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Emphatic Trials of a Teleassistance System for the Visually Impaired

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In this paper we focus on a special type of electronic travel aids for the visually impaired termed teleassistance systems. The operation principle of such systems is to transmit a video stream from a camera carried by a navigated user to a remote assistant that guides the traveller by short spoken instructions. First, we review different approaches to building the teleassistance systems for the visually impaired. Then, we explain the technical basis of our system and indicate important novelties in comparison to other systems. The key part of the paper reports on ergonomic, non-mobility tests with participation of blind volunteers and emphatic field trials (i.e., with the participation of sighted individuals) of the teleassistance system. The trials were conducted on the university campus with the participation of seven sighted individuals. They walked along three different paths, each approximately 400 m in length. During these trials, the sighted travellers, noted the number of potential lost ways or possible collisions. Also, the transmission performance of the system was monitored, recorded in server logs and evaluated. This paper also contains responses by the guided volunteers and their remote guides to our questionnaire. Comments from the target users, i.e., the visually impaired who assessed the ergonomic and communication quality in the static, non-mobility trials of the system, were also collected. On the basis of the conducted tests and the field trials, we conclude that the described teleassistance navigation system can be a prospective travel aid for the blind, partially sighted and the elderly.

Keywords: Blindness, Mobility, Remote Guidance, Teleassisted Navigation, Navigation Aids, Visually Impaired.

1. INTRODUCTION

Blindness deprives an individual of approx. 80% of sensory information. This most serious of sensory disabilities complicates or precludes activities of daily living of the affected person. In particular, the loss of space orientation and adequate mobility are indicated as the main barriers limiting the visually impaired in leading normal professional and social life. It is estimated that in Europe 3–4 persons in every 1000 are visually impaired. According to the World Health Organization report,[1] worldwide, 285 million people are visually impaired and 39 million are blind. These numbers will increase due to aging demographics.[2] Moreover, the number of the visually impaired is foreseen to increase by 20% within the next 50 years.

Recent achievements in ICT (Information and Communications Technology) have brought many technical aids assisting the visually impaired in accessing information and communicating with the environment. Portable Braille displays, desktop computers and mobile devices equipped with speech synthesizers, readers and printers and web pages conforming to World Wide Web Consortium (W3C) guidelines are the technologies accessible for the visually disabled.[3]

However, the problem of aiding the blind in moving and travelling safely, freely and independently still remains an unsolved problem awaiting breakthrough technology. The majority of the blind community use the so-called primary mobility aids such as, the white cane and rarely the guide dog.[4] These aids, although of substantial help, still provide limited enhancement of mobility capabilities and no support in navigation tasks. The white cane offers near-space perception only, occupies one hand and does not protect from obstacles at shoulder and face level.

A guide dog is good for avoiding obstacles, however in many cases does not help in navigation tasks. The dog requires long and expensive training and may not be accepted by a blind individual due to up-keep cost and the need for a change in life style.

Interestingly, in an American study, a group of 30 blind yet skilled travellers, rated getting around in unfamiliar train/bus stations (e.g., finding a stop or boarding gates, changing modes of transport, finding information or ticket office) as the most difficult task. On the other hand, crossing a busy street was rated as less difficult.[5]

There have been many research efforts devoted to building high-tech electronic travel aids (ETAs) for the visually impaired. These assistive technologies can be subdivided into obstacle

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detectors (OD) aids and navigation systems. The former help the blind in the so called *micro-navigation* tasks such as obstacle avoidance and near-space orientation that aid the blind in short distance locomotion. Whereas, the navigation systems help the user in *macro-navigation*, i.e., in long and medium distance locomotion, in which abilities of geographic orientation, wayfinding and navigation along a predefined path are important. Macro-navigation can be defined in short as a task focused on answering the questions: *Where am I? Where am I going? How to get there?*

Technologies applied in electronic ODs range from simple ultrasound or laser detectors to more complex vision-based environment imaging techniques. The acquired information about the environment structure, whatever the sensing modality used, is converted into vibrations or sounds accessible for blind users. Such a conversion method is frequently termed sensory substitution, which can be understood as transformation of visual modality (unavailable to the visually impaired) into other sensory modalities. Examples of personal OD aids are UltraCane, K-Sonar Cane, LaserCane, MiniGuide or Teletact. A recent review of high-tech wearable OD aids can be found in Ref. [6].

Another group of high-tech ETAs that are slowly and steadily gaining acceptance within the visually impaired community are systems assisting the users in macro-navigation. These are predominantly, GPS-based devices[7] and also prototype systems employing distributed networks of electronic tags (buoys) that are embedded into the urban infrastructure. These systems range from applications of custom built radio beacons[8] and Radio Frequency Identification Devices (RFID)[9] to infrared beacons (see e.g., the TalkingSigns system developed by the Smith-Kettlewell Eye Research Institute (www.ski.org)). Unfortunately, the GPS features large positioning errors reaching 100 m in an urban environment[10, 11] and embedded infrastructures for aiding the blind in navigation are prohibitively expensive. Many tags are needed to be installed and serviced.

One can conclude that, in spite of remarkable ICT achievements, a satisfactory solution to the problem of assisting the visually impaired in orientation and mobility (O&M) has not been found. Apart from expensive high-tech devices, the visually impaired complain about their unsuitable usability (to engage one hand while holding the white cane with the other), inappropriate auditory or haptic presentation (over cluttered sounds, cumbersome hardware respectively) and finally, poor reliability (missed obstacles) and robustness.[6] Consequently, the visually impaired fear to entrust their safety to mobility assistive technologies, in particular, outside their familiar environment.

In this paper we address yet another line of research on systems aimed at assisting the visually impaired in mobility and travel. The underpinning idea of this group of solutions is to offer blind and visually impaired persons teleassisted guidance from a remote operator by providing an on-line wireless transmission of video, voice and GPS data between the wearable terminal of the blind user and the remote terminal of the guide. The guide can communicate verbally with the blind traveller, warn him or her of obstacles and direct him or her to the destination. Early emphatic tests of such systems have revealed that such teleassistive systems can be helpful both in micro- and macro-navigation.

In the remainder of the paper we review, various research efforts aimed at implementing teleassistance systems and report on recent results of the emphatic filed trials of our in-house built teleassistance system.

2. TELEASSISTANCE SYSTEMS AIDING THE BLIND

In spite of long lasting research efforts in developing different ETAs for the visually impaired, none of the built devices have found wide acceptance among the visually impaired community. This is because of high cost, poor ergonomics and long learning curves.

Teleassistance is a new concept to navigating the blind. The underpinning idea of such navigation aid is that a blind pedestrian can be guided by spoken instructions from an operator who receives a video stream from a camera carried by the blind user. Although, another person is still involved in the guidance, this solution has a number of advantages (e.g., increased user privacy and independence) over traditional guidance by a sighted person.

