Assisting orientation and guidance for multimodal travelers in situations of modal change

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***Abstract*— Increasing the share of multimodal journeys will be necessary for society to guarantee a high level of mobility given current growth rates. However, while car drivers are already assisted by advanced guidance and navigation facilities, continuous on-trip assistance for multimodal travelers is still in its infancies. Especially when it comes to situations of modal change, travelers get discouraged by increased complexity and missing information and guidance. Thus, our goal is to develop a palm-based personal travel companion for multimodal travelers. The work presented in this paper especially focuses on pedestrian orientation and guidance in complex public transport interchange buildings.**

I. Introduction

TODAY'S increasing volume of motorized individual traffic can not only be accomplished by building new road infrastructure or by using more intelligent traffic management systems. To guarantee a high level of mobility for the long term, a shift towards an increased use of multimodal transportation is necessary. However, while more and more car drivers are assisted by advanced guidance and navigation facilities during their ride, traveler journey assistance for public transport systems is often poor or not available. Whereas multimodal trip planning via Web-based information systems in the pre-trip phase is commonly available, on-trip assistance for the planned trip (including trip information, guidance, orientation) is still an open issue. And especially when it comes to modal change, the situation for travelers becomes complex. Usually, many different information systems provide information at different levels of quality on totally different user interfaces. There exists no integrated traveler assistance system for palm use providing on-trip information during the whole journey. Thus, travelers often feel more comfortable with staying in their cars and being guided to their desired destination by the in-car navigation system, instead of using a possibility to change to other means of transportation.

In the Open-SPIRIT project, a consortium of Austrian and German transport associations, research organizations and companies, led by the biggest Austrian public transport association, the Verkehrsverbund Ost-Region, develops an on-trip personal travel companion for multimodal journeys. The goal is to overcome the deficiencies in passenger guidance and information in public transportation systems and to encourage more people to take advantage of multimodal transportation.

This paper is focused on the aspect of improving information and orientation for passengers in situations of modal change. Experiences with underground stations in Vienna show that the static guidance systems (signposts) are not always sufficient. Moreover, with these guidance systems, a personalization of information for the individual journey cannot be accomplished. Thus, we propose an integrated application of multimodal trip planning, multimodal trip information and outdoor as well as indoor passenger guidance for the use on Smartphones.

II. Situations of ModalChange

Typically, before starting a journey, people use trip planning software in order to plan and inform themselves about traveling from address A to address B. Recent multimodal trip planning systems [19] are able to calculate trips, consisting of different trip parts, e.g. one by car, one by underground, one by bus and at least a pedestrian path to the destination address. We define a situation of modal change as the transition between two (different) transportation means used on two following trip parts [14]. This transition is typically done by walking, however, e.g. for handicapped people it can also be necessary to do this transition with a wheelchair.

Concerning multimodal trips, we distinguish between five different situations of modal change:

-Changing from individual transport to public transport
-Changing from walking to individual transport
-Changing within public transport system
-Changing from public transport to walking
-Changing from walking to public transport

Depending on the situations of modal change, passengers can be provided with different information and guidance support. For changing from individual transport to public transport, information on park and ride facilities, on the departure of the public transportation vehicle and on the pedestrian route from the car to the station or platform is necessary. Returning from an public transport journey part requires assistance for retrieving the parked car. For changing within public transport, travelers have to know in

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which station to change, where the next public transport vehicle leaves, when it leaves and how to find the way from one platform to the other one. Changing from public transport to a footpath requires finding the right (nearest) exit of the station and the shortest footpath to the destination address. For changing from footpath to public transport, the calculation of the nearest station, which is connected to the destination station, is necessary. Moreover, the system has to assist with public transport information, the departure time of the next vehicle and orientation on the pedestrian route to the nearest station.

As is obvious from the examples above, navigation and orientation plays an important role in situations of modal change. While many of the situations require outdoor pedestrian navigation assistance, there is also a need for indoor guidance in complex station buildings like underground stations. For outdoor pedestrian navigation existing systems based on GPS[1] can be used, however, guidance and navigation in buildings is still subject of research.

In this paper we describe an approach for a pedestrian guidance system for public transport interchange facilities. We begin with an overview of related work. We continue with specific requirements and describe the prototype including implementation issues; we finish with conclusions and ongoing work.

