Metrol. Meas. Syst., Vol. XIX (2012), No. 2, pp. 245-256.

METROLOGY AND MEASUREMENT SYSTEMS

Index 330930, ISSN 0860-8229

www.metrology.pg.gda.pl

MOBILE NAVIGATION SYSTEM FOR VISUALLY IMPAIRED USERS IN THE URBAN ENVIRONMENT

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Abstract

This paper describes the prototype version of a mobile application supporting independent movement of the blind. Its objective is to improve the quality of life of visually impaired people, providing them with navigational assistance in urban areas. The authors present the most important modules of the application. The module for precise positioning using DGPS data from the ASG-EUPOS network as well as enhancements of positioning in urban areas, based on the fusion with other types of data sources, are presented. The devices, tools and software for the acquisition and maintenance of dedicated spatial data are also described. The module responsible for navigation with a focus on an algorithms' quality and complexity, as well as the user interface dedicated for the blind are discussed. The system's main advantages over existing solutions are emphasized, current results are described, and plans for future work briefly outlined.

Keywords: DGPS, navigation, spatial data, systems for the blind, user interface.

1. Introduction

The rapid development of satellite positioning systems, digital maps and mobile devices caused an unprecedented growth in the significance of navigation systems. Location-based applications are used in fields that were not in the area of developers' interest before. One of those fields is automatic navigational support for the blind. The first timid investigations were carried out several years ago [1-6] and were followed by commercial attempts to provide some usable solutions [7-9].

Existing solutions, both commercial and scientific, have some crucial flaws, which makes them not as useful as they could be. They are based on sets of points [9], or on maps, usually similar to car navigation maps [7], without many kinds of data needed by the blind. GPS receivers are used as the only positioning sensor [6-9], which causes inaccuracies in obtaining both location and a user's azimuth. Usually, dedicated hardware is used [7, 8], which increases the cost of existing solutions.

The authors propose that a more mature and inexpensive system can be developed, providing a tool for more independent movement for blind users. The key seems to be in better positioning accuracy, use of dedicated maps for blind users, and the creation of an easy-to-use interface based on a smartphone's touch screen. In the article, results of a current research and development project are presented.

2. System architecture

The system's architecture is presented in Fig. 1. It has two major parts: the Main system (also called navigation application), operating on an Android smartphone and a remote

Article history: received on Feb. 6, 2012; accepted on Apr. 17, 2012; available online on May 18, 2012.

Database, accessed via wireless internet connection. The whole system can be further divided into four modules:

1. Positioning (GPS Unit, Compass Unit and prototype Inertial Unit).
2. Spatial data, combining data from existing sources and dedicated data collected by trained operators.
3. User interface, based on the smartphone's touch screen and its speech synthesis capabilities.
4. The kernel, responsible for navigation algorithms.

All modules will be described in the next paragraphs.

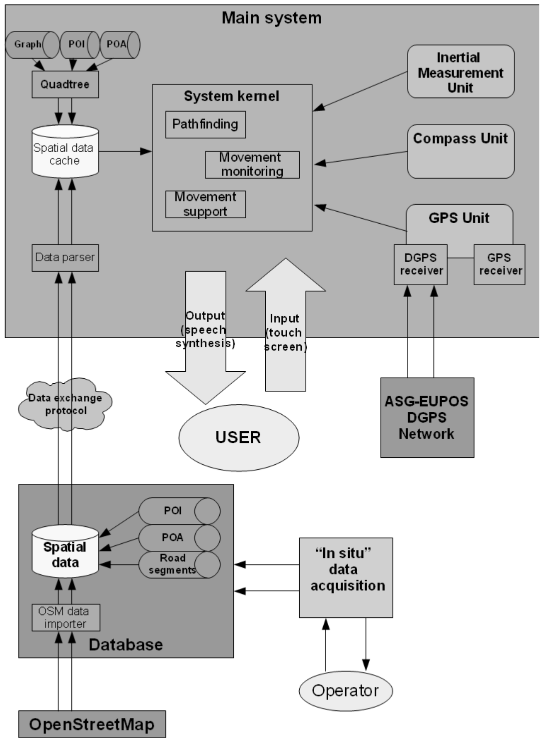


Fig. 1. Architecture of the system.

