Navigation of blind and visually impaired people

Smartphone-assisted navigation and crossing of signalized intersections using Car2x Communication technologies

Smartphone-assisted navigation, intra-urban mobility, handicapped persons

The mobility of the blind and visually impaired is associated with many barriers and risks. To secure crossings, signalized intersections are partially equipped with acoustic or tactile indicators. However, environmental conditions might interfere with the acoustic identification of the green time. Furthermore, information such as intersection topology, bicycle traffic or the curb structure is not accessible to visually impaired road users. Therefore, most trips are limited to trained routes. Within the research project InMoBS (intra-urban mobility support for the blind and visually impaired) a prototype of a route planning and navigation system has been developed and evaluated in an exploratory manner.

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To identify technical and functional requirements and to meet the user needs, a requirement analysis was carried out that considered the pre- and on-trip functionality of the assistance system. In this process different techniques like in-depth interviews and video documentation of typical street crossing situations provided important implications for the engineering of a web-based route planning and mobile navigation assistance system. The collected qualitative results have been verified as effectively as possible by an online survey of 719 visually impaired and blind users. Extracts of the most important functional and technical aspects are qualitatively summarized in the following.

The functionality of a web-based pre-trip route planning tool for the given user group is basically similar to already established and well-known online routing services used by people without any visual impairment. However, to ensure content interaction that is compatible with the use of a keyboard and braille terminal, specific accessibility guidelines need to be applied [1]. Moreover, standard routing services mainly allow a shortest-path routing [2] that minimizes the total costs (i.e. geometric route distance) between two nodes of a road network. Typical underlying road network models are primarily designed for turn-by-turn vehicle navigation. In this case network topology and geometry are modelled in a very simplified manner [3]. The existence of sidewalks needed for pedestrian navigation is usually logically generalized information linked to the modeled intra-urban street. Compared to this standard approach, a routing system for blind and visually impaired users requires a much more detailed network model [4] that allows the explicit modelling and attribution of sidewalks and intersections with a high spatial resolution. As a minimum, the routing calculation needs to take parameters like accessibility and route distance into account, and the accessibility level should cover aspects like the availability of acoustic or tactile indicators at signalized intersections and the existence of pedestrian crossings. In addition, obstacles and points of interest tagged during the user's daily mobility should be incorporated in the route planning, which will allow not only the exclusion of dangerous walkways, but also the planning of the route to cover supportive waypoints. Last but not least, users desire a storing functionality that simplifies the use of regularly used routes.

When talking about the needs of on-trip assistance, blind and visually impaired test persons often reported feeling uncertain in heavily motorized, complex intra-urban intersection scenarios, especially on intersections with asymmetric geometry. Traffic noise masks potential orientation signals at intersections. Missing information about curbs or mostly lowered curbs without tactile indicators makes it very difficult to securely identify the transition line between the sidewalk and the street. Therefore complementary and seamless mobile assistance is needed to compensate for these factors and provide the users with important situational information. Apart from the above-mentioned aspects, the availability of a continuous and reliable direction indicator, the current position (street name and number) and nearby POIs during the whole navigation are some of the most important requirements users brought up during the surveys. This multifaceted list of information and functionality, reported by the users, clearly emphasizes the need for a sophisticated prioritization of the information provided in order to avoid a mental overload during the navigation process.

Basic system design

Based on these requirements a system architecture composed of smartphone navigation "InMoBS mobile", web-based route planning "InMoBS home", server-sided routing and Wi-Fi-equipped traffic lights has been developed (*figure 1*). Within this architecture, a Component Server Platform (CSP) acts as a central information provider that supplies calculated routes on a high-precision digital map. The digital walkway network has been generated by processing standardized land register data from the city of Braunschweig. Three Wi-Fi-equipped traffic lights, as a part of the AIM-infrastructure [5] allowed for a unidirectional communication of real traffic signal states and timing, queried with a frequency of 1 Hz. For

