Combined indoor/outdoor Smartphone navigation for public transport travellers

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Abstract

Pedestrian navigation on Smartphones has recently gained high attention due to capable devices, off-board based navigation software and increased transmit rates of cellular networks. However, most of the available applications for pedestrian navigation are slightly adapted car-navigation systems and do not cope with specific requirements. Thus, in this paper we describe basic concepts of pedestrian navigation in indoor and outdoor environments. We focus on aspects of orientation and guidance for public transport travellers in complex interchange buildings. Moreover the paper describes the implementation of the proposed concepts on Off-the-shelf Smartphones.

1. Introduction

Due to the constantly increasing technical advantages of Smartphones, pedestrian navigation recently has gained high interest as one of the potential mobile killer-applications in the near future. Whereas in-car navigation systems have already reached a certain level of maturity, pedestrian navigation on Smartphones is still in its infancies. Most of the commercially available systems were designed as car navigation systems which are now sold as pedestrian navigation systems with only minor modifications. However, at a closer look, there can be identified a very clear set of differing requirements and conceptual shortcomings, which make the available navigation solutions useless when applied for pedestrian navigation purposes. In order to show the shortcomings of recent pedestrian navigation systems we give three examples.

Firstly, when we talk of pedestrian navigation on Smartphones, we talk about an off-board navigation, which allows route calculation to be done on a server and the Smartphone is used for navigating the pedestrians on a pre-calculated route. The basis for route calculation on the server has to be a pedestrian footpath network which is specifically targeted at modelling the environment from a pedestrian's point of view. However, most of the available solutions use the standard street network for route calculation.

Another important aspect is, that pedestrians can use navigation for different purposes. We can think of tourists using the navigation for exploring the sights of a city or public transport travellers using it for finding the stop for the next transportation mean. Pedestrian navigation systems have to be designed to consider these different situations and to provide users with the possibility to adapt the application to their information and guidance needs.

A third crucial requirement is that pedestrian navigation should not be limited to outdoor environments. Especially in cities, pedestrians spend a lot of their time in different kinds of buildings. Smartphone-based pedestrian navigation has all the pre-requisites to provide reliable combined indoor/outdoor guidance.

Having the different aspects of pedestrian navigation in mind, in this paper we focus on pedestrian navigation for public transport travellers. Wayfinding in public transport networks can currently be accomplished by means of timetable information and multimodal journey planners. As long as travellers are using the public transport network, ways are fixed in time and space. The situation becomes complex [10] whenever travellers have to leave the transport network as pedestrians for finding an address or changing to another mean of transportation. In towns, the situation of interchange mainly takes place in complex public interchange nodes. Orientation and guidance could help inexperienced travellers to navigate from one public transport stop to another or to find the most suitable exit on the way to a certain address.

Our concept for a multimodal travel assistance application on Smartphones combines two modules. The first is a browser-based mobile access to a server-based multimodal journey planner which allows users to calculate multimodal routes between given start and end points. The result is composed of individual trip segments with information about type of transportation and estimated travel time. The second provides an off-board navigation service that guides the user on outdoor as well as indoor pedestrian routes. Both components are integrated in a mobile application called the personal travel companion that can be accessed by public transport travellers whenever and wherever they want or need to.

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The paper is structured as follows: First we take a look at related work. We continue with describing the data model with focus on the modelling of buildings. The following sections describe route calculation, guidance and positioning. We finish with aspects of implementation, conclusion and ongoing work.

2. Related Work

We classify related work in the following categories: pedestrian navigation pilot systems, outdoor and indoor positioning technologies and conceptional models of wayfinding in public transport buildings.

In the project REAL [1] a hybrid navigation system for indoor and outdoor use has been developed. The indoor navigation component has been built with infrared transmitters mounted at the ceiling of buildings, the outdoor component works with a GPS system. In addition to the different positioning technologies the REAL project deals with the presentation of route directions on different output devices. The NAVIO project [7] analyzes major aspects being important when designing a pedestrian navigation system for indoor and outdoor environments. The main parts of the project are integrated positioning technologies, multi-criteria route planning and multimedia route communication. One part of the project LoL@ [3] describes the cartographic visualisation of multimedia content on Smartphones.