3. User positioning

Nowadays, satellite navigation is a non-negligible technology when developing an inexpensive, location-based system accessible for many people. Surveys conducted with the visually impaired, not only during the "Voice Maps" project, but also in other projects [6], proved that the accuracy of positioning is a key aspect of that kind of support system [10]. The desired accuracy should be at a level of few meters – depending on the actual application.

Adequate tests proved that positioning with inexpensive GPS receivers is often inaccurate and unreliable [6, 11], therefore, improvements of positioning accuracy are required.

3.1. Differential Global Navigation Satellite System

In order to improve the accuracy of positioning by a smartphone-based GPS receiver, the authors developed and implemented the Differential GPS (DGPS)-based module. A DGPS approach reduces some sources of errors occurring during the GPS-based positioning [12]. Among these errors one can distinguish the impact of ionosphere and troposphere effects, which could result in inaccuracies reaching tens of meters [12]. The implemented system uses additional information from Polish ground-based augmentation networks i.e., ASG-EUPOS [13].

The developed dedicated module was capable of providing position more accurately with the help of the ASG-EUPOS DGPS network. In Table 1, services, both real-time and post processing, available from ASG-EUPOS network are presented.

Table 1. Real-time and post processing services in the ASG-EUPOS System [13].

Real time services					
Service	**Method**	**Transmission**	**Accuracy**	**Format**	**Band**
NAWGEO	RTK	GSM/GPRS/UMTS, Internet	0.03m/0.05m horiz/vert	RTCM SC–104 v. 2.3, 3.0	L1/L2
KODGIS	DGPS	GSM/GPRS/UMTS, Internet	up to 0.5m	RTCM SC–104 v. 2.1	L1
NAWGIS	DGPS	GSM/GPRS/UMTS, Internet, FM(optional)	1m-3m	RTCM SC–104 v. 2.	L1
Post processing services					
POSGEO	post processing	Internet, CD-ROM	0.01m/0.02 horiz/vert	RINEX 2.x	L1, L1/L2

The hardware for a DGPS solution, presented in Fig. 2, consists of a GARMIN eTREX H GPS receiver (capable of interpreting DGPS corrections sent via the RTCM protocol) and a Bluetooth adapter responsible for communication between the mobile device and the GPS receiver. The adapter provides a wireless connection to the smartphone and the RS232-based connection to the GPS receiver. A mechanism implemented in the smartphone application is responsible for communication with the ASG-EUPOS network, and for sending corrections to the receiver via the adapter. In response, the receiver uses the adapter to provide a more accurate position for the smartphone application.

Fig. 2. DGPS measurement unit.

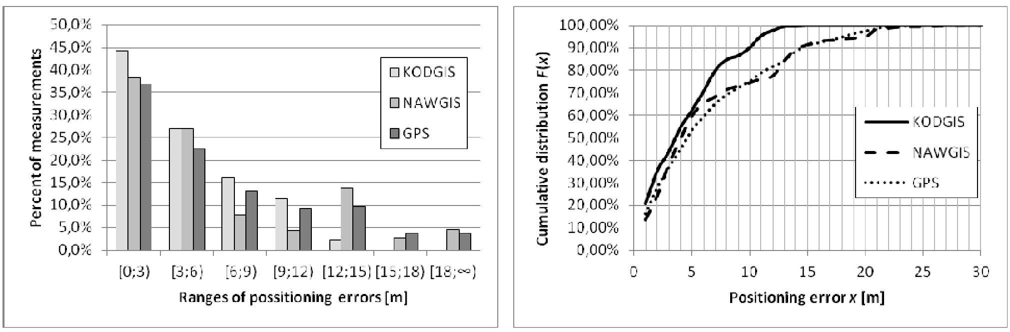
As the used DGPS receiver cannot measure the offsets in the GPS signals' carrier phase, it cannot operate in the Real Time Kinematic (RTK) mode. Two ASG-EUPOS services were used: the NAWGIS providing general corrections for the northern Poland, and the KODGIS, sending corrections specific for a certain coarse location. The KODGIS and NAWGIS services are suitable for receivers which measure the offsets in the GPS signals' code. The NAWGEO service requires a dedicated, highly expensive and unhandy RTK-enabled receiver, which can be used for data acquisition, but not for pedestrian navigation.

