structure (e.g. other features may not be part of a feature). In addition to the feature specification the *OpenGIS Abstract Specification, Topic* 8: *Relationships between Features* (Kottman 1999) adds the notion of *relationships*. Relationships are necessary to structure feature groups and feature hierarchies.

Since the OpenGIS Abstract Specification is a generic approach for modeling geographic phenomena it is considered a good conceptual foundation for modeling VGI, too. However, VGI projects typically do not build on OGC specifications due to various reasons (e.g. complexity, missing freedom) and come with their own, community-driven models. Despite of a number of differences, we also found similarities such as the notion of a *map feature* as digital representation of geographic phenomena in OpenStreetMap.[1] However, the description of features does not follow strict rules like feature types in the OGC model, but is community-defined. In many VGI projects the minimal necessity for the definition of a geographic feature is a geometry (at least a pair of coordinates). Meaning is attached to geometries with a set of optional *key-value pairs* (so-called *tags*). In order to build a VGI database like OpenStreetMap any community has to agree on a set of rules for sucessful collaboration (e.g. OpenStreetMap relies on a minimal data model and a community-driven Wiki describing domain concepts). The definition of useful attribute sets is an ongoing community process documented in the OSM Wiki. There are always several proposals how to tag features and it typically takes some time until the community agrees on one of the proposals (e.g. see Proposed Features in the OSM Wiki). In OpenStreetMap exists a well-established concept called *primary feature*, which comes near to the notion of a feature type, but it is not strongly typed. Since there is no strict validation in the data submission process, it is possible to submit a feature geometry to the OpenStreetMap database while omitting tags.

[1] http://wiki.openstreetmap.org/wiki/Map_Features

Having these differences in mind, our approach for a conceptual domain model builds on some of the concepts of existing models, but adds adaptations according to the needs of VGI. At least the model has to be capable of missing feature types as well as feature types with differing attribute sets (tag sets). We assume that attributes or attribute values do not follow strict rules and any attribute as well as any attribute value may be committed to the database. Although these findings are mainly based on VGI in the context of OpenStreetMap, we consider OpenStreetMap as being prototypical for similar VGI projects. It is worth to mention that the model is based on an object-based conceptualization of geographic phenomena and we assume that the spatial reference is described as vector in a 2-dimensional geometrical space. The model does not fully cope with other notions of VGI such as geo-tagged multimedia content (e.g. geo-tagged photographs at Flicker or geo-tagged Twitter messages). We further assume that the need for a relaxed conceptual domain model can be attributed to the aspect "volunteered" in VGI, providing the community with a high degree of flexibility and freedom. Ramm and Topf state "The intention of the OpenStreetMap project always was to implement the simplest thing that could possibly work." (Ramm and Topf 2010). This statement could be possibly taken as synonym for the flexibility and freedom of VGI projects.

In order to avoid any confusion between our conceptual domain model for VGI and the OpenGIS Abstract Specification, we call our domain model *Volunteered Feature Specification* (VFS). At the heart of the specification is the notion of a *Volunteered Feature* (*VF*), which is conceptually similar to the OpenGIS Feature Specification, but adds the following relaxations for being compatible to VGI dataset instances:

A *Volunteered Feature* (*VF*) is bound to a *Volunteered Geometry* (*VG*), but may exist without a *Volunteered Feature Type* (*VFT*) and thus a VF is considered not strongly typed.

The specification of a *Volunteered Geometry* (VG) is based on the geometry types in the OGC OpenGIS Object Model, but adds simplifications (Fig. 2).

A *Volunteered Feature Type* (*VFT*) is composed of a *primary volunteered attribute*, which defines the VFT. *Volunteered Attributes* (*VATT*) may be freely attached to VFs without following a strict scheme. The definition of VATTs and their values does not follow a strict scheme, but allows for arbitrary values. Schemes for VFTs and rules for attaching VATTs to VFs are community-defined. A typical medium for specifying the rules is a community Wiki.

A *Volunteered Relation* (*VR*) defines relationships between arbitrary VFs. As proposed in the OpenGIS Abstract Specification, Topic 8, Relationships between Features, VFs may have different VGs (e.g. points and polygons) and VFTs (e.g. features composing a public transport station). VRs may be recursive, meaning that VRs may include other VRs.

Figure 2 illustrates the proposed model of domain concepts as UML class diagram.

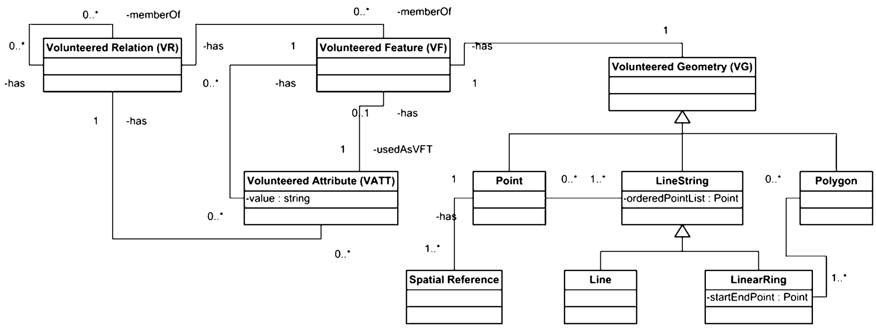

Fig. 2 Class diagram for modeling volunteered features

4 Combining Action and Domain Concepts

By now we have defined the conceptual basis for modeling *actions* (task-centric view) and the *domain of geographic information* (domain-centric view). A combination of both would facilitate a conceptual model being capable of dealing with arbitrary editing actions.

The first step towards a combined conceptual model is to define, which operation may be executed on which type of volunteered feature. As foundation for action concepts we defined a set of three atomic operations: CREATE, UPDATE, DELETE. In combination with the domain concepts *Volunteered Feature* (*VF*) and *Volunteered Relation* (*VR*) the following combined operations could be derived: CREATE VF, UPDATE VF, DELETE VF, CREATE VR, UPDATE VR and DELETE VR. From the domain model we assume that a VF is always created with a VG (volunteered geometry). If the VF gets deleted, also the VG is deleted. From the domain model we further derive that if a VF exists, it may be updated in the following ways: ADD VFT, ADD VATT, REMOVE VFT, REMOVE VATT, MODIFY VG, MODIFY VATT and MODIFY VFT. Thus, the action model has to be extended with the following operations ADD, REMOVE and MODIFY, which further detail the operation UPDATE. Table 1 lists possible combinations of operations and VFs/VRs.

The resulting set of operations already considers the previously defined relaxation rules for VFs. For example, the scheme allows to CREATE a VF without

Table 1 Conceptual scheme for combining action and domain concepts

Operation	Volunteered feature (VF)	Volunteered relation (VR)
CREATE	VF (VG)	VR
DELETE	VF (VG)	VR
ADD	ATT, VFT	VFT, VATT, VF, VR
REMOVE	ATT, VFT	VFT, VATT, VF, VR
MODIFY	ATT, VG	VFT, VATT

specifying the VFT or it is possible to ADD arbitrary VATTs without relying on a strict scheme of feature types. For simplicity we call combinations of operation and domain concepts "*domain operations*".

In addition to the overall scheme for domain operations, Table 2 further details the conceptual scheme with possible relationships between operations and OpenGIS Simple Geometry Types.

4.1 Towards Actions: Rule-Based Aggregations of Domain Operations

Based on action and domain concepts, the model can now be extended to the action and the activity layers. In contrast to operations, actions have to fulfill the following requirements: (1) the action can be fully described with a sequence of one or more domain operations, (2) each operation has to be executed by the same single user, (3) each operation has to be executed at a single moment in time and the timestamps of sequent operations have to be consecutive, meaning that no other operation of the same user has been executed in between and (4) the action fulfills a goal-oriented manipulation of a *VF* or *VR*. As an example we describe an instance of the action concept "contribution of a feature", which can be defined as a sequence of the following domain operations: (1) CREATE VF, (2) ADD VFT (optional), (3) ADD VATT (optional) and (4) ADD VATT (optional). If necessary, the action could be further detailed with more specific actions like "create point feature" or "create line feature". It is important to mention that the concept of an action is inherently seen as a "rule-based aggregation over domain operations". Thus, by adding aggregation rules for domain operations, as many actions as necessary could be defined. In order to demonstrate the applicability of the approach, we define a set of possible actions for VGI contributions (Table 3). The proposed action set is derived from typical user-tasks in the context of Open-StreetMap, but could be most likely applied to other VGI projects as well.

4.2 Towards Activities: Rule-Based Filtering of Action Sets

According to activity theory, user activities are based on concrete motives. In the context of VGI typical motives are: users strive towards fully mapping their local

Table 2 Operations in relationship to OpenGIS simple geometry types

Operation	Point	Line	Linear ring	Polygon
CREATE	X	X	X	X
DELETE	X	X	X	X
ADD		Point	Point	Linear ring
REMOVE		Point	Point	Point
MODIFY	VG, VATT	VATT, VG	VATT, VG	VATT, VG

Table 3 Proposed action set for describing VGI contribution tasks

Action	Description
Create point VF	A point feature with a point geometry is created
Update point VF	The spatial reference of a point VF is modified
Delete point VF	A point VF is deleted
Create line/polygon VF	A VF with a line or polygon geometry is created and a VFT is added
Update line/polygon VF	The spatial references of a line or polygon geometry are modified
Delete line/polygon VF	A VF with a line or polygon geometry is deleted
Add points line/polygon VF	One or more additional point VFs are added to a line or polygon VF
Remove points line/polygon VF	One or more point VFs are removed from a line or polygon VF
Split line/polygon VF	A line or polygon VF is split into two VFs
Merge line/polygon VF	Two line or polygon VFs are merged to one VF
Create VR	A relation is created
Delete VR	A relation is deleted
Add member VR	One or more VFs are added as members to a VR
Update member VR	The role of one or more members is modified
Remove member VR	One or more VFs are removed from a VR
Add VFT VF/VR	A primary attribute is added to a VF or VR
Update VFT VF/VR	The primary attribute of a VF or VR is modified
Remove VFT VF/VR	The primary attribute of a VF or VR is removed
Add attributes VF/VR	One or more attributes are added to a VF or VR
Update attributes VF/VR	An attribute value of one or more attributes is modified
Remove attributes VF/VR	One or more attributes are removed from a VF or VR

surrounds, users strive at getting the number one in the (local) community or users strive towards a high level of positional accuracy of their contributions. Thus, it makes sense to define an activity as "*a group of actions following specific motives*". Thus, in order to group actions to activities, actions have to be filtered by one or more criteria derived from one or more motives. Table 4 proposes possible filter rules for action sets.

5 Proof-of-Concept: Applying the Model on a Real-World Dataset

In order to prove the concept we apply the model on the OpenStreetMap change history. OpenStreetMap is one of the most relevant VGI projects and thus considered a good example for a proof-of-concept. On the one hand, due to the open license, the OSM dataset is of high value for the research community. On the other hand, the OSM community explicitly specifies the structure for interactions with

Table 4 Proposed activity groups and filter rules for action sets

Activity criteria	Filter rules for action sets
By users	All actions of a single user or a specific user group, e.g. female users
By location	All actions in a certain region, e.g. in UK
By action type	All actions of a certain type, e.g. creations of point features
By information category	All actions manipulating features of a certain feature type, e.g. land use, streets, buildings
By time	All actions within a certain timespan, e.g. during a month
Mixed criteria	Filter rules with different criteria, e.g. all creation actions of point features of female users in London

the OSM database in the OSM Wiki.[2] For deriving action and operations concepts we analyzed the OSM Wiki, especially the part on the OSM API,[3] related literature (Ramm and Topf 2010) as well as editing tools such as JOSM.[4] Operation concepts in OpenStreetMap are widely based on the CRUD paradigm. Domain concepts are specified in the OSM Wiki. The conceptual data model is rather simple and based on the concept of VFs. In OSM a *VF* could be a *node* or a *way,* depending on the VG. Linear Rings are modeled as a specific form of ways with the same start and end node. Polygons are either modeled as Linear Ring or as relation. The concept of VATT is called *tag* and the concept of a VFT is represented by the notion of a *primary tag*. In addition to VFs, the OSM data model also introduces the concept of *relations*, which is defined in analogy to the aforementioned VR concept. Table 3 instances the previously defined *Volunteered Feature Specification* (*VFS*) with the OpenStreetMap data model.

5.1 Building Model Instances from the OSM Change History

We test the conceptual model with sample data from the OSM change history. The OSM history includes all changes back to October 2007 (although the project was started in 2004, due to a change in the API the history is only accessible back to 2007). The basic algorithm for accessing the data has been previously described (Mooney and Corcoran 2011). For extracting the data using the OSM API we developed a standardized process (Fig. 3). This process is capable of building a graph-like representation of domain operations and action aggregates for arbitrary features or feature sets (within a configurable bounding box).

We conducted a preliminary test of the model with OSM data for different geographic regions in Europe and the US. In order to get first results concerning crowd activity we applied the extraction process on sample data from two Austrian

2 http://wiki.openstreetmap.org/wiki/Main_Page

3 http://wiki.openstreetmap.org/wiki/API_v0.6

4 http://josm.openstreetmap.de/

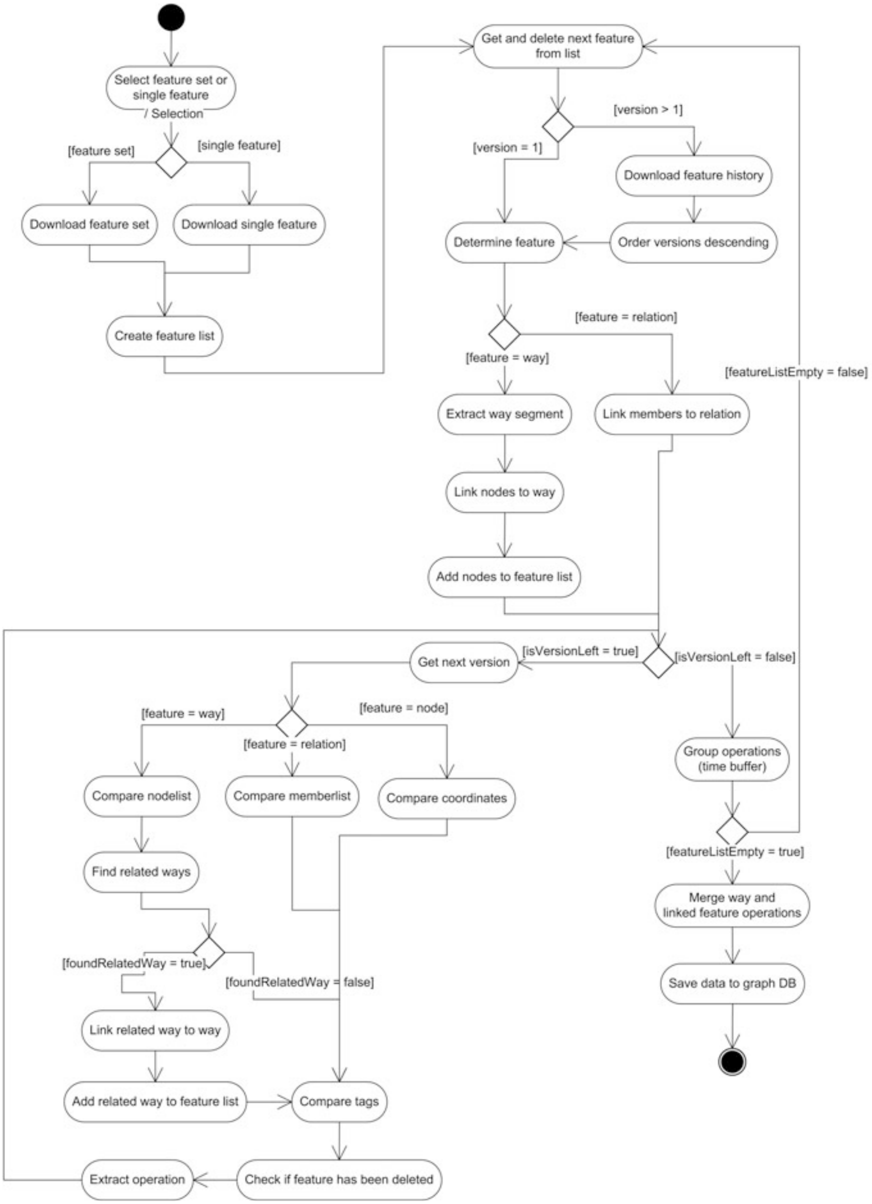

Fig. 3 UML activity diagram showing the data extraction and model building process for OSM

cities (Linz and Villach) for the years 2010 and 2011. Figure 4 shows two maps of the inner city districts and the bounding boxes (195,488 and 212,891 m^2) we used for data extraction.

Fig. 4 Bounding boxes for sample data extraction from the cities of Linz and Villach in Austria

Table 5 lists some contribution indicators. All indicators are calculated from the change history data within the bounding boxes.

A first comparison of editing activity in both cities shows that OSM mappers in Linz are by far more active compared to mappers in Villach (Fig. 5a). While there was a significant increase in editing actions (per user and year) in Linz from 2010 to 2011, this value remained nearly equal in Villach (although the number of mappers doubled in Villach and reached the number of mappers in Linz). Also the average number of editing actions per feature is lower in Villach, although there has been a significant increase from 2010 to 2011 (Fig. 5b). The mapper/inhabitant ratio (number of mappers per 1,000 inhabitants) reveals that there is an equal or better established OSM community in Villach compared to Linz. We consider the first results as good proof of the conceptual model as well as the extraction process. But we are also aware that the proposed approach can only be the foundation for a punch of analysis in the context of more detailed investigations on crowd activity.

Table 5 Contribution indicators for the years 2010 and 2011 extracted from the OSM change history

	Linz (2010)	Linz (2011)	Villach (2010)	Villach (2011)
Active mappers	32	24	11	24
Mappers/inhab. ($\times$1000)	0.17	0.13	0.18	0.40
Number of operations	4,644	8,757	206	1,194
Number of actions	1,222	2,262	132	408
Average. op./user/year	145.13	364.86	18.72	49.75
Average actions/user/year	38.19	94.25	12	17
Average op./feature	11.24	9.63	1.25	4.81
Average actions/feature	2.96	2.49	0.8	1.65

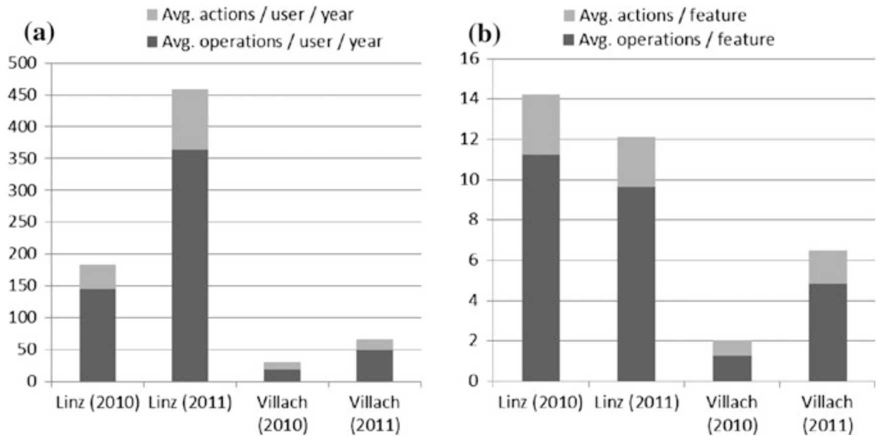

Fig. 5 Comparison of mapper activity over 2 years in two Austrian cities

Table 6 OSM domain operation concepts as instances of the conceptual model

	Node, way (*VF*)			*Relation* (*VR*)
Operation	Node (point)	Way (line)	Closed way (linear ring)	Relation (polygon, multipoint, multiline, multipolygon)
CREATE	X	X	X	X
DELETE	X	X	X	X
MODIFY	X	X	X	X
ADD	Tag	Tag, node	Tag, node	Type, member (node, way, closed way, relation), tag
REMOVE	Tag	Tag, node	Tag, node	Type, member (node, way, closed way, relation), tag
UPDATE	Coordinates, tag	Tag, node, startEnd	Tag, node, startEnd	Type, tag

6 Conclusions and Outlook

Analyzing patterns of user contributions in the context of VGI has gained considerable attention over the last years. VGI projects such as OpenStreetMap foster this research strand by offering access to the full history of changes. Although some authors have already analyzed minor parts of the dataset, the question of how to conceptually deal with the data still remains. The paper proposes a conceptual model as a foundation for a uniform and standardized process for analyzing user contributions. Although the paper only proves the concept of the proposed model with one VGI project (OpenStreetMap), we assume that instances of the conceptual model could be adapted to other VGI projects as well. The proposed conceptual model has to be adapted in the following way: (1) define a new instance of the model (similar to the instance we propose for OSM in Table 6), (2) adapt action concepts and aggregation rules and (3) adapt the process for accessing contribution data (Fig. 3). The proposed approach closes the gap between user contribution data and a conceptual model laying the foundation for comparable analysis of contribution patterns. It is worth mentioning that the proposed approach is only applicable to a VGI project if data about user contributions is accessible. This is the case for some VGI projects (e.g. OpenStreetMap), but not for others (e.g. Google Map Maker).[5]

The proposed conceptual model is considered as a first step towards more complex analyzes of crowd activity. At the end of the proposed extraction process we store operations and actions as a graph-like structure which we call "contribution graph" (e.g. a graph database like Neo4j[6] could be used). We expect a contribution graph to be a universal basis for complex analysis, especially for having a closer look at different kinds of crowd activities. One of the possible future research directions is to find "prototypical contribution patterns" leading to good or bad data quality. Identifying such patterns is considered a necessary step in the definition of quality indicators for VGI.

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[5] http://www.google.com/mapmaker?hl=de

[6] http://neo4j.org/

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Part V
Innovative LBS Systems and Applications

People as Sensors and Collective Sensing-Contextual Observations Complementing Geo-Sensor Network Measurements

Bernd Resch

Abstract Ubiquitous sensor networks and Location-based Services can potentially assist in taking decisions in near real time in a variety of application areas such as public safety, traffic management, environmental monitoring or in public health. Yet, analysing our surroundings in real time is still a major challenge due to sparsely available data sources for real-time monitoring. The innovative concept of People as Sensors defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but in which also humans can contribute their individual 'measurements' such as their subjective sensations, current perceptions or personal observations. This chapter contains a disambiguation between the terms People as Sensors (people contributing subjective observations), Collective Sensing (analysing aggregated anonymised data coming from collective networks) and Citizen Science (exploiting and elevating expertise of citizens and their personal, local experiences). Then, the particular significance of integrating the People as Sensors concept with established LBS, data analysis and visualisation systems is elaborated. Finally, the paper discusses current challenges, points out possible solutions, and pin-points directions for future research areas.

Keywords People as sensors · Human observations · Collective sensing · Location-based services · Privacy

B. Resch (✉)
SENSEable City Lab, MIT, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
e-mail: bernd.resch@geog.uni-heidelberg.de

B. Resch
Institute of Geography–GIScience, University of Heidelberg,
Berliner Street 48, 69120 Heidelberg, Germany

B. Resch
Institute for Geoinformatics and Remote Sensing, University of Osnabrück,
Barbara Street 22b, 49076 Osnabrück, Germany

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1 Introduction

Ubiquitous sensor networks can potentially assist in taking decisions in near real time in a variety of application areas such as public safety, traffic management, environmental monitoring or in public health (Resch et al. 2010a) Yet, analysing our surroundings in real time is still a major challenge due to sparsely available data sources for real-time monitoring.

The same issue applies to Location-based Services (LBS). LBS' potential economic value has been estimated around 20 billion US Dollars in 2010. But neither LBS nor smartphone-based apps could fulfil those enormous expectations. According to Beinat et al. (2007), reasons for this development comprise uncertainties in smartphone positioning, lacking usability, uncontrolled growth of non-standardised semantic models, and particularly a lack of personalised contextual information.

On the data analysis side, a significant limiting factor is that Geographic Information Systems (GIS) and GIS-based Spatial Decision Support Systems (SDSS) are often not—or only conditionally—suitable for the integration of measurement data in real time. Current systems are primarily designed for integrating quasi-static data without high spatio-temporal fluctuations (Resch et al. 2010a). This is partly due to the fact that geo-data is per definition historic and so far, geospatial processing has focused on analysing static data, with low temporal fluctuations.

These deficiencies have prevented the realisation of the comprehensive vision of *'People as Sensors'* up to now, which is currently being advanced in a number of academic and corporate research projects, for instance Nokia's 'Wearable Eco-Sensor' concept (Nokia 2012), On Line Disaster Response Community (Laituri and Kodrich 2008), or Lift Lab (Girardin et al. 2008).

People as Sensors defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but in which also humans can contribute their subjective 'measurements' such as their individual sensations, current perceptions or personal observations. These human sensors can thus complement—or in some cases even replace—specialised and expensive sensor networks. Throughout recent literature, the term *'People as Sensors'* is used interchangeably with 'Citizens as Sensors' (Goodchild 2007) or 'Humans as Sensors' (Forrest 2010). This chapter also aims to establish a clear disambiguation between the terms *'People as Sensors'* , 'Collective Sensing' and 'Citizen Science' in Sect. 2 of this chapter.

One driver towards the vision of *People as Sensors* and ubiquitous LBS is the diminishing digital divide on a global scale. The digital divide is basically explained by two factors: (1) that access to Internet and other information and communication technologies (ICT) is unevenly distributed throughout the world and also within countries; and (2) that this imbalance has profound societal effects in that people with access to modern communication technologies have higher chances for social and economic development. While the digital divide within countries is still strongly affecting the degree of access to information and knowledge, the global digital divide is decreasing due to the fast rise of ICT markets in China, India, South-East Asia, South America and Africa. Mobile phone penetration has been at 76.2 % of the world's population in 2010, where it is at 94.1 % in the Americas and at 131.5 % in CIS (Commonwealth of Independent States) (International Telecommunication Union 2010). The two fastest growing mobile phone markets China and India are currently facing penetration rates of 64 and 70 %, which makes a total number of 1.69 billion subscribers.

Another supporting factor for the concept of *People as Sensors* is the exponential growth of the number of Internet users. Prognoses state that the number of people who use the Internet will drastically increase between 2010 and 2020—from 2 billion Internet users in 2010 to more than 50 billion connected devices in 2020. This potential is a strong driving force towards the realisation of the concept of *People as Sensors*.

The remainder of this chapter, which partly builds upon previous research (Resch et al. 2011), is structured as follows. After this introduction, Sect. 2 comprises a disambiguation on the terms of*'People as Sensors'* , 'Collective Sensing' and 'Citizen Science'. The subsequent section contains the conceptual and technical description of a particular implementation called OpenSensTracker. Thereafter, the broader significance of *People as Sensors* is discussed, and challenges and future research avenues are laid out before the chapter ends with a short conclusion.

2 A Disambiguation: People as Sensors, Collective Sensing and Citizen Science

As mentioned in the introductory section of this chapter, the term ***People as Sensors*** can basically be used interchangeably with Humans as Sensors and Citizens as Sensors. *People as Sensors* describes a measurement model, in which people act as non-technical sensors with contextual intelligence and comprehensive knowledge. Like this, measurements are not created absolutely reproducibly by calibrated sensors, but through personal and subjective observations. Such observations could be air quality impressions, street damages, weather observations, or statements on public safety, submitted via dedicated mobile or web applications (including e.g. Twitter). Figure 1 shows a screenshot of Waze (Waze 2012), a smartphone app allowing people to send their personal traffic reports, which are directly used in other persons' routing requests.