Retscher and Thienelt [18] discuss suitable location technologies for pedestrians. In their study they test and demonstrate different positioning technologies like satellite-positioning technologies, cellular phone positioning, dead reckoning sensors for measurement of heading and travelled distance as well as barometric pressure sensors for height determination. Especially for indoor positioning technologies, most of the prototypes are based on Infrared, WLAN or Bluetooth ([5], [11], [13], [22]). Whereas Infrared needs line of sight, WLAN positioning needs costly calibration and can not be accessed by typical Smartphones. Bluetooth positioning systems are mainly server-based and thus require a costly installation procedure.

The human navigation and wayfinding process is based on concepts of human cognition ([4], [9]). Rüetschi and Timpf ([19], [20]) developed a conceptual model for describing the wayfinding process in public transport stations. They differ between the network space (the public transport network itself) and the scene space (the nodes of the public transport network, e.g. interchange

facilities). The scene space is modelled by the schematic geometry, which is based on image schemes [12] and affordances [8]. In another study Fontaine und Denis [6] analyse the spatial human cognition in subway stations. One of the results of the study with several users is that direction signs are important elements for the navigation and wayfinding in public transport stations. The signposts are significant elements for the orientation at decision points. This result is also confirmed in a requirement study of pedestrian navigation [16].
However, as far as we know, there is no existing pilot system, which focuses on guidance of public transport passengers in interchange facilities.

3. Data Model

In this section we take a look at the data model which was designed for pedestrian navigation in general but with a special focus on indoor navigation in public interchange buildings. Following theoretical concepts of wayfinding ([19], [20]) we model buildings with a logical representation of the scene space:

- Building
- Floors
- Regions
- Gateways
- Items

Buildings can be structured in different floors. A region is a coherent space on a single floor with specific characteristics. Instances could be a room, an entrance hall together with connected corridors or an entire floor, depending on the desired granularity. Regions are connected through gateways that indicate possible transitions between them. Typical representations are stairs, elevators, escalators and ramps. Items are specific objects from the scene space and can be linked to regions. Items can be used to model landmarks like signs and shops. The information from the scene space is mainly used to give users a detailed virtual representation of the physical environment and to generate precise textual route descriptions.
For route calculation, map generation and navigation we have connected the logical, hierarchical model of buildings with a geographical model based on a coordinate system. The resulting model is a hybrid location model [14]. All the regions are modeled with non-overlapping polygons, so-called zones. Gateways have gateway areas (polygons) in the origin region and target coordinates in the destination region. The coordinate system was extended with a third parameter called level, which indicates the floor of the building. Gateways are used for transitions between regions and floors.
The pedestrian network is built of decision and orientation points and segments connecting these points. Segments can have detailed attributes describing the nature of the footpath segment. Items from the scene space are linked to the directed footpath segments and can thus be used for the generation of textual path descriptions. Orientation points are used as anchor points for the navigation. The model is suited for outdoor environments as well. Regions can either be determined automatically along the calculated footpath or regions can also be pre-defined, which is suitable for town areas.
With this hybrid location model it is possible to do pedestrian route calculation, to use information from the virtual representation of the scene space for detailed textual route descriptions and map generation and to use the model for navigating users along pre-calculated pedestrian routes. Moreover, the model is the foundation for automatic positioning along the route and indoor/outdoor transitions.

4. Route calculation

Multimodal route calculation is done between two points. These points may be addresses, specific points of interest or coordinates provided by an automatic positioning system.

For route calculation an integrated routing network that is made up of the public transport network, the street network and the pedestrian network is used. Transitions between the networks take place at public transport stops.

The pedestrian footpath network is a graph-based network consisting of nodes and segments. Each node or segment holds specific attributes that provide detailed information for the computation of the route as well as the generation of path descriptions.

Among other things the attributes give information about the type of the segment. It can be an ordinary path segment, a stair, an escalator, an elevator or a ramp. With this information we are able to realise a selective route computation on the basis of personal demands to optimise interchange times, route complexity or walking effort [10]. Additionally, each segment can have specific attributes indicating the direction of escalators or the number of stairs. This way we can differentiate between stairs connecting floors and single step stairs that are hardly percepted by normal people but form an obstacle to wheel chair users.