3.2. Results of positioning measurements

Measurements of the DGPS accuracy show that the KODGIS-based positioning gives better results than the NAWGIS service. A comprehensive comparison of the KODGIS and the NAWGIS approaches is given in Fig. 3. Part (a) shows percentages of measurements of three GNSS approaches within selected ranges of positioning error and (b) shows the cumulative distribution of positioning error for all the measurements:

$$F(x) = \frac{|\{d \in D : \mathrm{error}(d) \le x\}|}{|D|} \cdot 100\% \tag{1}$$

where D is the set of all measurements.



(a) (b)

Fig. 3. Comparison of DGPS based KODGIS, NAWGIS and embedded GPS receiver positioning accuracy.

It can be seen that best results are obtained with the KODGIS corrections applied. The Circular Error Probability (CEP) for the 50% threshold CEP^{50} satisfies $F(CEP^{50})$=50%. For KODGIS, NAWGIS and standalone GPS the value of the CEP^{50} was respectively at the levels of approximately 3.5 m, 4 m and 5 m.

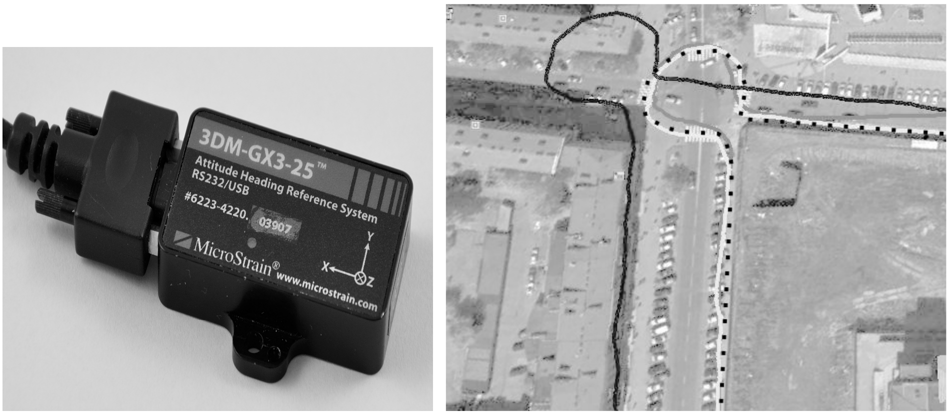
The results are worse than expectations based on the ASG-EUPOS specification (see Table 1). This is probably caused by difficult conditions in urban areas, especially multipath error, impossible to be corrected by the DGPS means.

3.3. Possible complementary positioning methods

As some activities of the visually impaired demand positioning accuracy and reliability exceeding those achieved by the DGPS approach, further improvements are desirable. Research on the improvement of the positioning accuracy and reliability [14-21] mostly concerns the utilization of the inertial measurements units (IMU) [14-19], electronic magnetometers, real-time camera pose reconstruction – based on the recognition of imagery [18-21], particle filtering [17], and the possible fusion of those complementary techniques with the core GPS navigation [17-19].

