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

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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.

[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.

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[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.

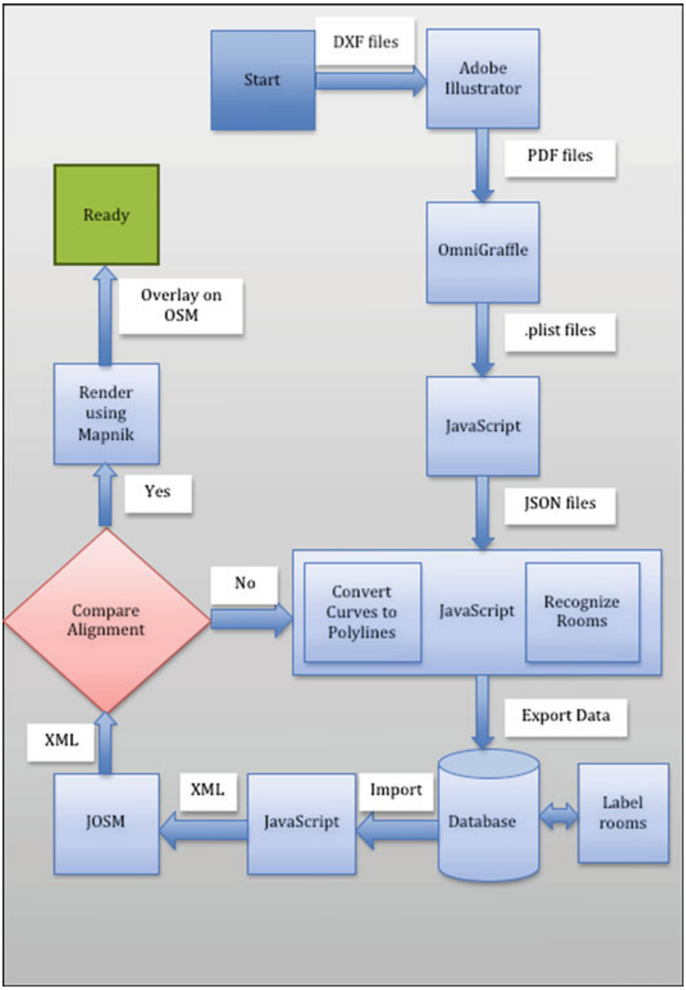

Fig. 2 Data preparation process

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.

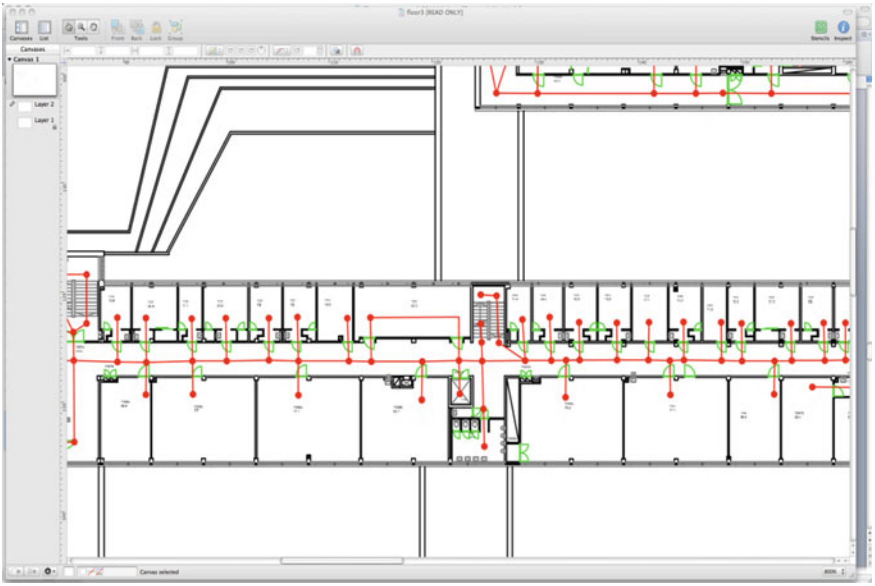

Fig. 3 2D graph generation process in omnigraffle

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.