III. Related Work

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

The human navigation and wayfinding process is based on concepts of human cognition [3],[7]. Rüetschi and Timpf [16] 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 modeled by the schematic geometry, which is based on image schemes [10] and affordances [6]. In another study Fontaine und Denis [5] analyze 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 by May et al. [12] in a requirement study of pedestrian navigation. Thus, our approach considers signs as navigational aids in the generation of maps and guidance instructions on the Smartphone.

There are many pilot projects which address different topics of pedestrian navigation, like user interaction, positioning, cartographic visualization and data transfer. REAL [1] and M3I [11] are developed for indoor and outdoor environments. REAL describes a hybrid navigation system that adapts the presentation of route directions to different output devices and modalities. M3I presents an approach that connects a variety of specialized user interfaces to achieve a personal navigation service spanning different situations. LoL@ [13] and TellMaris [17] are pedestrian navigation systems which operate on Smartphones. However, as far as we know, there is no existing pilot system, which focuses on guidance of public transport passengers in interchange facilities.

Concerning indoor positioning technologies, most of the prototypes are based on Infrared, WLAN or Bluetooth [9], [11], [18], [4]. 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. In our approach the main requirements were defined by an easy and cheap installation procedure and the use of Off-the-Shelf Smartphones.

IV. Requirements for Pedestrian Navigation in Situations of Modal Change

Recent research in pedestrian navigation has mainly focused on providing turn-by-turn instructions for pedestrians on mobile phones [12]. In outdoor environments, this approach is quite useful, however, indoor guidance in public transport stations affords different requirements, because in these building typically a static guidance system with signposts is available. We have identified a number of user or system requirements.

Firstly, wayfinding during multimodal journeys can be distinguished by the space in which it takes place [15]. Traveling within the public transport system takes place in the network space of public transport lines. The main property of the network space is that it is completely fixed in space and time by means of a timetable. Wayfinding in public transportation buildings takes place in the scene space, which ties together the public transport network. Wayfinding tasks in scene space are mainly controlled by the surrounding environment and possible interconnections of the transport network.

Secondly, detailed geographic data for multimodal route calculation and guidance has to be acquired. In outdoor environments, pedestrian navigation typically takes place on the street network, however, for improved pedestrian routes also the street-independent footpath network is necessary. For continuous route calculation footpaths and streets have to be connected to the public transport network. Data acquisition is even more complex in public transport interchange buildings. Route calculation and pedestrian navigation has to consider different floors of these buildings, the possible pedestrian routes, the character of these routes, the gateways between floors and the surrounding street- or the public transport network. Moreover, to give information

[1] http://www.wayfinder.com/products/product_en.php?id=1

related to the scene space, relevant objects such as signs and special "landmarks" like ticket machines, closed areas or shops have to be included. In any case, the effort for data acquisition should be manageable by the public transport operator.

Thirdly, pedestrian navigation should be accessible throughout the whole interchange situation including outdoor and indoor navigation in order to allow for continuous passenger orientation and navigation. Especially the transition from indoor to outdoor or the other direction has to be considered. Issues like different positioning technologies, availability of geographic data, network access or route descriptions have to be addressed.

Fourthly, the navigation service should be integrated with a travel assistant available on Off-the-shelf Smartphones. This means, that only resources typically available on a standard Smartphone should be used for implementing the traveler assistance application.

Finally, the real value of a travel assistant is the personalization of the service. This means, that information from the network and scene space is only used for passenger guidance, if the information is relevant for a passenger. For filtering relevant information the selected route and personal preferences can be used.

V. Concept for an Indoor Pedestrian Navigation Application on Smartphones

Our concept for a multimodal travel assistant application focuses on two main aspects. Firstly, we provide mobile access to a server-based multimodal trip planning system, which can be used for calculating or accessing pre-calculated multimodal trips from a Smartphone. Secondly, we provide an off-board navigation service included in the travel assistant, which allows for orientation and navigation of pedestrians on pedestrian routes included in multimodal journeys.

For the following description of the concept we focus on four main aspects of the system, namely data, route calculation, guidance and positioning.

A. Data(in Scene Space)

Concerning the data necessary for pedestrian navigation in public transport buildings we distinguish the following data categories building a hierarchical representation of the scene space [16]:

-Building
-Floors
-Regions
-Gateways
-Items

The logical modeling of buildings is the main difference compared to outdoor navigation. Public transport stations can have floors lying on top of each other, which makes a logical modeling of these floors necessary in order to position pedestrians, to show maps of the building and to give correct instructions. All the data gathered from the scene space like regions or items has to be linked to the corresponding floors. The modeling of regions is mainly used for drawing the maps. In combination with a cell based position system we can also determine the region, where a user is located.