The project team has developed some of the techniques mentioned above, focusing mainly on inertial navigation, as it provides positioning in locations where the satellite signal cannot be received (e.g., in tunnels, canyons between buildings), which is an important requirement for the urban navigation systems. Two hardware solutions have been recently finalised. The first developed, prototype IMU consists of three 2-axial digital accelerometers (i.e., ADIS16201, ADI), three digital gyroscopes (i.e., ADIS16260, ADI), and a 3-axial digital magnetometer (i.e., HMC5843, HON). The second (Fig. 4a) is based on the "out of the box" inertial measurement unit (3DM-GX3-25, MicroStrain).

Currently, application of developed IMUs as well as their integration with the smartphone are under investigation. In Fig. 4b. preliminary results are shown. The dotted line demonstrates the real path. The gray line represents the GPS track (mean error – 5.25m), the black line the inertial navigation output (mean error – 21.83m) and the white line the result of their fusion (mean error – 1.63m). Despite the fact that both inertial navigation algorithms and fusion algorithms are in an early phase of development, the results are promising. The fusion improves accuracy, what is visible in the Fig. 4b. (especially on the zebra crossings). It is expected to provide more precise positioning after decreasing accumulated error of inertial navigation.



(a) (b)

Fig. 4. MicroStrain inertial measurement unit (a) and preliminary results of its use (b).

4. Spatial data

As the demands for type and form of spatial information for blind users in the urban environment are specific, a special data model is proposed. Unlike systems which exploit raster maps in order to improve the accuracy of positioning [17] all of the spatial data in this system have a vector representation. Such a representation reduces the capacity of storage needed, simultaneously giving the highest resolution and accuracy possible.

The vector data have one additional, crucial advantage, important when considering urban areas. It can be used to model the three-dimensional aspect of spatial objects. With three dimensional data it is possible to map structures such as tunnels and ramps and effectively navigate pedestrians through them.

There are three main sets of vector data. The first represents paths accessible for pedestrians, discussed in more detail in section 5.

The second data set type, which was introduced during the project as very important in terms of navigation for visually impaired people, are Points of Attention (POA). The POAs represent obstacles, dangers and any other objects the system should inform the visually impaired person about. These are accurately localized in the spatial coordinates system and can be connected to segments from the road network.

The third data type which is helpful for finding important places in the urban environment are Points of Interests (POI). The POIs used in the system differ from these known from car navigation systems as they provide more detailed positioning and represent rather entrances to important buildings, bus stops etc., than general buildings and places.

4.1. Data structures

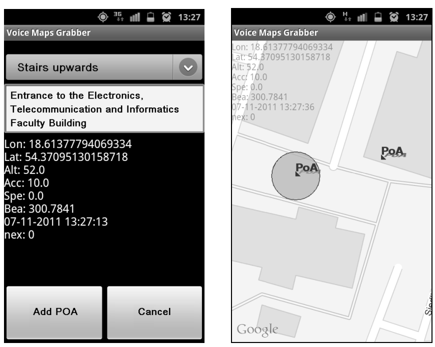
The spatial data are stored in two locations, on the server and in the mobile client. The data on the server consist of the full set used in the system, whereas the data in the mobile client can be just a part of all the data (e.g., part of the city). On the server side the data is stored with the use of a relational database with a spatial extension, i.e., PostgreSQL/PostGIS.

In order to increase the efficiency of the mobile application, a Spatial Data Cache (SDC), that stores the data in the device's persistent memory is used. All of the spatial data is stored in a quad tree-based data structure [22] in order to improve the system's efficiency.

The data can be served from the server to the mobile client in different ways. One is to use the exporter and prepare an XML-based pack of interesting data. A second option for accessing the data is to read it online with the use of a Web Feature Service (WFS), however in this option, the mobile client must be connected to the Internet, still due to the SDC, the connection does not need to be persistent.