The first reported teleassistance system for the blind, to the authors' best knowledge, was a system built at Brunel University, UK.[12] In their prototype, the following three ICT technologies were combined to provide system functionality, i.e.,: GPS, GIS (Geographic Information System) and video transmission over a UHF (Ultra High Frequency) radio link. The system consisted of two terminals. The mobile terminal carried by the blind user comprised of a small camera, headset and GPS receiver. Another terminal was a stationary PC running a dedicated application operated by a remote sighted guide. The application displayed a real-time video from the blind user's terminal and its GPS position on a digital map of the terrain. The guide and the blind user of the system had two-way voice communication via a GSM phone network. The trials of this prototype reported successful remote navigated walks of blind volunteers around the campus precinct. The UHF link for video transmission limits the usage of the system to several dozens of meters. Selected functional properties of the proposed system were tested by the authors of the system.[13] The study focused on evaluating how the frame rate of the transmitted video affects the performance of the remote guide in navigating the blind user. The authors argue that frame rate variations in the range of 2 fps to 25 fps are statistically insignificant. No commercial deployment of this system has been reported. More recently,[14] the same Authors have conducted performance assessment of consecutive generations of mobile communication links and concluded that 3G network seems to be suitable for application in a system for the navigation of visually impaired pedestrians.

A different navigation approach was proposed in the system reported in Ref. [15] whereby the navigation instructions are passed via haptic modality. The images are captured by a camera housed into the glasses worn by the visually impaired user. The image sequence is transmitted to the remote guide, who navigates the blind person by activating vibrotactile stimulations. The stimulations are provided by a pair of bracelets attached to the user's left and right hand wrists. The advantage of this solution is that the hearing sense of the blind user is not engaged in the navigation process. The video is streamed by means of Skype communicator whereas the navigation signals to the bracelets are send via the TCP/IP protocol. The authors have demonstrated system usefulness in navigating blind individuals in indoor environments. No GPS technology is incorporated into the system.

In Ref. [16] another teleassistance system, named TeleShop, was tested. The system turned out to be helpful in accessible shopping for the blind. The TeleShop consists of a server application running on the visually impaired user smartphone and a client application installed on the sighted caregiver's computer. The caregiver can adjust the streaming parameters of the video to provide best assistance for the blind individual, e.g., he/she can set resolution of the transmitted image sequences or freeze the image to inspect the captured scene. The TeleShop employs either WiFi or 3G technologies for wireless connection between the system terminals. Similar functionalities features, the Be My Eyes (www.bemyeyes.org) system, that is based on a mobile video chat application that enables to connect the visually impaired with volunteer helpers. These systems, however, are not designed to serve as an outdoor travel aid.

Finally, in a recent work,[17] it was postulated that the visually impaired can be more efficient in remote navigation of other blind individuals, providing the traversed paths are familiar to a blind guide. This is an appealing concept since the blind guides can better understand the required navigation cues on particular fragments of the paths. The shortcoming of such an approach is obviously a limited network of routes that are frequently walked by blind participants and no visual modality available. The reported work is in an early stage of studies, however, it is worth considering in future developments of teleassistive systems for the blind.

Our group has been working on different versions of teleassistance systems for a number of years. The early prototype was based on a small laptop and the Skype communicator.[18] An attempt was also made to use a smartphone as a mobile terminal for the blind user.[19] However, we encountered both hardware and software problems, e.g., difficulties with simultaneous recording of voice samples, playing sounds and capturing images from the built-in camera. Moreover, blind people are afraid of carrying a mobile phone in sight as it attracts potential robbery. Our final design decision was to base the mobile terminal of the teleassistance system on our in-house hardware design.[20] This has allowed us to have full control over the terminal hardware and to tailor the design to the requirements of blind users. We think that our prototype has important advantages over the Brunel system due to its mobile terminal being based on a "one-box" device specially designed for the blind user (ergonomic keyboard, simplified procedure of establishing the communication link between the user and a remote guide). Also, the early Brunel prototype transmits video from the blind person's camera by means of a UHF radio link which confines the transmission range to several dozens of metres. Our system has no distance limitations, since the GSM HSPA (High-Speed Packet Access) data transmission protocol is employed for transmitting the video stream. Finally, our system employs an adaptive algorithm for dynamic adjustment of video frame rate to reduce average transmission delays.[18]

3. SYSTEM ARCHITECTURE

Conceptually, the proposed system is presented in Figure 1, whereby a blind user wears a mobile terminal housing a GPS receiver, camera and headset. If needs be, the traveller connects through a GSM network to a remote operator being equipped with a PC program. The operator can see the video stream, geographical location of the blind user superimposed on a digital map. The users communicate by audio channel.

The system in more detail is shown in Figure 2 and from the point of technical implementation constitutes three main parts:

- mobile terminal being worn by a blind user,
- remote operator's terminal,
- server whose task is to establish the connection.

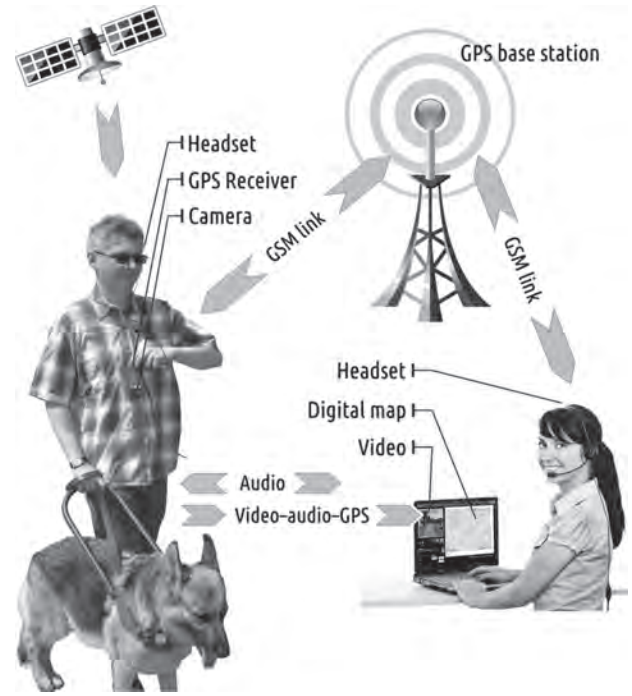

Fig. 1. A simplified diagram of the teleassistance system for the blind.