The central advantage of this approach is that no cost-intensive physical sensor networks have to be deployed, but people can use their everyday's devices (smartphones, desktop computers, tablet PCs etc.) to enter their observations into a specialised application or data warehouse. The essential drawbacks of the People of Sensors concept are limited comparability and interpretability of the 'sensed' data. As semantics research has shown, academic solutions cannot be imposed on

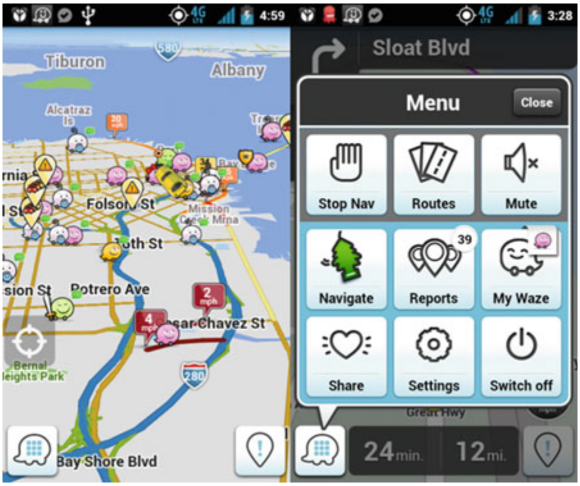

Fig. 1 Waze map (*left*) and input interface (*right*). (Waze 2012)

specific communities. Hence, other semantic models have to be found to extract information from human observations. These are discussed in the Sect. 5.

Consequently, the *People as Sensors* approach will not be able to replace current sensor network developments in the short term, but only complement them. This can be useful in a variety of application domains, in which objective measurements by sensors are highly expensive and highest measurement accuracy is not an absolute requirement. Here, the term 'observation' seems more suitable than 'measurement'.

One example, in which this kind of volunteered data was of invaluable importance, was the earthquake including the following tsunami in Japan in March 2011. In this case, the Tweet-o-Meter (UCL Centre for Advanced Spatial Analysis 2012) application has been used to find anomalies in Twitter activity. Right after the earthquake, people started to post status reports, video streams, and conditions of destroyed houses and cities, which could be interpreted in near real time as an indicator for an extraordinary event. Furthermore, information could be semantically extracted from personal comments and posts.

A related concept is *Participatory Sensing*, in which a number of persons with a common goal in a geographically limited area contribute geo-referenced data via their end user devices such as smartphones (Zacharias et al. 2012). From this definition it is evident that the term Participatory Sensing is highly similar to *People as Sensors*, but its definition is a little bit more restricted in terms of input devices, data acquisition and information processing.

Secondly, we are currently witnessing a fast rise of **Collective Sensing** approaches. This methodology tries not to exploit a single person's measurements and data. Thus, it is similar to User-generated Content (UGC) based and crowdsourcing approaches. However, Collective Sensing analyses aggregated anonymised data coming from collective networks, such as Flickr, Twitter, Foursquare or the mobile phone network. Like this, we can gain a coarse picture of the situation in our environment without involving personal data of single persons.

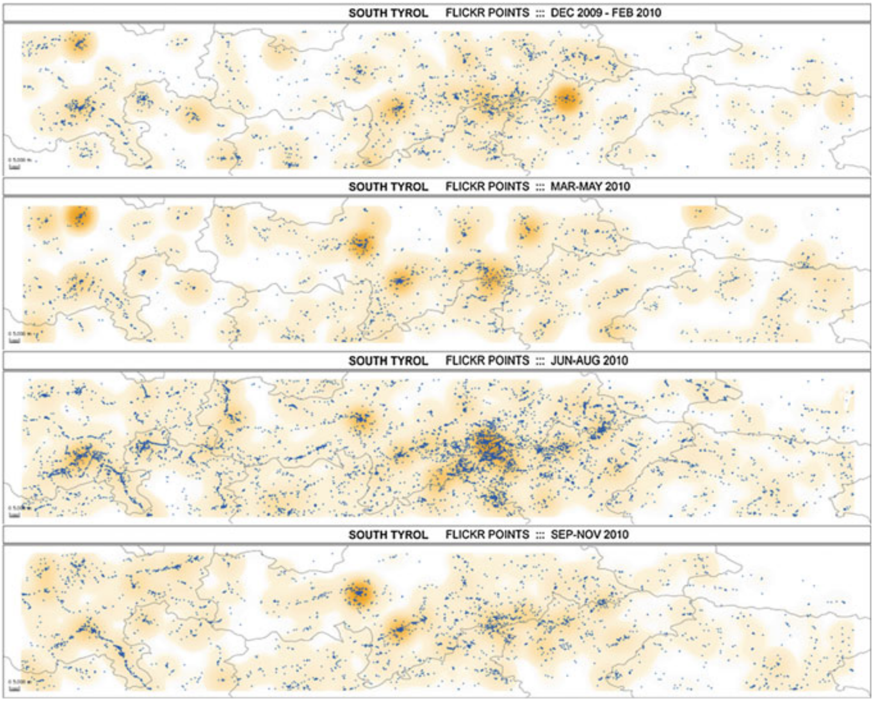

Fig. 2 Location-based tourist dynamics analysis using collective sensing technologies. (Sagl et al. 2012)

In contrast to *People as Sensors*, Collective Sensing is an infrastructure-based approach, which tries to leverage existing ICT networks to generate contextual information. Unlike smartphone-based or specialised web apps, which examine single input data sets, Collective Sensing holistically analyses events and processes in a network. For instance, increased traffic in the mobile phone network might be an indicator for the presence of a dense crowd of people (Reades et al. 2007). This information is generated without having to use a single person's data and their personal details.

Examples for exploiting collective information include using data from mobile phone networks to sense and influence urban dynamics (Reades et al. 2007; González et al. 2008), or leveraging Flickr photos to assess seasonal tourist behaviour (Sagl et al. 2012), which is depicted in Fig. 2 for the region of South Tyrol in Italy.

Finally, the term **Citizen Science** plays a key role in the context of *People as Sensors*. Citizen Science basically states that 'through the use of sensors paired with personal mobile phones, everyday people are invited to participate in collecting and sharing measurements of their everyday environment that matter to them' (Paulos et al. 2008). In other words, citizens augment their role, becoming agents of change by uncovering, visualising, and sharing real-time measurements from their own everyday environment by exploiting and elevating their expertise

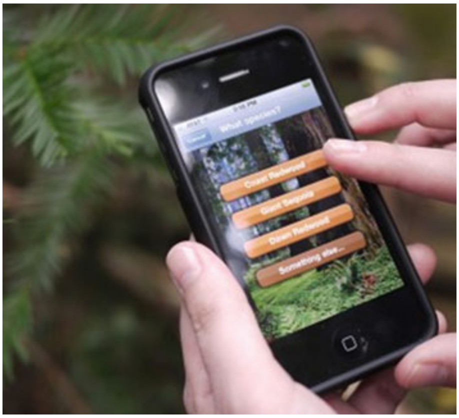

Fig. 3 Redwood watch application to monitor redwood forests (Save the Redwoods League 2010)

and their personal, local experiences. An example for promoting the Citizen Science concept is the 'Citizen Science—Community Involvement Today and in the Future' grant programme by the US Environmental Protection Agency (EPA) (US EPA 2012), which aims to encourage individuals and community groups in New York City to collect information on air and water pollution in their communities, and seek solutions to environmental and public health problems.

In consequence, researchers hope that public understandings of science and environmental issues will be improved and can have access to larger and more detailed data sets coupled with local knowledge. This access to environmental data of the city also becomes a tool to raise the citizen awareness of the state of their environment. Figure 3 shows the 'Redwood Watch' location-based application, which exploits Citizen Science to predict the growth of redwood forests (Save the Redwoods League 2010).

Concluding, Citizen Science can be considered a sub-part of *People as Sensors* in that users (citizen scientists) need to have some knowledge in a certain area—ranging from bird sighting to air pollution reports or wild animal classification. In effect, citizen science aims to exploit and elevate the local expertise of citizens and their personal, local experiences across their lives.

Table 1 summarises the comparison of the discussed concepts of *People as Sensors*, Collective Sensing and Citizen Science according to the following criteria.

- *Voluntary/Involuntary*: whether contributing people voluntarily (dedicatedly) share their data for further (geospatial) analysis or decision-making
- *Content*: type of data, which are contributed
- *A Priori Knowledge*: required knowledge of the user
- *Contextual Data*: whether the contributed data contain harvest contextual intelligence, for instance a person's local knowledge
- *Reliability*: quality level of the generated data and contributors' trustworthiness
- *Analysed Datasets*: whether single (individual) datasets are analysed or spatially and temporally aggregated (anonymised) data are used
- *Specific Infrastructure*: whether additional dedicated infrastructure is necessary to collect data

Table 1 Comparison of concepts

	People as sensors	Collective sensing	Citizen Science
Voluntary/ Involuntary	Voluntary	Involuntary	Voluntary
Content	Layman Observations	Raw geo-data (images, tags,…)	Semi-professional Observations
A priori knowledge	Medium	Low/none	High
Contextual data	Yes	Yes	Yes
Reliability	Medium	Mediocre	Good
Analysed datasets	Individual	Aggregated	Individual
Specific infrastructure	No	No	No

A number of applications have been developed in the area of *People as Sensors* throughout the last years. On the one hand, these are specialised applications and technologies to allow people to transmit their sensations; on the other hand, we see a number of data mining-like approaches that try to exploit existing ICT infrastructure data. One central issue with most existing systems is their implementation in singular mobile apps or monolithic and use-case-centred mobile applications.

3 OpenSensTracker: Concept, Implementation and Use Cases

OpenSensTracker is a concrete realisation in the area of *People as Sensors*. Similarly to the concept of Volunteered Geographic Information (VGI) (Goodchild 2007), the application allows people to send geo-referenced data to a data analysis and visualisation system via their smartphone (Resch et al. 2011). Like this, location data can be transmitted along with subjective 'measurements' (human observations) to a central server directly from a person's smartphone via a mobile network, e.g. the cellular network or a Wi-Fi network.

The OpenSensTracker application is characterised through the design of a very simple, easily usable and intuitive interface to minimise usage requirements and technical capabilities on the user's side. The smartphone application allows people to send their personal observations and sensations to a spatial decision support system using pre-defined classes—e.g. to submit air quality data on a traffic light based classification system (green = good, yellow = medium, red = bad). Figure 4 shows the user interface for sending observations and configuring the application.

The establishment of pre-defined classes is basically a trade-off between giving the user the opportunity to freely insert their observations and simplifying the generation of information from the 'sensed' data. Naturally, the restriction to pre-defined classes results in a certain fuzziness of the observations. This compromise will be discussed in Sect. 5.

Fig. 4 Mobile *people as sensors* application using pre-defined classes

A central advantage of the OpenSensTracker application is its modular structure and its broad reliance on design templates. This allows for simple adaptability of the app to a variety of application domains by just chaining the frontend. Application areas comprise public health (biometric surveillance of endangered patients), environmental monitoring (citizen information about local air quality), urban planning (feedback about street damage) or tourism (rating of slope conditions or service on skiing huts). Furthermore, this kind of user-generated content (UGC) is rapidly gaining importance in the area of disaster management, e.g. for the assessment of status data (severity of people's injuries, houses' degree of damage etc.) or for geo-tagging (current location of injured persons).

4 Adding Value: Integrating Human Measurements Into Geo-Service Infrastructures

The actual value of location-based *People as Sensors* applications is the integration of subjective observations into established analysis systems, their combination with sensor measurements and subsequent information provision to different users and user groups. Figure 5 illustrates such a system, the Live Geography infrastructure (Resch et al. 2010a) that provides components for data acquisition, sensor data access, sensor fusion, process modelling, real-time data analysis and information visualisation based on open (geospatial) standards.

The integration of human observations into comprehensive infrastructures for data analysis and decision support opens up wholly new possibilities for creating

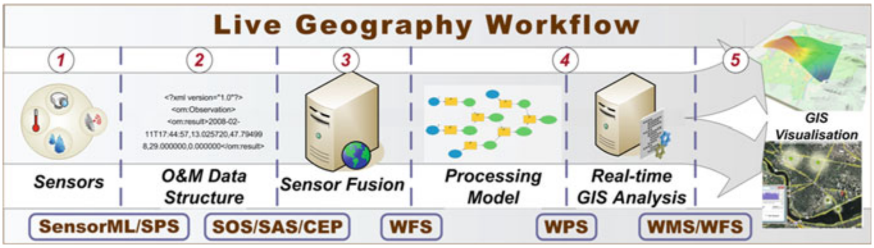

Fig. 5 Live geography workflow for the integration of measurements in real time

situational awareness. Particularly the use of open standards such as the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS) allows for simple integration of user-generated observations into geospatial data analysis and visualisation systems.

From a technical viewpoint, this integration can happen via pull-based mechanisms (OGC SOS, Keyhole Markup Language—KML or GeoRSS) or via push-based alerting services (OGC Sensor Alert Service—SAS, OGC Sensor Event Service—SES or Common Alerting Protocol—CAP).

This approach allows for the integration of human observations in real time and offers a number of advantages:

- Direct on-the-fly integration in GI systems without interim storage
- Mitigation of the risk of a performance bottleneck caused by too large data volumes
- No 'single point of failure' through a federated service-based sensor architecture
- No need for a use case motivated web portal for sensor data provision (but the use of standardised sensor services)

Figure 6 shows the basic workflow for integrating human observations and providing them via a variety of standardised interfaces. Currently, data are sent to the Geo-Tracking & Fusion Server by a simple HTTP GET request containing the measurements as GET key-value pairs. The next step will be to integrate those data via a transactional instance of the Sensor Observation Service (SOS-T).

5 Challenges and Future Research Avenues

As the concepts of *People as Sensors* and LBS are comprehensive in terms of technologies, semantic consistency, data integration and workflow integration, a number of research challenges and future research avenues can be identified. These can be divided into technical and technological, methodological, and privacy and legislation issues.

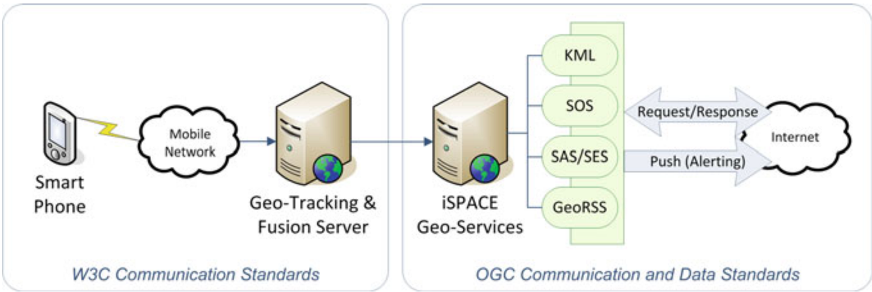

Fig. 6 Integration of human observations into analysis and visualisation systems

5.1 Technical and Technological Aspects

As mentioned above **Volunteered Geographic Information** (VGI) plays a key role in the context of *People as Sensors*. We are currently witnessing an overwhelming willingness of people to share their impressions, personal observations and emotional states in (semi-) public comments. These range from Facebook posts or Twitter tweets to commented geo-referenced image uploads onto Flickr. As elaborated above, this kind of contextual location-based information can potentially build a strong basis for operational real-time strategies in areas such as public safety, dynamic traffic management systems or urban planning. Yet, we are currently facing technical challenges in terms of connectivity, real-time integration of observations, sensor fusion and semantic models. The latter aspect will be discussed in the following sub-section.

In terms of integrating human observations with existing sensor and analysis systems, the creation of a **standardised measurement infrastructure** using well-conceived data and service standards is a major technical challenge. An essential factor will be the integration of new developments with existing community projects such as Ushahidi or Twitter to create new possibilities for qualitative information fusion. This will potentially result in increased LBS-driven situational awareness and enhanced Common Operational Pictures (COP). Furthermore, this development supports infrastructure-oriented approaches and directives such as Global Monitoring for Environment and Security (GMES), Infrastructure for Spatial Information in Europe (INSPIRE) and the Shared Environmental Information Space (SEIS).

5.2 Methodology: Semantic Models, Quality Assurance and VGI

A central issue in the integration of human observations with existing measurement systems is the definition of **consistent semantic encodings**. This requires standardisation on two levels—firstly on sensor data level (encodings for measurements) and secondly on phenomenon level (measurand encodings). Current research comprises 'Human Observations' (Förster et al. 2010) on data level and the Sensor Observable Registry (SOR) on phenomenon level. These top-down standardisation approaches can potentially build the basis for further development and distribution of community-based integration platforms such as *Crowd-Map* (http://www.crowdmap.org), *Singapore Live*! (http://senseable.mit.edu/singaporelive) or *GeigerCrowd* (http://www.geigercrowd.org).

A connected methodological issue in the field of semantics is **representativeness in VGI**. This question probably has to be tackled by a combined bottom-up/top-down approach. In bottom-up approaches, user groups and communities define their own semantic objects and interrelations between these in separate taxonomies. In contrast, top-down approaches try to define semantic rules and ontological relations as generically as possible—mostly before actual applications exist and decoupled from real-world use cases. Only the combination of those approaches can result in trans-domain semantic models, which are linked via object relations.

In these research areas of semantic encodings and representativeness of VGI, new and innovative approaches have to be found as previous ontology research has not kept its promises because these developments are too inflexible, ambiguous and bound to a specific community. Seminal approaches comprise **Linked Data** (for trans-domain definition of semantic rules and for flexible and generic definition of ontological relations), and **semantic search** (for natural language based search portals).

Furthermore, the requirement of high-quality information seems to be self-evident, but has not been tackled thoroughly for real-time geo-sensor networks and *People as Sensors* based approaches. Those systems, including the OpenSensTracker implementation, make use of pre-defined classes (categories), as described above. One disadvantage of this approach is the resulting **uncertainty** in the observed phenomenon, which emerges from different perceptions of every 'sensor' through people's subjective views of their environment. This issue can be solved by the definition of standardised uncertainty factors to qualitatively describe phenomena and their observations, which guarantees objectivity and lowers usage barriers for specialised *People as Sensors* applications.

If this development of increasing availability of user-based information generation continues, we will soon face a vast amount of data contributed by a variety of different data producers—mostly non-quality assured data stemming from private observations or sensor networks. Although we experience quickly increasing awareness of the opportunities of digital mobile communication and LBS, the question arises how we can dedicatedly **engage people** to contribute actively being 'human data sources'. This is necessary in order to leverage user-generated information in areas such as environmental monitoring, emergency management, traffic monitoring, or e-tourism. An important but yet poorly research issue is the use of incentive schemes to encourage people to contribute their data. Current approaches mostly comprise 'feedback' and 'gamification', but their practical suitability has not been fully proven yet.

The concept of *People as Sensors* naturally raises the question of trustworthiness of these data. Thus, automated **quality assurance** mechanisms have to be developed for uncertainty estimation, dynamic error detection, correction and prevention. In this research area, we are currently seeing different approaches in development including Complex Event Processing (CEP) (Resch et al. 2010b) for error detection, standardisation efforts for representing uncertainty in sensor data (e.g. Uncertainty Markup Language–UncertML) (Williams et al. 2008), or proprietary profiles to define validity ranges for particular observations. Only when these questions are solved, reliability and completeness of recommendations can be ensured.

Up to now quality analysis on VGI (e.g. Zielstra and Zipf 2010; Helbich et al. 2010) focused on completeness as well as geometrical and semantic accuracy, but considered only few timeslots and neglected the (near) real-time requirement of many sensor-based applications. Apart from the creation real-time sensor fusion mechanisms, VGI can also be used to improve the data quality through **intelligent algorithms**, as Hagenauer and Helbich (2012) show.

Another critical issue in the area of *People as Sensors* is the integration of user-contributed observations with established **decision-making workflows**. Research has to be performed on how to combine these data with analysis and visualisation tools and algorithms while preserving the working structures of professionals in a variety of areas. This requires development of task-oriented, user-tailored and transparent data integration and (sensor) fusion mechanisms.

5.3 Protecting People's Privacy

A crucial question in the context of *People as Sensors* and LBS is how we can **preserve people's privacy** dealing with user-generated information and partly personal data. In terms of privacy, the claim might arise that we need to be aware of our personal and private data *before* we share them. This also raises the need to discuss the concept of U-VGI, i.e. Un-Volunteered Geographic Information, in contrast to VGI. For instance, collective sensing approaches exploit anonymised data from digital networks (e.g. by deducing crowd movements from traffic distribution in the cell phone network) even though people have not intended to share their data in this way.

The essential question in this context, however, is *how* we can raise awareness of ways to deal with that matter. Terms and conditions of digital services and technology are mostly hardly understandable to non tech-experts. Thus, more simple and binding ways of communicating this kind of information have to be found.

Another central issue in deploying human observation based monitoring systems is the personal impact of fine-grained urban sensing, as terms like ‘air quality’ or ‘pollutant dispersion’ are only surrogates for a much wider and more **direct influence** on people, such as life expectation, respiratory diseases or quality of life. This raises the demand of finding the right level of information provision. More

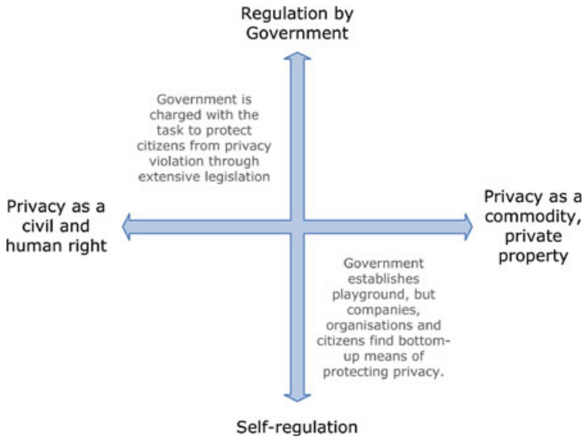

Fig. 7 Understanding of privacy versus the government's role in regulation

accurate, finer-grained or more complete information might in many cases not necessarily be worthwhile having, as this could allow for drawing conclusions on a very small scale, in extreme cases even on the individual. This again could entail a dramatic impact in a very wide range of areas like health care, the insurance sector, housing markets or urban planning and management.

As *People as Sensors* based systems and LBS are oftentimes dealing with personal or individually significant data, **legal frameworks** have to be developed on national, trans-national and global levels to protect those data. The largest limiting factor in this regard is the varying interpretation of 'privacy' in different parts of the world. For instance, privacy can be traded like an economic good by its owner in the USA, whereas it is protected by law in the European Union. This means that supra-national legislation bodies and initiatives are called upon to set up appropriate world-wide regulations. As shown in Fig. 7, legislation and governments play a highly different role in these two settings.

This also includes the critical question of **data ownership**—who owns the data: the data producers (i.e. the citizens or a mobile phone network operator), the institutions that host a system to collect data, or the data providers? Furthermore, if sensitive data is analysed to produce anonymised information layers, who is responsible if decisions that are based on this information are wrong due to lacking quality of the base data? In conclusion, the issues of privacy, data ownership, accessibility, integrity and liability have to be tackled thoroughly all at once and not separately from each other.

In case of tracking applications or services, in which personal data are involved, people should have an **opt-in/opt-out** possibility. This means that users can decide themselves whether they want to use the application—and also withdraw their consent—being aware of the type and amount of data that is collected and transmitted.

6 Conclusion

Ubiquitous sensor networks and LBS can potentially assist in taking decisions in near real time in a variety of application areas such as public safety, traffic management, environmental monitoring or in public health (Resch et al. 2010a). Yet, analysing our surroundings in real time is still a major challenge due to sparsely available data sources for real-time monitoring.

The innovative concept of *People as Sensors* defines a measurement model, in which measurements are not only taken by calibrated hardware sensors, but in which also humans can contribute their individual 'measurements' such as their subjective sensations, current perceptions or personal observations. These human sensors can thus complement—or in some cases even replace—specialised and expensive sensor networks. Throughout recent literature, the term *'People as Sensors'* is used interchangeably with 'Citizens as Sensors' (Goodchild 2007) or 'Humans as Sensors' (Forrest 2010).

This chapter tries to establish a distinct disambiguation between the terms *People as Sensors* (people contributing subjective observations), *Collective Sensing* (analysing aggregated anonymised data coming from collective networks) and *Citizen Science* (exploiting and elevating expertise of citizens and their personal, local experiences).

Furthermore, the particular significance of integrating the *People as Sensors* concept with established LBS, data analysis and visualisation systems is elaborated. Therefore, a special smartphone-based application called OpenSensTracker has been developed, which allows transmission of location data along with subjective 'measurements' (human observations) to a processing service directly from a person's smartphone via a mobile network.

In the course of the presented research, three main research challenges in the area of *People as Sensors* have been identified: methodological issues, technical/technological problems, as well as privacy and legislative questions. This chapter discussed these challenges, pointed out possible solutions, and pin-pointed ideas for future research areas.

Concluding, it can be stated that *People as Sensors* can potentially play a complementary key role in supporting decisions and holistically assessing our environment in a broad variety of application areas. Yet, a number of research questions are to be solved including semantic information extraction, privacy preservation, engaging people and uncertainty modelling.

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Design and Implementation of a Daily Activity Scheduler in the Context of a Personal Travel Information System

Jianwei Zhang and Theo Arentze

Abstract How to effectively schedule individual's daily activities in actual temporal–spatial environments is a challenging task especially when considering various dynamic conditions and constraints. In this chapter, we present a prototype of a personal daily activity scheduler based on our previously developed travel information system, where point of interest (POI) information and travel information have been integrated into an individual's agenda service. The scheduler provides all operations based on constraints checking, agenda operations (e.g., inserting, updating and deleting activities), recommending locations, detecting deviations from schedule, detecting real-time event consequences and detecting relevant POIs. Initial tests for the basic operations indicate that the approach works well and more comprehensive tests will be conducted in the future.

Keywords Activity schedule · Agenda · Point of interests · Travel information

1 Introduction

In everyday life people are engaged in activities (Vilhelmson 1999) for subsistence (e.g., work or school), maintenance (e.g., shopping) and social-leisure purposes (e.g., going out). Some of these activities take place at home. For other activities

J. Zhang (✉) · T. Arentze
Urban Planning Group, Eindhoven University of Technology, Den Dolech 2, 5612 AZ, Eindhoven, The Netherlands
e-mail: j.zhang@tue.nl

T. Arentze
e-mail: t.a.arentze@tue.nl

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individuals need to travel to reach a location where the activity can be conducted. A trip then is produced. Activities can be described in terms of an activity type, the location where the activity is conducted, the start time, the duration (time-use) and other persons, if any, with whom the activity is done together with. On the other hand, trips are episodes of travelling that occur in between two consecutive activities that are conducted at different locations. Trips are described also by a start time (departure time), duration (travel time) and accompanying persons. Furthermore, the transport mode used for the trip and the chosen route are relevant characteristics of a trip. How to effectively schedule individual's daily activity becomes a challenge task.

There is a large body of literature on activity scheduling problems (Arentze et al. 2010). In travel-behaviour research, activity-scheduling problems are generally seen from the perspective of analysing and predicting behaviour of individuals especially in the context of travel-demand and traffic modelling (for an overview see Timmermans et al. 2002). In operations research, activity-scheduling problems are viewed from a perspective of optimization—i.e., to find optimal solutions for particular scheduling problems given an objective function and a set of constraints. Examples of important scheduling problems are the Travelling Salesman Problem (Applegate et al. 2006) and the Vehicle Routing Problem (Bertsimas and van Ryzin 1991). These problems have been and still are extensively studied with a focus more on the travel part and less on the activity part. Besides that, recent advances in areas of POI services, travel information services and calendar services also benefit the development of an activity scheduler a lot.

A point of interest or, in short, POI is a specific point location that someone may find useful or interesting. POIs are an important part in geology data and transport data. In some applications, they are set up independently where you can check the opening hours for specific types of facilities. In other applications like travel information systems (e.g. Google Transit, TomTom in-car navigation), POI services have been seamlessly incorporated. On the other hand, calendar applications do not incorporate POI information or provide advanced operation functions considering various constraints.

In the area of travel information service, many systems emerged in the last decade (Abdel-Aty 1999; Rehrl et al. 2007; Zhang et al. 2011). Examples of commercial applications are Google transit, Transportdirect, TFL (Transport for London), 511, DB (Germany travel information service), NS (Dutch railway information service) and 9292ov (Dutch public-transport travel information service). Existing systems can be categorized into three groups: road transport service, public transport service and multimodal transport service. Most of the above services can only provide routing for single trips from point to point and some of them can provide routing for multi-trips with way points. They focus on either public transport or private transport modes implying that they do not support multimodal routing (involving some combination of a private vehicle and public transport). All above systems are stand-alone services that have no connection with an agenda or activity scheduling system. Hence, users normally have to spend quite a lot of time to checking their calendar and travel information systems alternately in scheduling their activities.

