Indoor and Outdoor Navigation in Smart Mobility Usage Scenarios

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Abstract

Business and privately motivated journeys today are often driven by ad hoc decisions and a mix of different means of transport. A very distinct property of any mobility scenario that claims to be Smart is the fact that it needs to incorporate contextual and personal preferences during the selection process of a given means of transport at a given time and place. This results in great challenges, especially where different means of transport intersect, like at train stations, park and ride spots, parking garages, where travelers switch from one mode to another. In order to support a smooth transition, Smart Mobility systems need to allow for a seamless transition supported by an indoor-outdoor navigation solution. This chapter will highlight the different components needed to build up a seamless indoor-outdoor navigation solution, including spatial data management, indoor positioning, visualization of indoor maps, and a user-friendly turn-by-turn navigation. Furthermore, it will also discuss possible business models to justify the investments needed for an indoor-outdoor navigation system.

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9.1 Introduction

Innovative mobility concepts as introduced in Chaps. 7 and 8 rely on the fact, that they support a context- and preference-driven selection of means of transport, in order to get from A to B via C. In a world with increasing mobility all around, travel decisions are taken rather more spontaneously than previously planned. Smart Mobility systems need to cope and support those dynamic travel decisions.

A change from one means of transport to another poses quite a lot of stress to a traveler, as he needs to orientate himself at often unknown places in a limited time frame. Transport service providers try to support a fast and efficient orientation by utilizing signs, wall charts, or color codes on walls or floors. In recent years, the general architecture of train or tram stations has been optimized to support an efficient orientation and boarding. Nearly 100 years ago, the Swedish architect Alfred Grenander [125] developed a color coding scheme for the Berlin tube stations. According to his concepts tube stations on a given track utilize different colors on their tiling, pillars, and signage framings. These strategies should facilitate orientation for the visually impaired (e.g. U-Bahnhof Samariterstraße) [126]. Even today in Berlin, these colors are used for U2, U5, U6, and U8. Cities and transport companies spend large amounts of money on multi-lingual pedestrian guides [127], but still cannot eliminate all sources of uncertainties and inconveniences.

Other explanations of public transport services describe that "one should know at least the direction of the desired destination stop in order to get in at the right stop" [128]. When changing transport, one does not only have to keep the number of the next means of transport and the direction to the next stop in mind but also the direction of the new means of transport is important (which can be indicated by the name of the final stop or the inter-station). Even more, the exact location of the boarding stop may be different depending on the direction. "It needs to be considered that stops for the opposite direction are not necessarily vis-a-vis but might be in another close by street" [128]. These conditions might cause trouble and confusion. Therefore transport services point to a last resort concerning orientation in public space: "Whoever is unsure about the choice of the stop or the direction of the tour should simply ask other passengers or the staff" [128].

This is exactly where the benefits of an IT supported system may lie. The traveler wants a simple and reliable navigation system which is easy to handle – just like the navigation system in his car. But while navigation systems in cars (running on a head unit or on smartphones) have been widely accepted, there are only a few navigation devices and solutions for pedestrians [128].

Table 9.1 sums up the main differences between vehicle and pedestrian navigation.

Table 9.1 Differences between vehicle and pedestrian navigation

Characteristic	Vehicle navigation	Pedestrian navigation
Data availability	Almost ubiquitously available in high data quality.	In urban areas already commonly available, also with a high accuracy. Indoor data primarily available for some public spaces like shopping malls, airports, train stations.
Degrees of freedom	Limits on public streets.	Three-dimensional degree of freedom. Indoor-outdoor transitions.
Hardware	Head units or smartphones, connected to the car's power supply.	Smartphones with limited battery capacities.
Positioning	GNNS-based, for head units supported by car sensors like wheel rotation, steering angle, etc.	Hybrid positioning, e.g. via GNSS, WiFi, Bluetooth Inertial Sensors, etc.
Interaction	Speech-driven or touch-/button-based interaction at the head units or smartphones.	Primarily touch interaction on smartphone displays.
Human focus	Traffic and navigation.	Environment, social interaction, and orientation.
Navigation instructions	Voice commands containing distance, angles, and street names.	Primarily visual but sometimes also haptic feedback or voice commands.

The support of pedestrians with mobile IT solutions is advisable in the course of the introduction of Smart Mobility offers, for example the introduction of a mobile pedestrian navigation solution with automatized localization via a built-in infrastructure.

9.2 Indoor-Outdoor Navigation – Requirements and Benefits

A number of requirements need to be considered in order to include the support of pedestrians in Smart Mobility solutions:

- Service provisioning needs a high grade of reliability.
- Orientation and navigation information has to be easy to understand and easy to adapt to the respective situation.
- Support of positioning and navigation has to work seamlessly in case of indoor-to-outdoor transition and vice versa.

