A system for remote sighted guidance of visually impaired pedestrians

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A system for remote sighted guidance of visually impaired pedestrians

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Sighted guidance is arguably the most efficient method for aiding visually impaired pedestrians in mobility. A sighted guide's verbal instructions compensate comprehensively for the insufficiency of visual input in navigation. Moreover, the companionship entails sharing of responsibilities and thus increases the blind traveller's sense of security during a journey. The disadvantages of the sighted guidance are that a sighted guide may not always be available or their presence may not be desirable because it restricts personal independence. This paper presents a novel system for navigation of visually impaired pedestrians, whereby advanced technologies were combined to allow a visually impaired user to remotely access the sighted guidance service. The user can choose when and for how long to use the system. The remote sighted guidance system is enabled by the integration of a remote vision facility with the Global Positioning System, the Geographic Information System and the third generation telecommunication network. A user trial is also reported in which the contribution of the system to the mobility of a visually impaired pedestrian was assessed. The results obtained lead to the conclusion that the remote sighted guidance is potentially a highly usable mobility aid.

Introduction

The process of navigation in humans entails the simultaneous performance of two basic tasks: micro- and macro-navigation (Petrie, Johnson, Strothotte, Raab, Michel, Reichert & Schalt, 1997; Loomis, Golledge & Klatzky). Micro-navigation includes avoiding obstacles and locating a clear path in the proximate surroundings, while macro-navigation refers to the actions required to find a way in a larger, not immediately perceptible environment. Principally, these two actions involve constant updating about the position and direction along the route and, in the event of becoming lost, the re-establishment of orientation. Successfully navigating in a variety of situations is a prerequisite for achieving independent mobility, one of the necessities of everyday life. Various perceptual inputs support navigation, with vision being the dominant source (Jansson, 1995). Visually impaired people must greatly rely on the remaining senses for information acquisition (Guth & Rieser, 1997). Today, a number of aids are available that substitute for visual impairment and that enhance the ability to access important navigational information and improve mobility.

Arguably, the most effective method of mobility assistance is sighted guidance (Farmer & Smith, 1997). The sighted guide's verbal instructions compensate for the visual input in micro- and macro-navigation. The sighted guidance reduces the level of psychological stress associated with travel and equalises it with the stress experienced by sighted travellers (Peake & Leonard, 1971). Consequently, it imposes less mental demand during the travel (Shingledecker, 1983) in relation to any other means of aid. These advantages are a result of the shared responsibilities between the guide and the pedestrian on the journey. However, the disadvantage of the sighted guidance is that it does not allow personal independence to the person being guided. For example, the sighted guide may not always be available and it may not always be desirable or necessary for a visually impaired person to be continuously accompanied.

The most commonly used traditional aids are white canes and guide dogs (Farmer & Smith, 1997). These aids are also referred to as primary aids. The cane detects for obstacles on the ground up to waist level and thus contributes to micro-navigation. Detection of obstacles at the level of the upper part of the body, in particular the head-height obstacles, remains a problem. Along with assisting in the avoidance of ground obstacles, the guide dog contributes to macro-navigation, but mainly on familiar routes. The presence of the guide dog also increases the sense of security, however to a lesser extent than the presence of a human guide.

A number of technologically advanced aids have been attempted to develop over the past few decades. These aids are not intended to replace the primary aids, but to complement them and add to their functionality. In the 1960s and 1970s, the majority of research was concerned with the development of a device that would provide assistance with micro-navigation in the area beyond the reach of the cane. The devices based on the utilisation of ultrasonic or electromagnetic technologies, such as the Sonic Pathfinder (Heyes, 1983), have failed to deliver a viable solution. Users often find these aids too complex to use and they do not add significantly to the information already available through the primary aids.