In the area of calendar or agenda systems, many applications have been introduced in recent years, as well, such as for example Google calendar, Microsoft outlook calendar and Yahoo calendar. These systems allow users to keep a personal daily activity agenda and obtain alert messages. However, the existing calendar services are not linked to a routing system (for planning and implementing trips) and neither support conflict or constraints checking. There are some standards (RFC 5545 2009) to define and exchange calendar information for these calendar applications. However, complicated travel information services are not well incorporated in these standards. Essentially, current calendar/agenda applications and standards are notification and alert-based and cannot meet the complicated constraints involved in an actual activity-travel scheduling system.

As this brief review indicates, there is a gap between POI service, travel-information service and calendar services in the sense that they operate separately whereas optimal support of activity-scheduling requires seamless integration of these services. The purpose of the activity Scheduler developed in this chapter is to fill this gap and realize this integration. The objective of the activity scheduler is fourfold:

1. Integration of POI service, routing service with calendar service
2. Checking activity-scheduling constraints in basic activity-calendar operations
3. Monitoring the execution of an activity schedule
4. Detecting conflicts and providing recommendations in all stages

The remainder of the chapter is structured as follows. First, we give a brief introduction of the system architecture of the proposed activity scheduler. Then, we describe each function module in the scheduler. We give an illustration of the scheduler in the section that follows. Finally, in the last section we summarize the major conclusions that can be drawn.

2 Architecture

Figure 1 schematically shows the relationships between the activity scheduler and other components in the larger personal travel information system. Discarding the client parts, the server side includes three components: the POI server which provides queries of location and time for POIs; the calendar server which provides all kinds of operation services including constraints checking and the travel information service which provides route planning information. The activity scheduler can be seen as a part of the calendar which plays a key role to integrate other services. The POI data may also be connected to a travel information server for location query.

As for the POIs server, in addition to the query for spatial information and location type, the other attributes query, like opening hours and rating, are also

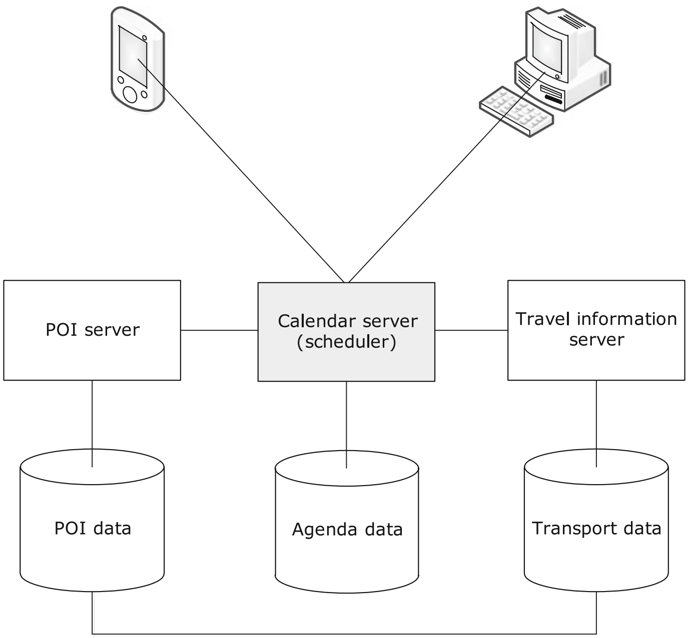


Fig. 1 Activity scheduler system architecture

important for users to make a choice. Further attributes may include website, email, telephone, payment etc.

As for the travel information server, the proposed system includes a multi-modal network routing system such as we developed in earlier work (i-Tour Report 2011). In this system, we model the multi-modal transport network by the idea of a supernetwork (Benjamins et al. 2001). We use the time dependent approach to model the private transport part (e.g. car) and the time expanded approach for the public transport part. Networks for different modes are connected by transfer links. Given the inputs of start place, end place, departure time or arrival time, travel option (e.g. fastest, cheapest, most environmental), the user can get as output a full list of trip-trace points with time stamp and for the trip as a whole the travel distance, travel cost, emission (CO_2) and generalized costs.

The calendar server manages and stores activity and travel entries in the calendar. Although existing calendar services, such as Google calendar, can be used as a user-interface for display and management of calendars, the storage facilities offered in existing tools are not flexible enough for our purpose. Therefore, the activity scheduler assumes an own database where the activity calendars of users are stored including all the augmented information required for the functions of the activity scheduler. The scheduler, which is part of the calendar, includes the functionality involved in constraints checking and recommendation. The general idea here is that the scheduler does not allow conflicts in the self-designed calendar/agenda database. Each time the user makes a change to the activity calendar (e.g., inserting, deleting or updating an activity) the scheduler checks whether constraints are met. Conflicts are not allowed because they cause operational difficulty and potential errors for the scheduler. An agenda should be free of errors in order for the scheduler to be able to function properly and provide assistance in later stages. The database of the calendar on a main level consists of two data tables: a table to store activity records and a table for storing trip records of users. Existing calendar services allow only one common event table where trips aren't handled specifically. Here, two separate tables are used because the attribute sets for activities and trips are different. The start time and end time includes the date of the calendar day. The activity schedule of a particular person on a particular day can be reconstructed by selecting all trip and activity records with a corresponding user-id and corresponding start-time date and rank the records in the order of start time.

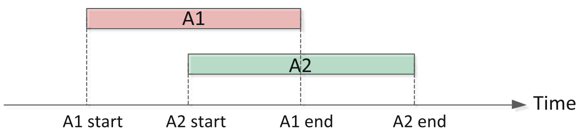
The functionalities of the proposed activity scheduler are categorised into three groups. The first group relates to basic calendar operations including inserting, deleting and updating activities. The second group refers to assistance operations consisting of (1) queries to view scheduled activities and trips by time frame (e.g., the scheduled activities of the coming week), (2) retrieving history information about activities as a reference or recommendation of location or other choice facets of an activity (e.g., show the supermarket where the person usually goes to on Wednesday afternoon). The last group focuses on the dynamics of an activity schedule. This group consists of two functions: (1) processing of real-time information and giving feedback on the deviation of an actual position and planned position in time or space and (2) generating location suggestions based on the current position of a user in space and time and his/her activity schedule. In the next section, we will describe these functionalities in more detail.

3 Functions

3.1 Schedule Conflicts

Before describing the various operations in detail, we first need to define the concept of a conflict in an activity schedule. A conflict (Fig. 2) is a situation where there is a time overlap between activities of a same person or not enough time between two activities for required travelling in-between the activities.

Fig. 2 Schedule conflict



3.2 Basic Calendar Operations

3.2.1 Insert

The insert operation is triggered when the user adds an activity to his calendar. Before inserting the activity, the activity scheduler checks whether no conflicts arise when the item is added. Furthermore, the Scheduler checks whether travelling is involved and whether there is enough time for a required trip. The scope for consistency checking is the time frame of a current day (24 h). Four different cases can be distinguished.

In the first case (Fig. 3I), there is no activity in the current agenda for the day. In that case, the activity can be directly inserted into the agenda. In the second case (Fig. 3II), there is an activity in the agenda after the planned new activity. In that case, a travel-episode (trip) should be specified and inserted if the two activities are in different locations. In the third case (Fig. 3III), there is an activity in the agenda before the planned new activity. In that case (Fig. 3IV), also a trip should be specified and inserted if the two activities are in different locations. In the last case, there are activities in the agenda before as well as after the planned new activity. If the new activity is in a different location than the preceding activity and the later activity, then the old trip has to be removed and, two new trips have to be specified and inserted. In all cases when new trips are inserted or existing trips updated, the scheduler checks whether conflicts with existing activities in the agenda occur.

Although the above rules are straight-forward, the system has to take into account the typical situation where the user plans specific activities while he is most of the time staying at a base location (typically at home). When the agenda for a day is empty, the system assumes by default that the base location is home. This means that, unless specified otherwise, if the new activity is an out-of-home

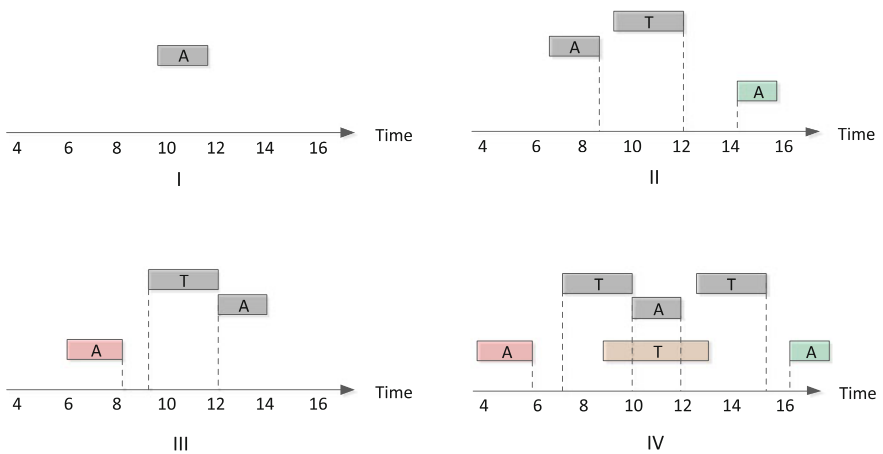


Fig. 3 Insert

activity then a trip should be specified before the activity (to reach the location of the activity) even if there is no preceding activity in the agenda. Furthermore, if the activity is an out-of-home activity, a further important data item is whether or not the individual plans to go home directly after the activity. If yes, then the system will generate a not-further specified in-home activity (of minimum duration) and inserts this activity directly after the new activity. A consequence, of this additional activity is that a trip back home needs to be specified directly after the activity for consistency. In sum, the algorithm for an insert operation is:

1. Check insert type
   Determine whether a trip before and/or after the new activity needs to be inserted
2. Check whether conflicts arise when the new activity is inserted
   Determine whether there is a case of time overlap with a preceding or a next activity in the agenda
   Determine whether there is enough time for travelling, if needed, before and/or after the new activity
3. If there is no time conflict
   Insert the activity
   Insert the trips, if any, before and/or after the activity

3.2.2 Delete

The delete operation will delete activities and related trips from an agenda. The delete operation also distinguishes four cases. In the first case, the activity planned to be deleted is the only activity in the agenda (for that day). The activity can be removed directly in this case. In the second case, there is an activity after the activity to be deleted. In that case, the activity can be removed directly while the trip between the delete activity and its later activity should also be removed. In the third case, there is an activity before the delete activity. Also in that case, the activity can be removed directly while the travel between the delete activity and its preceding activity should be removed.

In the last case, there is a previous activity as well as a later activity for the activity to be deleted (Fig. 4). In that case, the activity and trips to and from the activity should be deleted. In case the previous and later activities are in different locations, a new trip should be specified and inserted. In sum, the algorithm for a delete operation can be written as:

1. Check delete type
   Determine whether trips have to be deleted or updated
2. Check whether there is a time conflict for the updated trip
3. If there is no time conflict
   Delete the activity
   Insert new trips or update trips if and where needed

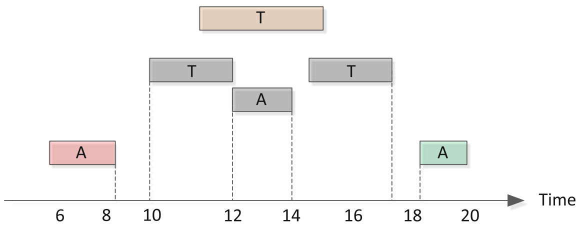


Fig. 4 Delete

3.2.3 Update

An update operation can be considered as a combination of an operation to delete an old activity and insert a new activity. Many more complicated operations can be defined as particular combinations of insert, delete and update operations. In the process of an update operation, the old activity and its related travel-episodes are backed up first before they are deleted. The insert operation is considered next. If the insert operation fails due to conflicts, the backed-up old activity and trips are recovered. Thus, the algorithm for the update operation can be written as:

1. Back up the old activity to be deleted and related travel episodes
2. Delete the old activity and related travel episodes
3. If the delete operation is successful
   insert the new activity and related travel-episodes
   if the insert operation failed then restore the old activity and travel episodes from the back up

3.3 Assistance Operations

3.3.1 Query

The purpose of a query is to retrieve a time segment of the existing calendar. Although there are many attributes that could be used to define a query condition, the system only provides queries by time. This reflects the assumed purpose of queries in the system which is twofold. First, a user might be interested in his agenda for a particular time window, e.g., to view the scheduled activities. For example, if a user queries the agenda for tomorrow, then the system will retrieve this time segment of his calendar and send it to the user-interface for display. Second, the query operation is a basic function that is used by the Activity Scheduler in the context of many other functions such as for consistency checking (e.g., in case of an insert operation). The query operation returns the activity and travel episodes of which the start-time and end time fall within the defined time window. The algorithm for queries is not complex. At the server end, the query task will be performed by SQL sentences.

3.3.2 Indicate

The purpose of the indicate operation is to provide statistics of activities conducted in the past. The activity history of a user is the part of the calendar that relates to the past and is stored in the activity database (activity and travel tables). Many of the daily activities of an individual have a more or less repetitious character with limited variation in terms of location, transport mode, day of the week, time of day and duration. For example, for grocery shopping an individual may visit only a few locations such as a supermarket in the own neighbourhood, a week market and a supermarket at a station. The indicate function will help the user to specify attributes of an activity according to existing habits. In the example, if the user inserts a grocery shopping activity then the system will retrieve all occurrences of grocery shopping activities from the database and retrieve the different locations (neighbourhood supermarket, week market and station) visited for this activity in the past. The indicate operation is implemented as query operations from the activity database. The query defines a time-window (a particular time of looking back in the past), a user-ID, a so-called activity template and a requested attribute. The template defines the known or required attributes for the activity (e.g., all grocery shopping activities on Friday) and the requested attribute defines the unknown attribute for which an indication is requested (e.g., location). The system retrieves all activities that meet the template, retrieves from this the specifications of the requested attribute (e.g., the grocery shopping locations) and returns this list of possible specifications in decreasing order of frequency of occurring. Since the purpose of Indicate is to give useful suggestions to the user, it is important that especially time attributes on both the levels of the activity-template and requested attribute are defined in not too narrow categories. For this reason, the system classifies a day into several episodes (7:00–9:00; 9:00–12:00; 12:00–13:00; 13:00–17:00; 17:00–19:00; 19:00–22:00 and 22:00–7:00) and, similarly, activity duration in several duration classes (<30; 30–60; 60–120; 120–240; 240–360 and >360 min). The algorithm for the indicate operation can be written as:

1. Determine the required attributes (i.e., activity-template) and requested attribute for the activity
2. Define the time-window (time of looking back in the past)
3. Retrieve from the database the activity records that meet the activity-template, user-ID and time-window
4. Determine the alternative specifications of the requested attribute and calculate the frequency of each specification in the list of retrieved records
5. Return the alternative specifications for the requested attribute in decreasing order of frequency

We emphasize that the indicate function is a specific case of a recommender function—it provides recommendations for attributes of an activity based on the history of a user. Currently, we assume that user-ID is always used as a filter to retrieve activity records. However, especially if a user is new or an activity is new, it is useful to extend the indicate operation and include in the search of the database also the activities of other users that have similar characteristics of the user under concern (e.g., live in the same neighbourhood). Then, the recommendation (indication) would include locations, durations, etc., that comparable others frequently use as suggestions.

3.4 Dynamic Operations

3.4.1 Recommending Locations

As said, the indicate function is a type of recommendation function that is based on history information about a user. In this section, we consider a second recommendation function that is not based on a search of the database, but rather on a spatial search of an area and is aimed at finding suitable locations for a given activity. There are two time moments when such spatial recommendations are relevant: during the planning stage and during implementation of an activity schedule. In the planning stage, a user inserts an activity in the agenda and may wish to receive a recommendation (of a location) for the planned activity prior to executing an activity schedule. In the implementation stage, the user is executing an activity schedule and may be interested in receiving recommendation for re-scheduling of an activity (e.g., in response to an unforeseen event). In this section, we consider recommendation in the planning stage—i.e., the recommendation function that is triggered when the user inserts a new activity in his calendar.

The recommend function is about suggesting a location to the user taking into account schedule constraints. This function can help the user to find an optimal activity location in the planning stage when he inserts a new activity in his calendar. Apart from space–time constraints, also user preferences are taken into account that determine how the person makes trade-offs between travel demands (time and costs) and attractiveness of a location. There are four cases for the location recommender function.

In the first case (Fig. 5I), there is no activity in the current agenda (for the day considered). In this case, the user has to specify the departure location (often this is home or another base location on that day), the maximum distance he wants to travel from the departure location, the location type of the arrival location (that matches the activity type), the start time of the activity time window, the end time of the activity time window, the duration of the activity and the list of available modes for the trip.

In the second case (Fig. 5II), there is only a later activity in the agenda which then determines the next destination (directly) after the activity. In that case, the user does not need to specify the end-time of the time window for the activity as this is determined by the next activity.

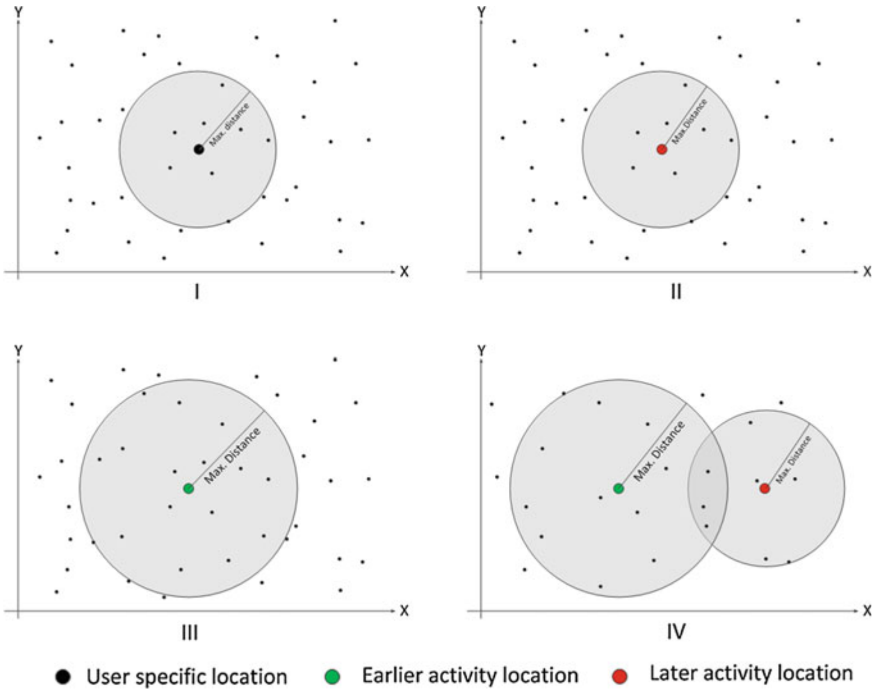


Fig. 5 Recommend

In the third case (Fig. 5III), there is only a previous activity in the agenda. In that case, the user does not have to specify a start-time for the time window of the activity as this is determined by the previous activity.

In the last case (Fig. 5IV), the user wants to get location recommendation for an activity between a previous activity and a later activity. In this case there is a natural time window for the activity.

The maximum travel distance in combination with the time-window for the activity and the available transport modes determine the set of possible locations for the activity, as shown schematically in Fig. 5 for the four cases. If multiple transport modes are available, the system uses the fastest transport mode to determine feasible locations. If the user has defined a trip for the new activity when it is inserted, the check function will judge whether the travel is feasible.

The location set found in this way determines the locations that are within reach given the time-window, the anchor locations (previous and next locations) and the available transport modes. The ranking of feasible locations is based on a utility function that should represent the preferences of the user. The utility of a location L for an activity A is defined as:

$$U(Ls, L, Le, A) = V(L, A) + b \times DT(Ls, La, Le)$$

where:

V(L, A) = a1 if L is a first-class location for A
V(L, A) = a2 if L is a second-class location for A
V(L, A) = a3 if L is a third-class location for A

where b, a1, a2 and a3 are preference parameters ($b < 0$ and $a1 > a2 > a3$) stored in the system for each activity category and each user. The values of V relative to b determine the extent to which the user is willing to travel a longer distance to reach a more attractive location. As implied by this equation, a three-way classification is used for locations in general. These classes are defined depending on the activity type under concern and generally represent the suitability of available facilities at the location. The parameters are estimated based on a choice experiment specifically conducted for this recommendation system. Given space constraints, the estimation of parameters and the classification of locations will not be described here.

The algorithm for this recommendation function can be written as:

1. Check the type of recommendation request
2. Determine the anchor locations for the planned activity
3. Determine the time window for the planned activity
4. Determine maximum travel distance before and after the planned activity
5. Identify the location type
6. Identify the fastest available transport mode
7. Identify the duration of the activity
8. Find the first-round location set based on distance and mode constraints
9. Filter out the locations that do not meet the time-window constraints or opening hour constraints
10. Determine the utilities of filtered locations
11. Return the filtered location set ranked on utility

Note: anchor locations of an activity are the locations before and after the activity, i.e. the location where the trip for the activity starts from and the location where the trip after the activity is headed to.

3.4.2 Detect Deviations from Schedule

Due to unforeseen events such as travel delays, the actual space–time path of the person may differ from the scheduled one. The purpose of the detect function is to monitor the execution of a schedule and every time when requested give feedback based on a comparison between the actual position and planned position according to the schedule. A discrepancy can be measured in space and in time. When measured in space the feedback has the form 'you are X m away from the place where you are supposed to be at this time' and when measured in time the

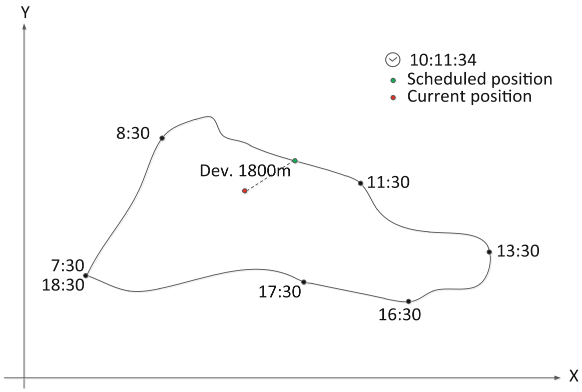


Fig. 6 Detect deviations from schedule

feedback has the form ‘You will arrive X min late (or early) at the destination for the next activity’.

The first, distance-based detection type measures the distance between the current position of the traveller and the scheduled position as illustrated in Fig. 6. Through the routing system, we can calculate the deviation to see whether this will induce a delay of a next event and give a corresponding alert. The user can set an alert distance, e.g., 500 m.

The algorithm for distance-based deviation detection is:

1. Check the current position
2. Check the planned position in schedule (could be travelling or doing an activity)
3. Return the distance between current position and schedule position.

The second, time-based detection function considers the time between the earliest possible arrival time at a next destination and the scheduled arrival time (i.e., start time of the activity at that destination).

The algorithm for time-based deviation detection is:

1. Determine the earliest possible arrival time at the location for the next activity
2. Check the corresponding planned arrival time in the schedule
3. Return the delay time (positive or negative)

A crucial issue in both the distance and time-based deviation detection mode is the input data about the current position of the user. In principle, just time and location co-ordinates (X, Y and clock time) would suffice to detect a distance-based or time-based deviation by simple projection. However, to determine deviations more realistically it is necessary to know in addition whether the person is currently in a vehicle, the type of vehicle (e.g., bus or train) and in case of public transport the transport service (e.g., bus line 6). For example, in case the person is in a wrong bus, the earliest possible arrival time will be substantially later due to the fact that a transfer to another bus is required. To cover the general case, the detection model assumes as input co-ordinate information (X, Y and clock time) as well as mode information (vehicle type and public transport service ID). Detection of the current mode is not a trivial task and requires a separate model.

3.4.3 Detect Real-Time Event Consequences

The third detection function considered here is triggered when a real-time event occurs. Traffic jams, traffic congestion, road construction works, public transport failures and so on may cause foreseeable travel time delays in the execution of activity schedules of travellers. We use the term real-time event to refer to any such type of delay (e.g., a slowing down of traffic due to unexpected traffic congestion is a real-time event). Although the possible types of real-time events are diverse, we can classify them into node real-time events and link real-time events. Both types of events will affect predicted arrival times at nodes. When a real-time event occurs, the detect function identifies the node(s) that is affected and the extent of the delay. Having identified the node and the delay, it identifies the users whose schedules are affected and sends notifications of the delay.

The algorithm for real-time event detection is:

1. Update arrival times at nodes (of road and public transport networks)
2. Identify those nodes where the expected arrival time has changed
3. Identify those users whose schedules are affected
4. Send notifications about delayed arrival times to those users

3.4.4 Detect Relevant POIs

This third detection function checks for a given time moment and user whether there are locations in the vicinity of the user that are potentially of interest given the activity schedule of the user. Consider for example a user who has planned to visit a store of a certain type (e.g., a book store) later on the day and currently is at a location where a book store is nearby. Even though the visit to the book store is planned later on the day, it may be beneficial to take the opportunity and visit the store right away. The POI detection function receives as input the current position of a user (time, place and mode co-ordinates) and carries out a search within a predefined radius from the current position for locations that match the purposes of activities that are scheduled later on the day. The assumed radius is defined depending on the mode. For faster modes (e.g., car) a wider radius is assumed than for slower modes (e.g., walking). When the user is currently inside a vehicle of public transport (e.g., a bus or train) no such locations will be identified. When a location is detected, the system sends a message to the user that he may consider doing the activity right now at the found location.

3.4.5 Others

Above we described basic functions of the activity scheduler. Complex scenarios can be realized by combinations of basic operations. For example, the following scenario could be the result of a user–system interaction process (words in bold refer to basic operations):

1. Initially, the *location detection* function does not result in identifying a suitable location
2. When the user has travelled for a while, the system returns a list of possible locations in the vicinity regarding the user's future activities
3. The user *updates* a later activity with a location in the list
4. However, the update failed due to a time conflict
5. The user evokes the *recommending locations* function with precise location specification
6. The system returns a filtered list of locations
7. The user selects a preferred location and then *updates* the activity
8. The system returns a success message

4 Illustration

We consider the Naples region in Italy as a case. For the POI sever, we currently use the Navteq data where there are hundreds of kinds of POI. To reduce response time and considering the server focuses on local, urban travel, only POIs in the Campania region are selected. There are 11174 POIs in total for in our POI server. Since there is no data on opening hours, we currently assume that the opening hours for all facilities are 9:00–17:00. In reality, the POI opening times are more complicated and diverse.

For the travel information server, transport data, we also use Navteq data for road network. There are in total 267,284 nodes and 320,494 links for campania region. There are also timetable data for public transport (bus and train) for the region, including in total 4,792,810 arrival/departure events. The real-time data is expected to be collected in the future.

We have tested the basic functions by now, for more details please check appendix part. Complex functions and work flow will be the product of combinations of the basic operations and be tested in the future.

5 Conclusions

We presented our recent progress on developing a daily activity scheduler where a POI service, travel information service and calendar service are seamlessly integrated with constraints checking and scheduling through seven basic calendar operations. For the POI service, we set up our own service. For the calendar, we use the data table as storage means and for the travel information provision we use the routing service developed in earlier work. The illustration shows how our calendar server provides the basic requirements for daily activity-travel scheduling. There are three main features of this system: (1) advanced constraints checking of activity plans; (2) monitoring of activity schedule implementation and (3) utility-based location recommendation taking the activity schedule into account. Although activity scheduling problems have received much attention in transportation research, the scheduler developed in this work package is the first operational system that integrates the two sets of functionalities—activity and travel planning—in the framework of a personal mobility system. In future work more testing is required especially for dynamic part. Furthermore, the activity scheduling assistant can be further enhanced especially with regard to scheduling of group activities.