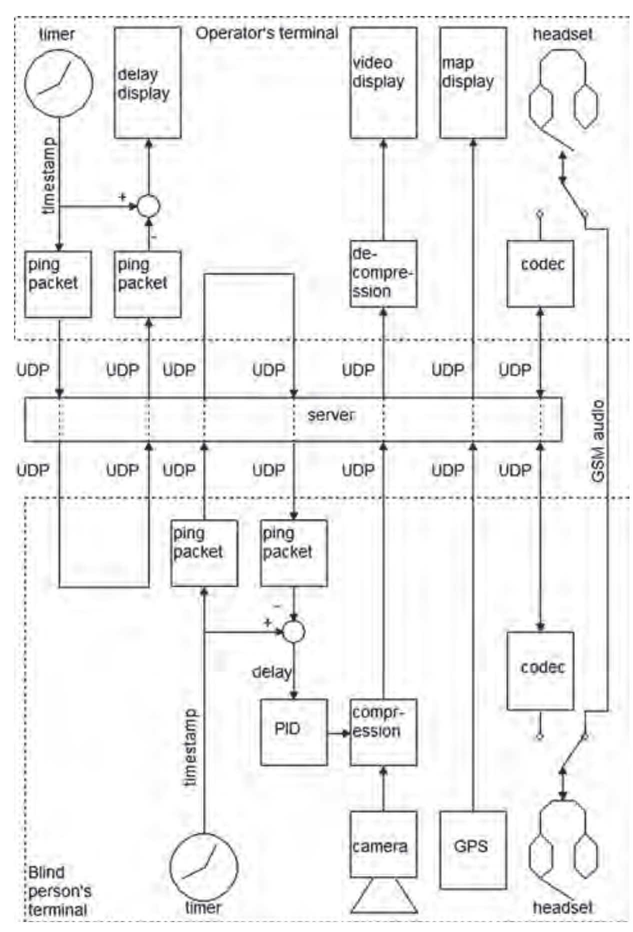

Fig. 2. The connection schematic and protocols used.

In the proposed system a server application mediates in transferring data between the terminals. The connection between the server and the mobile terminal is established through the GSM network and the connection between the server and the terminal of the remote guide is provided via the Internet. The role of the server is to provide communication between many tandems of remote guides and the navigated individuals. Current implementation of the server software enables the handling of up to several dozens of tandems. At a single time instance, one remote guide can guide only one traveller. Each navigation session is monitored by the server recording data logs of the sessions.

The system enables to transmit voice in two ways (see Fig. 2):
- over the Internet which is less reliable, exhibits delays and packet losses,
- over GSM audio channel (used for standard voice calls) which is reliable but more expensive. Therefore the voice communication is always of high quality as opposed to video stream being subject to breakdowns.

Both terminals send ping packets to estimate the link delay. The remote operator's application sends a ping packet containing a locally generated time-stamp. The mobile terminal sends back this packet upon its reception. The operator's application, therefore, can calculate the roundtrip delay and display it to the operator. In some situations the transmission lag might be important—crossing a street, embarking on a bus or tram. There are applications where transmission delay of single seconds can be acceptable, e.g., reading a price of or expiry date of a product, identifying the colour of an object.

By analogy, the remote terminal calculates the round trip delay. If the said delay is increasing, the wireless channel cannot accommodate the data stream, and the packets are buffered at the physical interface of the GSM modem of the mobile terminal. In order to keep the latency at minimum, the data rate needs to be reduced e.g., by lowering frame rate. For that purpose, the PID (Proportional Integral Derivative) controller was employed. The device constantly monitors the transmission delay and adjusts the video frame rate to keep a lag at the value of ca. 200 ms via the PID algorithm. The role of the algorithm is to maintain transmission of the video stream even at the cost of lower frame rate. This adaptive algorithm minimizes average delays of the video transmission to a remote guide. This system feature is particularly important for time periods of heavy congestion of the GSM network. However, when the link quality deteriorates for a couple of seconds, only GPS coordinates are sent.

3.1. Mobile Terminal

The mobile terminal is presented in Figure 3. The device evolved through several prototypes to its current form based on remarks received from blind users. The terminal features a large keyboard with convex keys that "clicks" when pressed. The terminal is composed of the following units:
- microcontroller,
- GSM modem (GPRS, EDGE, HSDPA),
- GPS receiver,
- camera of wide field of view (ca. 90° horizontally),
- microphone and loudspeaker,
- externally connected headset.

The device is operated by the hierarchical menu which is speech-synthesized. The terminal has an inconspicuous look.

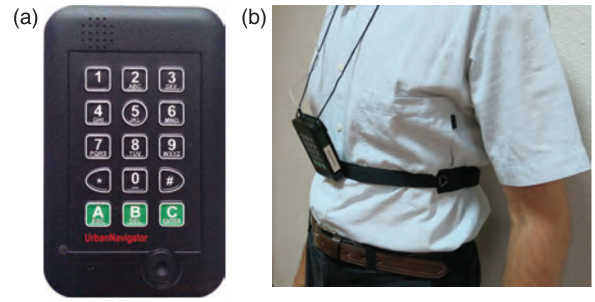

Fig. 3. (a) Photograph of the mobile terminal. (b) Photograph illustrating attachment of the mobile terminal to a user's body.

This is important factor as blind respondents complained about being subject to robberies.

A wide angle camera is very important in the crucial tasks of guiding a blind person across a street or helping with directions in an unknown environment. Standard phone cameras usually have a narrow view of ca. 20° and changing the lens is not an option. Our device activates within 10 seconds and about another 30 seconds are required to connect to the remote operator.

The pictures acquired from the camera are compressed using still JPEG (no motion compensation). The voice, when sent through Internet (see Fig. 2), is losslessly compressed utilizing Huffman codes and silence detection, which results in a voice stream of ca. 2 kB/s.[18] The GPS receiver provides coordinates every second and with the same frequency they are sent wirelessly to the remote guide terminal. Ping packets are sent every 500 ms and the battery status is sent every 5 seconds. The nominal capacity of the used battery is 1450 mA. In the scenario, when voice is routed through GSM audio channel and data is sent at available speed in HSPA mode, the operating time ranges from ca. 1.5 hour to 3 hours.

The device is fastened to the traveller's chest with a help of a thin cord and a velcro strap. The length of the cord can be adjusted, so that the camera points towards the ground where possible obstacles can emerge.

The device also houses an infra-red diode to light-up the closest environment in case of poorly lit surroundings. The diode is controlled by the remote guide.

The terminal features functions of a regular mobile phone such as calling, text messaging, contact lists, etc. The designed mobile terminal is able to transmit audio over a dedicated GSM voice channel and data over the Internet simultaneously. This setup was chosen to avoid latency in voice transmission and provide stable audio communication between a blind traveller and their guide. This is an important backup mechanism providing sustained communication in case of video transmission blackouts.

3.2. Remote Guide's Terminal

The graphical user interface of the remote guide's terminal is shown in Figure 4. The interface consists of three panels. In the upper-left corner there is a window with the video stream. This window can be enlarged. On the right, there is a map window with the traveller's geographical location and walking direction denoted by an arrow. The direction is provided by the GPS receiver, based on the velocity vector, estimated from the Doppler effect.