Within the past 15 years, the focus of research has been on the development of aids to facilitate macro-navigation, primarily based on the use of the Global Positioning System (GPS) (Parkinson & Spilker Jr., 1996) and the Global Information System (GIS) (Kang-Tsung, 2001) technologies. The most notable projects in this field are the MoBIC (Petrie et al., 1997), which has contributed valuably to user requirement specifications, and the GPS-Talk (May, 2002), which is the first commercially available system of its kind. These systems are designed to guide the visually impaired pedestrian by providing the automatic navigation instructions in the form of synthesised voice messages. They also facilitate journey planning, which enables the user to explore the route before undertaking the journey. Even though the GPS and the GIS systems are potentially a very effective mobility aid, more needs to be done to improve their usability. The encountered problems can be divided into three categories (Farmer & Smith, 1997), referring to the limitations of applied technology, the system architecture and the related user interfacing. Tall buildings and other environmental features in so-called urban canyon areas can easily block reception of the GPS signal. As a result, the use of the system is disabled. For similar reasons, the systems cannot be used for indoor navigation. The relatively poor positioning accuracy of commercially available GPS receivers restricts the reliability and the content of the provided information. The available information is limited to the capacity of the GIS databases, which normally do not accommodate for dynamic changes in the represented real-life environments. As the systems are self-contained, the visually impaired user is solely responsible for operating and maintaining the complex set-up, which makes the use of the system highly demanding. Furthermore, the automatic navigational instructions are not flexible enough in the content choice and the syntax to meet the individual user needs.

It is worth noting that hitherto the mobility aids offered only partial solutions to the requirements of visually impaired pedestrians. An 'ideal' mobility aid (Wycherley & Nicklin, 1970) should fulfil two main criteria of usability. First is the effectiveness; the visually impaired pedestrian using the 'ideal' aid should be allowed equal or a similar level of mobility as sighted pedestrians. Secondly, the travel supported by such an aid should not be more stressful and mentally demanding than what is tolerated in travel with vision.

This paper describes a novel approach to develop a mobility aid system for visually impaired pedestrians, which aims to bring together the best qualities of the technologically advanced aids and the traditional sighted guidance. The system expands on the previous developments in the area of the GPS and the GIS-based mobility aids, in that it complements the automatic navigation with the facility to support the remote guidance by a sighted human guide. By combining the technological solutions with the human factor in such a way, a number of limitations of the aforementioned aids are circumvented to improve the overall usability of mobility assistance.

The system for remote sighted guidance

The system architecture

The key features of the new system are the distribution of the functional components and the integration of the remote vision facility (digital video camera) with the GPS and the GIS. The functional components of the system are allocated into two terminals: one mobile, at the remote site of a visually impaired pedestrian (the user), and the other stationary, at the site of a sighted guide (the guide). The architecture scheme of the system prototype is depicted in Figure 1.

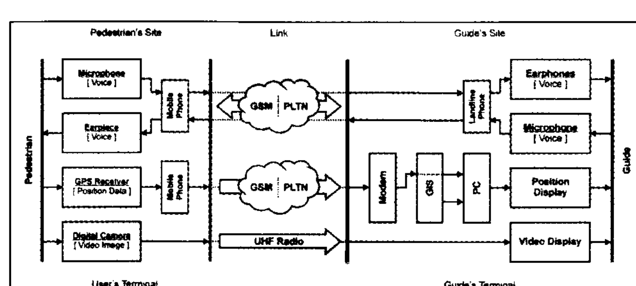

Figure 1: The architecture of the system prototype

The user's terminal includes two information acquisition sensors: a digital video camera and a GPS receiver. This terminal is mobile and all the components are contained in a wearable backpack that allows for hands-free use (Figure 2). The camera is positioned on the user's chest and pointed onwards in the direction of the environment in front of the user. An external antenna, positioned at the user's shoulder, is used in conjunction with the GPS receiver to minimise blockage of the GPS signal reception by the user's body (Garaj, 2001).

Figure 2: The user's terminal

The guide's terminal is a personal computer, which contains a GIS database, and a display to present the video image and the user's location on a digital map (Figure 3). The GIS database contains information on the general layout of the environment and other travel-specific information, such as locations of bus stops etc. The GIS database contents can be easily updated for the up-to-date changes in the environment in which the navigational assistance is required. The guide's terminal is stationary and located in the designated navigation centre, from where a trained guide provides the guidance service (Figure 4).