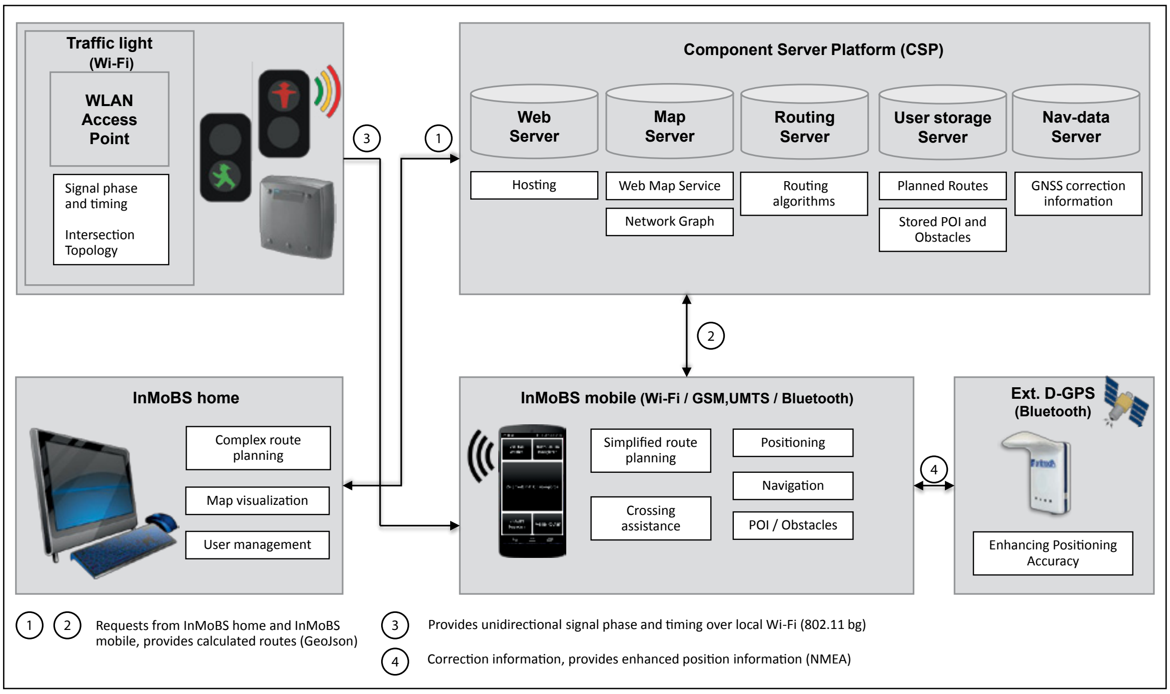

Figure 1: Basic system architecture and communication interfaces

communication purposes, a standardized protocol stack [6, 7], originally designed for 802.11 p vehicular communication, has been adapted to consumer Wi-Fi (802.11 b/g) enabled devices. To obtain more reliable and accurate position information in urban areas, a Google Nexus 5 smartphone was connected via Bluetooth to a small external differential GPS (Global Positioning System), which could be fastened on the upper arm of a test participant. In urban areas, the positioning system (Alberding A07) reached an accuracy of 1.3 - 2.2 m (1σ), depending on the surrounding environment and satellite constellation.

Smartphone application

"InMoBS Mobile" is the digital companion of the blind or visually impaired and guides the user safely to the chosen destination. In the scope of an iterative development process, blind and visually impaired participants were invited to test the app at various development stages. Their feedback was used to design the app's human machine interface (HMI). Several approaches were tested and led to the final interface, which is based on a simple layout scheme of five tiles used throughout the application (*figure 2*). The app's main menu offers the user the option to start a navigation process based on current position and desired destination (point of interest, street and house number). Furthermore, the user can select a previously defined route, stored by using the web-based route planner "InMoBS home". The route is calculated on the server, transmitted to the cell phone via mobile internet connection and handed over to the app's navigation process (see *figure 1*). The downloaded route allows the app to execute a sophisticated navigation algorithm that keeps the users on track, provides information about the surroundings and supports them in street-crossing situations.

Figure 2: Test participant (left) and InMoBS Mobile user interface

Route guidance

The computed route represents a safe path to the destination. Deviations from this path may result in dangerous situations such as leaving the sidewalk and entering the vehicle lane. Accordingly, helping the user to remain on track is important. At any time during the navigation, "InMoBS mobile" helps the user to align the direction of movement with the help of vibration impulses, emitted by the smartphone, similar to the approach suggested by Pielot et al [8]. The impulse frequency indicates the extent of the deviation from the correct heading. The higher the deviation, the higher the impulse frequency. The actual heading is determined by using the smartphone's magnetic compass or internal GPS, whereas the desired heading can be obtained from combining the routing data with the user's current position. In addition to this instant feedback, the app provides turning information by automatically notifying the user of upcoming curves using speech output, hence allowing the user to prepare for a direction change in advance.