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Appendix

Basic Calendar Operations

Insert

We tested four cases for the insert operation: insert an activity in an empty agenda; insert an activity where there is an activity after the insert activity; insert an activity where there is an activity before the insert activity, and insert an activity where there are activities before and after the insert activity.

In the first case, we insert an activity into an empty agenda (Fig. A.1 in appendix). The activity is specified as (1, "Work", 2011-10-05 09:15:00, 2011-10-05 11:45:00, "Naples", 14.279, 40.864, "Boss, Tom and Lucy", "project progress"). We receive a 'correct' response and the item can be found in the server's data table (Fig. A.2 in appendix).

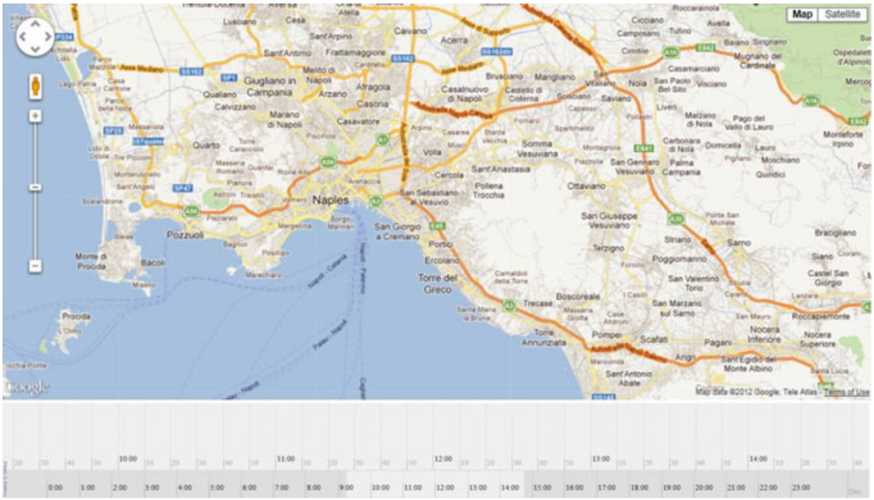

Fig. A.1 Insert-I

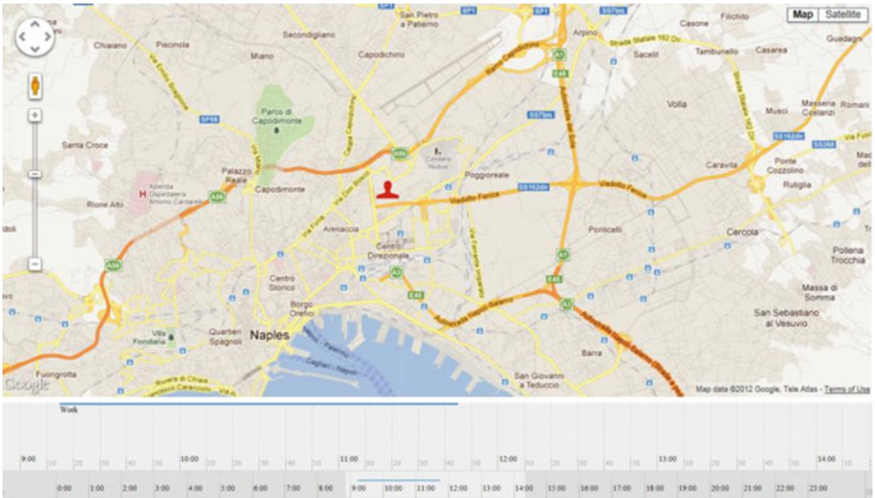

Fig. A.2 Insert-II

In the second case, there is already one item in the agenda. The new activity is specified as: (1, “Breakfast”, 2011-10-05 07:00:00, 2011-10-05 07:30:00, “Naples”, 14.222, 40.85, “”, “”) which is earlier than the previously inserted activity. A trip needs to be inserted as the new insert activity has a different location than the later activity. A trip request to the routing system is specified as: (1, “foot, bus, train”, 2011-10-05 07:30:00, “departure”, “MinmalTimeCost”, “Naples”, 14.222, 40.85, “Naples”, 14.279, 40.864). The routing system suggests

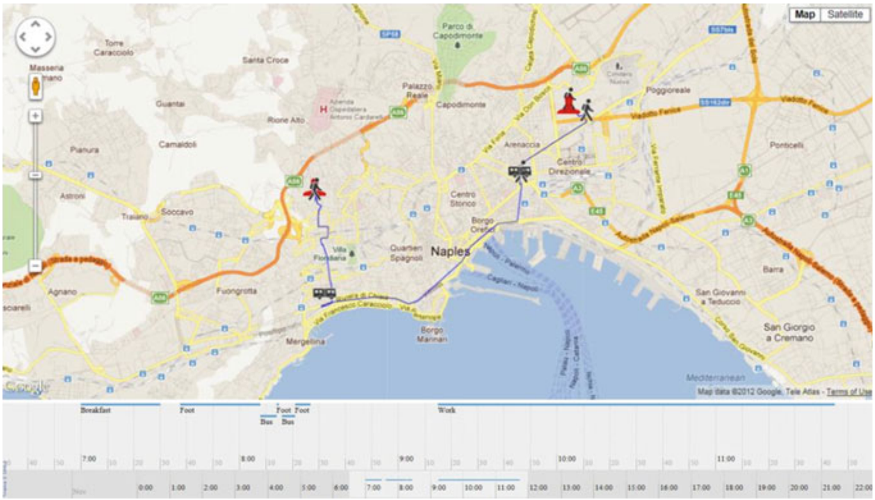

Fig. A.3 Insert-III

departure at 07:33:21 and estimates arrival at 08:26:47. The detailed schedule for the trip is stored in the table which may involve several transfers and which the user can use as a route plan for public transport. The travel information can be retrieved and displayed for the user through the standard interface. We receive a ‘correct’ response from the scheduler and the item can be found in the server’s data table (Fig. A.3 in appendix).

In the third case, we insert a next new activity specified as: (1, “Work”, 2011-10-05 15:30:00, 2011-10-05 16:30:00, “Naples”, 14.34, 40.84, “”, “”) which is later than the activity inserted in the first case. A trip needs to be inserted as the new insert activity has a different location than the earlier activity. A trip request to the routing system is specified as (1, “foot, bus, train”, 2011-10-05 12:30:00, “arrival”, “MinmalTimeCost”, “Naples”, 14.279, 40.864, “Naples”, 14.34, 40.84). The routing system suggests departure at 14:25:10 and estimates arrival at 15:27:33. The detailed trip information is stored in the table. We also receive a ‘correct’ response and the item can be found in the server’s data table (Fig. A.4 in appendix).

In the last case, we again add a new activity specified as (1, “Work”, 2011-10-05 13:00:00, 2011-10-05 13:30:00, “Naples”, 14.342, 40.864, “Jimmy”, “budget application”). This time there is a previous activity and a later activity. Two trips need to be inserted as the newly added activity has a different location compared to both the earlier activity and later activity. This time, we define the routing request for the earlier trip as: (1, “foot, bus, train”, 2011-10-05 13:00:00, “arrival”, “MinmalTimeCost”, “Naples”, 14.279, 40.864, “Naples”, 14.342, 40.864). The routing system suggests departure at 12:06:15 and estimates arrival at 12:56:05 for this trip. Next the routing request for the later trip is specified as: (1, “foot, bus, train”, 2011-10-05 12:30:00, “departure”, “MinmalTimeCost”, “Naples”, 14.342, 40.864, “Naples”, 14.34, 40.84). The routing system suggests departure at

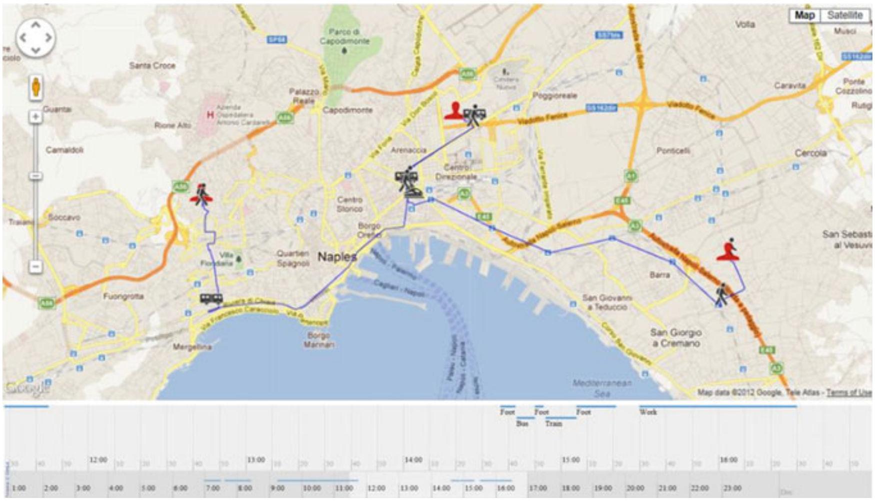

Fig. A.4 Insert-IV

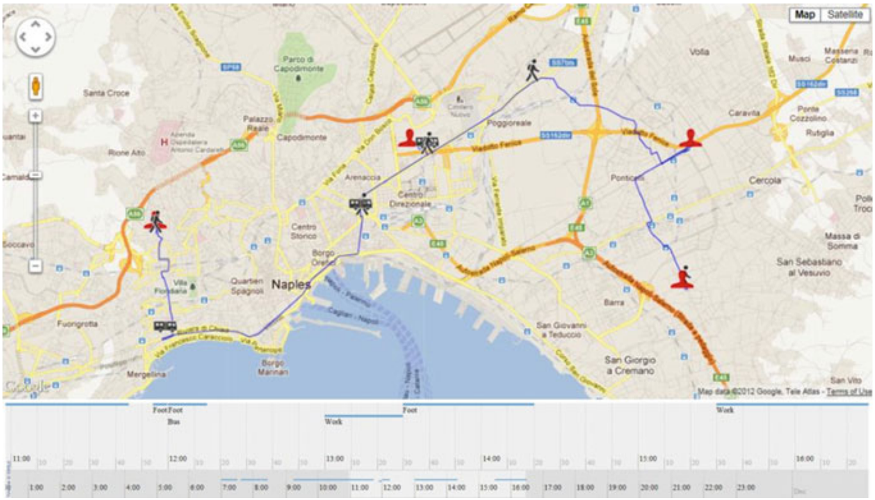

Fig. A.5 Insert-V

13:30:00 and estimates arrival at 14:20:35 for this trip. Again, the detailed travel information is stored in the table. We also receive a ‘correct’ response and the item can be found in the server’s data table (Fig. A.5 in appendix).

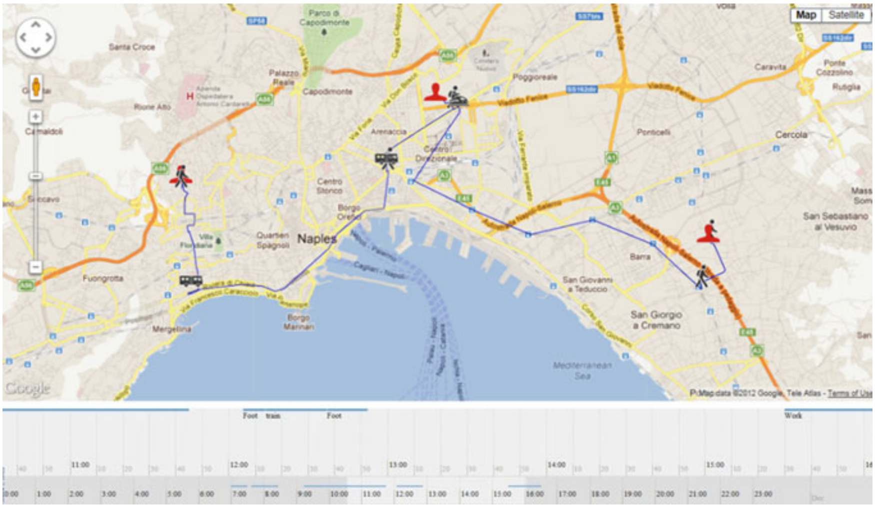

Fig. A.6 Delete-I

Delete

We consider four cases to illustrate the delete operation: delete a solo activity; delete an activity where there is an activity before; delete an activity where there is an activity after, and delete an activity where there are activities before and after. We will consider the schedule that resulted from the activity insert operations explained in final stage of previous section (Fig. A.5 in appendix). We change the order a little bit to make sure that all cases can be tested.

First, we delete the second work activity: (1, “work”, 2011-10-05 13:00:00, 2011-10-05 13:30:00, “Naples”, 14.342, 40.864, “Jimmy”, “budget application”).

The travel episodes related to the activity should be replaced by new trips. For this the scheduler sends the following request to the routing system: (1, “foot, bus, train”, 2011-10-05 12:30:00, “arrival”, “MinmalTimeCost”, “Naples”, 14.377, 40.852, “Naples”, 14.377, 40.852). The routing system suggests departure at 12:01:02 and estimates arrival at 12:56:05. The database is updated and a ‘correct’ response is obtained (Fig. A.6 in appendix).

Next, we delete the activity with value (1, “Work”, 2011-10-05 15:30:00, 2011-10-05 16:30:00, “Naples”, 14.34, 40.84, “”, “”) which is the last activity in the agenda. Its related travel should be deleted. This is done automatically and we receive a ‘correct’ response (Fig. A.7 in appendix).

Then, we delete the activity (1, “Breakfast”, 2011-10-05 07:00:00, 2011-10-05 07:30:00, “Naples”, 14.222, 40.85, “”, “”) which is the first activity in the agenda. Its related travel is deleted too. We receive a ‘correct’ response and the data table has been updated (Fig. A.8 in appendix).

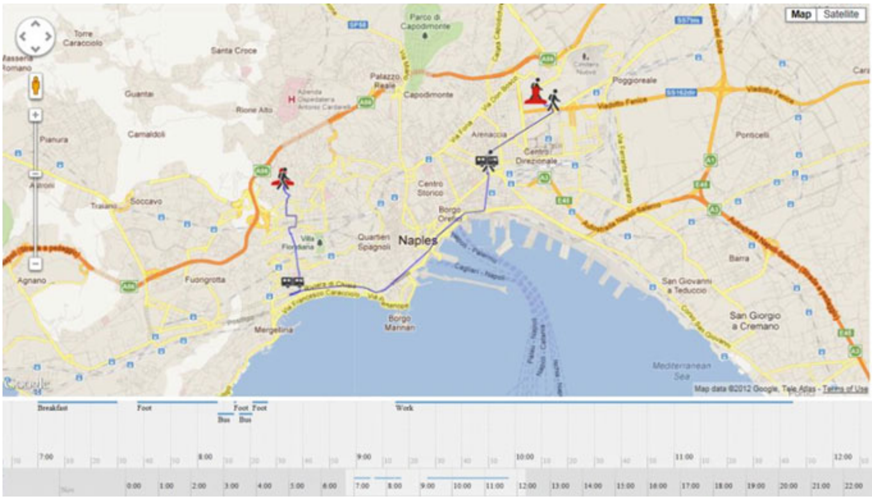

Fig. A.7 Delete-II

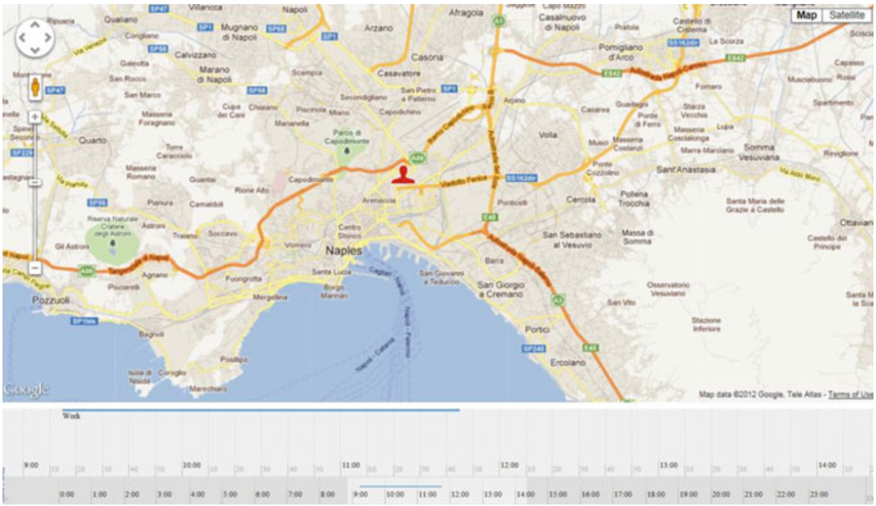

Fig. A.8 Delete-III

Finally, we delete the last activity left in the agenda: (1, "Work", 2011-10-05 09:15:00, 2011-10-05 10:45:00, "Naples", 14.377, 40.852, "Boss, Tom and Lucy", "project progress"). After the delete operation, we receive a 'correct' response and the data table has been updated (Fig. A.9 in appendix).

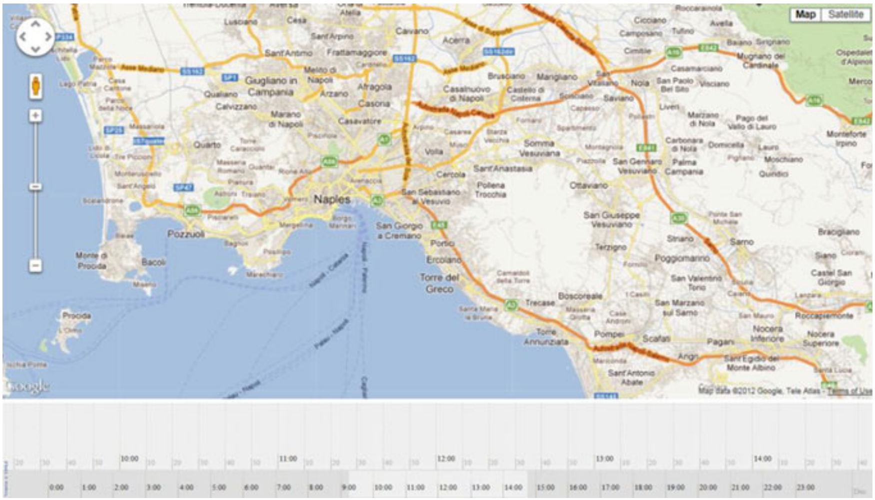

Fig. A.9 Delete-IV

Update

The update operation, which can be seen as a combination of delete and insert, usually needs interface support such that the user can view all time allocations to episodes of activity and travel in sequence of scheduling. The user can then specify for example an update to utilize a free time slot. The update operation can refer to a change in one or more attributes of an activity or travel episode. For activities, changes of start time, end time or location is typically considered. For travel, most changes will be about departure time or arrival time, transport mode or travel preference (e.g. fastest, cheapest, most environmental). More complex operations can be implemented as combinations of “insert”, “delete” and “update”.

Assume an agenda that includes the inserted activities described in (Fig. A.5 in appendix). We consider the old activity: (1, “Work”, 2011-10-05 13:00:00, 2011-10-05 13:30:00, “Naples”, 14.342, 40.854, “”, “”) and update this activity involving a change in start time so that the new specification of the activity becomes: (1, “Work”, 2011-10-05 12:45:00, 2011-10-05 13:15:00, “Naples”, 14.34, 40.85, “”, “”). For the new update of the activity, we furthermore implement an update of the earlier travel: (1, “foot, bus, train”, 2011-10-05 07:30:00, “arrival”, “MinmalTimeCost”, “Naples”, 14.279, 40.864, “Naples”, 14.3, 40.85) and later travel: (1, “foot, bus, train”, 2011-10-05 07:30:00, “departure”, “MinmalTimeCost”, “Naples”, 14.3, 40.85, “Naples”, 14.34, 40.84). For the earlier travel we get a suggested departure time of 12:09:42 and arrival time of 12:39:49. For the later travel, we get a suggested departure time of 13:15:00 and arrival time of 14:10:18 (Fig. A.10 in appendix).

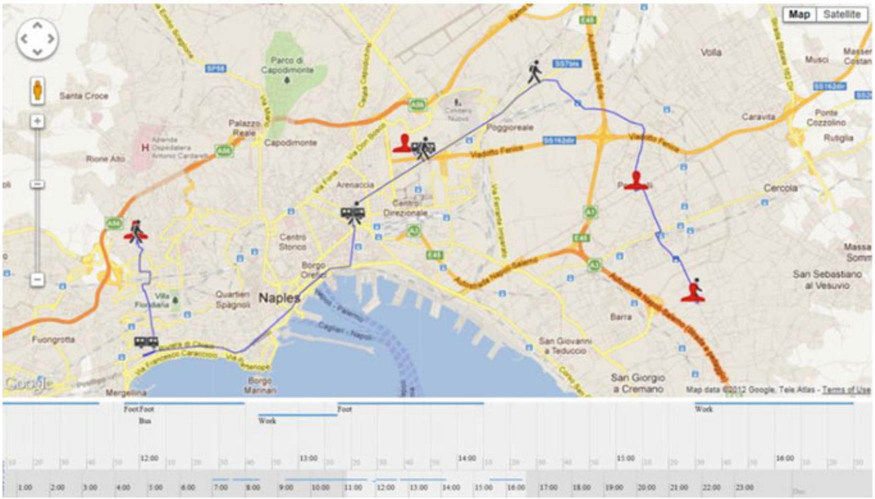

Fig. A.10 Update

Assistance Operations

Query

The query operation may be called by other activity scheduler functions or by the user-interface to display a certain time segment of a calendar (e.g., a whole day travel trace, whole day activity series). Here we assume a case where the inserted activities in Fig. A.5 in appendix are in the current agenda and define the query as:

(1, "activity", 2011-10-05 13:00:00, 2011-10-05 17:00:00)

This query results in the following list of activities:

1. Work, 2011-10-05 13:00:00, 2011-10-05 13:30:00, Naples 14.342, 40.864
2. Work, 2011-10-05 15:30:00, 2011-10-05 16:30:00, Naples 14.34, 40.84

A query for travel episodes follows a same process. The simultaneous activity travel episodes can be easily obtained by ordering the combination list of activities and travels.

Indicate

Assume we have the activity data table related to user with ID 1. The indicate function performs an aggregation of the activities in the activity table and calculates the frequency of each unique activity specification in the table (for the person considered). This function can help the user in finding the most preferred attribute specification (e.g., location) for a particular activity or saving the effort of specifying all attributes of a newly planned activity from scratch. As an example of

Table A.1 Activities in activity table

Id	Type	Start_time	End_time	Location_name	x	y	Companion	Note
1	Shopping	10/5/11 18:45	10/5/11 19:15	Naples	14.25	40.74		
1	Shopping	10/7/11 17:45	10/7/11 18:45	Naples	14.263	40.89		
1	Shopping	10/12/11 18:30	10/12/11 19:15	Naples	14.25	40.74		
1	Work	10/3/11 8:45	10/3/11 16:45	Naples	14.272	40.866		
1	Work	10/4/11 8:45	10/4/11 16:45	Naples	14.272	40.866		
1	Work	10/5/11 8:45	10/5/11 16:45	Naples	14.272	40.866		
1	Work	10/6/11 9:15	10/6/11 16:45	Naples	14.272	40.866		
1	Work	10/7/11 8:45	10/7/11 16:45	Naples	14.272	40.866		
1	Work	10/10/11 8:45	10/10/11 16:45	Naples	14.272	40.866		
1	Work	10/11/11 8:45	10/11/11 16:45	Naples	14.272	40.866		

this function, Table A.1 in appendix shows the activity table (of the person) and Table A.2 in appendix shows the result of the indicate operation on this table. In this case, the template and requested attribute are both empty. This means that the filter let all activities pass through and in fact only frequencies are calculated for the profiles that are present.

Dynamic Operations

Recommending Locations

There are four test cases for the recommend function. We assume the location type as "42", which is shopping center. The first case illustrates the recommendation of locations from a specific point. We specify this recommendation request as:

("A", "", 14.3, 40.84, 3, "42", 2011-09-05 12:00:00, 2011-09-05 13:00:00, 10, "foot, bike train")

where recommend type is A (recommend from user specific location); the origin position is defined by coordinates (14.3, 40.86), the maximum distance is specified as 3 km, location type is "42" (shopping center), the time window is from 2011-09-05 12:00:00 to 2011-09-05 13:00:00, available transport modes are specified as "foot, bike, train" and the planned activity duration is 10 min. We obtain one recommended location as a response:

1. Mercatodue, 14.301, 40.8444

The second case we consider is about recommending locations for an activity where there is a later activity in the agenda. Assume the later activity has the value:

(1, "Work", 2011-10-05 18:30:00, 2011-10-05 19:00:00, "Naples", 14.33, 40.84, "", "")

We set the recommendation request as:

("B", laterActivity, 5, "42", 2011-09-05 12:00:00, 10, "foot, bike train")

Table A.2 Activity pattern

Id	Type	Day of week	Start time	Duration	Location_name	x	y	Companion	Frequency
1	Work	1	7:00–9:00	>360	Naples	40.866	14.272		2
1	Work	2	7:00–9:00	>360	Naples	40.866	14.272		2
1	Work	3	7:00–9:00	>360	Naples	40.866	14.272		1
1	Work	4	7:00–9:00	>360	Naples	40.866	14.272		1
1	Work	5	7:00–9:00	>360	Naples	40.866	14.272		1
1	Shopping	3	17:00–19:00	30–60	Naples	40.74	14.25		2
1	Shopping	5	13:00–17:00	60–120	Naples	40.89	14.263		1

where recommend type is B (recommend where there is a later activity in the agenda), the variable name of the later activity is laterActivity, the maximum distance to later activity is 5 km, location type is "42" (shopping center), the begin time of the time window is 2011-09-05 12:00:00, the end time of time window is the begin time of the later activity—2011-09-05 18:30:00; the duration of the activity is 10 min and the available transport modes are specified with "foot, bike, train". Now we get the following recommended locations:

1. Le Ginestre, 14.349, 40.8742
2. Sedicicasa, 14.3472, 40.8742
3. Il Borgo, 14.3079, 40.8734

The third case we consider is about recommending locations for an activity where there is already an earlier activity. Assume the earlier activity has the value:

(1, "Work", 2011-10-05 09:30:00, 2011-10-05 10:30:00, "Naples", 14.216, 40.85, "", "").

We set the recommendation request as:

("C", earlierActivity, 2, "42", 2011-09-05 12:00:00, 10, "foot, bike train")

where recommend type is C (recommend where there is an earlier activity in agenda) and other fields are defined similarly as before. In this case, we get the following recommended locations:

1. Epomeo, 14.2074, 40.8441
2. Galleria Scarlatti, 14.23, 40.8437

The last case we consider concerns a recommendation request for an activity where there is both an earlier and a later activity. Assume the earlier activity has the value

(1, "Work", 2011-10-05 09:30:00, 2011-10-05 10:30:00, "Naples", 14.216, 40.85, "", "")

and the later activity:

(1, "Work", 2011-10-05 18:30:00, 2011-10-05 19:00:00, "Naples", 14.33, 40.84, "", "") The recommendation request is specified as:

("D", earlierActivity, laterActivity, 4, 9, "42", 10, "foot, bike train", "foot, bike, train")

Where recommend type is D (recommend where there are an earlier activity and a later activity in agenda) and other fields are defined in a similar way as before. This time we get the recommended locations:

1. Galleria Scarlatti, 14.23, 40.8437
2. Galleria Umberto I, 14.2499, 40.8385

Detect Deviations from Schedule

The distance-based deviation detection function returns the deviation between a current actual position and scheduled position. To illustrate this, we assume here again that the activities described in Fig. 11 in appendix populate the agenda. Assume the current clock time is 2011-10-05 8:15:00 and the current position is (14.252, 40.865). We receive the response that the deviation between the current actual position and the scheduled position at this time moment is 900 m (to be precise: 898.6 m). Thus the person receives the message that he is 900 m away from the place where he had planned to be.

On the other hand, the time-based deviation detection function returns the time between the earliest possible arrival time at a next destination and the planned start time of the activity at the destination. Here again we assume that the agenda contains the activities specified in Fig. 11 in appendix. Assume the current clock time is 2011-10-05 14:00:00 and the current position is (14.3, 40.83). We receive the response that the expected arrival time is 40 min later than the planned arrival time (to be precise: 2261 s later).