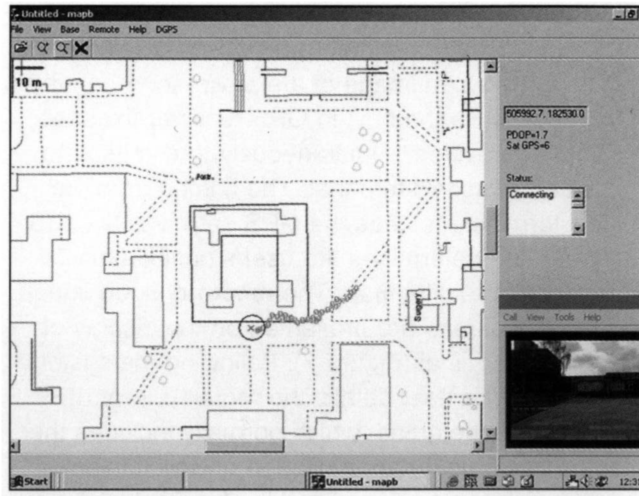

Figure 3: The screen capture of the guide's terminal display

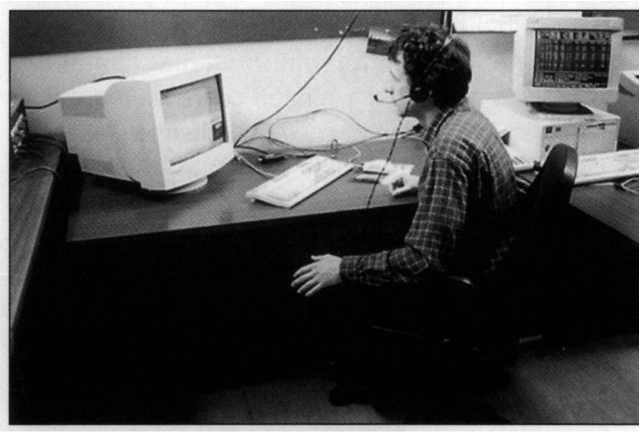

Figure 4: The navigation centre

In the current system prototype, the wireless link, which is composed of three separate communication channels, connects the terminals. A GSM (Global System for Mobile Communications) mobile phone with a hands-free set containing a microphone and earpieces is used by the user for voice communication with the guide. This phone is linked to the PLTN (Public Landline Telephone Network) phone in the guide's terminal. The second GSM phone, also contained in the user's terminal, is utilised to transmit the positioning data acquired by the GPS receiver. This phone is linked to the landline telephone modem in the guide's terminal. The video image from the digital camera is transmitted via a UHF radio link. The future work will aim to integrate the communication channels over a third generation telecommunications network, such as UMTS (Universal Mobile Telecommunications Service).

Functionality of the system

Before embarking or at any point during the journey when in need (e.g. in the case of orientation loss), the traveller uses his/her terminal to connect with the guide and request navigation assistance. When the link is established, the integrated video camera starts capturing the video image of the environment ahead of the user, while the built-in GPS receiver fixes the position. The system simultaneously transmits both inputs to the guide's terminal. The computer in the guide's terminal matches the GPS data with the GIS database and determines the user's position on the corresponding digital map. The received video image and the digital map are presented on the display of the guide's terminal (Figure 3). Following the system initialisation, the user details the required form of assistance to the guide, which normally includes the desired travel destination. Based on the current location of the user determined by the GPS and the given travel destination, the guide uses the system's GIS module to determine the optimal travel route. Prior to the start of the journey, the guide provides the user with the verbal description of the route in order to enable them to gain the initial spatial orientation by building the related cognitive map. As the user sets out on the journey and changes location, the video and the GPS inputs are continuously updated. The guide interprets the received information and verbally communicates the navigational instructions to the user. The video image is used as the input for micro-navigational assistance, while the GPS and GIS database provide the source of information for macro-navigation.