4.2. Acquisition of spatial data

The data is acquired with different means. The most accurate are surveys with the use of geodetic GPS RTK receivers. They give positional accuracy at the level of a few centimetres and are possible in real time. However, albeit the most accurate, it is also the most time-consuming and expensive, so the system introduced other methods of data acquisition. Surveying with the use of a dedicated smartphone-based acquisition application presented in Fig. 5 is a much cheaper form of data acquisition, however the positional accuracy of such surveys is hard to determine. The third method of data acquisition is vectorization of the ortophotomap. However this method could result in severe errors from recognition of false paths, and omission of the actual ones.



(a) (b)

Fig. 5. Screen layouts of smartphone-based acquisition application; (a) description of POA, (b) situational map.

To eliminate mutual shortcomings of these two types of data collection approaches, a combination of smartphone-based acquisition and verification methods was proposed.

All of the ways of spatial data acquisition could be driven by the system administrators. A community-based approach for collecting data is also available with use of the OpenLayers web-based spatial data editor which is accessible for registered users of the community portal. The editor can also be used to import, verify and possibly correct the data collected with the smartphone-based acquisition application.

4.3. Use of third-party data

In areas where there is no availability of dedicated data, the system is capable of using third-party data sources. In that case data from the OpenStreetMap project are used. OpenStreetMap is a collaborative service which offers significant amounts of spatial data with no charge [23]. In the system, vector data from OpenStreetMap are used mainly for navigational purposes. Spatial data are delivered together with attributes (meta-data), describing features of spatial objects. The set of tags is extensive, which is very important during the process of describing surroundings, which needs to be verbose in the case of a blind user. The main flaw of the OpenStreetMap portal is the small amount of data describing POAs, detailed POIs (e.g., entrances to the buildings) and paths accessible to the visually impaired pedestrians (e.g., pavements).

5. Navigation

The spatial data used in the system have the form of a graph. Its edges represent fragments of a track, while nodes define connection points between them. The graph is sparse, so it is represented by an adjacency list. Additionally, references to nodes are kept in a quad tree, which improves the navigation algorithm's efficiency. The graph is undirected (as each edge can be walked through in both directions by a pedestrian) and weighted, with each edge having an additional attribute, called cost, which is a number specifying the total effort that a blind person needs to make in order to walk through the track represented by that edge.

The actual pathfinding is achieved with the use of an A* algorithm [24]. The algorithm is a modification of well-known Dijkstra's algorithm, using heuristics of the cost of a prospective path between any two nodes. The knowledge included in the heuristics allows us to lower the number of nodes traversed during pathfinding, preferring nodes closer to a goal, which results in higher efficiency of the whole process.

In most of the navigation systems, the cost of edges is obtained on the basis of only one factor – the edge's length. In that case the concepts of optimal and shortest path are identical. In the presented navigation system for the blind, the optimal path is the path that can be walked through by the blind with less effort than any other possible path. Therefore the cost of each edge has to be calculated not only on the basis of its length, but also on the other attributes, which include mainly**:** surface type, track width, assessment of a track's safety. Of course the presented definition of the optimal path in navigation systems for the blind is far away from being strict. It is mainly due to the different type of tracks various users may prefer, which is caused not only by diverse types of visual impairment, but also by many individual, personal factors, including mentality, character type and previous experience. That is why the impact that each edge's attributes have on the final edge's cost calculation result is configurable. Because the navigation application operates on a constrained device, increasing pathfinding execution time may improve the whole application's efficiency, especially on the low-end Android smartphones. Two optimization methods were tested: hierarchical pathfinding [25] and heuristic over-estimation. Both techniques do not guarantee a returning optimal path (see Fig. 6). However, they are configurable and one can change the behavior of those families of algorithms, either making them extremely fast but also inaccurate, or achieving almost optimal precision with small efficiency gains. Hierarchical pathfinding algorithms are configured mainly by changing the hierarchical graph's density. The behavior of an A* algorithm with over-estimated heuristics is modified by changing the value of overestimation. Investigations on the optimal trade-off between pathfinding accuracy and execution time are carried out.