The real-time event detection function returns a judgment whether a current real-time event will affect the current schedule of a user. Again, we assume here the activities described in Fig. 11 in appendix are in the agenda. Assume that the following bus arrival event:

(event, bus, 2257810, 14.240268, 40.833, arrive, 8874)

with a scheduled arrival time of 8:10:00 experiences a delay and will arrive at 8:15:00. The real-time detection function discovers that this event affects the schedule of the person considered and sends a 'confirmed' message which can be further handled to send an alert to the person that the bus has a delay.

Finally, we illustrate the POI location detection function. This function identifies and returns the locations of a pre-defined type that are within a certain distance from the current position of a user. Assume the type is "42" (shopping center), the current location is (14.23, 40.84) and the search distance is 5 km. Upon this request, the POI-detection function returns the locations:

1. Epomeo, 40.8441, 14.2074
2. Galleria Scarlatti, 40.8437, 14.23

3. Galleria Umberto I, 40.8385, 14.2499
4. Epomeo, 40.8476, 14.1912
5. Sanpaolo, 40.836, 14.1906

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Map-Based Storytelling Tool for Real-World Walking Tour

Min Lu and Masatoshi Arikawa

Abstract Paper route maps are common for tools assisting walking tours, but they are not so kind to readers. Some commercial mobile applications for walking tours are available; it is difficult in manual operation for maps. There are fewer frameworks to integrate multiple hand-drawing well-designed maps with GPS and other digital content such as photographs and audios. In this paper, we proposed a new framework for supporting walking tours with stories and maps implemented on a smartphone. The main purpose of the tool is easiness for operating the device and for finding and acquiring necessary information. Design method of map-based storytelling allows users to smoothly interact with mobile devices with location-based pull style information service. We discuss the feasibility and usefulness of our proposed framework by implementing real mobile software and testing real applications in the real world.

Keywords Location-based pull style information service · Storytelling · User interface

1 Introduction

As the development of technologies in the field of geo-information processing become an impact to the traditional way of conveying cartographic information, more and more researchers realized the gap between cartographic theories and

M. Lu (✉) · M. Arikawa
Center for Spatial Information Science, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, Chiba 277-8568, Japan
e-mail: lu@csis.u-tokyo.ac.jp

M. Arikawa
e-mail: arikawa@csis.u-tokyo.ac.jp

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increasing technological possibilities. New methods and applications of mappings integrating the latest technologies of communication, positioning, data processing and imaging within multimedia vehicles are developing quickly in recent years. As the products like Web mappings and car navigation systems become common in the daily life, more researchers and companies are concerning about pedestrians and walkers.

Different from researches on pedestrian navigation applications, which concern about more precise positioning, indoor positioning and pedestrian path planning, researches on walking tour assistant concern more about representing maps and location-related information of a well-designed existing route from more friendly interactive methods (Hauthal and Burghardt 2012; Bortenschlager et al. 2010).

Audio guide devices and services have been used for many years in parks and museums. This kind of special device is designed for just one particular destination. User must rent and carry the special device when touring. The cost of manufacturing such devices and maintaining such services is not reasonable. As a result, it is not common.

Many researches have been done trying to integrate GPS positioning and and multimedia functions on mobile phones to provide location-based tour guide services. Some researches focus on tour planning with existing map data, POIs and current GPS position (Bao et al. 2009). Another trend is concerning more about frameworks and technologies of user-generated tour guide contents and experience sharing in touring (Suh et al. 2009). Audio tour guide using common mobile handset with map is also discussed (Tsuruoka and Arikawa 2008).

Except for the prototypes created by researchers, there also have been some applications on Apple's App Store or Android Market Place that support walking tours. Some of the applications focus on one place of interest, and provide detailed, high quality maps and related multimedia introductions. Some of them provide more general information about the places to visit in a town or a city. For example, a transportation company in Japan names Odakyu, which is organizing walking tours, provides an application for the participants on the platform of Google Android (Odakyu Electric Railway Co., Ltd. 2012). This application can browse the briefing introductions of the excursions and show the course on Google Maps. Some others provide maps of famous area for tourists, which also include hand-drawing maps (Takahashi 2010).

Walking is a daily activity of people for relax and keeping healthy. Nowadays there is a boom in Japan that people are fond of hiking or walking excursions organized by transportation companies, local communities and organizations (Figs. 1 and 2). These excursions are usually designed and organized very well. Participants can gain knowledge of the places, explore history, and know the society and culture of a local area more deeply. It is comfortable and good for health. The organizers usually have good relationships with local companies, museums, shops and communities. Attracting people to visit is also one of the main purposes.

There are two types of walking tours in general. Some of them have a particular date and time to hold, participants need registration beforehand, and check both at the start and goal. Map of the walking tour is delivered at the start. In addition,

Fig. 1 Examples of a route map for walking tour provided by Odakyu Electric Railway (Odakyu Electric Railway Co., Ltd. 2012). The *left* figure shows an interface to choose conditions of information retrieval. The *middle* one shows information about a point of interest. The *right* one shows a route map with pieces of points of interest

Fig. 2 Scenes of walking tours in Tokyo, Japan. The *left* picture shows participants waiting for the registration of a walking tour event provided by JR East. The *right* picture shows a scene of students' trying a map-based audio tour at a campus of Aoyama Gakuin University

there are some marks and staff to indicate the right way in some difficult place. Participants need to get to the start and goal in time, to get some small prize or memento. This kind of walking tour is sometimes charged. Some others do not have a particular date to hold. The companies or organizations only provide the well-designed courses and the maps are delivered in public place like railway stations and on the Web, but they do not raise any events. The participants can enjoy the courses freely as they like.

The paper route maps provided for the walking tours usually include routes from the start to the goal, and the interesting places to visit along the route.

In some well-designed maps, they also include some additional information to help the participants to go along the right way, such as the detailed maps of route in intersections, landmarks of the places you have to make turns or go up and down the stairs. Some of the maps also include short introductions of the places to visit. Some even include coupons or advertisements.

The paper route maps are, however, easily damaged by strong wind, heavy rain and even folding by the participants. The space for the map is limited to the size of paper. It is a challenge between putting as much information as possible and making the map clear and easy to read. This point is the same to the guidebooks for the travellers, but guidebooks can use multiple pages to introduce one place.

Currently, high performance handsets such as smartphones provide us more possibilities to solve the problems. With the colorful screen, large storage space, multimedia and positioning function, a smartphone can present a route map and its corresponding information more attractively and flexibly. Current Web mapping API is often used in map-based or location-based mobile applications. The maps they provided are usually generic and consistent. These global maps usually contains much useful information for various purpose, but sometimes become difficult to read and redundant for some specific purpose, such as guiding the way and telling stories during an excursion.

In this paper, we propose a framework of designing story-centric mapping using *picture maps* and *hand drawings map* as well as photographs, texts and audios to implement good mobile applications to enhance the participants' experiences of the walking tours, and for making contents efficiently for these applications. Also, a new style geotagging function called *POI-based inter-georeference* for both digital content and its components such as hand-drawing maps, photographs, texts and audios will be presented. This function enable location-based pull style information services, that is, automatic provision of choosing buttons relevant to current positions.

2 Storytelling and Map

Humans gain experience and knowledge from the real world as well as from each other. People use various vehicles for conveying information to others, such as stories, maps, slideshows, interactive visualizations, and so on. People gain new knowledge from these media, at the base of connecting to their existing knowledge, experience and current circumstance. The new knowledge will enhance their behaviors and relationships with the society and natural world.

Story is made of a sequence of events. The events in one story are usually not isolated. There must be some relations between those events, which make their meaning easier to be understood more deeply. These relations are varies, e.g. spatial, temporal, causal ones and so on, and are as important as the events in a story. Story is a comfortable way of acquiring knowledge, because within these relations we extend our knowledge step by step continuously.

Map is an important and useful vehicle for conveying spatial related information. However, conventional maps are not efficient in learning knowledge from them by ordinary people who are not well trained to read maps. These maps are usually too large sets of static symbols. This kind of maps is not efficient to be used and applied to our daily life. One reason is that they have weak relations with people's existing knowledge and within the symbols in the maps.

When appreciating stories with maps, readers are able to aware where the events in the story happen and learn the context such as distance, area, position relation, environment and so on. So maps can make it easier to imagine the situation, and then understandings can be deeper. Maps are often used in history textbook, historical novels and even fantasy novels.

Maps with event positions, time labels, lines and arrows of movement and changing borders are often used in books to tell stories. These maps contain stories. Nowadays, texts, audios, pictures and videos that are related to a story can be geocoded and tagged to the map. When readers visit the real places in stories, the multimedia story maps can help them to connect the stories to the existing places, and enhance their experience of the stories and the real world.

Emphasis, ellipsis and overstatement are often used in stories to make richer imagination. Similarly, an art map is usually distorted, inconsistent and not precise, but more acceptable, attractive and useful to users. In designing a story-based map, chapters, sequence, emphasis, decorations and simplifications should be used to make it more impressive and helpful.

2.1 Consistent and Inconsistent Maps

Current Web mappings usually use consistent maps. Consistent maps (Fig. 3a) are accurate and precise, more close to the real world. They are easy to locate positions if we know coordinates of longitude and latitude. However, with presenting every feature in the same scale, they sometimes lose emphasis on really important things for a particular purpose. Within the limited space of the screen of smartphones, users cannot easily browse both details and surroundings of a place at the same while. As a result, it can be difficult for ordinary users to get useful information from these maps in a short time. They are more like detailed report forms, but not stories.

Inconsistent maps (Fig. 3b) are often used in daily lives, from tourist maps to advertise materials, and even hand drawing maps. In this kind of map, features are not in the same scale, and are often stretched or rotated in parts, and quite different from the real world. These maps are "wrong", but usually easier for ordinary people to understand and good at appearance. These maps usually emphasize important buildings and areas but omit others, and the scale of the emphasized area is sometimes larger than that of the others in the same map. Streets and roads are often made vertical and horizontal, although they are curving in the real world. So the maps are often rotated and distorted. They focus on location relationships and connectivity, but care less about real size and distance. The distortion we are

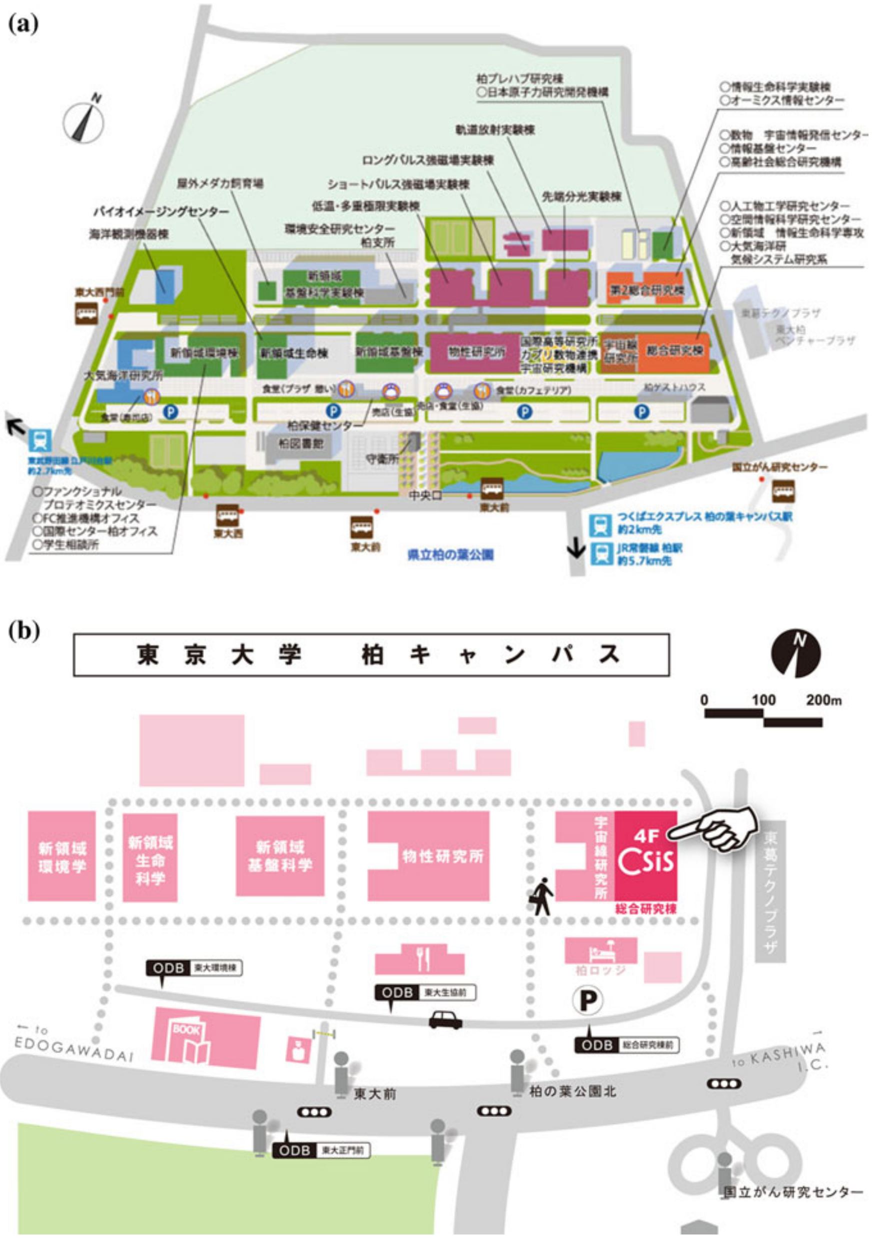

Fig. 3 Consistent map and inconsistent map. (**a**) is an example of a consistent map with accurate positions and shapes. On the other hand, (**b**) is one of an inconsistent map with inaccurate positions and shapes because directions and lengths of graphic components are created under constraints of graphic design to provide good-looking appearance and to allow users to quickly and efficiently acquire significant information from the map. [The maps (**a**) and (**b**) are provided by Kashiwa Campus and Center for Spatial Information Science of the University of Tokyo, respectively]

discussing is different from that caused by map projections, but more about map generalization and map authors' intentions.

Well-designed inconsistent maps can help users understand their meaning at only a glance, because they fit human's knowledge acquisition processes. When we learn a new thing, first we find the differences and connections to the things we have already known, and then we find order and relationships. Measuring of size and distance usually comes last. Simplification, omitting and generalization are always happening in our brains.

However, inconsistent maps are not good for positioning because the irregular distortings bring much difficulties for geocoding. In our research, we use *picture maps* or *hand drawing maps* which are usually easy to get but are often inconsistent maps. We will provide a simple solution called *POI-based inter-georeference* of positioning in these maps.

3 Framework of Map-Based Storytelling

The concept of map-based storytelling we want to propose here basicly contains three meanings. The first meaning is telling a story with map. Listeners are able to aware where the events in the story happen and learn the context with the help of map, and understand it more deeply. The second meaning is that maps contains stories. Texts, audios, pictures and videos that are related to the story are geocoded and tagged to the map. When listeners visit the places in the real world, the map can help them to connect the stories to the existing places, and enhance their experience of the stories and the real world. The third meaning is map itself is designed like a story which has chapters, sequence, emphasis, details and simplifications.

3.1 Basic Elements

We provide two basic event elements to maps, in order to make stories.

1. Point event:

Point event is usually a place of interest for people to visit and gain knowledge. It include or have links to information related to the location. Texts, pictures, audios and videos can be used to represent related information, such as historical photos, old maps, photos in different seasons, movie clips, audio records of legends, text introductions, and so on.

Point event can also be an important point on the route such as start, goal, intersection, folk point and so on. For such a point, there can be a detailed map or photo of the street, with arrows to indicate the right way to go.

2. Line event:

Line event is usually a way to move alone, connect one point the next, and often has a direction to follow. Line event can contain introductions of the connection of the two point events, for example the guidance of the way. It can also link to other related information, like introduction of the surrounding area.

A relatively large and enclosing place can be represented by a nest of points as well as lines, and can be abstract to a point in small-scale views.

With the two basic elements, we can design a story and locate it to maps by make several point and line events and make them a sequence.

3.2 Basic Structure: Stage

If a story is long, the author often divides it into several chapters. We also divide a long story in maps into parts, and we call every part a *stage*. The principles of dividing of a story to stages may be various, which usually depends on the designer's purposes, for example, for users to browse the contents more easily or to understand more deeply. Anyway, a stage should be relatively complete, contain several point and line events, and there must be connections to other stages with point events. The scales of stages in the same story may not be the same, one stage can be a big park or just one building.

With dividing the story to stages, we form a layered structure to organize maps and related data as shown in Fig. 4. Multimedia contents are related to different layers to provide information in different scales.

Detailed maps are needed for each stage, but not necessary for the whole story. Within the limits of screen sizes of smartphones, we want to make a balance between detailedness and the size of the map. We believe that frequent operations of zoom in, zoom out and pan are not friendly to users. In one stage, we ignore the areas not related to the route, and also ignore other stages' information, so that we can reduce the redundance and help users to get focus. With this approach, we can also make use of various existing maps, such as guide maps of parks, temples and museums. Fig. 5 shows an instance of dividing a story to stages.

Connections of neighbouring stages are important, which are actually starts and goals of these stages. A content maker should indicate clearly the way to next stage and the start point of a new stage. With achieving the subgoals one by one, participants can experience the route and story step by step, which make the understanding firmer and deeper.

4 Positioning Using Inconsistent Maps

4.1 Algorithm

An inconsistent map is distorted, with rotating, stretching or shrinking in different area of the map. In our application, we do not need very precise positioning all over

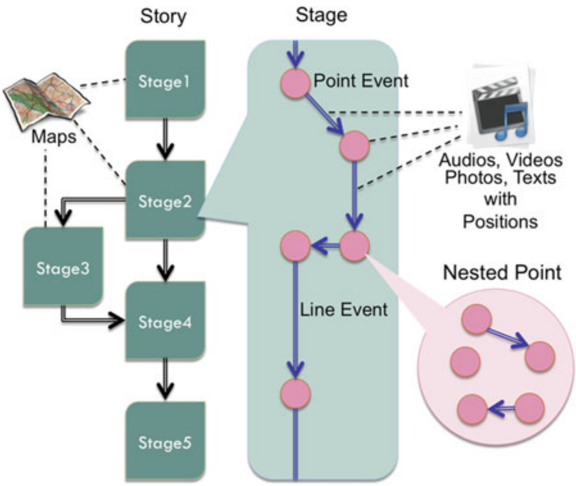

Fig. 4 A structure for representing a *map-based story* based on stages and feature events

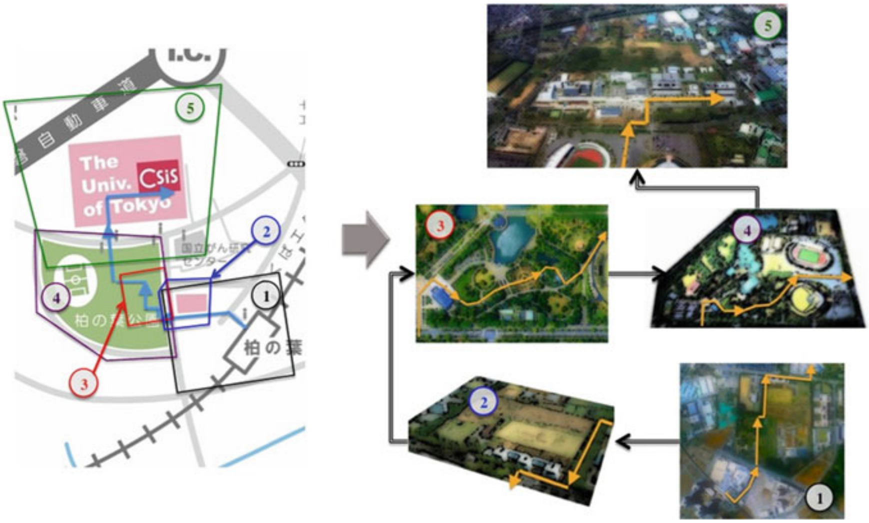

Fig. 5 Instance of dividing a story to stages. Maps of different types and scales are used for stages in the same story. Stage 1, 2 and 4 are mainly about moving from one place of interest to the next, so the maps focus on the detail of the route and the sightseeing spots along the route, and simplified other parts. Stage 3 and 5 are places for touring, stage 3 is a Japanese garden in a park. So the maps are more detailed and larger scaled for these stages. [The map on left was produced based on the map (**b**) of Fig. 11. The maps on right are produced from aerial photos provided by Kashiwa Campus of the University of Tokyo]

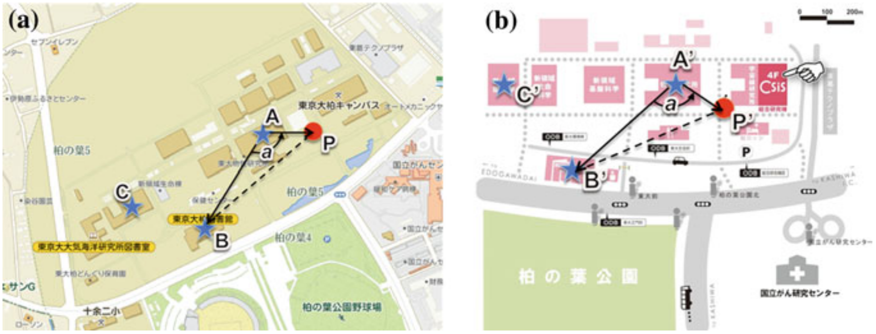

Fig. 6 Positioning in an inconsistent map. (The base map on *left* is provided by ZENRIN Co., Ltd. The base map on the *right* is provided by Center for spatial information science, the University of Tokyo.) (**a**) Consistent map as the real world (**b**) Inconsistent map

the map. What we concern is positioning along the route and near the POI, which can be very helpful for users to find where they are and where to go. Usually, we may have several point events (POI) tagged to the map alone the route, which are supposed to have coordinates of longitude and latitude and also coordinates in the map image. We can make use of these coordinates to make an easy solution of positioning in calculating the position relations between current GPS coordinates and the nearest point events, which is called *POI-based inter-georeference*.

In Fig. 6, A, B and C are POIs. We know their precise longitude and latitude and also coordinates on the image (b) as A', B' and C'. Now we get a GPS position P, we want to get its coordinates P' on the map image. The main steps of the algorithm is outlined as follows:

1. Calculate distances from each point event in the map to P and find the nearest 2 points;
2. Suppose A and B are the nearest 2 points to current position P. Calculate the rotate angle α from vector AB to AP, and the proportion of the length of the 2 vectors $k = |AP|/|AB|$;
3. Triangle ABP and A'B'P' should be similar. We rotate the vector A'B' with center A' and angle α, and then we find P' along the new vector to make $|A'P'|/|A'B'| = k$.

4.2 Error Analysis

This method is easy to implement and does not need extra reference points except existing POIs. However, the method may be not precise, it depends on many facts, for example, accuracy of coordinates of the POIs, the distances to current position and so on. For inconsistent maps, the most important factor that affect the accuracy of the algorithm is the distortion, which will be discussed as follows:

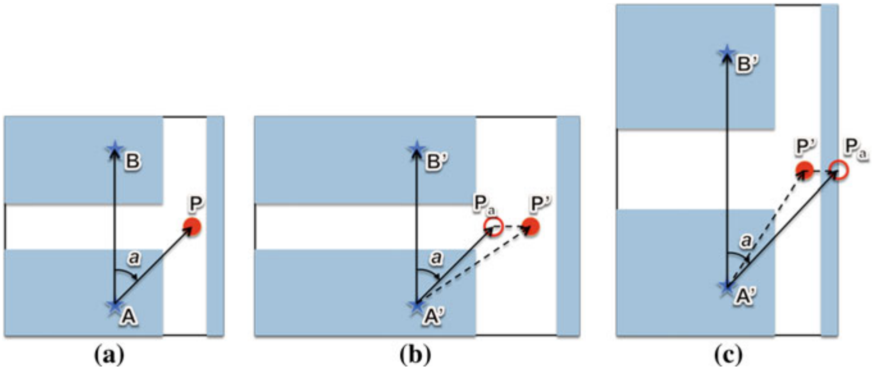

Fig. 7 Error caused by the algorithm in a stretched map. Because of stretching, the rotate angle from vector A'B' to A'P' is changed. In the algorithm, we still keep the same rotate angle, and locate the position at P_a, which causes the error. (**a**) Original map (**b**) Stretched *horizontally* by 40 % (**c**) Stretched *vertically* by 40 %

1. Rotation: the accuracy only depends on the coordinates' accuracy, and not depends on the algorithm.
2. Stretching: the accuracy may be affected, as shown in Fig. 7. According to the map, the original current point P should be at the position P' in the stretched maps, but the algorithm will get the result at the point P_a. We did some analysis about the error caused by the algorithm when the map was stretched vertically or horizontally. The analysis did not consider about the error caused by other facts like the position of point events. The results are shown in Fig. 8. We can find when the map is more strongly stretched, the error caused by the algorithm become more serious, and it is more accurate if the position is near the vector.

For the applications of our framework, the point events are usually along the route, and the user's position is also usually along the route. That means the users' positions are usually not far away from those vectors from one point event to the next. So the effect of stretching may be acceptable.

3. Inconsistent scales in different areas: the situation can become more complex, and error may also become bigger, as shown in Fig. 9. Generally speaking, when the number of POI is more, the density becomes bigger, and there would be less chances for the situation as the above to happen, and the accuracy can become better.

5 Implementation

Based on the framework above, we implemented a prototype with Apple's iOS platform on iPhone. We realized main functions of browsing maps and multimedia contents, which are organized as stages. We also made some contents for the App,

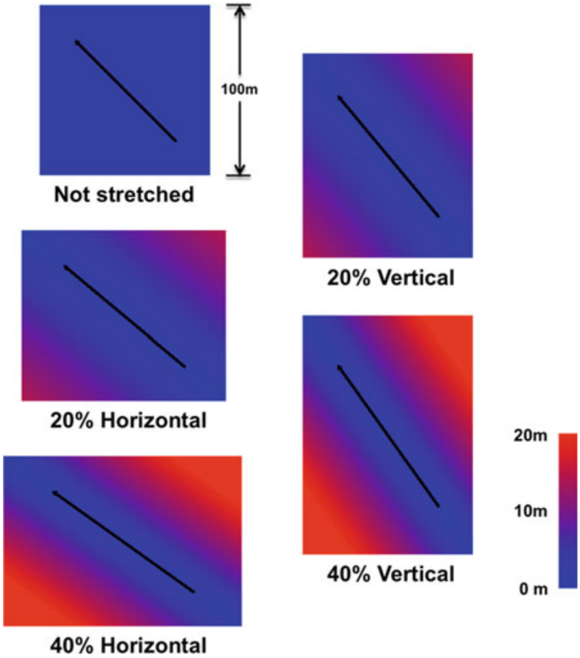

Fig. 8 Error analysis around the vector

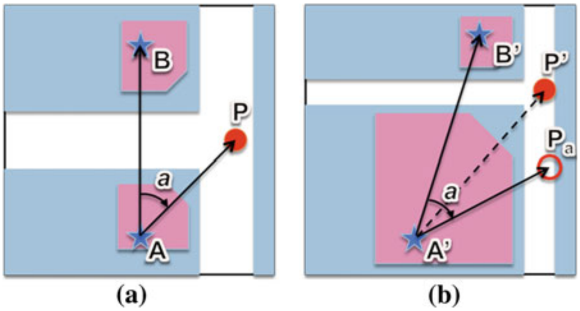

Fig. 9 Error caused by the algorithm when scale is inconsistent in the map. In (**b**), the area near A is emphasized and the scale is larger then other parts as where B is located. According to the algorithm, the position will be located at P_a. (**a**) Consistent scale (**b**) Inconsistent scale

and have tested them when we took part in the walking tours around Tokyo. Figures 10 and 11 shows the structure and user interface of the prototype with contents. Details are explained with the figures as follows.