In the lower-left corner there is a control panel with a number of icons displayed. The control panel shows the different

Fig. 4. View of the graphical user interface of the remote guide terminal.

icons and control tools (from left to right starting from top of the panel): "Brightening" scroll bar for brightening pictures, the loudspeaker icon showing audio transmission rate (3.4 kB/s), the icon showing video transmission rate (3.9 kB/s) and the corresponding video frames per second (1 fps), the star-like icon blinking when the GPS readouts arrive, the icon with the red-line used to create a path from GPS readouts, the icon with circular arrows refreshing the map, a ruler showing transmission roundtrip delay (310 ms), and the battery icon for showing the mobile terminal battery level (27%). The video window can be opened in a separate window by pressing the "Big image" button. The radio buttons in the "Video quality" box enable to remotely and dynamically change the resolution of the mobile terminal's camera. In the map window, the arrow denotes the walking direction, and the adjacent dot—GPS accuracy (e.g., green indicates that GPS readouts are accurate to single metres). The checkbox "Light" is used to remotely switch on or off the LED diode in the mobile terminal to light up the immediate surroundings.

An option of non-linear intensity conversion (button "Brightening" in Fig. 4) is available for seeing more details in dark surroundings (e.g., in the evening). This feature proved to be helpful on several occasions when guiding a blind itinerant, e.g., through narrow and poorly lit pedestrian under-paths.

The guide can dynamically change the camera's resolution, by using the radio button box named 'Video quality' displayed in the terminal graphics user interface (Fig. 4). The user can select one of the three resolutions of the transmitted video images. The lowest resolution of 160×120 pixels is used for guiding as it provides highest frame rate. A resolution of 320×240 pixels is used for seeing more details (e.g., a bus, tram or room number), however, it slows down the video transmission rate by a factor of ca. 4. The highest resolution of 640×480 pixels is helpful for reading small print and details such as timetables and product expiry dates. The frame rate is reduced by a factor of ca. 16 (in reference to a resolution of 160×120 pixels).

The application makes use of Google maps to denote the blind pedestrian's location and walking direction. The colour of the dot and arrow reflects the estimated accuracy of the GPS readouts that is based on the HDOP parameter value (Horizontal Dilution of Precision) provided by the GPS receiver. Green corresponds to accuracy within single metres, orange—to a dozen or so metres and red—to several dozens of metres. The map can be moved, zoomed, e.g., to find the nearest bus stop. By default, the displayed map fragment of the terrain is shifted automatically so that the position of the mobile terminal is located in the centre of the map window.

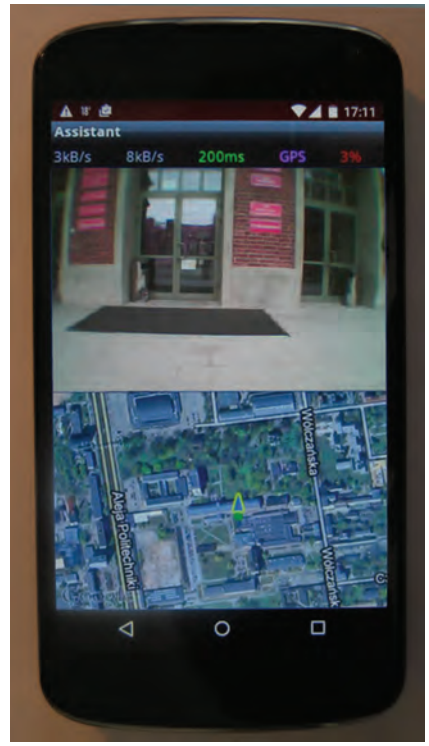

Fig. 5. Remote operator's application on a mobile phone with the Android operating system. The upper part of the screen displays the image captured by the wearable camera and the lower part of the screen shows the web map and the geographic position of the navigated person.

An important parameter of the system is the transmission delay of the video images sent from the mobile terminal. This delay is constantly monitored and its instantaneous value displayed on the screen of the remote guide terminal. When data packets are lost, this information is immediately displayed on the screen in the roundtrip delay panel (see Fig. 4). Therefore, the remote operator is instantly informed of the connection conditions.

The remote operator can also use a mobile phone or a tablet with Android OS to guide a blind person. A picture of a phone with the remote guide's application is shown in Figure 5. As the screen of the phone or tablet is small, the operator can change layouts between:

- video and map,
- map only,
- video only.

3.3. Server

Data transfer between the remote operator's terminal and the blind person's follows through the server which involves a small delay. The server is necessary because the IP addresses of both the mobile and remote terminal are, in most cases, dynamic and internal. Apart from this, the server performs the following functions:

- authorization of users,
- storing contact lists for users,
- logging transmission parameters.

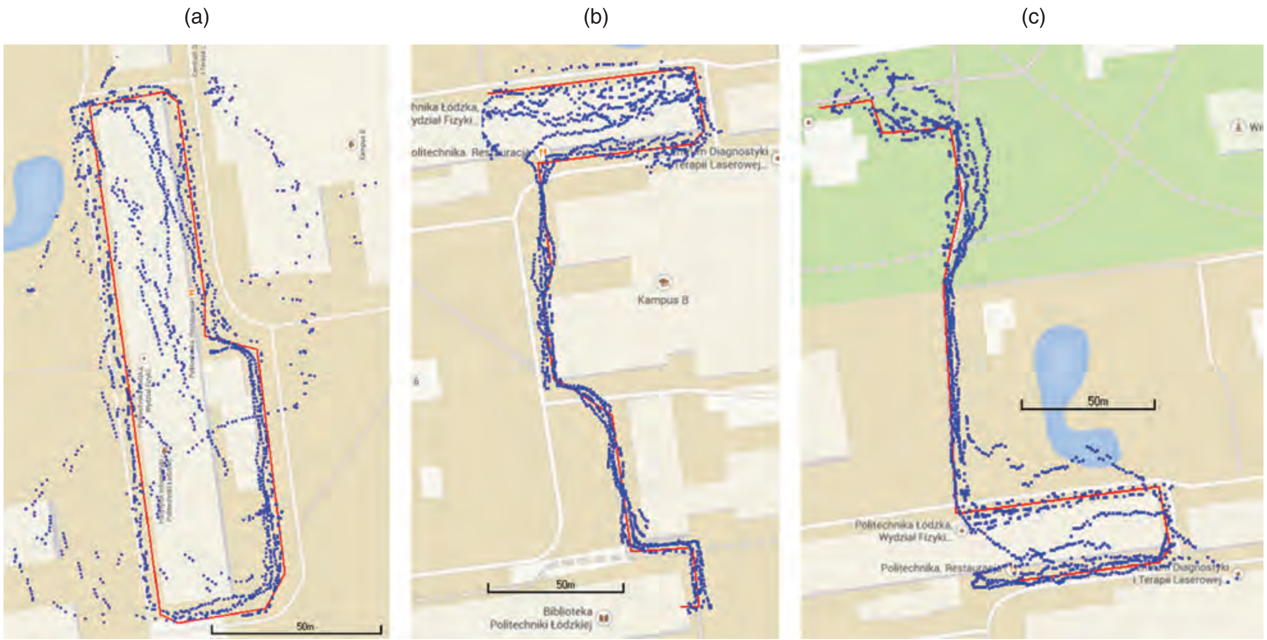

Fig. 6. Red lines denote the desired paths along which the travellers were to follow. The actual traversed paths did not deviate much and therefore were not drawn. Blue dots are GPS indications (for all travellers) recorded along each path. (a) Path I: length-ca. 374 m. (b) Path II: length-ca. 371 m. (c) Path III: length-368 m.