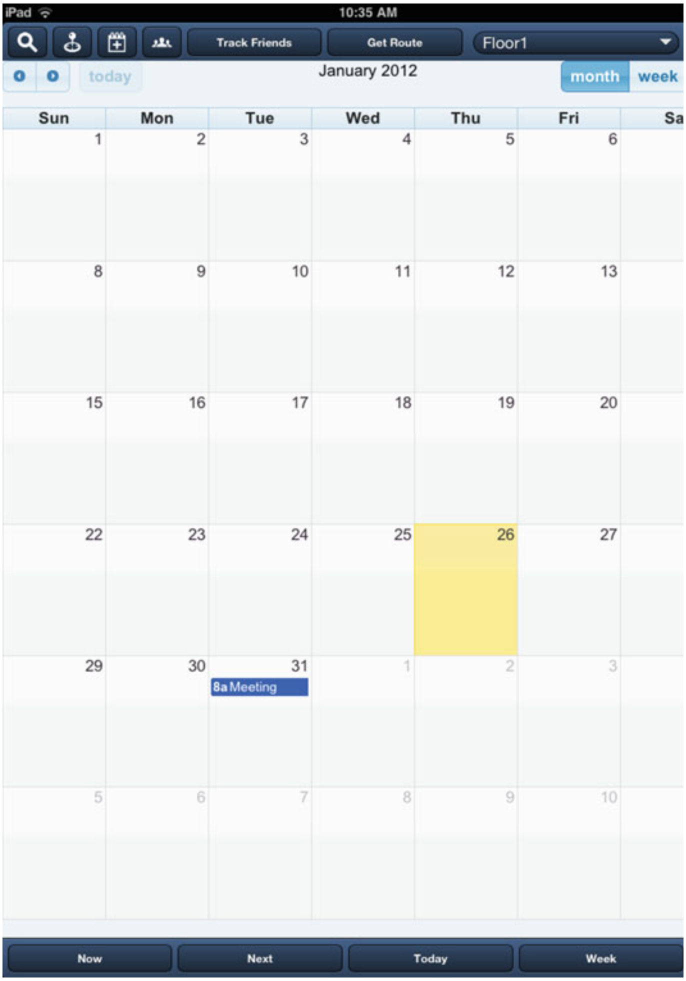

Fig. 5 Calendar screen in the application

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.

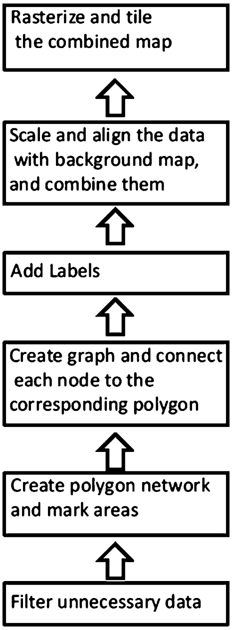

Fig. 6 Generalization of the data conversion process

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.

References

Campusguiden (2012) The campusguiden web page, http://www.campusguiden.no/. Accessed on 12 April 2012

Dudas MP, Ghafourian M, Karimi AH (2009) ONALIN: ontology and algorithm for indoor routing. In: Tenth international conference on mobile data management: systems, services and middleware, Taipei, Taiwan, pp 720–725

EPFL map (2012) The EPFL map web page, http://plan.epfl.ch/. Accessed on 12 April 2012

Gu Y, Lo A, Niemegeers I (2009) A survey of indoor positioning systems for wireless personal networks. IEEE Commun Surv Tutorials 11(1):13–32

Harter A, Hopper A, Steggles p, Ward A, Webster P (1999) The anatomy of a context-aware application. In: Proceedings of the fifth annual ACM/IEEE international conference on mobile computing and networking, Seattle, Washington, USA, pp 59–68

Hub A, Diepstraten J, Ertl T (2003) Design and development of an indoor navigation and object identification system for the blind. In: Proceedings of the 6th international ACM SIGACCESS conference on computers and accessibility (Assets '04), Atlanta, USA, pp 147–152

Lau Y, Patil A, Ni L, Liu Y (2004) LANDMARC: indoor location sensing using active RFID. Wireless Networks 10(6):701–710

Li, b, Salter J, Dempster AG, Rizos C (2006) Indoor positioning techniques based on wireless LAN. In: 1st IEEE international conference on wireless broadband and ultra wideband communications, Sydney, Australia, pp 13–16

Liu H, Darabi H, Banerjee P, Liu J (2007) Survey of wireless indoor positioning techniques and systems. IEEE Trans Syst Man Cybern 37(6):1067–1080

Luimula M, Sääskilahti K, Partala T, Pieskä S, Alaspää J (2010) Remote navigation of a mobile robot in an RFID-augmented environment. Pers Ubiquitous Comput 14(2):125–136

McClendon B (2012) A new frontier for Google maps: mapping the indoors. Posted on offical blog of Google, http://googleblog.blogspot.com/2011/11/new-frontier-for-google-maps-mapping.html. Accessed on 12 April 2012

Mehta P, Kant P, Shah P, Roy AK (2011) VI-Navi: a novel indoor navigation system for visually impaired people. In: Proceedings of the 12th international conference on computer systems and technologies, Sofia, Bulgaria, pp 365–371

Ning F, Kao S, Chang C, Meng X (2004) Preliminary testing of pseudolite to improve GPS precision. In: 1st FIG international symposium on engineering surveys for construction works and structural engineering, Nottingham, England

Papataxiarhis V, Riga V, Nomikos V, Sekkas O, Kolomvatsos K, Tsetsos V, Papageorgas P, Vourakis S, Xouris V, Hadjiefthymiades S, Kouroupetroglou G (2009) MNISIKLIS: indoor

location based services for all—location based services and telecartography II, lecture notes in geoinformation and cartography, pp 263–282
Priyantha N, Chakraborty A, Balakrishnan H (2000) The cricket location-support system. In: Proceedings of the 6th annual international conference on mobile computing and networking, Boston, USA, pp 32–43
Rizos C, Li Y, Politi N, Barnes J, Gambale N (2011) Locata: a new constellation for high accuracy outdoor and indoor positioning. In FIG working week 2011, Marrakech, Morocco
Ruppel P, Gschwandtner F (2009) Spontaneous and privacy-friendly mobile indoor routing and navigation. GI Jahrestagung, Lübeck, Germany, pp 2574–2583
Stook J (2011) Planning an indoor navigation service for a smartphone with Wi-Fi fingerprinting localization—Master thesis, TU Delft, The Netherlands
Ting S, Kwok S, Tsang A, Ho G (2011) The study on using passive RFID tags for indoor positioning. Int J Eng Bus Manag 3(1):9–15
Wang J (2002) Pseudolite applications in positioning and navigation: Progress and problems. J Glob Position Syst 1:48–56