5.1 Maps and Stories in Prototype

The form of the map can be various: generic map, tourist map, satellite map, floor map, so long as they can meet the needs. The maps can be found easily on Internet or even from scanning of paper maps. We have developed basic map browsing

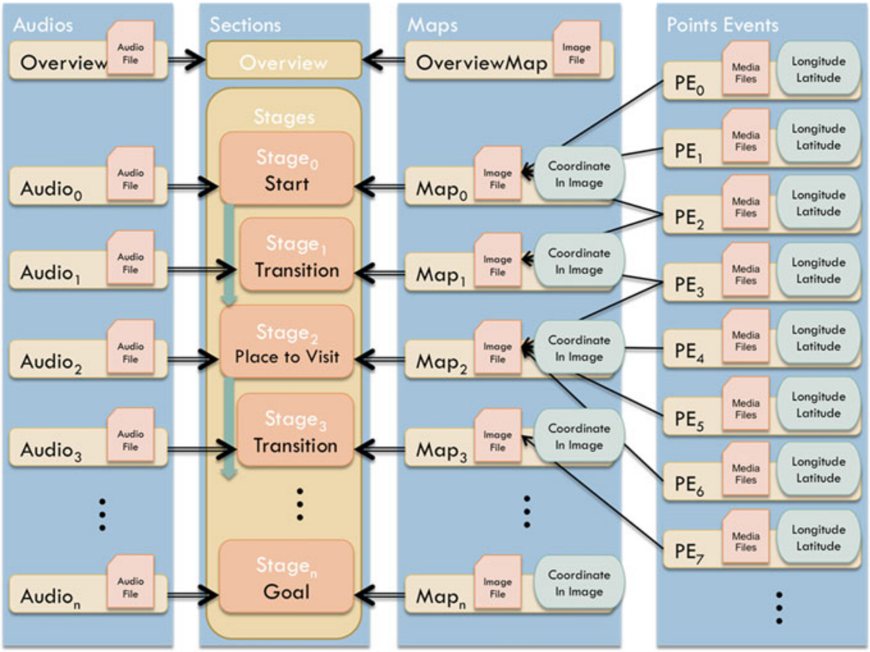

Fig. 10 Data structure of the prototype. There is an overview stage for the browse the outline of the excursion, and the following is the sequence of stages in detail. Every stage has at least one map in form of image file, and multimedia content files are linked to the map. Arrays of POIs that have GPS coordinates are tagged to the maps. Coordinates POIs in the map images are also recorded on each stage, for displaying and positioning

functions like pan, zoom in and zoom out, using buttons and gestures. Some lines and arrows are added to the map to indicate the route. Point events are displayed on the map, and have the coordinates of longitude and latitude on the real world. They link to texts, photos and audios, and can be accessed by pushing the button on the map view or the list view.

In the example showed in Fig. 11, we have made content for the walking route showed in Fig. 5, which is from a railway station to our campus through a park.

When users are walking in the tour, they can browse and appreciate contents on every stage in sequence. They can listen to the audio tours while walking, check their positions and the route on maps, and browse the photos or video of a point event when they get close. In the example showed in Fig. 11, we provide many photos of good views and audios of introductions of the area and also famous places.

User's current position is showed on the map using GPS of iPhone and the positioning algorithm we discussed above. Trajectory also can be recorded and showed to help users finding their way. When user's position is detected to be close to the point event, some prompt will automatically be pushed to user by highlighted and blinking button, as well as alert sound. It would be easier for users to find and access the contents related to nearest point event and appreciate related

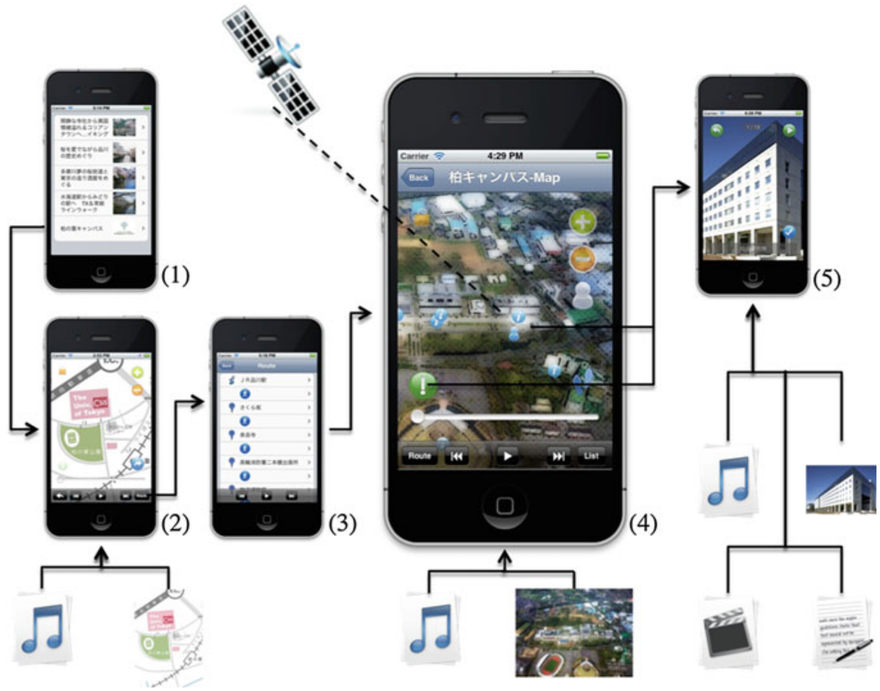

Fig. 11 User interface and structure of the prototype. (*1*) is a list of walking tour courses that available in the prototype; (*2*) shows the overview of one of the courses, in which we see all the stages briefly on the map and listen to the introduction of the course; (*3*) shows a list of stages in the course in sequence; (*4*) shows the view browsing one stages with an inconsistent map, audio tour of different categories is available; current GPS position and positions of point and line events are showed on the map; when user's position is close to some events, the green button in the left bottom will be enabled and link to the related contents; (*5*) is a view for browsing the contents of an event, including pictures, audios, movies, and texts. The map content is provided by Kashiwa Campus of the University of Tokyo

contents with the surrounding atmosphere. This function is also useful for guiding the way. For example, when users are near an intersection, a photo of the crossroad with arrows is shown to help them find the right way.

Figure 12 shows an other example using a walking tour map of Kawagoe City in Saitama Prefecture, Japan, provided by SEIBU Railway Co., LTD. We can find the user's position and footprints, and also the prompt button of the highlighted POI which is near the user.

5.2 Text and Audio

In our prototype, audio is a very important vehicle to tell story as well as to guide the way. During the way of walking, our eyes are busy in finding the way,

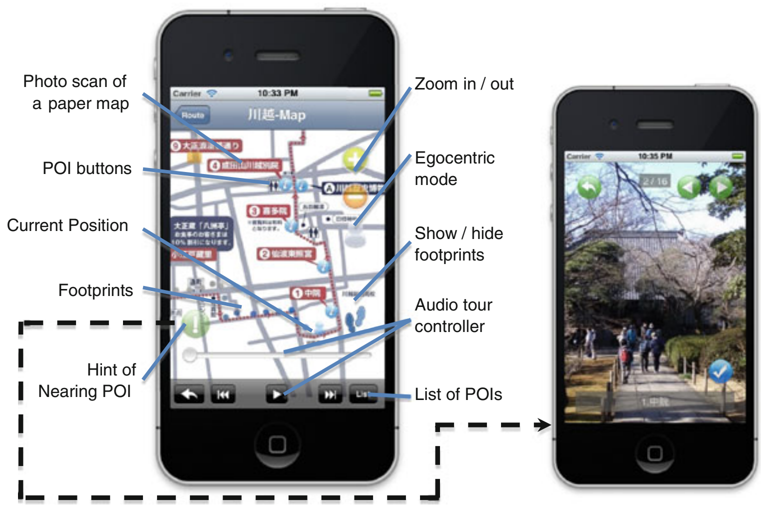

Fig. 12 Main interface of the prototype. The map is provided as a paper map by SEIBU Railway Co., Ltd. for a walking tour event around center of Kawagoe area, Saitama Prefecture in Japan on May 6th, 2012. The number of participants is about two thousands. We have created a location-based service on iPhone using the paper map of Kawagoe as a base map and experienced on the same time

watching the cars and experience the surroundings. Reading text while is uncomfortable and also dangerous. Listening to the related stories while watch a historical building, or listening to an introduction of the town while walking on the street, is a much more comfortable way.

Audio contents can be various. Some are linked to point events, while some are related to the stage. So the access points of these audios are different. We can provide contents of different categories for users to choose. When users get close to some point event with audio content, they can choose to interrupt in the point's content and return to the previous one they were listening.

Recording audio content is a difficult job. In the prototype, we tried to use a high quality voice generate engine produced by Toshiba (2012) to make it more easily.

6 Concluding Remarks

Commercial Web mappings become popular on mobile services, but most people are going to think that maps are commodity and almost free, but not art works. Also, maps are considered there are not various. Thus, diversity of maps is decreasing now on the Internet. On the other hand, diversity of maps is increasing in paper guide books for tour such as designed for ladies, for town walking, for exploring history, for personal preference like fashion and food, and for bicycle riders in Japan. LBS for tours is also getting popular in Japan, but most of them are just extensions of electronic books of paper guide book which can be referred to through location information using commercial Web mappings and GPS (Shobunsha 2012, JTB 2012). They are usually delivered as supplemental content with commercial paper guide books. Maps included in the guide books are well-designed, but they are provided as part of electronic books which cannot be used as part of LBS. Because it is difficult to make profit from LBS in the field of tour business, only simple maps as commercial Web mappings are used.

The reason why many people buy well-designed guide books in Japan is to easily and efficiently gain good experience through their real-world tours. One of the most important factors of maps in the guide books is easiness to image good experience of future tours from the book using well-designed photographs and route maps. The guide books are created using human-centered and story-centered design. Maps are also designed for activating users' imaging for their future tours, and are decorated for attracting people. Some of maps can be considered as art-works created by map artists.

We proposed a new framework of designing, implementing, and testing storytelling with multiple inconsistent maps for mobile applications. As the result of testing our developed mobile application, we have found that users could use them more naturally and more easily, because multiple maps used in the applications are prepared for each stages, which have inherent cartographic properties such as scale and screen size. We insisted in less use of zooming and panning functions for user interface of our applications. Stage concept enables natural browsing digital content in the real world. Also, our proposed POI-based inter-georeference function is useful to provide users most relevant menus for invoking maps, photographs, texts, and audios depending on the current positions of users using positioning functions of smartphones. We will apply the framework of map-based storytelling to more complex tour, mobile learning, and edutainment in the future.

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A 3D Indoor Routing Service with 2D Visualization Based on the Multi-Layered Space-Event Model

Andreas Donaubauer, Florian Straub, Nadia Panchaud and Claude Vessaz

Abstract In this chapter the draft for a novel conceptual model for indoor navigation, the multi layered space-event model (MLSM), is combined with existing standards for Geo Web Services in order to define a framework for a 3D indoor routing service with rule-based 2D visualization. We prove that the MLSM in the test scenarios we defined can be used as a conceptual model for an indoor routing service. With the help of a prototype we also show that the MLSM needs some extensions if a 3D MLSM graph shall be visualized in 2D. Our case scenarios and visualization examples are based on an existing Building Information Model (BIM) of a specific building.

Keywords 3D · Indoor routing · Standards · OpenLS · GML · Visualization · Multi-layered space-event model

A. Donaubauer (✉)
Technische Universität München, Arcisstraße 21 80333 Munich, Germany
e-mail: andreas.donaubauer@tum.de

F. Straub · N. Panchaud · C. Vessaz
Eidgenössische Technische Universität Zürich, Wolfgang-Pauli-Strasse 15 8093 Zurich, Switzerland
e-mail: straubf@ethz.ch

N. Panchaud
e-mail: nadiap@student.ethz.ch

C. Vessaz
e-mail: c.vessaz@gmail.com

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1 Introduction

Driven by the positiong capabilities of a new class of mobile devices like smartphones it is quite common to use such devices for outdoor navigation. A lot of effort is put into indoor positioning research and development at the moment in order to allow for seamless indoor-outdoor applications. Indoor routing as a possible application in this context differs from outdoor routing not only by the required positioning method. Also the requirements regarding the conceptual model of the data behind a routing application differs.

In this chapter the draft for a novel conceptual model for indoor navigation, the multi-layered space-event model (MLSM), is combined with existing standards for Geo Web Services in order to define a framework for a 3D indoor routing service with 2D visualization. The following research questions will be discussed:

1. To which extent do current standards for routing service protocols meet indoor routing requirements?
2. Which additional information is needed in order to account for rule-based 2D visualization based on the 3D nature of MLSM?
3. Can these rules be described using existing standards like Styled Layer Descriptor/Symbology Encoding (SLD)?
4. How can simple and useful symbols, pictograms and route instructions for 2D indoor routing look like?
5. How can a system architecture of an indoor routing framework based on loosely coupled services look like?

The remainder of the chapter is structured as follows: First, we give an overview of the standards including the MLSM draft and point out related work in the field of indoor route visualization. We then define a conceptual model of a 3D indoor routing service with 2D visualization including extensions of the OpenLS protocol and the MLSM schema. Based on a prototypical implementation, we prove the feasibility of our concept. Finally, we conclude on our research questions and raise some open issues.

2 Related Work

This section gives an overview of the foundations our work is based on. First we give a short introduction to the interface standards we adapted for our service, namely the OpenGIS Location Services Interface Standards (OpenLS) and the visualization standards Web Map Service (WMS), Styled Layer Descriptor (SLD) and Symbology Encoding (SE). Next we introduce the Multi-Layered Space-event Model (MLSM) which provides a conceptual framework for 3D indoor navigation. The section ends with a brief summary of visualization theory for indoor environments.

2.1 OpenGIS Location Services Interface Standards (OpenLS)

The OpenLS standard defines several Web service interfaces in the context of location based services. The standard describes five core services: "Directory Service", "Gateway Service", "Location Utility Service", "Presentation Service" and "Route Service" (Open Geospatial Consortium Inc. 2008). For each of the service interfaces, a request and a response schema is defined. OpenLS is designed for any kind of location services but there is no special focus on indoor application requirements.

Most important for our approach is the Route Service which allows a client application to request routing information by defining a start and end location for a desired route with optional parameters like waypoints along the route and route preferences. The location of start and end point can be defined in different ways. By default, the route service allows to define the location by address, Point of Interest, coordinates or a custom location type.

In addition to a route service, an indoor routing application needs to provide visualizations of the route. The OpenLS standard therefore defines a Presentation Service. The service interface allows to render geographic information for display on a mobile terminal directly from the service that calculates the route (no transfer format needed between different services with different standards). The interface also allows to display a background map as with a GetMap request from a Web Map Service and to generate multiple maps within one request and additional content to be displayed can be chosen quite flexibly by the client. Some extensions have been made to the OpenLS, Symbology Encoding and Styled Layer Descriptor standards to support 3D routing and visualization (Neis and Zipf 2008). However, both the interface standards and the extensions are still highly focused on outdoor environments.

2.2 WMS and Related Standards

Our concept uses the Web Map Service (WMS) from the Open Geospatial Consortium as rendering engine and visualization service both for the background map and the routing graph and instructions. WMS is defined as a standard that "specifies the behavior of a service that produces spatially referenced maps dynamically from geographic information" (Open Geospatial Consortium Inc. 2006b, p. 6).

The most interesting capabilities of WMS regarding our approach come from its possibility to be combined with the Styled Layer Descriptor (SLD), Symbology Encoding (SE) and Filter Encoding (FE) standards. This combination allows to realize loosely coupled WMS instances which serve as rendering engines for geospatial data provided at run-time by other services in a service chain. For this purpose, the Styled Layer Descriptor standard specifies so called User Layers which allow for integrating the geospatial data to be rendered into the map request at run-time (Open Geospatial Consortium Inc. 2007). Additionally the Symbology Encoding specifies a map-styling language for producing georeferenced maps with user-defined styling (Open Geospatial Consortium Inc. 2006a). The Symbology Encoding complements the Styled Layer Descriptor standard by using different kinds of Symbolizers to apply colors, shape, orientation, symbols etc., to features on the map. The Filter Encoding standard describes an XML and KVP (key-value pair) encoding of a system neutral syntax for expressing projections, selection and sorting clauses collectively called a query expression (Open Geospatial Consortium Inc. 2010a). Regarding the service chain in our approach the Filter Encoding standard is used by the WMS for extracting relevant information from the routing service response. We apply the Symbology Encoding standard for defining the symbology and annotations for visualizing the routing graph.

2.3 Multi-Layered Space-Event Model

The main idea of the Multi-Layered Space-event Model (MLSM) (Open Geospatial Consortium Inc. 2010b) is "the clear separation of different space models, such as topographic space, sensor space and logical space" and "this approach allows for the decomposition of a specific space into smaller units according to respective semantics, without influencing other space representation" (Open Geospatial Consortium Inc. 2010b, p. 67). The different space models are called layers. Each layer is divided into a geometry space and a topology space in the so called primal space. To obtain the topological graph within the so called dual space, a transformation based on the Poincaré duality (Munkres 1984) is applied, transforming 3D cells in primal topological space into nodes in dual space. The connections between these cells are mapped as edge between two nodes. In the topological space the nodes are called states and the edges are called transitions. The MLSM also defines how to connect different layers and derive so called joint states of navigation which "can be utilized to enable localization and route planning strategies" (Open Geospatial Consortium Inc. 2010b, p. 23). Examples of layers are topography layer, sensor layer, opening hours layer (a logical layer). For the encoding of data structured according to the MLSM conceptual schema, IndoorGML, a Geography Markup Language (GML) application schema is defined. Regarding our approach the MLSM had to be extended in order to fulfill the requirements of 2D visualization.

2.4 Visualization Theory

Several authors identify common basic characteristics of visualization systems for indoor navigation. The two main characteristics often mentioned in the literature are the display of the current location of the user on a map and the calculation and display of a route to a specific goal (Open Geospatial Consortium Inc. 2010b; Inoue et al. 2008; Hagedorn et al. 2009). All other more complex requirements found in the literature can be linked to these two basic ones. However, it is worth to mention the following: guidance along the route, update of the route according to changes in the network conditions and display of the information in different forms and details. Furthermore, the ability for the user to set multiple starts, ways and end points and to look up previous plans is mentioned as advanced settings (Smith et al. 2004).

Concerning the visualization itself, several authors advocate a simple and intuitive graphic user interface for a better ease of use and for a facilitated knowledge construction (Agrawala and Stolte 2001; Buxton 2002; Jones et al. 2009). The concept less-is-more fosters a user-centered design of geo-visualization applications: “Tools developed specially for the task at hand, which consider the human aspects of the interactions, are more likely to lead to useful and usable application” (Jones et al. 2009, p. 1081). Examinations of the relevant information, the complexity of the system, the tasks, the skills and limitations of the users along with the properties of the device help to reach this user-centered point of view while following the less-is-more concept (Jones et al. 2009; Hagedorn et al. 2009). A significant number of papers talk about 3D visualization and how to deal with walls obstructing the user’s view and how to display more information related to 3D visualization (Schilling and Geotz 2010; Kim et al. 2009; Open Geospatial Consortium Inc. 2009; Hagedorn et al. 2009). Optional indoor structures are defined based on requirements and uses of a product. Often the visualization does not encompass the walls to avoid blocking the view of the user and thus hindering the orientation and navigation tasks. Another option is to make the building structure transparent or to clip a horizontal cross section (Schilling and Geotz 2010). It shows that, for most uses, a 3D representation is too complex and that there is a gain in cognitive processing, usability and orientation to simplify the 3D space, either to a reduced 3D representation or to a 2D representation. The problem of deciding which built features of the environment to represent is here avoided by using a 2D representation.

Regarding the implementation of these visualization concepts, a study on indoor mobile navigation systems in commercial facilities which was conducted in Japan (Inoue et al. 2008) is worth looking at. It includes a 2D view floor by floor, a navigation view with pictures of the mall and some additional thematic information about the destination (mostly shops). The navigation system was designed for smart phones. It additionally also displays complex navigation instructions on the way. One conclusion from this study is that written navigation instructions such as left and right are not always well interpreted because of orientation mismatch between the map orientation and the orientation of the person in the real world. However, they are not useless when well and timely used.

In context of our visualization approach we decided to follow a 2D representation with minimal background information and minimal written user instructions.

3 Conceptual Model of a 3D Indoor Routing Service with 2D Visualization

3.1 Requirements

As mentioned in the introduction, the requirements for indoor routing services are different from outdoor routing services, being well defined in (Open Geospatial Consortium Inc. 2010b). Furthermore, it is to point out that indoor route calculation is not working in two dimensions. Different floors in a building with vertical connections like stairs or elevators make it necessary to build a 3D graph to calculate efficient and valid routes. In addition to the requirements defined by (Open Geospatial Consortium Inc. 2010b) such as support for different modes of locomotion, logical navigation constraints, reaction to dynamic events and compatibility with existing 3D building models including the ability to create subspaces from existing models, the requirements for our conceptual model of an indoor routing service and indoor route visualization are as follows:

The **Routing Service** needs to have the following capabilities: The internal data structure must support 3D geometry and topology. Additionally the service must be able to split the routing graph floor by floor (see requirements for the visualization service below). For interoperability reasons, the service protocol shall be based on existing standards. As the routing graph shall be visualized using an SLD-WMS as rendering engine, the transfer format must be defined by a valid GML application schema. Additionally the service must support an addressing scheme for internal buildings which includes identifiers for rooms, floors, elevators etc.

As mentioned in the related work section the **visualization** should be in 2D. Furthermore it should be based on the simplified blueprints of the building, displayed floor by floor. To help users to lower the workload of reading the map and simultaneously orient themselves, simple and intuitively recognizable symbols should be used. The background plan has to show, if possible, the basic spaces of the floor, such as rooms, corridors and doors. The route should be displayed as a set of nodes and edges, the nodes being different locations in space and the edges the links between those. Nodes serve different purposes. They can be a start or end point of the graph (terminal node), a crossing of more than two hallways (decision node) or a change of direction at a corner (corner node) (Karimi and Ghafourian 2010). For this project, there is a need for a specific decision node indicating a change of floor. These points are crucial because the visualization only displays one floor at a time. Thus, these nodes are not only important for the user, but also for the application and the selection of the data displayed. The attributes of these nodes have to provide the information of the current floor, the next floor to be displayed and the number of floors between. Breaking down the 3D graphs to the 2D environment and displaying the floors one after another is the main challenge. The user has to be able to see the route overlapping the blueprints background and this floor, by floor, requiring that both nodes and edges have an attribute indicating the floor they belong to. For each floor, there is a path with a node at each end. The floor indication should be visible at all time to avoid misreading of the map. The end point and the starting point should be clearly differentiated by means of color and symbols. Ideally, the end node attribute would contain the room number of the destination as a means of confirmation for the user once he or she gets there. Some basic instructions will help the users at the decision points, such as at elevators and stairs. Instructions about the destination floor and the floor difference would help the users not to get lost on the wrong floor.

Our conceptual model which fulfills these requirements and which is based on existing standards for Geo Web Services as mentioned in the related work section therefore consists of the three elements "routing service protocol", "visualization service" and a "common conceptual schema of the routing graph" as core element. A common conceptual schema of the routing graph is required because in our service-chaining-based approach the response part of the routing service protocol must be understandable by the visualization service.

3.2 Conceptual Schema of the Routing Graph: Extension of the Multi-Layered Space-Event Model

For our approach, the Multi-layered Space-Event Model (MLSM) (see related work section), which is used to model the space and calculate the route, needs to be extended in order to allow its 2D visualization. The extensions to the original model serves the visualization, by adding attributes to existing classes. They make the depiction of thematic information, such as floor, mode of transfer and type of node, possible at the visualization stage. These attributes allow to filter the different features of the route according to the floor criteria and node type. The *State* and *Transition* features are the link with the original model (see Open Geospatial Consortium Inc. 2010b). In detail the following extensions to the original model have been made (see Fig. 1).

A new class *TransferState2d* extending the MLSM class *State* has been defined. The new class contains all the attributes which are needed for discriminating between nodes in the 2D visualization. The *instructionClassifier* gives the instructions to be displayed, telling the user to change floor, to exit the building and when he reaches his or her destination. Depending on the uses, the building and the project, they can easily be changed and extended to give more information along the route if necessary. The *stateTypeClassifier* gives information about the kind of node, allowing to differentiate nodes visually. The *transferTypeClassifier* says whether stairs, elevator, escalator or ramp are used to change floor, which is also used for the representation. The new class *TranferGraph* which is a composition of *State* and *Transition* objects has been introduced in order to aggregate nodes and edges of the graph at the floor level. This was necessary in order to fulfill the requirement of a 2D floor by floor representation of the routing graph. Analogous to the extension of the conceptual schema, the IndoorGML encoding has been extended.

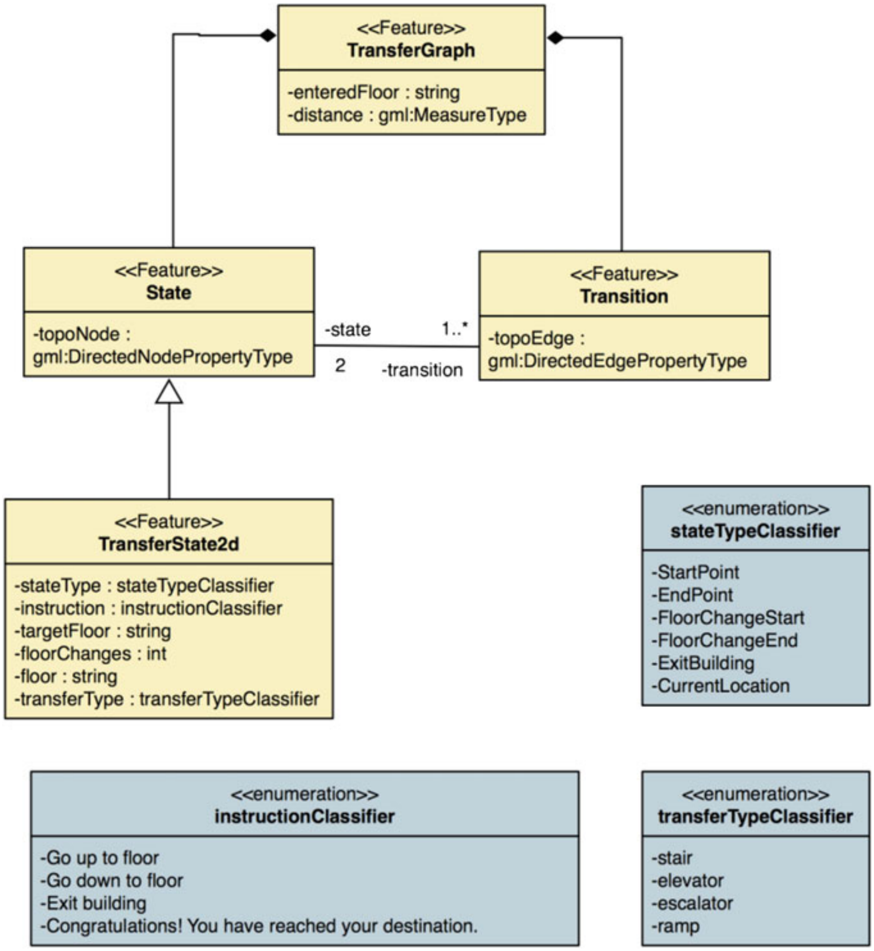


Fig. 1 Extensions to the MLSM

3.3 Routing Service Protocol

Regarding the routing service protocol the following standards have to be extended in order to fulfill the requirements described above.