The two main functions of the micro-navigational support are the detection of obstacles and the description of the layout of immediate environment. Based on the received video image, the guide can detect and provide the real-time information to the user regarding the objects in the environment that are obstructing the user's path, such as the cars parked on the pavement, street furniture, road works etc. The available information also includes the head-height obstacles, for instance overhanging tree branches. Additionally, a detailed verbal description of a more complex environment can be provided. For example, the description of the pedestrian crossing that the user is about to cross, including the dynamic information regarding the crowdedness of a crossing the presence of cyclists in the near vicinity, or the description of a layout of an entrance to a building, etc. This is the information that is not available through other mobility aids. The macro-navigational support entails assisting the user in travelling to a desired destination in a distant and unfamiliar environment. This information includes update of the user's current location along the route, e.g. position in the given street or position relative to the specific landmarks along the route, as well as directions and update of distance to the destination as the location changes. The desired journey destination can be precisely specified by the user, e.g. the address of a friend's house, or may be suggested by the guide, based on the user expressing their needs, e.g. the nearest bus stop, a shop or a restaurant etc.

Advantages

Besides enabling the micro-navigational function of the system, the synergy of the sighted human guide and the technology, as applied in this system, entails additional benefits to the visually impaired users of the system. Placing the entire responsibility of operating and maintaining the system with a sighted guide minimises the level of demand imposed on the user. Furthermore, the verbal interaction between the guide and the user facilitates significant flexibility of the navigational information output. The high demand related to the use of the system and the limited flexibility of the output are often seen as the weak points in other technologically advanced mobility aids.

In certain situations, the interpretation abilities of the guide combined with the remote vision facility incorporated in the system can perform the function of a remedy for some of the technological problems related to the GPS. When the GPS signal is unavailable, the guide can utilise the video image as a form of dead reckoning tool. The wireless video transmission is not significantly obstructed by the certain environmental features such as tall buildings or indoors where the GPS signal reception is blocked. In such circumstances, although the macro-navigational facility of the system is disabled, the guide still receives the video image and hence continuous guidance service can be provided based on the visual information. In addition, the video image can be used to enhance the accuracy of the GPS positioning. For example, in some situations the GPS positioning is not accurate enough to determine with certainty whether the user is walking on the pavement or the adjacent road. The real position of the user can then be decided upon by comparing the location on the digital map with the related video image of the environment ahead.

A very important feature of the remote sighted guidance is that it reduces the travel-related stress experienced by visually impaired pedestrians in a similar manner to real sighted guidance. Nevertheless, it allows for a considerably higher level of journey independence. The remote sighted guidance service is available at all times and it is entirely up to the visually impaired user to decide on the occasion on which to use it.

Preliminary user trial

A preliminary user trial was conducted to assess the contribution of the established system for remote sighted guidance to the mobility of visually impaired pedestrians. In the trial, the system was employed as the secondary navigation aid, supplementing the use of a guide dog. The usability of the system was tested in the context of both micro and macro-navigation.

Participants

The trial included two participants; one participated as the user of the system and the other one as the guide. The subject who participated as the user was an adventitiously blind male, aged 40 years at the time of the trial, who has suffered the complete loss of vision at the age of 18. As an experienced guide dog user, he frequently travels independently on a number of familiar routes in everyday life. In addition, he has occasionally undertaken journeys in unfamiliar environment, although less frequently than in familiar environments. Based on these facts, he defined himself as a 'very mobile' individual. The subject who undertook the role of the guide was a sighted male aged 28. Neither participant had previous experience in the use of the system for remote guidance.

Procedure

A one-hour meeting preceded the trial in which the functionality of the system was explained to the participants. The trial tasks were also explicated individually and the participants were provided with a half-hour training program in order to learn how to use the system terminals.

In two trial sessions, the blind participant walked along two different routes, as shown in Figures 5 and 6 respectively. Both routes were similar in length (approximately 160 metres) and environment setting, with the identical starting and ending points. The choice of the routes was restricted due to the limited range of the video transmission enabled by the system prototype, which is approximately 200 meters. The main parts of the routes were placed outdoors and they were free of any obstacles. Hence, the primary concern for the blind participant during the walk was the macro-navigation. However, both routes ended indoors; the blind participant had to locate the particular building entrance, open the door to enter the building and then locate another door in the proximity of the entrance to the building. This set of actions can be classified as the task of micro-navigation. Before the start of both sessions, the experimenter accompanied the blind participant to the starting point of the route. From there, the communication was established with the guide, who was located at the provisional navigation centre inside one of the buildings. The initial task of the guide was to provide the blind participant with the detailed verbal description of the route through the voice link. The description contained instructions on how to travel the route from start to finish, including the number of turns, relative distances and directions between the turns and the landmarks along the route. Special attention was given to the description of the environment in the final stage of the journey, that is the entrance to the building. The blind participant was allowed to have the description repeated several times, until he was confident he had gained a good understanding of the route. In addition, before the start of the second session, the blind participant communicated his preferences on the form of the guidance information provision to the guide; for example, he preferred to have the distances expressed in imperial units and the directions corresponding to the clock face.