Information about surroundings

Navigation in unfamiliar areas is a challenging task for the blind and visually impaired. Orientation is difficult, and unknown obstacles are a dangerous threat. To support the user in such situations the app supplies pre-stored information about important or interesting points and obstacles. The location and other information about these so-called 'points of interest' (POI) are part of the digital map. Public POIs, like museums, supermarkets and bus stops, are available to all users, while private POIs are only related to a single user. The app provides functionality to add private POIs and annotate them using speech input. When the navigation is started, the smartphone receives data about public and private POIs along the route. During navigation, information about a POI is provided automatically when the user approaches the POI's location. Furthermore, the user can request information about nearby POIs and POIs that are located along the remaining route. The speech output includes a description as well as the distance and bearing of the POI relative to the user's position and heading.

Crossing support

When the user approaches a crossing, crossing properties are announced automatically, for instance the type of crossing (signalized or unsignalized), the crossing distance and the availability of an acoustic or tactile indicator. The app indicates how to reach the waiting area and warns the user of crossing bicycle lanes. Acoustic information output can also be triggered manually using the accessible app interface. While standing in front of the street crossing, the haptic impulses allow the users to align their direction of movement. The Wi-Fi-equipped signalized intersections are broadcasting SPaT and TOPO messages (see *figure 1*). Based on these messages and the route information, the current signal phase of the crossing can be determined by the app. When the user has safely reached the waiting area and is ready to cross the street, the app monitors the crossing's signal state and emits an acoustic green light indicator as soon as the traffic light switches to green. No signal is given in case the user enters the waiting area within a running green time interval. In such cases, the user needs to wait for the next cycle to ensure that the maximum green time interval is available.

Entire system evaluation

Sample

The entire system was evaluated between 16 September and 23 October 2014 by a group of blind and visually impaired test persons. The realization effort for the tests and the extent of support that this specific group of users required during the test phase were relatively high. This resulted in a comparatively small sample (N = 8) and an exploratory, qualitative system assessment.

All participants (four women and four men) lived in Braunschweig. Contact was established by the Deutscher Blinden- und Sehbehindertenverband e.V., the German Federation of the Blind and Partially Sighted. All subjects had previously completed trainings in orientation and mobility. Participation was voluntary.

Five of the participants were blind (63 %) and three were visually impaired (38 %). The mean age was M = 60.0 years (Min = 44, Med = 63.0, Max = 67, SD = 8.1). 50 % (n = 4) of the participants had basic knowledge of working with tactile cards and smartphones and 63 % (n = 5) had experience with navigation apps or navigation devices. All users had basic knowledge of working with computers or laptops, as well as with tools for computers or laptops for blind and visually impaired and the Internet.

Procedure

The blind and visually impaired participants walked a 1,900 m long section of the ring road of Braunschweig twice (*figure 3*). Each subject walked the route once with the support of the navigation system (test setting) and once without navigation system (comparison setting). The participants experienced a walk in the direction of traffic on one date and a walk against the flow of traffic on the other date. The combination of the characteristics of the walking direction (with and against the flow of traffic) and the use of the navigation app (with and without) resulted in four study settings. The subjects were randomly assigned to these settings. The study design was fully balanced.

The route had different characteristics, which generally restrict the mobility behavior of blind and visually impaired persons in road traffic. There were some intersections with acoustic or tactile signal indicators and some intersections without these features. Loud traffic noise, traffic islands, bicycle lanes running in parallel to the sidewalk, different curb heights and, at one intersection, crossing tram rails further added to the difficulty of the situations.

In all study settings, the test walk started with a general explanation of the study process. Additionally, on the first date an informed consent as well as the participants' socio-demographic data were collected. In the study settings with navigation app, the examiner explained the operation of InMoBS mobile and InMoBS home to the participants. Then, the participants were given time for to practice the operation of the navigation device.