With respect to the request format, the OpenLS Route Service interface provides a well-defined schema to send routing requests. However, the request is not designed with focus to the options provided by MLSM, thus there is no possibility to select layers or types of locomotion. For this reason, the schema (see Fig. 2) is extended with a class called "DetermineIndoorRouteRequest" which is a specialization of "DeterminRouteRequest" and includes an attribute for specifying a

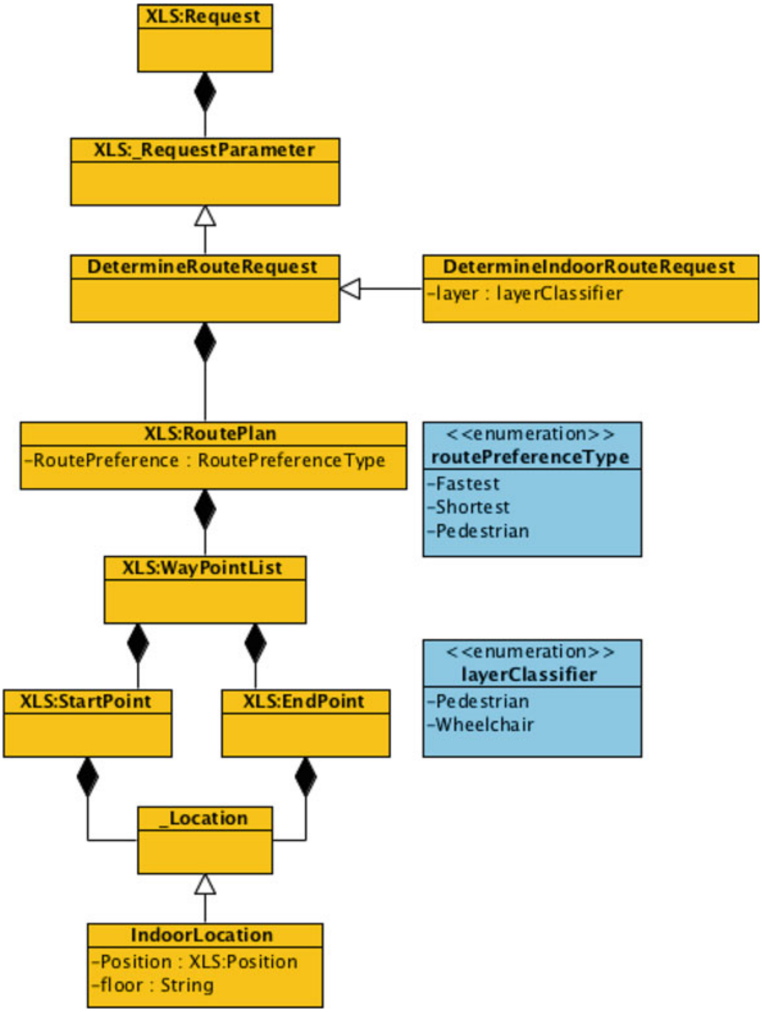


Fig. 2 Extended OpenLS route request

layer as defined by the MLSM (see related work section). The associated enumeration "layerClassifier" contains the layer names and has to be adapted to the supported layers of different implementations. Furthermore, the location type "IndoorLocation" has been introduced in order to model the concept "floor" which is not provided by the standard.

The extended IndoorGML encoding as described above is used for the response part of the routing service protocol.

3.4 Visualization Service

The interest of using web-based visualization for indoor routing graph lies in the need for orientation in complex, mainly public, buildings such as administration complexes, universities and hospitals. Being web-based allows to access the navigation system with smartphones without any application or plugin. Because the visualization aims at being smartphone-compatible, the size and format of the service response is important, especially regarding speed and readability on a small screen.

Going from 3D to 2D may not seem complicated, but regarding an indoor space, the crucial question is how to deal with floors in a 2D space? It was chosen to display the floors one by one to solve this problem. The routing service calculates the route based on the 3D model of the building and then the graph is split and rendered floor by floor by the visualization service. The idea is to use instructions and symbols to tell the users to change floor and how many floors up or down they have to go. Whenever a floor is entered, the corresponding map will be requested from the visualization service, either manually by the user or automatically in case the user's position is known by the application.

For the background map, the 2D blueprints display the structure of the building including walls, stairs and elevators as well as significant indoor landmarks.

Our symbolization and visualization concept is based on the less-is-more approach (Jones et al. 2009) and on the different aspects of a building's route network, such as choice points and directional changes (Hölscher et al. 2006). The choice or decision points are here defined as the points with specific meaning not only to the users, but also to the successful visualization of the path. These points can be starting point, ending point and floor change point for instance.

For these reasons, simple, intuitive and universal symbols have been designed (see Fig. 3). The pictograms for elevator and stairs are easily recognizable and understandable because they are found at many locations, such as in airports and museums. They are adapted from the AIGA symbol signs collection, which comprises 50 standard symbols to be used on signs "in airports and other transportation hubs and at large international events" (AIGA 2011). For the elevator, an arrow shows the direction of the movement and the stairs follow the direction of reading, thus giving the impression they go up or down. The symbols used for the starting and ending points and the current location are simpler than the pictograms, first, because their meaning is simpler and second, because the requirements ask for simple symbols. The colors for the symbols are inspired by the colors of GoogleMaps.

In order to integrate these symbols and pictograms into the visualization service, they have to be described in an machine interpretable way and also machine interpretable rules have to be created which control the transformation from the routing graph encoded according to the common conceptual schema (see Fig. 1) into a visual representation of the graph. Figure 4 shows the decision flow diagram used to assign the symbols. First, the right floor is selected using the corresponding

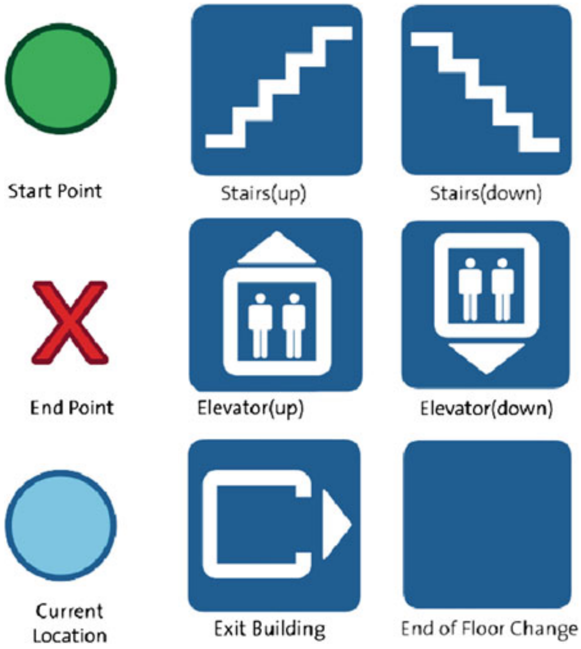


Fig. 3 Symbols and pictograms

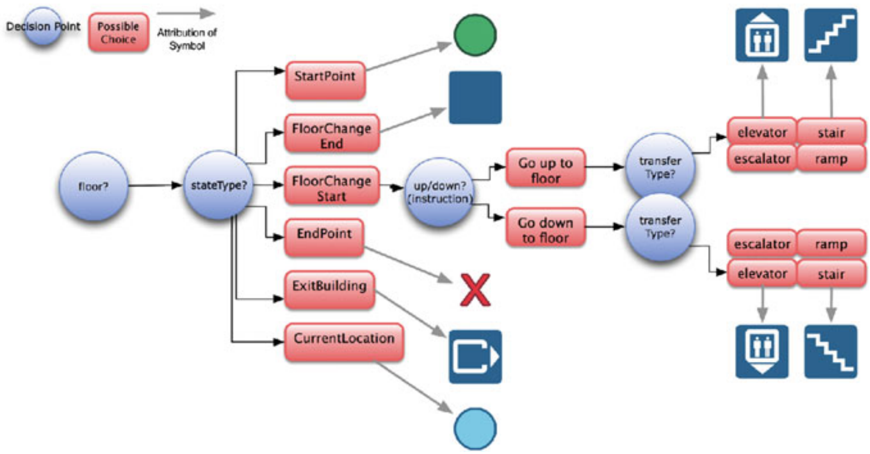


Fig. 4 Rule-based visualization of the routing graph

attribute of the class *TransferGraph*, then the *stateType* attribute of the class *TransferState2d* allows to select the function of the node. The symbol can be applied right away, for the following node functions: starting point, the ending point, the current location, the end of a floor change and exiting the building.

However, when a floor change is required, the decision flow keeps on because there are different types of floor change, specified by the *transferType* attribute of the class *TransferState2d*.

Additionally to the symbols, there are also labels used to give instructions and further information about floor changes. The attribute "instruction" is used for the display of the label for exiting the building and upon reaching destination. For the floor changes, the attributes *instruction* and *targetFloor* of the class *TransferState2d* are used.

We use the WMS service and its styling capabilities as a rendering engine for the indoor routing graphs generated and provided by the routing service. The background maps are static and are therefore stored as *NamedLayer*, with their attributed *NamedStyle*, whereas the layers containing the routing graphs are generated on the fly by the routing service and thus have to be integrated inline within a WMS GetMap-request, as well as their styling parameters under a *UserStyle*. The *UserStyles* are used to filter features of the routing graph and apply symbols and labels to them. The symbols can be stored on the server or also included inline within the request. The formal, machine interpretable description of the symbols and instructions as well rules therefore are corresponding SE and SLD documents.

4 Implementation and Test of a Prototype

The following section describes a prototypical implementation of our concept and some tests which will prove the feasibility of the concept.

4.1 System Architecture

The prototype follows a classic three-tier-architecture (see Fig. 5). On the persistence tier the 2D background maps are stored as shape files and the 3D routing graph is stored in an ORACLE database the schema of which was derived from the MLSM conceptual schema. The middle tier consists of two independent Web services, the visualization service which was implemented using GeoServer and the routing service, realized as a Java Servlet which uses the ORACLE Spatial 11 g NetworkManager package for 3D route calculation. On the client tier a simple Web browser can be used. All components are loosely coupled and standardized communication protocols are applied.

A complete service chain based on this architecture implies the following steps: First of all, the client application sends a routing request encoded according to our extension of the OpenLS protocol to the routing service. The routing service then calculates the route based on the 3D graph stored in the ORACLE database and sends the result back to the client. The response is encoded according to our extension of the MLSM (a GML 3.2.1 application schema). Next, this document is

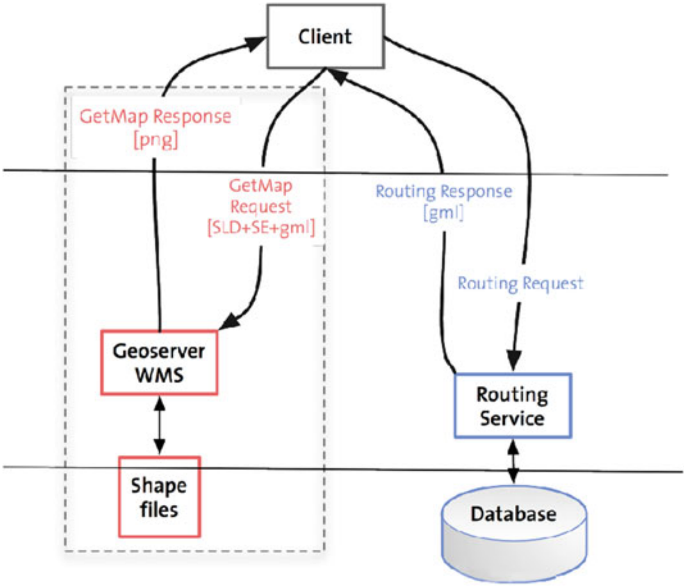


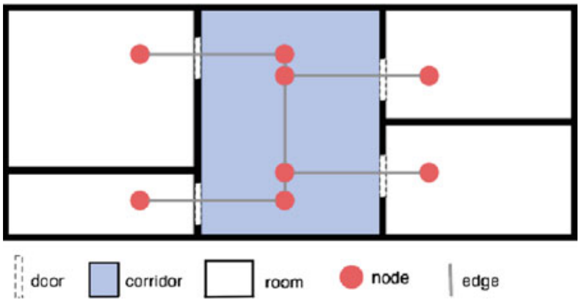
Fig. 5 System architecture of the prototype

received by the client and forwarded as inline-feature in a GetMap request to GeoServer as our rendering engine. The version of GeoServer used for this prototype is 2.0.2 and it supports the version 1.1.1 of WMS. This means that GML 2.1.2 instead of GML 3.2.1 is supported. The latest versions of SE and SLD are not supported either and thus the version 1.0.0 of SLD, without SE, is supported. Concerning FE, it is the same problem, the version supported is the 1.0.0. As a consequence, the latest versions of the standards could not be used. However, the main functions needed for the prototype are already available in previous versions of the standards and it only requires some adaptations. To cope with the different GML versions, the routing service response has to be transformed to be read by GeoServer, thus an XSLT transformation is performed by the client before the GetMap request can be built. GeoServer parses the GetMap request, renders the routing graph on top of the background map and sends back the response to the browser, which displays it as a complete map of a specific floor (see Fig. 7).

4.2 Case Scenarios and Examples of Visualization

Based on a 3D model of a building at ETH Zurich modeled by (Sidler 2010) which exists both as a Builing Information Model (BIM) and a CityGML data set several case scenarios were developed to test the service. A semantic translation between the 3D building data and the MLSM in order to derive a 3D routing network has been carried out and proved to be feasible. However, further questions related to

Fig. 6 Nodes resulting from the sub spacing strategy applied



data acquisition are out of scope of this paper. With regard to the MLSM one layer representing topographic space was modelled. The following subspacing strategy was applied in order to divide corridors into smaller units: Each door which connects the corridor to another room implies the creation of a new subspace which results in a new node in the dual representation. However, each room (excluding corridors) is represented by only one node, no matter how many doors it has (see Fig. 6).

Case scenario 1 describes a simple change of location on the same floor. Case scenario 2, and respectively 3, describe one change of floor with the elevator or the stairs respectively. Scenarios 2 und 3 involve a path on the first floor, a change of floor and then a path on the second floor. Scenario 4, and respectively 5, describe two floor changes, with an intermediate stop on a third floor. It comprises a path on each floor concerned and two floor changes with the elevator or with the stairs respectively. Scenario 6 describes a path where the user has to exit the building. The following example (see Fig. 7) shows the response of the rendering engine for case scenario 3. The path goes from floor D to floor C, where the hypothetical user reaches his or her goal.

A few map features are to be noticed. A label shows at all time which floor the map depicts to avoid any confusion from the users. To implement that label, a fictive point in the upper left corner was defined with an SE TextSymbolizer. Each floor has a different color to help differentiate them further. By the node where one has to change floor, the label shows the means (stairs or elevator) and the direction (up or down), while the instruction tells the users to which floor to go. Additionally, the users know how many floors down or up the change represents. By the ending node, a congratulation message is displayed.

5 Conclusions and Future Work

With the prototype of the 3D routing service with 2D visualization, it is proved that the MLSM in the test scenarios we defined can be used as a conceptual model for an indoor routing service. But it also clearly shows that the MLSM needs some extensions if a 3D MLSM graph shall be visualized in 2D.

Fig. 7 Responses of the rendering engine for case scenario 3

The prototype showed that a rule-based visualization of an indoor route using Styled Layer Descriptor/Symbology Encoding and simple pictograms and instructions on a 2D web-based map is feasible and useful. Styled Layer Descriptor and Symbology Encoding offer a wide range of possibilities to symbolize and apply style to geographic features, that are inline or stored on the server. Building rules for different applications of the symbols is a flexible process that can lead to complex conditions with Filter Encoding. These standards bring enough adaptability and visualization options to satisfy for a 2D visualization of indoor routing graphs. The instructions additionally help the users to reach the right floor and not to get lost on the wrong floor. The map is thus a map to read and to look at. There is active interaction between the users and the map and it is not an instructions list of turns that the users have to follow blindly.

The use of standards and being compliant within the all system architecture is crucial to allow interoperability and convenient combination or chaining of different services. In the case of this project, it could allow to combine the routing service with data from outdoor routing services or other indoor routing services for instance or to use different client implementations.

Future work should focus on the following open issues. The prototype in this stage handles the topographic layer only. It does not provide a full multilayer support and positioning based on a 3D model which are both core elements of the MLSM. An algorithm for combining several layers on the fly would have to be realized. Although the calculation of joint states of the multi-layer model is not required at run-time when the joint states and the resulting routing graphs of all possible layer combinations are precalculated, we favor a real-time approach. This is because such an approach would allow to react on events which can hardly be precalculated such as emergency situations. In addition to these technical issues, a user study should be carried out in order to evaluate and improve the usability, especially in the context of symbolization and visualization on small devices which includes the evaluation of the underlying sub spacing approach.

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Adapting OSM-3D to the Mobile World: Challenges and Potentials

Ming Li, Marcus Goetz, Hongchao Fan and Alexander Zipf

Abstract Location-Based-Services (LBS), such as route planning or Point-of-Interest (POI) search are well-known and their consumption is quite common on personal computers. Simultaneously, mobile devices, such as tablets or smart phones, penetrate the market and offer great potentials for sophisticated and advanced LBS. Based on the open and free OSM data, the current project OSM-3D has already demonstrated that such data can be perfectly used for the generation of a 3D virtual globe and for the provision of various 3D-LBS. Trying to merge the phenomenon of 3D-VGI with the increasingly available mobile devices, the here conducted work discusses potentials and challenges arising from a mobile OSM-3D application, and divides the challenges into platform adaptation, physical adaptation and scenario adaptation. For platform adaptation, this chapter selects one very promising technology for adapting OSM-3D to mobile devices by critically evaluating different technologies for the aimed work. For physical adaptation, the here conducted work discusses ideas for fast and apprehensible rendering of 3D objects on mobile devices. Since a good knowledge of context is essential for both physical adaptation and scenario adaptation, the presented framework also incorporates a tailored analysis of the mobile using context of OSM-3D. Thereby, this chapter provides a comprehensive framework and proposal towards a context-aware OSM-3D mobile application.

Keywords 3D geodata · Crowdsourced geodata · Mobile applications · LBS · OpenStreetMap · Volunteered geographic information · Adaptation · Context-awareness

M. Li (✉) · M. Goetz · H. Fan · A. Zipf
Chair of GIScience, Department of Geography, University of Heidelberg,
Berliner Straße 48, 69120 Heidelberg, Germany
e-mail: ming.li@geog.uni-heidelberg.de

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1 Introduction

Thanks to the technological improvement and evolution of mobile devices, such as tablets or smart phones, today's markets offer a wide variety of different so called Location-Based-Services (LBS), which incorporate the location of the user and/or deal with location information. The market and the demand for such applications are likely to increase even further, because people continuously use mobile devices more and more often. Furthermore, the majority of mobile users does not only utilize the integrated functionality, but also use broadband internet connection for the consumption of mobile services. Very impressively, according to ITU (2011), only 10 % of the world's population does not have a mobile phone signal. It seems likely that mobile devices will probably even replace ordinary personal computers, as last year (2011) already more smart-phones and tablets than personal computers have been sold (Cooper 2012). According to Arthur (2011), every fourth mobiles is a smart-phone and it seems as if the tipping point of more than 50 % can be reached in 2012. Furthermore, Google expects that by 2013 (at the latest), the number of search queries from mobile devices will exceed that from PCs (Arthur 2011). However, existing LBS basically stick to a two-dimensional representation. Yet, it has been demonstrated that 3D city models are advantageous for navigation purposes on mobile devices (Coors and Zipf 2007), and Zlatanova and Verbree (2005) also emphasize the actual need for three-dimensional information for LBS.

Regarding the data for such LBS, the last years revealed a new source of open and free to use geo-data, namely Volunteered Geographic Information (VGI). Thereby, both laymen and professionals collaboratively collect and share geo-data in a Web 2.0 community. Whereas in the early beginnings of VGI the users mainly contributed two-dimensional data, in the last few years they also started to collect 3D information, such as height information, roof geometry information etc. Such data can be utilized for the provision of comprehensive and advanced 3D LBS, such as 3D routing and navigation, Point-of-Interest (POI) searching, or simply a 3D virtual model of our globe for browsing and investigating. One of the most mature and advanced examples for the usage of 3D VGI is the OSM-3D project[1]: a virtual globe for visualizing VGI from OpenStreetMap (will be introduced later) as 3D models and providing a variety of services. Furthermore, it is fully based on the standards and drafts of the Open Geospatial Consortium (OGC), such as Web Map Service (WMS), Web3DService (W3DS) and the OpenGIS Location Services (OpenLS). The fundamental ideas, architecture details and processes of OSM-3D are described by Over et al. (2010), Goetz and Zipf (2012a, b), and some relevant details will be given in a later section of this chapter. Within OSM-3D, users can get a better working experience with map services because 3D maps can be easily read and understood by taking advantages of visual similarity with the environment (Aydin et al. 2012).

[1] www.osm-3d.org

Although modern PCs often offer better processing and rendering abilities to deal with massive 3D data, map-based services tend to be more preferred on mobile devices, because such services are mostly demanded when people are outside where a PC is unreachable. There are already several car navigation systems today, but they are mostly based on commercial thus expensive datasets. Therefore, combining OSM-3D and mobile environments raises great potentials, because well-known 3D-LBS based on crowd-sourced data will be consumable on mobile devices. Furthermore, an OSM-3D application could also be used for enriching or enhancing the current OSM data. Since users can orientate themselves and identify the environment better, they can also discover and directly correct the errors or imperfections in the OSM dataset, regarding both geometry and semantics. As an example, a person can easily validate the height of a building, the roof type or textural information, when actually standing in front of the corresponding building and comparing it to the data set in OSM-3D.

The main contribution of this chapter is the discussion and elaboration of challenges and potentials arising from the adaptation of OSM-3D to mobile devices. By evaluating different technical frameworks for the aimed work, elaborating techniques of fast and apprehensible rendering as well as analyzing the mobile using context, this chapter provides a comprehensive framework and proposal towards building a mobile OSM-3D application with context-awareness.

The rest of this chapter is organized as follows: first there is a brief overview about related work on context-aware mobile applications. Thereafter, the OpenStreetMap community is briefly described, followed by a detailed introduction to OSM-3D. Thereafter, the main part of this chapter describes the adaptation of OSM-3D to mobile devices. Dividing the challenges of such an adaptation into platform adaptation, physical adaptation and scenario adaptation, this chapter then discusses the different mobile development frameworks, fast and apprehensible rendering techniques, as well as the using context in the mobile environment. The last chapter then concludes the conducted work and provides an outlook on future research.

2 Related Work

In recent years, a number of map-based applications and services have been made available to users on mobile devices, with a particular emphasis on smart phones. Among others, many location-based services such as route planning and navigation are widely used by a diverse range of users.

Different from the relatively constant using context of the desktop environment, the using context of the mobile environment is more dynamic, diverse and therefore complicated. More specifically, the users' intention and location, the physical surroundings such as illumination or the internet connection are always changing, which will result in different user demands for the mobile services.

Therefore, researchers have performed many investigations in the mobile using context to make their mobile services context-aware.

The earliest integrated definition of context is from Abowd and Dey (1999), who define context as "*any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object*". Based on that, many researchers have created more concrete models of context from different point of view. For example, Reichenbacher (2003) and Dransch (2005) propose models for context based on the activity theory (AT), while Nivala and Sarjakoski (2003) and Sarjakoski and Nivala (2005) study the context based on results of field tests. But they all agree that context should at least contain location, time, user, surroundings and other elements, and these elements are not independent and their significances in different using context are also varying.

To further evaluate the significance of a certain element or the geo-objects in a certain context, the concept of geographic relevance (GR) is raised by Raper (2007) in order to help information seeking in mobile environment. Actually, the concept of GR is an extension of the situational relevance (SR) with a special concern of mobility of geography. Another conceptual model for geographic relevance is given by Reichenbacher et al. (2009) based on activity theory, whereby the "distance" (spatial) is abstracted to a more semantic measurement to evaluate the relevance not only from spatial location but also the semantic distance between the user's activity and the object.

Based on the evaluation of the relevance, researchers have also investigated into the context-adaptation strategy. Zipf (2002) raises a fundamental framework towards building a smart user-centric map services; Reichenbacher (2003) summarizes the adaptable items in the geo-visualization process from categories of geo-information, user interface and visualization respectively; and Zipf (2005) further presents how to utilize the user and context models and generate an adapted mobile maps based on the well-known OGC Styled Layer Descriptor (SLD) specification, just to name a few.

However, such researches are mainly aiming at 2D mobile maps which are mostly applied in the common Location-based services (LBS). In the recent years, mobile 3D environment representations are attaining increasing interest in both academia and industry (e.g. Burigat and Chittaro 2005; Bladauf and Musialski 2010; and others), because 3D representation allows direct matching of visual cues without interpreting and mentally transforming the symbols and two-dimensional shapes of the classical 2D map to the real world environment (Nurminen 2006). Therefore, a context model together with an evaluation of geographic relevance more tailored to 3D environment should be investigated.

With respect to the 3D representation in mobile devices, a lot of challenges remain to be met. On the one hand, despite the rapid development in the last years, distinct physical restrictions of mobile devices (such as small screen size, poor processing capability and unstable internet connection) are still the bottlenecks to deal with complex and large volume of data. On the other hand, as the third dimension brings more geometric and additional semantic information, it increases the workload of the hardware, and meanwhile may impose more complexity and make the map hard to understand. To solve such issues, new techniques of rendering and data structures are required.

A number of approaches have been proposed for the aforementioned challenges. For example, Follin and Bouju (2008) and Wang et al. (2006) adapt mechanism of level of detail for real-time rendering of 3D maps on small displays, while Döllner et al. (2005) promote using non-photorealistic city model for a clearly legible visualization of the real world environment. To achieve efficient up-to-date 3D environment and services, Przybilski et al. (2005) propose to segment 3D maps into cells and designed the techniques to access and download location-specific services related to given map segment, and Nurminen (2006) develops an efficient mobile 3D city map engine to speed up the visualization of realistically textured city models in mobile devices and support the client–server network services.

3 (3D) Crowdsourced Geo-Data from OpenStreetMap

The following section briefly describes one of the most prominent, diverse and rich data sources for VGI, namely OpenStreetMap (OSM). It is divided into two subsections: a short general introduction to OSM and a specific and detailed description of OSM-3D.

3.1 The OpenStreetMap Community

Trying to use the tremendous potential arising from billions of humans acting as remote sensors, and to combine the widespread availability of GPS-enabled devices, such as smart-phones or tablets, with the trend of user-generated content (UGC), a couple of years ago the term Volunteered Geographic Information (VGI) has been described by Goodchild (2007). VGI aims at the collaborative and voluntary collection of geo-referenced data, by both laymen and professionals.

In the author's opinion, one of the most prominent and rich data source for VGI is the OpenStreetMap (OSM) project. Originally aiming at providing a free global map, the project's objective soon turned far beyond that. Today, OSM can be considered as one of the biggest free global database of different kinds of geo-data. Everybody can contribute, alter and improve the data of the OSM database. Initiated in 2004, the project currently profits from more than 500,000 registered users (OSM 2012). Within OSM, the contributors can not only provide geometries, but also additional (semantic) information about different map features by adding so called key-value pairs to an OSM feature (in OSM terminology this is called tagging). Thereby, the key describes some kind of information or information domain and the value refines this information, e.g. *building* = *yes*, *maxspeed* = *30* or *highway* = *residential*. The amount of key-value pairs is unlimited, thus users can add as much information as required.

Therefore, OSM is more than just a global map. This statement is also emphasized by the fact that more and more users collect three-dimensional data such as height information, or 3D-related information such as roof types etc.

3.2 OSM-3D

Trying to generate comprehensive 3D models based on the OSM data, the project OSM-3D has been initiated. Although, according to Goetz and Zipf (2012a, b), there is not yet much 3D-related information available, it seems to be desirable to utilize the existing data for the generation of 3D models. Even if it is not directly available in OSM, the OSM-3D project demonstrates that appealing 3D visualizations can be created from such data sets, and to enhance the quality of this visualization even in spite of the missing data is an interesting research challenge. On the one hand, this demonstrates the power and manifoldness of VGI from OSM, and on the other hand it is likely to motivate and convince the OSM members to contribute further 3D information.