- While outdoor navigation can rely on the well-proven satellite positioning technologies (GPS, Galileo), indoor navigation has to utilize specific technologies and a dedicated infrastructure to acquire a position.
- Calculated routes have to include the pedestrian's individual and situational preconditions (i.e. state of health, handicaps, pieces of luggage, companions).
- Routing and description need to be up-to-date, i.e. currently closed areas or newly opened arcades have to be taken into account for calculating the route; landmarks mentioned in the navigation instructions have to actually be there.
- A great variety of devices needs to be supported.
- High investment costs need to be backed up by low integration efforts of new devices and new technologies.
- The required data volume has to be handled with care due to the costs of data packages and roaming offers for users.
- Offline functionality should be part of the solution because of the eventuality of poor mobile communication coverage in some building areas (e.g. underground areas).

The above list of requirements for pedestrian navigation systems in Smart Mobility scenarios reveals that the initiation and operation of such a system is highly cost intensive. For this reason, there has to be a certain benefit for the user.

Benefits of the system are both individual and social in nature. An essential individual benefit of a personal orientation and navigation system is an increase in the user's safety. The user can determine his position and the route to his destination. It helps him to find his orientation as well as ways to places where he can seek further help. Therefore, it satisfies the second most important basic need of mankind (according to *Maslow*'s *hierarchy of needs*): the need for safety [129].

Furthermore, the system covers many aspects which define pleasant, comfortable, cost- and time-saving travelling. The user can take for granted that a change of transport as well as his orientation at traffic junctions will flow as smoothly as possible.

Thus, the acceptance of using different means of transport and transport offers rises because the travel recommendations will take personal preferences into account. Individual positive experiences with Smart Mobility solutions concerning safety, reliability, comfort, and the saving of time and costs will lead to an increase of the system's usage. Therefore, establishing pedestrian navigation systems will lead to a stronger use of public transport and car/ride-sharing and reduces private traffic.

The above mentioned values of individual and social benefits justify efforts for the development and operation of indoor and outdoor pedestrian navigation systems at traffic junctions.

9.3 Technical Requirements

The conception, implementation, and operation of a pedestrian navigation system requires a number of technical prerequisites. Navigation of pedestrians in urban spaces differs significantly from navigation of other means of transport: higher degrees in choice of movement, complex spatial situations, more blurred positioning, and the user's shared attention necessitate new and more intuitive concepts of interaction with this kind of system. Well-known, classic, map-based approaches cover only parts of the requirements profile.

9.3.1 Spatial Data Management

The underlying geo-database is the basis of the provision of navigation systems. While previously two companies from the Netherlands and the USA, TeleAtlas [130] und HERE [131] have dominated the market, most recently, the quantity, quality and correctness of free geo-data (initiated by crowd-based services like OpenStreetMap [132] has soared. In many metropolitan/urban areas in Western Europe these data do not take second place to commercial data – they even outperform them [133]. This is primarily true when the focus is not on mere car navigation services but on other more individual means of transport (bicycle, inline skating, routing for the handicapped) or pedestrian navigation.

By extending the field of application to indoor navigation, the geo-data aspect gains additional weight, since extensive data sets from commercial or free suppliers are hardly available or are right in the process of construction.

The following aspects, which have partly been mentioned in the requirements above, describe the special challenges of indoor navigation:

- Data formats. Often based on Computer Aided Design (CAD) plans that incorporate fine-granular building construction data and structural properties that are not relevant for navigation purposes. Also the non-spatial information of those building plans is related to structural information and not to navigation aspects (e.g. whether a door is usually open or not).
- Complexity and fragmentation. Large buildings like stations often have a very complex spatial structure (i.e. several floors, halls, transitions, galleries, and much more) and complex ownership structure, which results in different contact persons and access restrictions to the spatial data and the premises for the installation of positioning technologies.
- Correctness of data. In indoor navigation, the pattern of utilization is often alterable and dynamic, especially with regard to frequently changing lines of shops in arcades. Furthermore, some doors or gateways might be closed at night or blocked during modifications of the building.

First approaches and procedures try to use the enthusiasm of free (non-commercial) spatial data communities in order to include indoor areas and buildings in a wide range [134]. But to date, these approaches have failed because of missing tools and the agreement about the method of collecting data and prospects for an automated indoor positioning technology.