Users of the system are granted logins and passwords. No other configuration data is required to use the system. When a client logs in, the server changes his status to active. When the client disconnects, the status is assigned inactive. Additionally, when a connection is established between two terminals, their status is denoted as busy. Upon logging into the server, the user receives his assigned contact list. The entry of a contact list consists of a login, first and family name, terminal type (mobile or stationary) and current status (available, busy, unavailable). This data is speech-synthesized for blind users or displayed for sighted operators. The server sorts the lists according to users' current status so that blind travellers first receive active, then busy and finally inactive users. The clients can add or remove users to and from their contact lists respectively.

There is no restriction as to terminal types that need connecting. Two mobile or two stationary terminals can be paired as well. Therefore the system can be used as a voice communicator.

The server additionally logs the events of the client connecting or disconnecting to the database. The following system parameters are logged on-line to the database:

- transmission delays,
- video/audio throughput—instantaneous transmission throughput for the audio and video data,
- lost packets—number of lost round-trip packets used for testing the link quality,
- lost connections—is the time of occurrence and the number of lost connections between the terminals; this system malfunction requires reestablishment of the connection that can last up to ca. 30 sec,
- user geographical location—are the GPS coordinates of the mobile terminal along with HDOP parameter recorded once per second (see Fig. 6 containing blue dots with the recorded GPS readouts).

The logged data allows for detailed monitoring of system performance. We plan to use these data for larger scale statistical analysis of the connection robustness and its influence on the guiding efficiency and fatigue evaluation of the remote guide.

4. RESULTS OF THE TRIALS OF THE TELEASSISTANCE SYSTEM

Two types of trials were conducted. The first was the emphatic field trials that were intended to test the navigation efficiency of the remote guide whose task was to navigate sighted volunteers with the use of the system. The second trial was the non-mobility trials in which blind volunteers were asked to view their opinion on how user-friendly the mobile terminal is in terms of its overall ergonomics, i.e., its size, weight, mounting to the body. An important aspect of the test was to evaluate the terminal functionality in terms of setting up a connection with the remote guide and the quality of voice communication.

4.1. The Emphatic Field Trials

The trials were carried out with the participation of seven sighted volunteers. We have initiated the procedure of getting a consent of a bioethical commission for carrying out the trials with the visually impaired participants. In the emphatic trials, seven sighted individuals (aged 26–55, five men and two women) played the role of the navigated visual impaired persons. We did not blindfold the volunteers, however, we asked them to follow the remote guides instructions and to note potential navigation issues, e.g., delayed reaction of the remote guide, imprecise angular directions etc.

Before starting the trial runs, each volunteer was informed about the purpose of the test. The principles of the teleassistance system were explained in detail to each of the volunteers separately with a pre-trial presentation of the system's key functions.

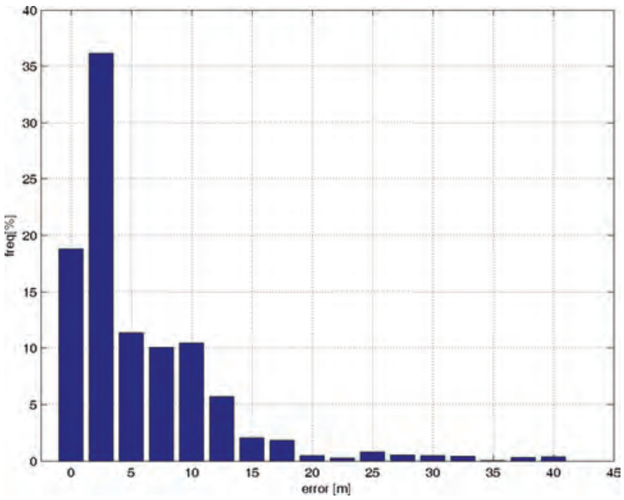

Fig. 7. Histogram of positioning errors aggregated for the three traversed paths.

The trials were conducted on the campus of the Lodz University of Technology. Each participant was asked to walk a different path, each of them ca. 370 m long. The route of a selected path is shown in Figure 6 by a red line.

The travellers were guided by the remote guide from a starting point (exit from a building) all the way to the destination point which was an entry door to a different building. The trials were conducted on a flat area of the University campus, each time from 11 am to 4 pm, with good lighting conditions (approx. 70% clear sky), no rain. There are detailed server logs regarding connection parameters: time, duration and transmission delays.

At the end of the trials, the travellers were presented with a questionnaire to answer closed and opened questions. The questionnaires were prepared with the target—blind users in mind. The trials took three working days to complete. A trial run, including the pre-trial instruction, the navigated walk of the three paths and the post-trial questionnaire interview, took up to two hours for a single participant.

Figure 7 shows the distribution of positioning errors for the three traversed paths. The mode of the histogram, i.e., the most frequent error is approx. 2.5 m, whereas the maximum error reaches 58 m (not shown in the histogram). Other statistical parameters of the distribution of distance errors are: root-mean-square: 8.5 m, mean: 5.7 m and median: 3.3 m. During the trial, the locations of a pedestrian with reference to pavements, curbs, streets, etc. were noted on a cartographic map, which is accurate to centimetres. The maximum error of the registered location of a pedestrian might have been 1.5 m. Then the walking path was created. The GPS coordinates of a pedestrian were projected onto the nearest path segment and the location error was calculated in this way. This was a simplistic approach where only a perpendicular component of location error was registered. The parallel component of location error is difficult to measure as it would require to note down the precise pedestrian location with the time instant. However, the error perpendicular to the walking path is much bigger than the one parallel—see Ref. [11] for a more detailed explanation.

Note in Figure 6, that the largest positioning errors occur in the vicinity of a tall university building (Fig. 6(a)) and in the campus park with tall and big crown trees (upper part in Fig. 6(c)) that obscure the direct visibility of GPS satellites. The reader is referred to Ref. [11] for a detailed analysis of GPS errors.

Table I. Parameters noted for Path I of length-ca. 374 m for trial participants (TP1–TP3).