Another important factor for determining the ideal route is the time needed for walking along a specific segment. This value is not fixed but is dependent on the user. In order to provide personalized interchange times we use time factors together with a configurable walking speed that is part of the traveller's personal profile.

5. Guidance

We define guidance as an information technology based tool assisting pedestrians in the process of wayfinding, which means a purposeful interaction with an environment where the purpose is to reach a certain place or goal ([19], [20]). Our guidance system provides the following services:

- to select an optimised footpath according to the user's profile given a starting point and a destination (an address or public transport stop)
- to give instructions for pedestrians in order to optimise their interchange and to improve their orientation
- to select the most relevant information out of the scene space based on the calculated footpath in order to improve the interaction between wayfinders and the environment
- to reduce the complexity of the pedestrian's navigation task by giving him a digital personal travel assistant at hand

Our system uses two guidance concepts: maps and textual instructions. Tiny screens and scarce resources make the use of maps on mobile devices a challenging task. We opted for a simplified presentation that includes only data that is relevant for the chosen route like floor plans, walkable regions, calculated route segments, gateways, signs and optional orientation marks. Therefore the maps are generated dynamically out of the geographical model. For outdoor areas existing data like city maps or ortho-photos can be adopted.

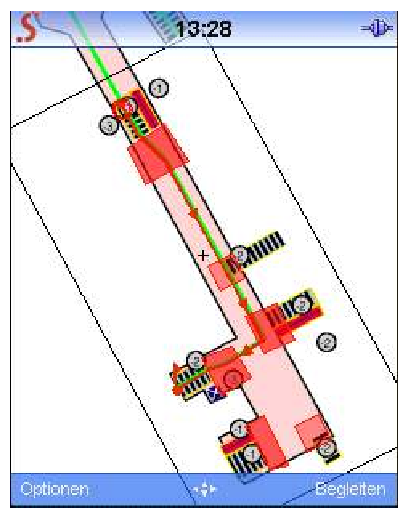

Fig. 1: Navigable maps on the Smartphone

Regarding the instructions it was important to us to avoid simple turn-by-turn instructions that are solely based on geometric information of the form "Walk nine meters straight and turn left."

Instead instructions should be more natural sounding and contain references to objects in the scene space in order to improve the interaction of pedestrians and the environment. Referenced objects can be gateways, signs or orientation marks. The generation of route instructions is based on a set of standardised text building blocks which allow us to create appropriate path descriptions for most cases. For complex scenes it is possible to link manual route directions to a specific path segment that will be integrated. This basic path description is combined with information from nearby landmarks and signs that are stored in the database. This way it is possible to reference signs that do not explicitly refer to the traveller's destination but point at the right direction. In this fashion we are able to automatically generate instructions like "Walk to the lower end of the stairs marked with the sign 'Neubaugasse'. Walk up the stairs."

6. Positioning

The proposed system is able to guide travellers by a list of step-by-step instructions. Manual acknowledgement of passed route segments is necessary. However, we feel that automatic positioning increases convenience of use and improves orientation.

For indoor positioning there exist numerous different approaches that vary greatly in terms of accuracy, cost and used technology ([11], [16]). In order to be applicable for our scenario we determined the following criteria:

- to provide high enough accuracy to determine the region where the user is currently in
- to have broad support of end user devices (Smartphones)
- to work without (GSM-)network connection
- to be cost effective
- to require little installation effort

We opted for a Bluetooth based solution, because it met our requirements most closely. First of all a great share of the Smartphones sold today incorporate this technology and thus will support automatic positioning without additional hardware on the client side. Furthermore we felt confident to reach a high enough accuracy for providing orientation and useful instructions for the wayfinding process.