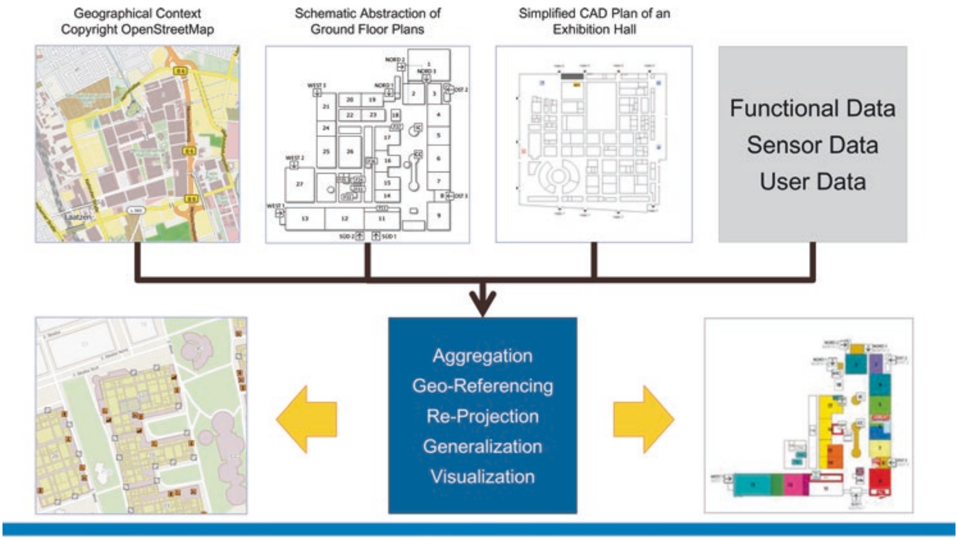

Fig. 9.1 Spatial data integration and fusion: Fusion of GIS data, CAD and record of detailed measure plans using the example of the exhibition grounds of Deutsche Messe AG in Hanover, Germany (with kind approval © Heidelberg mobil international GmbH 2016, Deutsche Messe AG 2016, OpenStreetMap.org 2016)

Figure 9.1 highlights a synchronized approach which integrates both spatial data from non-commercial databases (in common formats) and spatial data from facility management applications (in the form of CAD maps), in order to generate a joint spatial presentation, that is furthermore extended by non-spatial data like sensor information or point of interest data.

9.3.2 Indoor Positioning

The first basic requirement for every navigation is accurate localization (positioning). Localization approaches can be distinguished in absolute and relative techniques. Relative methods use the known starting point and calculate the change of position with the help of sensors. Absolute methods locate within the known reference system, for example Global Positioning System (GPS). IT/radio engineering is the basis of most of the methods.

Mere satellite-based location solutions in urban spaces with street canyons and above ground and underground buildings (like stations) are too error prone and need more time to locate the user. Therefore, they do not support the situational and quick use required for pedestrian navigation. More recent approaches try to solve the problems of positioning by using hybrid localization which combines different localization strategies and sensor data. In a first step, rough localization is carried out by the radio cells of the mobile telephone supplier, which is then – in a second step – refined by WiFi signals and thirdly – if available – supplemented by GPS data. This well-known method is only partly applicable to indoor scenarios as radio signals are absorbed or modified by the structural environment and lead to inaccurate or even wrong user positioning.

Complexity and fragmentation of buildings directly influence the possibilities and reliability of the use of indoor localization technologies. Reliable positioning can only be ensured by a combination of different approaches and techniques (sensor fusion).

Table 9.2 compares different positioning technologies and rates them with regard to their specific advantages and disadvantages and the capital expenditure for realizing them.

Many solutions also offer the possibility of a more or less intuitive manual positioning since sufficient results of an automatic localization are not given. Examples for manual positioning are manual input of names of shops or stopovers or scanning of location barcodes.

Table 9.2 Comparison of positioning technologies

Type	Method	Pros	Cons	Overall costs
WiFi	Cell of origin	Device independent	Less robust, precision	$
WiFi	RSS fingerprint	Precision	Operating system restrictions, calibrations	$$
WiFi	Triangulation (TOA, RSS)	Precision	Operating system restrictions, fragile	$$$
Tags and Marker	BLE/iBeacon/Eddystone	Device support, energy consumption	Operation, robustness	$$
	RFID (active, passive), NFC	Precision	Range, user interaction, infrastructure, device support	$$–$$$
	QR tags	Robust, flexible	User interaction	$
Other	Magnetic	Precision, autonomous	Calibration, robustness, device support	$$
	Inertial sensors	Autonomous	Calibration, precision	$
	Image recognition	Autonomous	User interaction, calibration, device storage or connectivity, energy consumption	$$
	Ultra-wideband	High precision	Special hardware	$$$
	Light (normal/infrared)	Precision	Infrastructure necessary, error prone	$$

$ stands for low-cost realization, usage of current technology and infrastructure;
$$ stands for medium costs to develop, implement, and operate;
$$$ stands for high costs to develop, implement, and operate.