	TP1	TP2	TP3	TP4	TP5	TP6	TP7
Walking duration [min]	11.0	8.1	9.2	9.3	8.6	7.9	13.1
Average walking speed [km/h]	2.0	2.8	2.4	2.4	2.6	2.8	1.7
Missteps	1						
Minor collisions							
Potential major collisions							
Lost ways							
Lost connections	2						2

For each trial path, the following parameters were noted down:
- duration of the walk,
- number of potential minor collisions (e.g., touching an obstacle),
- number of potentially dangerous collisions (necessary interventions of a sighted assistant),
- number of lost directions,
- number of lost connections.

The system server also logged the geographical position of the mobile terminal (see blue dots in Fig. 6) and the following parameters, reflecting the connection quality between the system terminals:
- transmission delay,
- number of video frames per second,
- duration of transmission blackouts.

Tables I–III shows quantitative results of how the travellers completed the paths with the help of the remote guide. The last row in the tables indicates the number of transmission breakdowns that required reestablishment of the connection between the system terminals.

At the onset of the analysis of the trial results, that we summarise in Tables I–III, we need to note that an average walking speed of a sighted person in a straight path is ca. 4.5 km/h. As the sighted participants of the trial were instructed to walk strictly according to remote guide commands, their walking speed dropped approximately two-fold. Obviously, the participants were instructed to stop immediately if a potential minor or major collision was imminent due to imprecise remote guide navigation instructions.

Path I was the route in which there were the most frequent connection losses (4 times). Thus an average walking speed was the lowest for TP1 and TP7 in comparison to other passes. Another reason for this result was also the effect of a learning curve for the navigated travellers who, for the first time, walked in such a supervised manner. Path II lead along a wide pavement, hence

Table II. Parameters noted for Path II of length–ca. 371 m for trial participants TP1–TP3.

	TP1	TP2	TP3	TP4	TP5	TP6	TP7
Walking duration [min]	9.7	8.5	9.5	9.9	9.1	7.4	12.1
Average walking speed [km/h]	2.3	2.6	2.3	2.3	2.5	3.0	1.8
Missteps			1			1	
Minor collisions		Parked car					
Potential major collisions							
Lost ways							
Lost connections				1			1

Table III. Parameters noted for Path III of length–ca. 368 m for trial participants TP1–TP3.

	TP1	TP2	TP3	TP4	TP5	TP6	TP7
Walking duration [min]	9.5	8.5	9	9.8	8.9	7	10.6
Average walking speed [km/h]	2.3	2.6	2.5	2.3	2.5	3.2	2.1
Missteps							
Minor collisions					Parked car		
Potential major collisions							
Lost ways							
Lost connections							1

the average walking speeds were the highest. For most of this path, the GPS readouts were the most accurate except for the part leading around a tall building where the maximum distance errors reached 30 m. Path III, again, was a straightforward one. TP7 noted the lowest average walking speed, partly due to connection losses.

Overall, there were two potential minor collisions and three missteps noted in the trials. Potential minor collisions with parked cars could have taken place when the remote operator failed to warn travellers TP2 and TP5 in time. After checking the server data logs, we managed to identify that these potential minor collisions coincided with a transmission lag exceeding 1 sec.

Finally, it is important to note that there were no potential major collisions or lost ways during the trials. The latter was mainly due to the fact that the remote guide was familiar with all the university campus paths. We note here that familiarity of the terrain by a remote guide is an important issue that needs to be studied (and tested) in future trials.

As the quality of the video streamed from the mobile terminal to the remote guide was deemed to be the main factor determining the safety of a guided person, we analyzed a number of parameters defining this said quality. Please note that voice is transmitted over a dedicated GSM audio channel and does not experience latencies and blackouts.

Figure 8 shows the histogram of transmission delays of the video stream registered throughout the trials. At times, the delays reached as much as several dozens of seconds, but these were extremely rare and occurred in the 2000 ms histogram bin. The average delay was 206 ms with a standard deviation of 975 ms with a strongly skewed distribution. The delays depended on the GSM operator and the time of the trial.

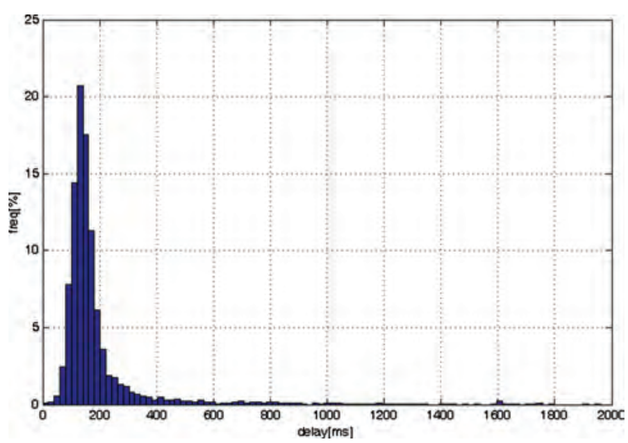

Fig. 8. Histogram of transmission delays of the video stream during the trials.

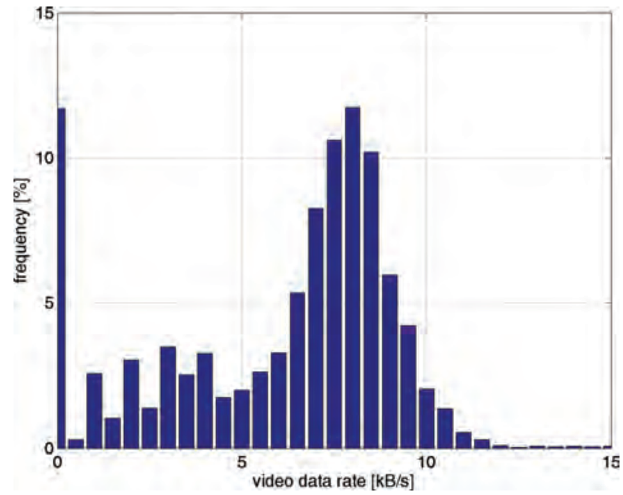

Fig. 9. Histogram of the video data rate measured during the trials.

The transmission delay is a problem that need to be addressed if the system is to be used as a guiding aid. Walking speed of a traveler is ca. 4 km/h, that is ca. 1 m/s. Blind pedestrians use the white cane for local navigation and they prefer to receive information about obstacles and not how to avoid them precisely. A remote operator can recognize obstacles when they are at least 20 m away, giving ca. 20 s to inform the navigated person. Certainly, the delays above 1 s exclude guiding a blind person through a busy street with no pedestrian light.

The histogram of the data rate required for transmitting the video stream is shown in Figure 9. The average video data rate was 6 kB/s with a 3.2 kB/s standard deviation and a 8 kB/s mode. Please note that this is up-link transfer. Internet provided by GSM network results in much better down-link transfer, as the clients usually download data rather than upload.