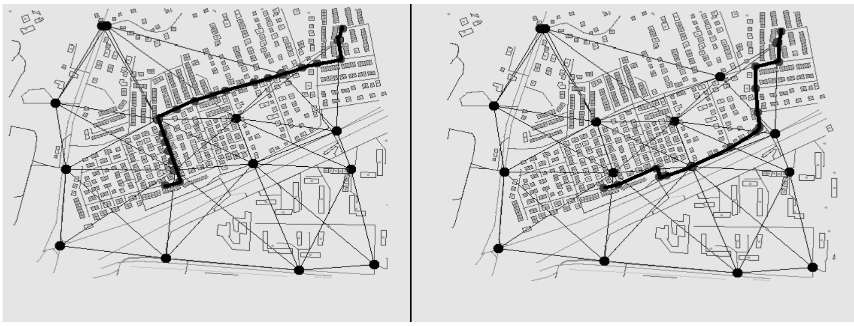


Fig. 6. Different paths (thick lines) found by a hierarchical A* algorithm (left) and an A* algorithm (right).

Once the pathfinding is accomplished, the system's task is to guide the user along the path. The user is guided to successive nodes of the path. The user's azimuth and the distance to the proper edge are permanently calculated, and in case of any mistakes the user is informed what she/he should do to correct their movement's inaccuracies. On each crossing a message is generated, describing how that crossing should be passed. If the user continues to move incorrectly, the application tries to perform a new pathfinding, using the current user's position. The surrounding can be constantly described, if the user asks the system to work in verbose mode. In that case, data about POI and POA are used. Each navigation message can be read on demand, or configured to be read on a regular basis.

6. User interface

The system needs dedicated methods of bi-directional communication with a blind user. The part of the user interface responsible for interpreting that blind user's commands will be called input, while all the methods of providing messages for the said user will be called output.

6.1. The output

As visual information is useless for the blind: the output is based on two other senses, i.e., hearing and touch.

Primary output functionality is based on speech synthesis. Built-in Android text-to-speech (TTS) mechanisms are used. They provide the functionality of seamless synthesizer exchange, configuration of its parameters (mainly the speed of message reading) and easy-to-implement use of the core speech synthesis functionality. The application uses a commercial SVOX [26] synthesizer, mainly because of its relatively low price and the good quality of its Polish voice – Eva.

Unfortunately, the default mechanism of message queuing in Android TTS is insufficient. Each message can be read immediately, interrupting any messages being currently read, or can be placed at the end of the queue of messages. Because of intense message generation by the application, and default queuing constraints, a custom queuing mechanism was implemented. Every message for the blind has additional attributes that must be taken into consideration while attempting to read a message, or place it in a queue:

– Message priority, which helps to distinguish important messages from the common ones. The highest priority is characteristic for announcements about danger, which should be read immediately, always interrupting any low-priority messages. This priority was the primary factor taken into consideration whilst placing messages in the queue.
– Message expiration time, which defines how long each message will be valid after its creation. Some messages are short-lived (e.g., information about actions made in the menu or current azimuth/direction), others can be read with a higher delay (e.g., description of the surroundings). After losing their validity, outdated messages are removed from the queue and irretrievably lost, as it is considered to be a better solution to miss an outdated message rather than to read it, causing user's confusion. However, the effect of losing messages occurs only during the most intense message generation periods, and messages that are lost are always of low priority.

Smartphone vibrations are the main way to communicate with the user utilizing the sense of touch. They are mainly used in conjunction with the input, providing additional information related to the touch screen functionality. Vibration intensity and duration are configurable.

6.2. The input

The input is based on a touch screen. It consists of two parts: a menu for choosing the application's options, and keyboards for entering text. Both parts can be used with one hand, as the user needs one free hand to use a white cane or keep in touch with a guide dog etc.

6.2.1 Menu

Users communicate with the systems using mainly a touch screen. The menu is arranged in the form of a tree. The options of the current part of that tree (the part that the user has entered) are placed on the screen, each of them occupies a rectangular area of significant size (see Fig. 7).