More and more ideas and projects towards a three-dimensional representation of OSM data are currently under discussion and development, such as the OSM2World[2] software and the Kendzi3D plug-in (Kendzi 2011), but the OSM-3D project is one of the most promising and technically advanced projects in this context. Contrary to other approaches, OSM-3D utilizes standards and draft specifications of Open Geospatial Consortium (OGC) and dedicated (java-based) client software, aiming for global coverage in contrast to small regions. The project provides a highly detailed virtual globe which can be investigated by the user in great detail. The current client (namely XNavigator) even features atmospheric visualization effects, as well as different rendering methods (normal, wireframe etc.). Regarding the data, OSM-3D features a comprehensive number of different types of data, ranging over a Digital Terrain Model (based on SRTM), building models, Point-of-Interest (POI), streets, labels, natural areas, trees, lights and so on (Goetz and Zipf 2012b). As an exemplar, Fig. 1 depicts the three-dimensional building model of the Petronas Towers in Kuala Lumpur (left) and an exemplary perspective for Heidelberg, featuring building models, street network, trees, streetlights, natural areas etc. (right).

Also, contrary to other approaches, OSM-3D does not only provide visualization of the globe, but does also integrate different services for the users, such as integration and querying of sensor data, fog simulations and etc. Essentially, there are two useful and well known services which are very relevant for the broad public: (1) Yellow Pages query for distinct Point-of-Interests in a definable area

[2] http://osm2world.org

Fig. 1 Three-dimensional building model of the Petronas Towers in Kuala Lumpur (*left*) and an exemplary perspective for Heidelberg (*right*) in OSM-3D

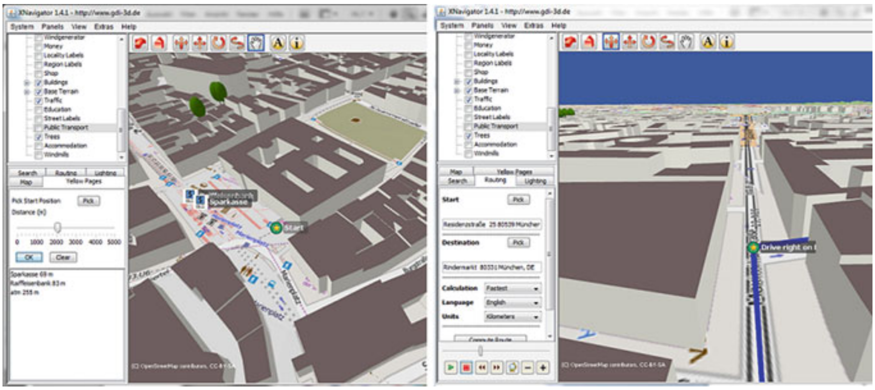

Fig. 2 Yellow Page search for an ATM (*left*) and 3D routing (*right*) in XNavigator/OSM-3D

around a distinct point and (2) three-dimensional route computation for vehicles and/or pedestrians. Figure 2 depicts an exemplary query for ATMs within 2,000 m around the Marienplatz in Munich (left) as well as an exemplary route from *Residenzstraße 25* to *Rindermarkt* in Munich (right).

The Yellow Page service functions as follows: the user can pick an arbitrary location in the 3D environment and define the search radius for the POI search. Thereafter, the user defines what kind of POI should be searched, such as hotel, motel, coffee shop, ATM etc. The service then performs the POI search and visualizes all possible POIs in the 3D scene. Meanwhile, the three-dimensional route computation functions as follows: a user can define an arbitrary start and destination point, either by entering the corresponding address or location in the corresponding forms (currently only for Europe), or by picking the desired location in the 3D scene. In the former case, a Geo-coder decodes the address into longitude and latitude information, whereby in the latter case the geo-coordinates are directly retrieved from the scene. There are furthermore different options available for the route computation, such as *shortest route*, *fastest route*, *pedestrian* or *bicycle*. After computing the route (which is done by an OGC Open Location Service, OpenLS), the route—if available—is visualized in 3D in the scene. Routing instructions, such as turns, are additionally depicted as icons with text. The user can then individually explore the route from any desired location, or use the fly-mode, which will automatically pre-ride the route.

4 Adaptation to Mobile Devices

OSM-3D is currently only consumable via personal computers, either via the Java application XNavigator or the webpage with a Java plug-in. However, especially for the previously described services, an application for OSM-3D on mobile devices is very desirable. Having such an application, the user will be allowed to compute and consume three-dimensional routes as well as perform Yellow Page POI searches while actually being on-site. Of course, by integrating the user's current location (via GPS etc.), those services could be perfectly tailored to the user's context. However, in order to bring it to the mobile world, we are facing a series of challenges. This section therefore aims at emphasizing the arising challenges and offering some possible solutions for adapting OSM-3D to mobile devices.

4.1 Challenges Towards Bringing OSM-3D to Mobile Devices

In this subsection, we will elaborate the numerous challenges we are facing when trying to adapt the OSM-3D to the mobile devices. In general, these adaptation challenges can be divided into three aspects, i.e.: platform adaptation, physical adaptation and scenario adaptation, as depicted in Fig. 3.

For the platform adaptation, the challenges are more technical and mainly caused by the differences between computer platform and mobile platform. Typical challenges in this aspect include:

- A dedicated development framework for mobile app, because Java, the framework adopted in the current desktop client of OSM-3D (XNavigator), is resource consumable and not directly suitable for the mobile platform;
- Eligible 3D graphics techniques tailored to the mobile devices, because the 3D techniques adopted in the current client is Java3D together with VRML (but also e.g. KML, X3D are supported by convertors), which are out-of-date and not supported in modern mobile device.

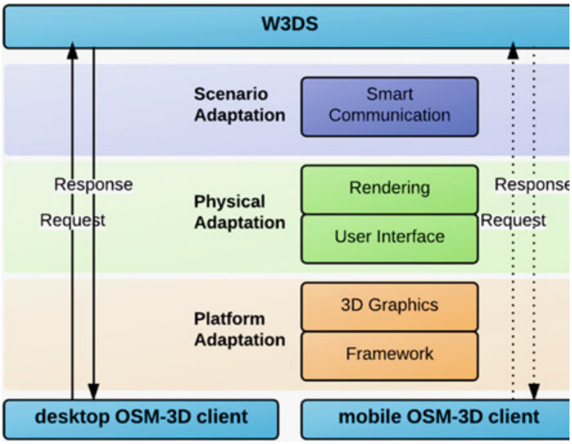

Fig. 3 Challenges raised by different platform and different context

Within this chapter, we will focus on the first challenge in the second sub-section of this chapter; that is, to compare a series of mobile development framework and offer a promising solution.

For the physical adaptation, the challenges are mainly imposed by the physical restrictions/characteristics of mobile devices, such as their smaller display sizes, poorer processing capabilities, unstable internet connections, and also their special way of interaction. Typical challenges in this aspect include:

- A new user interface specifically designed for mobile screens, because otherwise too dense information on small screens will make the map very hard to read. The different way of interaction should also be taken into consideration when designing a new user interface;
- Fast and apprehensible rendering, because on the one hand, the future users would demand the service to be fast and apprehensible as they would typically follow other tasks (such as walking or driving) rather than just focusing on their devices and reading maps; on the other hand, the processing capability of mobile devices are limited while the OSM-3D tends to contain complex geometries and large data volume.

The first challenge in the physical adaptation is more a design issue, while the fast and apprehensible rendering is both technical and theoretical. Within this chapter, we will focus on the second challenge and discuss it in the third sub-section.

For the scenario adaptation, the challenges are imposed by the moving scenarios. When the service is on use, the using context (including the location, time, user's intention, network condition, etc.) keeps changing because the users are always moving. The major challenge in this aspect therefore is:

- A smart OSM-3D client that can have smart communications with users on smart devices. With context-aware communications, the users can get better help from the service more efficiently; therefore the usability of the service can be largely enhanced.

To achieve the smart context-aware communications, a thorough knowledge of context is required. Moreover, the understanding of context is also vital to the aforementioned rendering issue. To achieve fast and apprehensible rendering, we have to eliminate many geographic information objects (GIOs) without losing the most essential and crucial ones. But whether a GIO is essential or not depends heavily on the context. Therefore, it is clear that a good knowledge of the mobile using context is essential for both challenges of rendering and smart communication. Consequently, we will perform an analysis on the mobile using context in the fourth sub-section of this chapter.

4.2 Selection of Technical Frameworks

One of the most resounding themes in terms of mobile application developments in the past two years is the debate of building a native app or a mobile web app (Warren 2011). Nowadays, millions of native apps are sold on the app stores. Although those native apps enrich the functionalities and facilitate the use of mobile devices, the numerous mobile operation systems (including iOS, Android, BlackBerry OS, Windows Phone, Symbian etc.), each with their own developing kit, bring rather a big trouble to developers for developing and maintaining their applications. To offer a certain service to users, developers have to rewrite the code for each operating system. Such a drawback is one of the reasons why web apps are now gaining popularity, since a website can be accessed via browsers (basically regardless of the underlying operating system or device).

The advancement of HTML5 even intensifies the trend. Although the full specification has not been published by W3C[3] and WHATWG,[4] it has already brought a tremendous storm not only to the desktop website but also to the development of mobile applications. In terms of 3D world, the combination of HTML5 and WebGL (together with a lot of more advanced WebGL-based libraries and SDKs such as X3DOM, three.js, OpenWebGlobe, etc.) is gaining popularity in offering 3D scenes and 3D services without any cumbersome plug-ins. In the recent years, several frameworks for developing a HMTL5-based web apps have emerged, and the most popular ones among them including *Sencha Touch,*[5] *JQuery Mobile,*[6] *JQtouch*[7] and so on.

However, native apps are not supposed to be extinct ever since, as it still has some proprietary merits over web apps. For example, web apps are not designed to have full access to the native device APIs, such as GPS, compass etc.

[3] http://www.w3.org/

[4] http://www.whatwg.org/

[5] http://www.sencha.com/

[6] http://jquerymobile.com/

[7] http://www.jqtouch.com/

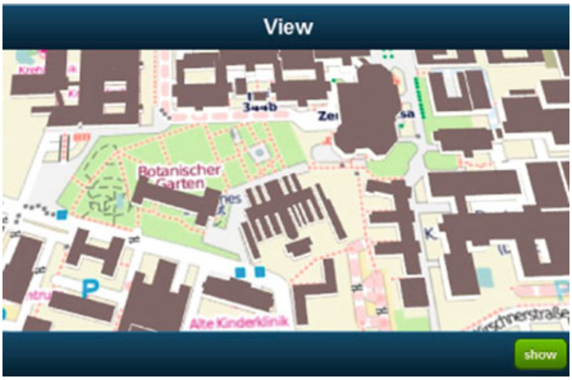

Fig. 4 A simple web app that utilizes HTML 5 and WebGL to visualize a single 3D building scene received from W3DS (within the framework of *Sencha Touch* + *PhoneGap* of Android version)

Nevertheless, having access to APIs of those sensors can be regarded as crucial for the development of powerful but safe mobile apps. Besides, native apps tend to have better graphics and a smooth user experience due to the interface with the device (Weber 2011).

Thereby, for bringing OSM-3D to the mobile world, a possible method is combining the characteristics and advantages of both kinds of frameworks. It should on the one hand be both user- and developer-friendly; on the other hand provide all envisioned features. There also emerge some frameworks aiming at such kind of apps, that is, hybrid apps. Specifically, they are developed using web developing technology such as HTML, Javascript and CSS like any web apps, but will work on local machine and have full access to sensors like any native apps. *PhoneGap*[8] and *Titanium*[9] are the most popular frameworks among them. Taking *PhoneGap* as an example, it serves as a wrapper of web apps for the browser. The apps appear as if they are native ones because they can be directly started by an icon-touching, but inside they are HTML/Javascript apps. Consequently, it shares the advantages of both kinds of apps. Here we propose a combination of *Sencha Touch* and *PhoneGap* as the developing framework for mobile OSM-3D.

Figure 4 depicts a 3D scene received from W3DS within the combined framework of *Sencha Touch* and *PhoneGap*, which also demonstrates the feasibility of the combination of HTML5 and WebGL on mobile devices.

4.3 Fast and Apprehensible Rendering

Concerning the rendering of OSM-3D on mobile devices, special algorithms and techniques must be employed to the simplify/generalize the 3D scene, as the display space cannot accommodate too many details due to its limited size and

8 http://phonegap.com

9 http://www.appcelerator.com/products/titanium-mobile-application-development/

Fig. 5 3D focus map with focus on area around the route

resolution. Otherwise the high density of geometrical and semantical information will make it impossible to recognize important aspects of the 3D objects. Meanwhile, generalized 3D scene with less data volumes can be transmitted over the internet and processed by the device more efficiently. Furthermore, generalized 3D scene with a special focus on the region/target that is currently of interest to the user can draw user's attention directly towards the needed information and reduce user's workload of interpretation, thus make the map more apprehensible.

The concept of *Focus Maps* for 2D mobile maps is raised by Zipf and Richter (2002) to reduce the data volume thereby to ensure the rendering speed and emphasizes the relevant information. Two major factors are involved to attracting users' attention: generalization and color. That is, the regions/targets of user's interest will be shown with more details as well as in a more noticeable color; whilst the rest of the map will be displayed with fewer details and in an e.g. grayish color. In this way, maps will have less data volume and can be interpreted by users very easily. Neis and Zipf (2008) has extended such concept into the third dimension and realized 3D focus maps with landmarks for (mobile) web based on a series of OGC standards (OpenLS, OGC SLD and etc.), as shown in Fig. 5.

A possible extension to what is already available in the existing 3D focus map would be using 3D template models of POIs according to the specific LOD and context. Such templates with various LODs can, on the one hand, contribute to map comprehending process because they can attract the users' attention and be interpreted easily; on the other hand, be handled easily by the mobile client because the templates of POI objects are a small database.

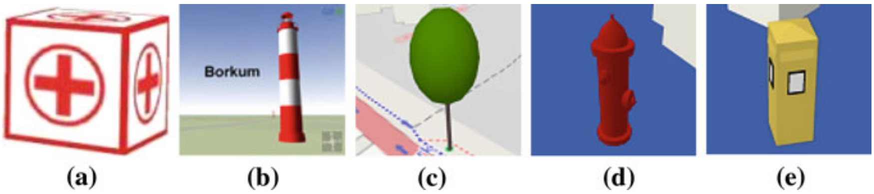

Fig. 6 3D templates. **a** hospital. **b** Light house. **c** Trees. **d** Fire hydrant (new). **e** Post box (new)

Currently in our OSM-3D database, we already have several 3D template models including 3D POI models[10] such as restaurant, hospital and 3D facility models[11] like light house, wind generator, wind mill, trees and so on. Recently new 3D models for post boxes and fire hydrants are also created in our database repository, as shown in Fig. 6. Furthermore, we are trying to take this a step further by building up a free 3D model repository called OpenBuildingsModels (OBM) which can be linked to the OSM database (Uden and Zipf 2012). It will not only include 3D building models as the name has suggested, but also other geographic objects such as street furniture. With the OBM, the models and templates in the OSM-3D world will largely be enriched and make the service more effectively and efficiently.

Other methodologies can also be applied to mobile OSM-3D, such as non-photorealistic visualization. Non-photorealistic rendering (*NPR*) techniques intentionally disregard the idea of images close to reality and present 3D city models in a comic-strip like style rendered by computers (e.g. Döllner et al. 2005). In this way, cost in time and resource can be reduced. Meanwhile, user's understanding towards the map will not be interrupted (or in some situations can turn even better) because studies have shown that human image interpretation is influenced by factors that have little to do with realism (Plesa and Cartwright 2008). However, so far a standard for 3D non-photorealistic models is still missing, let alone a standard process to generate 3D non-photorealistic models. Consequently, dedicated work is required to generate and visualize non-photorealistic models tailored to OSM-3D.

Layer selection is also a simple but effective approach. Considering the context of mobile usage for OSM-3D, layers such as DTMs may not be as important as street labels or buildings in most situations, therefore it can be displayed in low level of details or sometimes even be neglected. And in most cases, 3D street labels are more essential for navigation purpose, while 3D building models are more efficient for orientation. However, we have not yet performed enough tests to give a complete list of situations when a certain layer should be selected or not, since it depends heavily on a series of factors within the using context and their correlations. Nevertheless, it is among of our future schedules.

[10] http://wiki.openstreetmap.org/wiki/OSM-3D#Points_of_Interest

[11] http://wiki.openstreetmap.org/wiki/OSM-3D#Technical_Facilities

To further enhance the intelligence of the software and accelerate the rendering in the mobile OSM-3D, we also plan to adopt pull-service (implicit requests) and pre-cashing strategy. For example, when the user tries to find way to a certain location, this might suggest that the user would go there later. In this case, the service will not only send a request for route planning (explicit request), but also keep asking for more 3D data along the route (implicit request) when the resource is free of use (which indicates the user might be walking). A sufficient knowledge of the context is vital for effective pull-service; otherwise such kind of service would be dangerous because it may extract and deliver wrong information at wrong time.

4.4 Context Model and Context Adaptation

Nivala and Sarjakoski (2003) have demonstrated that embedding context awareness into the mobile application could increase the usability of mobile map services. Meanwhile, we also have demonstrated in the earlier sub-sections that a thorough understanding of mobile using context is essential not only for achieving context-awareness, but also for realizing fast and apprehensible rendering. To achieve a mobile OSM-3D that can have smart communications with users as well as render the 3D scenes in a fast and apprehensible way, the elements of context have to be investigated and their impacts to the usability have to be evaluated. Then the adaptation strategy can be designed based on the evaluation.

As a Location-Based service, the location information is always the most fundamental factor, because users normally care more about the information around their current location. As a map-based service, the users' intension is also a significant factor to decide what kind of information should be retrieved and how should it be displayed. For example, von Hunolstein and Zipf (2003) have argued the importance of providing task/intention-oriented functionality and visualization for mobile tourist navigation. As a graphic user interface (GUI) for geo-information, the user's preference and the physical condition of the devices should be specially considered. It seems an obvious compromise to reduce details of 3D scenes for fast processing and rendering due to the limited communication bandwidth and low capability of processor in mobile devices.

The elements of context is more than the abovementioned. Figure 7 depicts the fundamental elements of OSM-3D context. As shown in the figure, we divided context into three categories: (1) User, which basically contains the most dominant elements in the context such as the users' intentions, location, preference, and etc.; (2) Technology, which contains elements that usually act as restrictions, such as display size, capability, internet connection, and so on; and (3) Surroundings, which contains elements that can used to further optimize the service, such as illumination, season, time, and so forth.

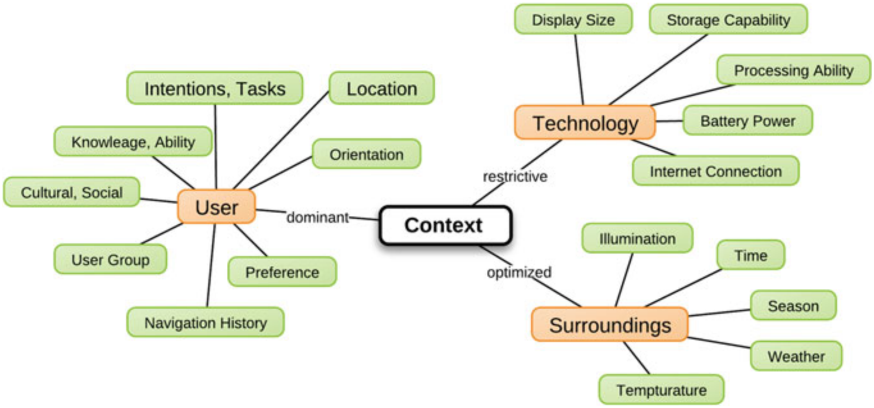

Fig. 7 Some potential elements of context for mobile OSM-3D

Table 1 explains how these elements can affect the appearance of the 3D scene. It describes what items in the mobile 3D scenes can be adapted, and offers some scenario examples or notes as well. It is not yet exhaustive and final, but can be regarded as a start for further discussions.

However, the adaptation situations are more complicated than what have been listed on the table. Take the "color" item in the table as an example. The color is mainly adapted to the users' intention when it is used to highlight the most relevant GIOs thereby ease the reading of 3D scenes (see Focus Maps). But in case of colorblind users, the color schema should also further adapted to the users' group or preference. The surrounding elements such as illumination could also change the color schema because some highlighting colors (e.g.: bright yellow) cannot be observed easily under high intensity of light. Furthermore, adaptation items such as information amount, LOD and generalization are tightly interlinked, and more research on their interdependencies is needed.

Also, those elements in Fig. 7 that do not appear in Table 1, such as navigation history, can also contribute a lot to a context-aware service. For example, if the evaluation of the GPS signal reveals that the user's present location represents a city the user has never been to before (not exist in the navigation history), this might indicates that the user is traveling, thus a possible adaptation would be to retrieve and display more detailed information for 3D POIs, such as central transport stations, hotels or tourist attractions, in the mobile application. Such information could then be furthermore adapted to the present time (day or night) as well as season (summer or winter).

In general, both the context model and the adaptation strategy are challenging work and we will put more studying efforts on them in our future work.

Table 1 Exemplary selected items of a mobile 3D scene that could be adapted to the elements of context for OSM-3D

Category	Adaptable Items	Most Relevant Elements	Notes / Scenario examples
Scene features (What information to be visualized)	Layer selection	intentions, user group	e.g.: many users may not care about the topographic layer, while it is crucial to the professional orienteer or the disabled.
	Boundary box	location	Users are more interested in the information around their current location.
	Priorities of GIOs	intentions	e.g.: fire hydrants will be especially important for fire emergency.
	Level of detail (LOD)	intentions, location	e.g.: different LOD is required for different intentions; also as there is not a fixed scale in 3D scenes, the LOD may also vary with the distance from the user.
Scene style (How the information be visualized)	Generalization	intensions, processing ability, internet connections	Very important for fast rendering, and specific algorithms should be developed according to users' intention and physical restrictions.
	Perspective	orientation, preference	e.g.: pedestrian (walking) view, bird eyes view, etc.
	Dimension	intention, preference	e.g.: 3D POIs are more useful when the LOD is high. As the LODget lower, the POIs can appear in 2D or even as points.
	Color	intention	e.g.: the usage in Focus maps.
	Layout	screen size, preference	e.g.: tablets can have a different way of layout from smart phones, because they have bigger screen.
	Interaction	preference	e.g.: a single touch-move event could mean pan or rotate, depending on the user's preference.
	Symbol styles	preference	Switch between predefined styles according to user's preference.
	Language	preference	Display the map in the language that the user prefers.
	Text style	User group, preference	e.g.: change the size for the old group; display the street labelson the street or as a billboard box,etc.

5 Conclusion and Future Work

Due to the large scale availability of mobile devices, the demand for mobile applications increases. Especially Location-Based-Services, such as route planning, navigation or Point-of-Interest search, are well-known on personal computers and the users demand the adaptation of such services to mobile devices. Having such mobile applications can increase the quality of life for the users, without the need of actually sitting in front of a computer. Essentially three-dimensional applications, which provide a more realistic perspective and orientation to the users, are desirable. Trying to decrease the costs of such applications, it is furthermore advisable to use open and free geo-data, instead of proprietary and licensed data. Based on OSM data and several Open Geospatial Consortium (OGC) standards and draft specifications, OSM-3D provides a highly detailed virtual globe with various 3D data/models and offers utilizable functionalities including Yellow Page query and 3D routing service. By combining the proficient 3D map service and the agile mobile platform, users can get a better and more brisk map service. Meanwhile, as an OSM-based service, the adapted mobile OSM-3D is also promising to enrich OSM dataset and enhance its quality. However, the non-negligible gap that lies between PC world and mobile world calls for adaptation.

After the short introduction on the increasing demand for 3D-LBS on mobile devices, a brief overview about related work has been conducted. Following, a brief overview about the OpenStreetMap community has been provided, because OSM is one of the most prominent and manifold sources for different kinds of open geo-data. Closely related to OSM, the OSM-3D project has been described in detail. Since the main aim of this chapter is to describe a framework towards the adaptation of OSM-3D to mobile devices, this OSM-3D introduction is a very important part. Focusing on the aimed adaptation, the challenges have been elaborated in three aspects, i.e.: platform adaptation, physical adaptation and scenario adaptation. For the platform adaptation, a critical discussion and final selection of a technical framework for achieving the goal has been provided. For physical adaptation, techniques for fast and apprehensible rendering of 3D features have been discussed, including an extension to the current 3D Focus Maps and several other possible solutions. Since the understanding of context is fundamental for both physical adaptation and scenario adaptation, a context model for adaptation together with the adaptable items in mobile 3D scenes have been discussed and tailored to OSM-3D.

In line with adapting OSM-3D on mobile devices, generalization of the 3D information would be the most significant task towards fast and comprehensive rendering, and a thorough knowledge of the changing context is the most fundamental above all. In the future, we will put efforts on elaborating more detailed a context model and the corresponding adaptation strategy, and conducting investigations on visual cognitions to develop reasonable algorithms of generalization, thereby gain good performance and usability. With all the efforts, we aim to be able to present the users a platform-independent mobile OSM-3D with good performance in both rendering and interaction, thereby offer them effective and efficient location-based 3D map services. In general, a standard-based, platform-independent, context-aware visualization of 3D content on mobile devices is an important, but challenging task, and will be an integral part of our future research efforts.

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Erratum to: App-Free Zone: Paper Maps as Alternative to Electronic Indoor Navigation Aids and Their Empirical Evaluation with Large User Bases

Alexandra Lorenz, Cornelia Thierbach, Nina Baur and Thomas H. Kolbe

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Page	Item or line	Correction
330	Chapter 18	The 'Table 3' is replaced with 'new Table 3'.

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A. Lorenz (✉) · T. H. Kolbe
Department of Geodesy and Geoinformation Science, Technische Universität Berlin, Straße des 17. Juni 135 10623 Berlin, Germany
e-mail: alexandra.lorenz@tu-berlin.de

C. Thierbach · N. Baur
Department of Sociology, Technische Universität Berlin, Fraunhoferstr. 33–36 10587 Berlin, Germany

J. M. Krisp (ed.), *Progress in Location-Based Services*,
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Table 3 Who prefers paper maps over apps? Results of a multiple linear regression analysis (From 2010) explaining the relation between sets of different independent variables (Models 1–6) and users' media preference

	Bivariate Analyses		**Model 1: Sociodemographics**			**Model 2: Media Experience**			**Model 3: Other Experience**			**Model 4: Orientation Praxis**			**Model 5: Complete Model**			**Model 6: Final Model**		
	Pearson's r	Sig.	Beta	Sig.	S.E.	Beta	Sig.	S.E.	Beta	Sig.	S.E.	Beta	Sig.	S.E.	Beta	Sig.	S.E.	Beta	Sig.	S.E.
Sociodemographics																				
Gender	-0.13	***	-0.12	**	0.04										-0.04		0.04			
Age	0.2	***	0.19	***	0.04										0.11	*	0.05	0.09	*	0.04
Media Experience																				
Printed Maps	0.22	***				0.2	***	0.04							0.14	**	0.05	0.13	**	0.05
Floor Plans of Buildings or Engineering Drawings	0.02					0.06		0.04							0.04		0.04			
Maps in the Internet	-0.14	***				-0.11	**	0.04							-0.1	*	0.05	-0.1	*	0.04
GPS and other electronic Maps	-0.29	***				-0.25	***	0.04							-0.22	***	0.04	-0.25	***	0.04
Other Experience Helping Orientation																				
Movement Type	-0.01								-0.05		0.04				-0.06		0.04			
Necessity of Orientation in New Environments	-0.12	**							-0.1	*	0.04				-0.06		0.04			
Playing Games	-0.15	***							-0.15	***	0.04				-0.07	+	0.04	-0.09	*	0.04
Orientation Praxis																				
Reading Maps Oneself	0.13	***										0.13	***	0.04	0.1	+	0.05	0.11	*	0.05
Using External Help	-0.01											0.01		0.04	-0.04		0.04			
R-Square			*5%*			*13%*			*3%*			*2%*			*17%*			*16%*		

For this analysis, the sample size reduces to 613, since not all participants responded to all relevant questions (variables/factors)

Data Base LNDW Survey 2011. n = 613. *Significance Levels* + α = 0.1; * α = 0.05; ** α = 0.01; *** α = 0.001