Accordingly, Figure 10 shows the histogram of video frames per second (fps) for a 160×120 resolution. The average frame rate was 1.7 fps with a 1 fps standard deviation. This low frame rate stems from a lack of interframe compression (still JPEG

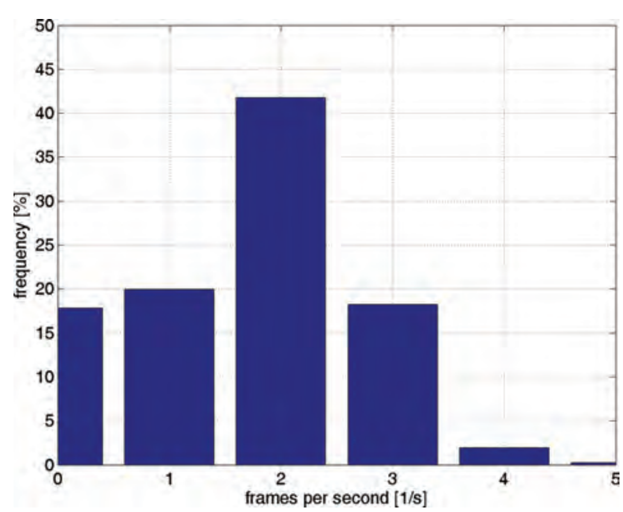

Fig. 10. Histogram of video frames per second.

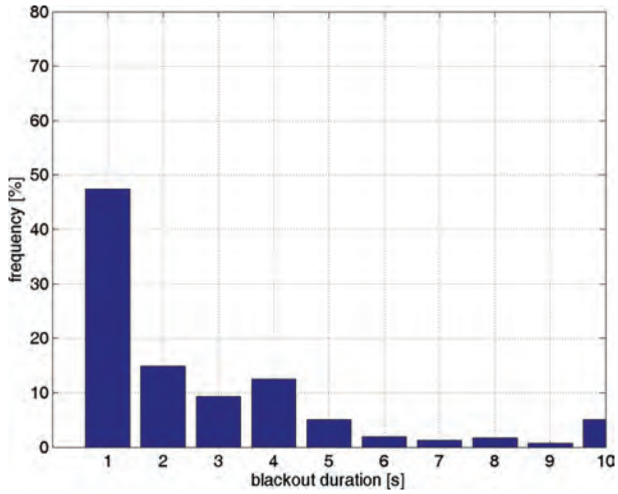

Fig. 11. Histogram of transmission blackouts duration.

images are sent). It is estimated that motion compensation could improve the frame rate by a factor of 4, which would result in a 7 fps average frame rate. A small frame rate may not significantly influence obstacle detection performance by a remote guide, as shown in study,[13] however, it results in a tiring effect. This phenomenon was also noticed during our study.

Aside from the frame rate parameter, the type of transmission blackout is also important. Short, yet frequent transmission losses are less detrimental than the rare, longer ones. Short transmission outages might not even be noticed. Figure 11 depicts the distribution of the duration of the transmission blackouts. Around 48% of transmission blackouts (8.5% of the total trial time) were of short duration (around 1 s). Around 11% of the blackouts (2% of the total time) lasted more than 5 s, which was irritating for the remote guide and potentially dangerous for the guided blind person. 5% of blackouts (0.89% of the trial time) lasted more than 10 s, which gave the impression of the transmission being lost. The average duration of the transmission outage was 3.2 s with a standard deviation of 5.1 s. The issue of large delays or breakdowns of video transmissions were handled by the remote guide with a voiced warning. During the trials, the GSM audio connection mode was selected, thus no latencies in audio connection between the traveller and the remote guide were experienced.

Directly after the completion of each trial, the participant and the remote guide were asked to answer the questionnaire consisting of open and closed questions to assess the system functionality according to different measures. The scale for answers to the closed questions was the following:

1—poor
2—fair
3—good
4—very good

The answers to the closed questions from the blind participants are summarized in Table IV.

The poorest scores were assigned to questions evaluating the system's friendliness Q3 (Table IV). The second lowest grade was assigned to walking speed Q4b—this is understandable because the sighted individuals had to slow down their walking speed to a pace at which the remote guide felt confident in guiding the travellers.

Table IV. Answers to the closed questions from the seven emphatic test participants.

Q1: How do you score the system usefulness in detecting obstacles?

Grade	1	2	3	4	Avg.
No. of answers	0	1	4	2	3.1

Q2: How do you score the system usefulness in guiding along an unknown route?

Grade	1	2	3	4	Avg.
No. of answers	0	1	1	5	3.6

Q3: How do you score the user-friendliness of the system?

Grade	1	2	3	4	Avg.
No. of answers	1	6	0	0	1.9

Q4a: How do you score safety when travelling with the system?

Grade	1	2	3	4	Avg.
No. of answers	0	0	4	3	3.4

Q4b: How do you score your walking speed when travelling with the system?

Grade	1	2	3	4	Avg.
No. of answers	0	1	5	1	3.0

Q4c: How do you score efficiency for walking with the system?

Grade	1	2	3	4	Avg.
No. of answers	0	1	4	2	3.1

Q5: How do you score the navigation commands given by the remote guide?

Grade	1	2	3	4	Avg.
No. of answers	0	0	2	5	3.7

After the field trials, the questionnaire was also presented to the remote guide. The role of the guide was taken by a male aged 30 who underwent training in remote navigation under the supervision of the certified instructor of the visually impaired. His answers to the closed questions are summarized in Table V.

Answers to two questions in Table V were rated at a fair level by the remote guide, namely the frame rate of the transmitted video and the precision of the GPS readouts. Low frame rate tired the remote guide. This was because he had to be unduly attentive and react instantly to sudden changes in the images transmitted at a lower rate. Poor GPS precision does not pose a big problem as long as a guide is familiar with the area. In fact, the remote guide mentioned that familiarity with a path is very helpful in

Table V. The remote guide's answers to the closed questions.

No.	Question	Answer (1–4)
1.	How would you rate the quality of the transmitted video?	–
	(a) image resolution	3
	(b) image stability	3
	(c) the brightness/contrast	4
	(d) frame rate	2
2.	How would you rate the quality of the audio connection?	4
3.	How would you rate the graphical interface of the terminal?	3
4.	How would you rate the GPS accuracy of the navigated person?	2
5.	How would you rate the ability to detect obstacles and alert participants on the basis of video (the micro-navigation task)?	3

efficient remote navigation. We plan to perform trials in an area unfamiliar to a remote guide.

A summary of remote guide's answers to the open questions is provided below:

Q1. What are the main difficulties you have encountered while navigating a person remotely?

A very important factor in navigation is a good rapport with the traveller. One of the difficulties encountered was instructing the navigated person about walking directions. In some cases, the video transmission was suspended for a few or more seconds which created a feeling of losing control over the navigation task. In order to regain control, the traveller was asked to stop, until video transmission was resumed. In general, the frame rate was low, but over time the remote guides learned to anticipate situations.