9.3.3 Map Visualization

The traveler's surroundings are visualized by current spatial data and positioning information. During the past decade the use of digital map services like Google Maps [135] or Bing Maps [136] has developed from desktop platforms to mobile devices (e.g. smartphones). These applications are, however, often mere adaptions of desktop applications which are adjusted to touch interactions for smartphones with big screens.

One can generally distinguish two types of the digital map displays:

- Grid-based visualization relying on pre-calculated image tiles
- Vector-based map rendering on the smartphone as 2D or 3D maps.

Because of the increasing data volume and increasing processing capabilities of smartphones, vector-based map applications have proven to be (most) suitable devices. This is particularly valid for indoor applications without publicly available online map services. 3D visualizations have to be easily operable because of the very complex interactions induced by the situated and spontaneous use of mobile indoor navigation solutions. Figure 9.2 shows examples of visualizations.

Limitations of mobile web browsers are the reason for grid-based map displays as state of the art for mobile websites. These solutions can hardly be found in indoor services because a server-based map generation is inevitable.

Augmented Reality (AR) views have gained importance compared to the map-based view. AR includes extra information via live images from a camera and requires an especially accurate positioning which is frequently restricted by spatial conditions.

9.3.4 Turn-by-Turn Navigation – Landmark-Based Guidance

Apart from geo-data, localization, and visualization, calculating the routes and their presentation in apps is the fourth pillar of realizing interactive indoor navigation systems. In the past decades, mathematical literature has comprehensively analyzed the problem of calculating routes. On the basis of graphs made of edges and nodes, algorithms calculate the fastest way from a starting point to the desired destination [137]. The route is then visualized either as linear cartographic symbol on the map or divided into single segments and then presented as navigation instructions. Both methods are used for motorized mobility but are only of limited suitability for pedestrian navigation because the user does not focus constantly on the mobile device. The required detailed segmentation of routes would also include too many and even inappropriate navigation instructions.

Procedures based on landmarks appear to be (most) appropriate for pedestrian navigation. The user does not receive instructions based on distances but is directed with the help of (only) a few significant landmarks (and therefore does not have to look at his mobile device continuously). The challenge of this approach lies in the selection of

Fig. 9.2 Examples of visualizations – indoor and outdoor map services (with kind approval © Heidelberg mobil international GmbH 2016, Deutsche Messe AG 2016, OpenStreetMap.org 2016)

suitable landmarks and in the allocation of the necessary current data [138]. Essential characteristics of the selection of landmarks are [138, 139]:

- Visibility and location of the landmark
- Uniqueness and attractiveness with regard to visual, semantic, and structural qualities of the landmark.

The development of future indoor navigation services still has plenty of room for improvement in order to realize intuitive and appropriate results.

9.4 Indoor Navigation and Business Models

The investment in indoor and outdoor navigation solutions opens the field for new sources of revenue which can in turn be connected with innovative *business models*. Sources of revenue are, among others:

- Higher level of utilization of public mobility offers
- Location-based service offerings alongside the indoor/outdoor routes
- Big data analyses on the basis of spatial data.

Mobility offers in urban areas are characterized by an increasing variety of choices and include both classic offers of public transport networks as well as customized offers like Uber [30] or myTaxi [140].

A distinctive feature for all providers is the user's convenience, which includes not only the type of transport itself but also the usability of new digital accesses (payment and services information apps) as well as convenient transport changes at intersections and interchange stops like stations, parking garages, or Park & Ride sites. Indoor navigation services can increase the user's convenience and can lead to a higher degree of capacity utilization.

The upside of providing an indoor navigation systems and the potential knowledge of the user's position might be the possibility of location-based marketing. Prospects range from simple mobile advertising to push messages and even complex advertising campaigns (a combination of display ads and mobile ads) so as to call attention to shopping facilities and services along the route. Stored user profiles enable the application to calculate and display routes which cater to the user's personal interests and preferences. A route can then be calculated either along shops for clothes and cosmetics or electronics stores.

A third, new marketing channel can be developed through big data analyses of compiled spatial data. The evaluation of aggregated and anonymized movement profiles enables service providers along the route taken by mobility users to tailor their offerings to the user's needs and be more efficient.

The provision of a seamless indoor/outdoor navigation still requires extensive technical work. Up-to-date data, reliable indoor positioning, and intuitive handling are preconditions for the user's acceptance of such a system. Provision of an integrated indoor/outdoor navigation solution will be an essential element for the acceptance of a transport service provider and the success of Smart Mobility scenarios, and could be a unique feature of competing providers of urban mobility.