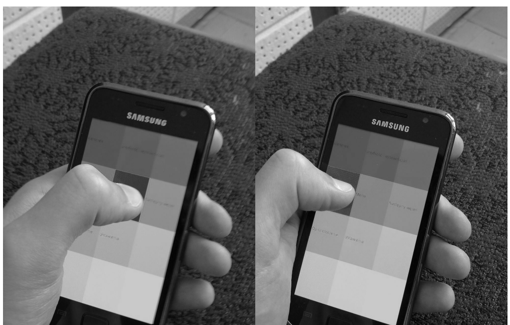


Fig. 7. Menu of the application.

When the user’s finger leaves one rectangular area and enters another, vibrations and vocal information about the option that was reached are generated. The last touched option is considered as the selected one. Double tapping on the screen will activate a selected option, either moving the user to another sub-tree of the menu, or triggering a certain action, e.g., activating the verbose mode of messages. The right-bottom corner of the screen is reserved for a “Back” option, which takes the user to the previous part of the menu. The menu can also be used on devices without touch screens. In that case, arrow keys are used to move around, and one of the action keys replaces double tapping.

6.2.2. Keyboards

A different type of user interface is needed for entering text. Currently, the application contains three different keyboards for the blind – two of them, which are considered to be the most interesting ones, will be presented in this article.

The first keyboard uses Android's gesture recognition functionality. Two alphabets of gestures were prepared, one based on Moon's language [27] for the blind, the other using gestures similar to Latin letters. Because of the inconsiderable, faint knowledge of Moon's alphabet among non-Anglo-Saxon users and significant similarities between its letters, it was eventually abandoned. At present only the second option is used. It offers very good correctness of recognition and is preferred by the users who know the Latin alphabet.

The second keyboard uses another approach. The user touches the screen to start choosing letters, moves his/her finger around to choose the proper letter and raises a finger in order to accept the letter and append it to the text. During the whole process users are accompanied by vibrations and voice messages, describing current letters and text entered so far.

Fig. 8. Usage of system's keyboards.

6.3. Alternative input methods

Some additional input methods were implemented and tested, but are not currently used. In urban noise the intelligibility of the Polish language is insufficient for the voice recognition mechanism of the Android platform. The motion sensing based on the solution described in [28] does not offer a satisfying correctness.

7. Tests

The user interface was tested by blind experts, familiar with using systems for the visually impaired people. The testers were satisfied with the user interface. As there were significantly different preferences regarding the methods for entering the text, the choice between various keyboards has to be maintained configurable.

Tests of the system as a whole were also carried out with the help of a blind consultant (see Fig. 9). The greatest emphasis was put on the core functionality, which is the navigation. The consultant confirmed that some flaws of existing solutions, which he had encountered, were eliminated in our system. The tests were remarkably helpful in identifying some minor system deficiencies and obtaining suggestions about possible improvements. The system worked correctly most of the time. After the intentional incorrect movements of the user the system generated vocal warnings, appropriate in such situations. There were only a few misleading messages, caused by spatial data inaccuracies, or temporary, but relatively significant, errors in DGPS receiver positioning.

Fig. 9. A consultant participating in the field tests.

8. Conclusions

The results of preliminary tests proved that the prototype is useful and almost fully functional. In the near future, the greatest impact is planned to be put on increasing positioning accuracy, implementing additional requested functionalities and reaching high stability of the application. The system is now used only in chosen locations, and our consultants are usually accompanied by a team member. Next year the commercialisation phase is going to take place, giving wider access to our solution.

Acknowledgements

This research work is a part of the “Voice Maps” project, which was supported by Narodowe Centrum Badan i Rozwoju (National Center of Research and Development) within the “IniTech” program (project code: ZPB /37/679 01/IT2/10).

We are highly grateful to Mr Rafał Charłampowicz and Dr Ryszard Kowalik for participating in our system’s tests, and supporting the team with useful suggestions.

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