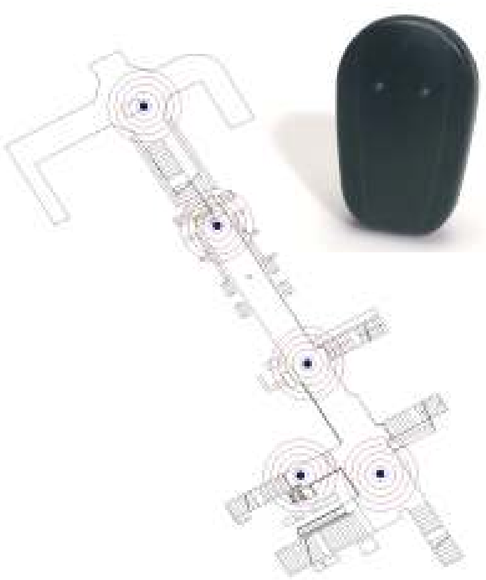

Fig. 2: Bluetooth beacon and plan of beacon positions

Most of the commercially available location systems based on Bluetooth (e.g. [23], [15], [2]) use an infrastructure of interconnected Bluetooth access points. These access points permanently execute inquiries in order to detect nearby Bluetooth devices. Once discovered, their location is determined on the server side and appropriate information is pushed onto the detected device. In large public transport stations, however, it would be very resource consuming or even impossible to install a LAN interconnecting the access points.

Our approach to a cell-based positioning system makes use of a client-side inquiry and a set of passive Bluetooth beacons. The Smartphone clients are constantly looking for beacons in the proximity that broadcast their unique ID. After receiving a beacon ID the client looks up the associated position information in

a list that is part of the building description. If all the relevant data for an interchange building is cached on the device, navigation will work without any network connection. This is a crucial requirement for underground stations suffering from low cellular network coverage.
The beacons utilised for this project (BlueLon Bodytags [2]) have an adjustable transmit power which makes them very flexible, because we can control the cell size. This way we are able to adapt it to the needed accuracy or to the room topology at hand (i.e. hall, room or corridor). Ideally cell sizes should be selected in a way that the covered area is not overlapping with other beacons, otherwise this would result in an ambiguous position.
Due to the signals' spherical propagation behaviour however, it is not always possible to completely separate individual cells (i.e. signals crossing floor bounds). To overcome this problem we exploit the data model's hierarchical nature and use knowledge from the calculated path as well as information known from history. In a first step we sort out detected beacons that are outside the current region. Furthermore we can determine a sequence of beacons that will be passed when walking along the calculated route. If still more than one beacon is seen and one of them is the next expected beacon, it is assumed that the user most probably moved one step further along the way. Likewise, if the next logical beacon is not found but the one following thereafter, we consider one beacon has been skipped.