The computer for the operation of InMoBS home was equipped with tools for the blind and visually impaired (e.g. braille console). InMoBS mobile was installed on a smartphone. Through this, users were given

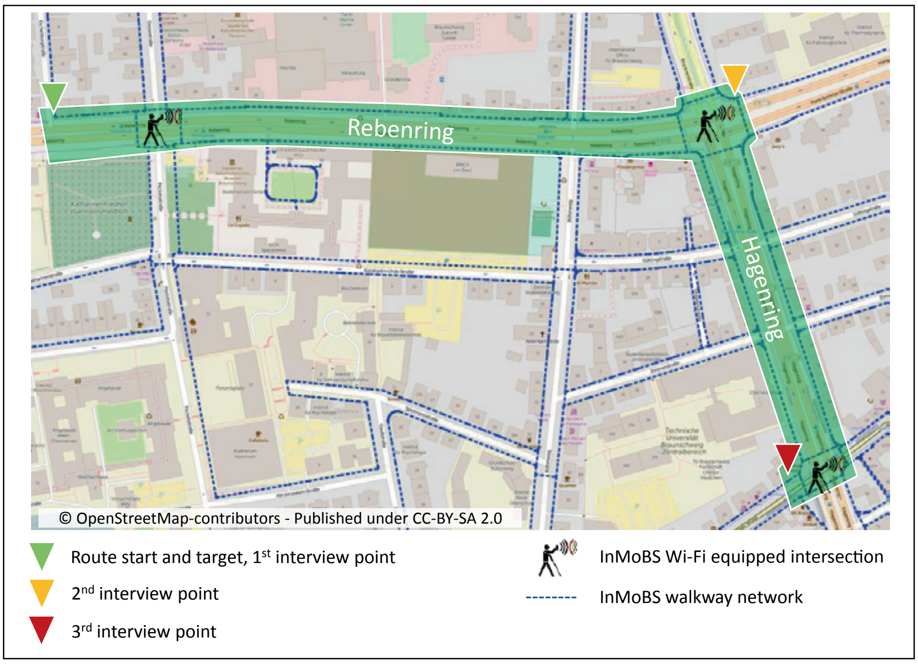

Figure 3: Overview of the InMoBS test site

acoustic and tactile information about the route and their own position. In addition, a Bluetooth speaker was used.

In the study settings with a navigation app, the users first enabled the route on InMoBS home. They then walked the route with the assistance of the navigation system. During the walk they added a POI to a position on the route. After completing the route, they were asked to rename this POI in InMoBS home. In the study settings without a navigation app, a tactile map or high-contrast map of the route was handed out to the participants. All participants were interviewed at three route points (see *figure 3*). The interviews were recorded with a voice recorder.

All participants were accompanied by at least one full-sighted research associate and at least one full-sighted student of the Technische Universität Braunschweig along the entire the route. An interview guide was developed for each study setting. The interviews included questions that could be answered on a 5-point scale of response, as well as open-ended questions. The participants were asked about their subjective experience with regard to managing the task of walking the route with and without a navigation app. The participants were also interviewed regarding general aspects of mobility. For example, one question was: "How well could you orient yourself about your position in respect to the entire route?" Participants were also asked what they thought were good and bad aspects of InMoBS mobile and InMoBS home.

Results

All participants positively evaluated the concept of the InMoBS system. The features of InMoBS mobile that provided the participants with information at intersections without acoustic or tactile signal indicators met with especial appreciation. The same was true for the announcement of bicycle lanes, as well as the option "Where am I?", which provided information about the current position on the route. The information content of the menu provided at crossings and intersections was also positively assessed. This menu offered information about traffic lights and acoustic or tactile signal indicators at the intersections, as well as the topology of the intersection and the names and number of incoming roads. Furthermore, intersection-specific information about traffic islands, tram rails, bus lanes and curbs was offered in this menu. The study participants especially liked the relatively autonomous operability and the orientation and navigation on the web page offered by InMoBS home. Almost all of the participants were able to handle the processing of tasks in InMoBS home. On the other hand, participants criticized the message delay caused by partially inaccurate positioning. Furthermore, sometimes the operation of both systems was difficult due to the lack of experience and training with the system.

Conclusion

The participants repeatedly expressed that the navigation app, with reservations regarding the localization problems, would considerably improve the quality of mobility for the blind and visually impaired. Also, the system would be suitable for providing assistance to additional groups, such as full-sighted elderly pedestrians. Thus, the next steps should be to develop the prototype further, including a larger area and the integration of public transport. ■

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