Gateways connect regions. Typical representations of gateways are stairs, elevators, escalators or ramps. For better orientation it can be necessary to collect data of certain items in the scene space. These items can be signs, ticket machines, shops etc. Items can either afford a user interaction like ticket machines, or they can be used as orientation marks like signs. Items are mainly used to provide a better interaction between wayfinders and the scene space.

B. Route Calculation (in Network Space)

Multimodal route calculation is done between two points. These points may be addresses, entrances of a POI (point of interest) or a coordinate coming from a GPS-device. The complete route is calculated on the public transport network, the street network and the pedestrian network. Often pedestrian routes are identical with streets. All networks together build the integrated routing network. The transitions between the networks take place at the stopping points of the public transport. To access public transport, pedestrian routes to entrances of stations and within the station to the platforms are needed for route calculation.

For the calculation of pedestrian routes inside of buildings we use a specific pedestrian network. This graph-based network consists of nodes and segments and has to be modeled manually. To each node or segment certain attributes are assigned, which are used for route computation and generation of wayfinding instructions. Nodes are marked with a floor number. When a path is computed, the ordering of floor numbers provides details, whether the segment between two nodes leads up or down.

Segments have type attributes. The type attribute can be ordinary path (even level), stairs, escalators, elevators or ramps. With this information we are able to realize a selective route computation on basis of personal demands in order to optimize interchanging time, route complexity or walking effort [8]. Additionally, each segment has to be tagged with a direction, because of the possibility, that escalators are only available in one direction or the direction can be changed. Especially for wheel chair users it is also important to acquire single steps or the grade of ramps.

Another important attribute is the time needed to walk along a certain segment. The complete time for the interchange has to be considered for continuous route calculation. In order to provide personalized interchange times, we use time factors for each path. During the route calculation these time factors are multiplied by the default velocity settings in the traveler's personal profile.

In order to give travelers detailed, personalized information for orientation inside the building, we have collected description data about existing signs. These signs are linked to the segments. Having computed a route, the relevant signs are selected and the corresponding text is included in the route description. Guidance is supported with references to these signs.

Guidance and navigation described in the next section is based on the computed footpaths together with the attributes which belong to their segments.

C. *Guidance*

We defined guidance as an information technology based tool, assisting pedestrians in their wayfinding process, which means a purposeful interaction with an environment, where the purpose is to reach a certain place or goal [15]. The main goals for a guidance system in public transport interchange buildings are:

-to select an optimized footpath given a starting public transport stop or address, a destination public transport stop or address and certain parameters

-to select the most relevant information out of the scene space based on the calculated footpath and personal settings in order to improve the interaction between wayfinders and environment [3]

-to give instructions for pedestrians in order to optimize their interchange and to improve their orientation

-to reduce complexity of interchange buildings by giving travelers a personal digital travel assistant at hand.

Our system uses two main guidance concepts: maps and instructions. Maps are generated dynamically out of the GIS data. For the generation of maps we use only data relevant for the calculated pedestrian route like floor plans, walkable regions, calculated route segments, gateways, signs and optional orientation marks.

a) b)

Fig. 1: Map examples a) Outdoor b) Indoor

The instructions for wayfinding are linked to directed segments. We use a set of standardized text building blocks, which describe a segment in one and the other direction. For the generation of instructions we combine these building blocks and add additional information from linked signs. An instruction could be “Walk to the lower end of the stairs marked with the sign ‘Neubaugasse’. Walk up the stairs.”. The instruction in this example can be generated automatically. All the information is available as attributes in the footpath network.

The most relevant aspect of the guidance system is that we do not use a simple turn-by-turn guidance based on geometry, where pedestrians are told “to walk five meters straight and then turn left”. Instead instructions contain referenced objects of the scene space in order to improve the interaction of pedestrians and environment. Referenced objects can be gateways, signs describing a certain entrance or kind of orientation marks marking a decision point.

D. *Positioning*

For wayfinding in complex interchange buildings, we give step-by-step instructions, which can be manually acknowledged by the pedestrian after reaching the decision points. However, to improve orientation, we think, that a kind of automatic positioning of pedestrians will be useful. Many different indoor positioning technologies exist ([9], [12]). We have decided on positioning based on Bluetooth Inquiry. The main goal for the decision was the broad availability of this technology on recent Smartphones. Furthermore, we believe that cell based positioning with carefully selected and variable cell size provides sufficient accuracy for giving orientation and useful instructions for the wayfinding process.