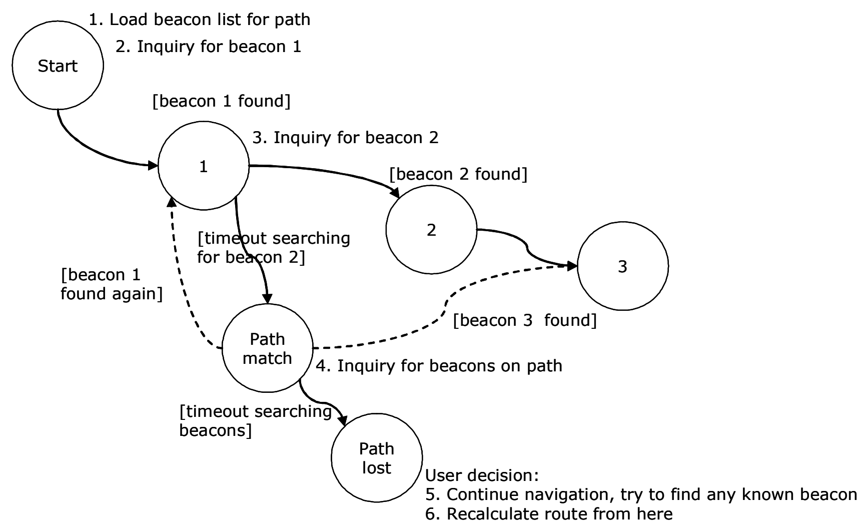

Fig. 3: Schematic overview of Bluetooth inquiry

Another challenging characteristic of the Bluetooth technology is the rather long delay from entering a device's transmit range until its actual detection. This can take up to 13 seconds and imposes a lower bound to the usable cell sizes, because a user may have passed the beacon without detecting it. However, most of the time beacons are found within the first five seconds [21]. Practical tests have shown that restarting the inquiry after this duration yields higher detection probability. Together with the fault tolerant mechanism outlined above we achieved a usable cell size of down to 4 meters which is sufficient for providing useful route instructions.
Outdoor positioning is supported as well through the use of a GPS receiver in combination with a route matching algorithm. Automatic transition from indoor to outdoor or vice versa is achieved through tagging regions with information on the positioning system. This approach works well for outdoor to indoor transitions, where the navigation application simply disconnects from the GPS receiver and starts searching for Bluetooth beacons. When leaving a building and entering an outdoor area however, we are facing the problem that currently available GPS receivers need an initialization time of about 30 seconds up to several minutes to deliver a reliable position. We try to address the problem by pretending to the user he is constantly moving along the calculated route until we are able to determine the exact location. In most of the cases this behaviour will lead to better results, because there is the chance of leaving the shadowed area during walk.

7. Implementation

In this section we give some implementation specific details on the prototype application called the personal travel companion. The application is split up in a server side and a client side part. For the multimodal trip planning on the server-side we use the Intermodal Journey Planner [17]. This service was adopted for calculating pedestrian routes and providing maps, path descriptions and data of interchange buildings. Communication between client and server or vice versa is done via XML. Maps are delivered as geo-referenced bitmaps and can be split up in single tiles in order to improve loading times.

The client running on the Smartphone is realized with J2ME. The test platform was the Off-the-Shelf Smartphone Nokia 6630. A micro browser is used for interaction with the journey planner and rendering server-generated pages containing an XML-based markup language . The markup pages may contain anchor elements for small functional modules called Smartlets that extend the browser's functionality. This mechanism guarantees a trade-off between server-generated user interfaces where design and content is easily exchangeable and additional functionality which allows for better use of local resources.

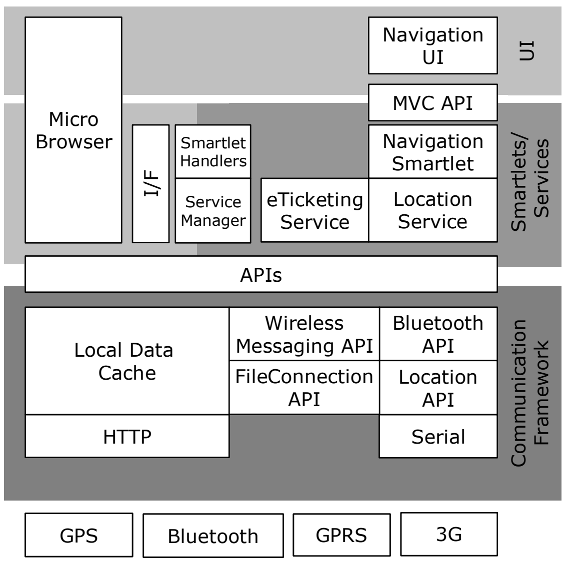

Fig 1: System architecture of the J2ME-Client

The navigation module called Navigation Smartlet is implemented to use a local data cache for accessing trip data. The cache decides whether trip data is locally available on the Smartphone or it has to be fetched from the server. This mechanism allows for preloading of data for a whole journey or at least parts of it. The Navigation Smartlet then gets the user's position from the location service that is fed by several location providers. Once the traveller's position is known the Navigation Smartlet determines the associated region and route segment and presents the map and route instructions to the user.

8. Conclusion and ongoing work

Smartphone-based pedestrian navigation can provide orientation and guidance not only to public transport travellers. During summer we conducted a small user survey with an early prototype of the personal travel companion and an amount of about 20 participants. Their technical proficiency ranged from sketchy to profound.

The participants were asked to navigate along three pre-calculated routes, one of which was located completely indoors, one led from an outdoor starting point to an indoor destination and one incorporated an indoor to outdoor transition. Most people found the provided maps useful for orientation. The automatic transition from indoor to outdoor or vice versa was on of the most astonishing features. Although we were facing some technical problems, the participants liked the idea to be continuously guided from a bus stop to certain rooms inside buildings.

We are planning a larger survey in the Vienna underground tram station Matzleinsdorferplatz in the middle of October in order to test the system in a larger test setting and to get profound feedback from a larger group of participants.

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