Q2. What would you change in the graphical interface of the terminal?

Perhaps the map window is too large compared to the video window.

Q3. Is familiarity with the route helpful in navigating a blind person?

Good knowledge of the path is of paramount importance when navigating. It would be much more difficult to guide a person in a completely new environment, e.g., an unknown university campus. GPS readout errors, especially in the presence of buildings, reached ca. 30 metres. More importantly, the direction headed was often inaccurate.

Q4. How would you rate the level of concentration required and the degree of fatigue (or stress) while navigating a blind person?

The low frame rate created a feeling of tiredness. The remote guide needed to be focused to anticipate the oncoming situation and predict the time that the traveller needed to reach an obstacle. Also, low resolution required mental effort to recognize objects further away. Transmission blackouts and lost connections question the system reliability. However, the secure audio connection proved vital in order to warn the traveller about the connection loss.

Q5. Do you have any other comments concerning the teleassistance system?

The time required to establish the connection between the terminals was too long, especially when the connection was lost while traversing a path.

4.2. The Non-Mobility Tests of the Mobile Terminal by the Visually Impaired Users

The aim of these non-mobility tests was to collect opinions of the visually impaired users about the ergonomics of the mobile terminal. We should note here that the visually impaired target users of the teleassistance system have been taking part in the design and development phases of this system terminal.

The non-mobility tests of the mobile terminal were carried out with the participation of seven visually impaired volunteers. All but one were male, aged 29, 30, 31, 38, 44, 57 and 65. Three of them were born blind (category 5 in the ICD-10 WHOS classification scale—no light perception). Two of them had significantly reduced vision (category 4 in the ICD-10 WHOS scale—blindness with light perception).

Before the test, as with the emphatic field trials, each volunteer was informed about the purpose of the test. The remote navigation idea was explained to each of the visually impaired volunteers. Each of the volunteers was delivered a half-an-hour tutorial and had ample time for hands-on experience in order to familiarize themselves with the device keyboard layout, its mounting on the body and the speech synthesized menu of the device.

This non-mobility test with the participation of visually impaired individuals consisted of three parts:

(1) Mounting of the device on the user's body
(2) Testing functionality of the device by asking them to perform the following tasks:
(a) switching the device on and off,
(b) setting up the connection with a remote guide from the available list of guides,
(c) carrying out a short conversation with the guide,
(d) changing specific menu settings of the device (e.g., reading time and setting the alarm clock, switching between the available audio transmission modes: data/GSM).

The test participants were asked to summarize their opinion about the terminal and the system concept by filling in the questionnaire. The visually impaired participants' answers are summed up by the following points:

Q1. What could be the main advantages of the system?

- ability to find a place unknown to the blind person,
- possibility to read textual information,
- detecting unexpected obstacles,
- finding a place in a secluded area,
- having continuous contact with a human which evokes a feeling of safety,
- right size and weight of the mobile terminal,
- ergonomic keyboard with membrane keys.

Q2. What are the main disadvantages of the mobile terminal?

- cable headset,
- cumbersome way of attaching the device to the body (the velcro strap and cord),
- the micro-USB socket for charging the battery of the mobile terminal is too small,
- rather long delay to connect to a remote guide.

Q3. What would you change in the device?

- reduce size of the mobile terminal to make it more inconspicuous,
- quicker way to attach the device to the chest,
- possibly a different design incorporated into glasses,
- longer battery life–e.g., for out of town travel.

Q4. On which occasions do you foresee the system to be particularly useful?

- navigating along unknown routes,
- in large office buildings while looking for a given room,
- to find a pedestrian crossing at a crossroad,
- to get back on the right track after getting lost,
- in shopping centres,
- detecting obstacles.

All the visually impaired testers have underlined that the key problem conditioning acceptance of this system is the portability and convenient attachment (fast and reliable) of the mobile terminal to a user's body. The test participants agreed that after a short period they would be able to efficiently handle the mobile terminal. Interestingly, no complaints were reported on the speech-synthesizer used for guiding the user through the menu. This is an in-house developed, simple diaphone synthesizer which the users preferred to set at a higher speech speeds.

Currently, were are writing a user guide for the mobile terminal that is specially designed for visually impaired users.

5. CONCLUSIONS

The results of the conducted emphatic trials of the teleassistance system with participation of the sighted individuals allows us to conclude that the concept of teleassisted navigation is a prospective solution for aiding the mobility of blind and visually impaired people. This is in accord with earlier documented work on similar systems reported in Refs. [12–14]. In our emphatic tests, the prototype system has proven effective in both short distance locomotion (e.g., avoiding obstacles) and medium-distance locomotion tasks (sighted volunteers walking along paths of length ca. 400 m from start to destination).

The results of the field emphatic trials and the non-mobility ergonomic tests of the system have allowed us to draw valuable conclusions about the system's usefulness and functionalities. From the system users' perspective, the conclusions are as follows:

- blind people evaluate the system as potentially useful in walking and learning new tracks and as an indispensable aid in case of getting lost,
- in many cases, a short navigation session with a remote guide can be sufficient to help the visually impaired in finding directions while walking or travelling,
- the system can be very helpful for shopping and other daily activities,
- the users should be aware of the system's limitations, e.g., transmission delays of video images and reduced quality of the transmitted images (these issues are strongly underlined in the foreseen training course for the systems users),
- users of the system should be considered as a "navigation-tandem" that should be adequately trained in the use of the system,
- an important, not yet discussed legal issue, is the responsibility that the remote guide takes responsibility for the safety of a blind person, thus the remote guide should be aware not to undertake such a navigation task while in a diminished psychophysical state.

As for the technical performance and functional aspects of the system, the conclusions are as follows:

- teleassisted guidance systems in general improve on the GPS-based pedestrian navigation systems in several ways, e.g., a remote guide can verbally describe the environment to the guided traveller (micro-navigation) and can verify the geographical location on the basis of the transmitted sequence of images (macro-navigation); furthermore, the guide can be called for assistance at any time and from any place,
- many ergonomic aspects of the prototype version of the mobile terminal have been verified, some of them should be improved, e.g., the keyboard layout, the way the terminal is attached to the clothes of the blind user or more efficient procedures for establishing connection between the terminals,
- the current main weakness of the prototype is the transmission delay of the video stream; it is hoped however, that new, high-speed wireless communication technologies, e.g., 4G LTE (Long Term Evolution) standard will bring a quick solution to this issue. The LTE technology flourishes, although it is only available in large cities.

Further work will concentrate on conducting system trials with participation of the partially sighted individuals in a model environment. Such tests, with a special pre-training sessions, are required to evaluate system true usefulness as a viable travel aid for the visually impaired. We reckon, this system can also find an application in aiding the elderly suffering from fading vision or dementia.

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