Positioning with Bluetooth beacons allows us to determine the user's current position and thus we are able to map the person on the segment of the route crossing the region. Bluetooth beacons have a unique identifier and are referenced with the same coordinate system as the GIS data. By selecting the current segment on the pedestrian route we can provide passengers with maps and instructions related to their current position and their personal route.

Most of the commercially available Bluetooth location systems (e.g. LOCON[2], Lesswire[3], BlueLon[4]) use a networked infrastructure of interconnected Bluetooth access points. The access points permanently execute inquiries in order to detect Bluetooth devices. The current location is determined on the server side and the appropriate information is pushed to the corresponding device. However, in large public transport stations, it will be very resource consuming or even impossible to install a LAN for connecting the access points. Thus, our approach is based on a client-side inquiry. Smartphone clients are permanently looking for visible Bluetooth beacons. In case all relevant data for an interchange building is cached on the device (including maps, beacon list, route segments, segment descriptions), off-board navigation will work without any network connection. This is often a crucial requirement for underground stations suffering from low cellular network coverage.

Another problem described in literature [2] is the very long inquiry time (~ 10s) for Bluetooth devices. Most of the devices respond faster but inquiry has to try to find devices within this fixed time period. This reduces position accuracy.

[2] http://www.3united.com
[3] http://www.lesswire.de
[4] http://www.bluelon.com/

We try to solve the problem by termination and restart of the continuous inquiry after 5 seconds and by combining knowledge about the calculated path and information known from history. Among the relevant route data, we have an ordered list of beacon IDs along the directed path. For navigation we therefore have the knowledge about the beacons' sequences. This allows us to improve the inquiry process and provides for more reliable and also faster detection of valid path segments.

The navigation algorithm is modeled as a state machine, doing transitions from one state (beacon) to another allowed state. If the user leaves the calculated footpath corridor, we use a timeout setting for the state transitions. If we do not see the expected Bluetooth beacon within a specified time period, we go to the state “undefined position”. In this state we inform the user that the calculated path was left and ask, what to do next. “Continue navigation” continues the inquiry, until we come back to a defined state. “Recalculate trip” tries to calculate a new trip on the server from the current position to the original destination.

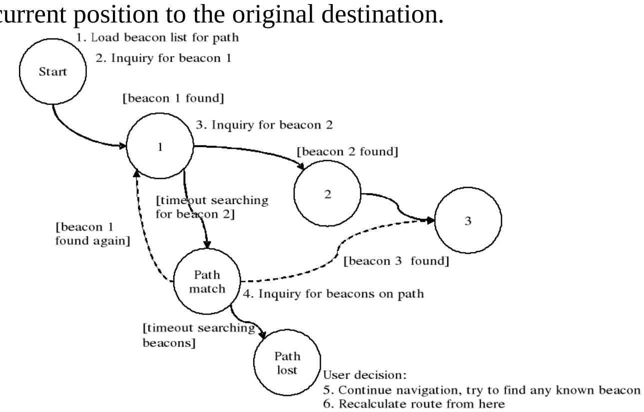

Fig. 2: State transitions of navigation algorithm

For outdoor positioning we use GPS. The transition from outdoor to indoor or vice versa can be done automatically, since the supported location mode is stored as an attribute of regions. The user’s position is always determined by WGS 84 coordinates. This guarantees interoperability between indoor and outdoor navigation and simplifies data acquisition. In addition to the coordinate mappings for beacons we have to consider the floor number.

VI. Implementation

As mentioned before, the Open-SPIRIT project consortium has defined the goal to develop a personal travel companion for multimodal journeys on Smartphones. We have decided on using a hybrid mobile application with one part of the application running on the Smartphone and the other part running on the server. We use a service-oriented architecture on the server, which means, that all modules are implemented and executed as Web-Services. Requests from the clients are processed by a server-side business process called Travel Agent. This business process decides which services to execute. The main functions on the server are media transformation, multimodal trip planning and map generation.

As a provider for the multimodal trip planning we use the IJP (Intermodal Journey Planner) from Mentz Datenverarbeitung GmbH[5]. This existing service was adopted for calculating pedestrian routes and for requesting trip information, maps, descriptions of route segments and descriptions of interchange buildings. Maps are delivered as bitmaps with metadata concerning the geo-references and also the floor numbers (for indoor maps). Maps are split up in tiles and it is possible to request single tiles in order to improve loading.

The client part is realized with J2ME. The building blocks on the client are:

-a micro browser for interaction with the multimodal journey planner and presenting server-calculated journeys information

-a plugin mechanism for the micro browser to start specific extension modules (Smartlets and Services)

-a navigation plugin (Navigation-Smartlet) for handling all navigation specific user interactions

-a location service and two different location providers for automatic location acquisition

-a local data cache for caching trip and navigation relevant data (necessary for offline use)

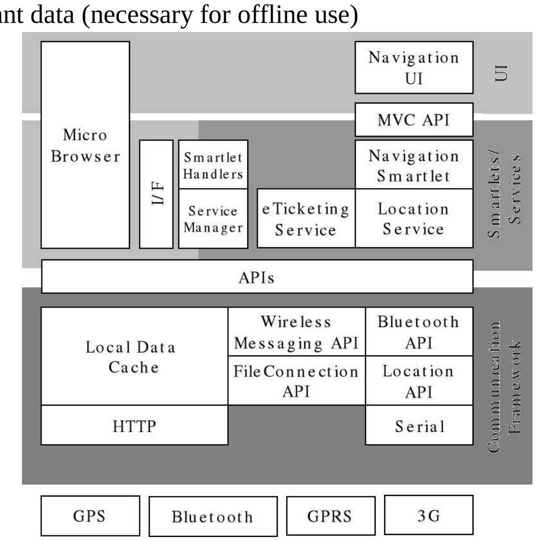

Fig. 3. Overview of the J2ME-Client Architecture

The main interaction concerning trip planning and viewing trip information on the client is done via a micro browser. This micro browser allows rendering of server generated pages similar to xHTML pages. However, advanced functionality on the client can not be handled appropriately by a standard xHTML browser. Thus, the browser is enabled for handling small functional extension modules called Smartlets. Smartlets are referenced in the markup language by proprietary tags. Upon activating a Smartlet link, the micro browser starts the corresponding Smartlet and hands over the control to this module. This mechanism guarantees a trade-off between server-generated user interfaces, where the design is easily exchangeable and additional functionality, which allows using local resources like

[5] http://www.mentzdv.de/en/produkte/efa.htm

positioning technologies on the Smartphone device.

One of these Smartlets is the Navigation Smartlet. The Navigation Smartlet asks the local data cache for the journey data of the current trip. The local data cache either uses locally stored data or fetches data from the server. This mechanism allows for preloading all the data for a whole journey or at least for one interchange building. Different strategies for preloading of data are possible.

The Navigation Smartlet performs the entire map rendering itself and communicates with locally available positioning providers like GPS and/or Bluetooth providers. Communication with Bluetooth is implemented using the Java Bluetooth API (JSR-82), which is available on recent Smartphones like the Nokia 6630. Communication with the GPS receiver is done via the NMEA protocol over a serial Bluetooth connection.

A typical execution of the Navigation Smartlet is:

1. Determine the active journey part from the parameters passed via the Smartlet call
2. Load a list of instructions for the pedestrian route from the local data cache
3. Try to determine the current position automatically via the location provider (Bluetooth or GPS)
4. Try to match the current position with the calculated footpath corridor
5. Get a map for the determined location from the local data cache
6. Render the map on the display and draw the current position on the map
7. Display the wayfinding instruction for the current position of the user
8. Repeat steps 3 to 8 until the user reaches the destination or exits navigation

Without automatic positioning, the user has the possibility to scroll maps manually and to switch to other floors by selecting marked gateways on the map. Moreover, users can also jump step-by-step through the instruction list and match the instructions with their actual position manually.

VII. Conclusion and Ongoing Work

Barriers in situations of modal change are omnipresent and prevent people from changing means of transportation. Surveys among travelers have shown, that the rate of multimodal transport compared to individual transport can be significantly increased with the availability of an integrated, personal travel assistance, which allows for continuous information and guidance.

In this paper we described an approach for a guidance system for complex public transport interchange buildings. The main goal of the system is to simplify situations of modal change by providing continuous guidance and orientation, by reducing interchange times and by optimizing pedestrian routes. Moreover, the personalization of these routes is possible.

A pilot test of the system in the Vienna underground tram station Matzleinsdorfer Platz will allow us to get feedback on the usefulness of applied guidance instructions and orientation maps. We organize a test setting, where travelers can be guided from one tramway stop to another under consideration of their personal preferences. We also use the test for getting experiences with our approach for Bluetooth positioning in a large interchange facility.

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