In the first session, after the route description was provided, the communication with the guide was terminated. The blind participant was requested to walk along the route without being assisted in navigation using the system. The only aid he utilised was the guide dog. In the second session, along with the guide dog, the blind participant was continuously navigated along the route by the guide, using the system. An experimenter attended the walk in both sessions in order to observe the participant's actions and provide any assistance if necessary. The behaviour of the participant was videotaped. Based on the video records, the corresponding behavioural maps were traced (Figures 5 and 6), which were subsequently used to analyse the effectiveness of the system.

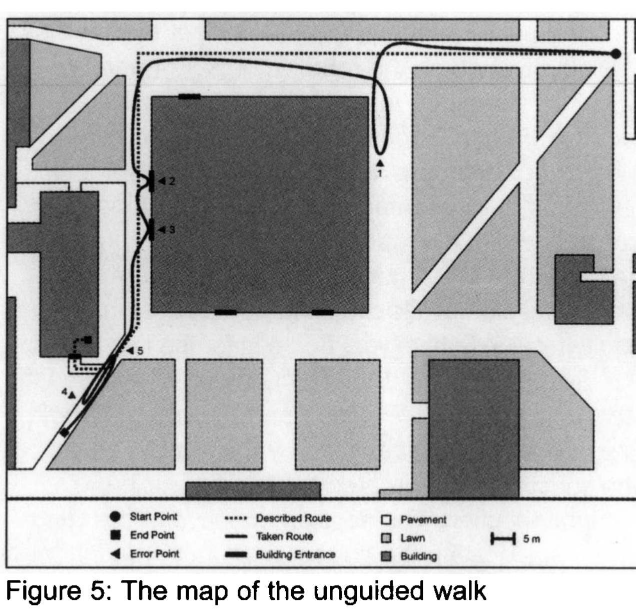

Figure 5: The map of the unguided walk

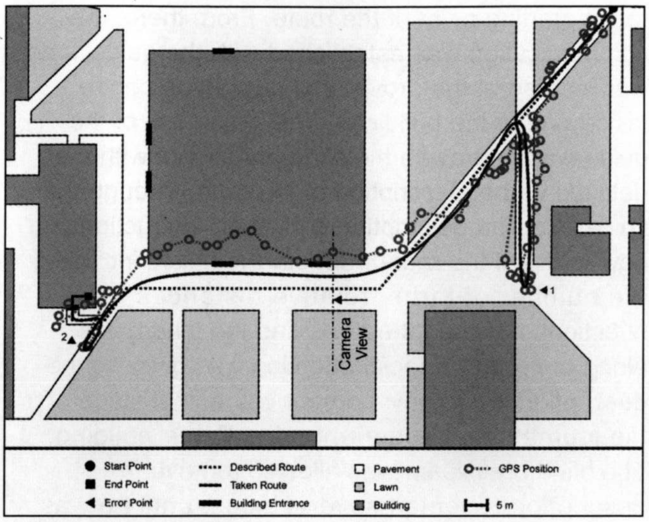

Figure 6: The map of the guided walk

Results

Effectiveness of mobility was defined as a function of the number of errors committed during the walk. It was considered that an error was committed when the blind participant had lost his way along the route and therefore unknowingly headed in the incorrect direction. On such occasions, the experimenter assisted the participant in re-establishing the orientation and helped him to return on the course. A similar method of analysis was applied in previous experiments conducted to examine the mobility of visually impaired pedestrians (Espinosa & Ochaita, 1998). Owing to the clarity of the obtained results, it was deemed superfluous to exercise additional measures of mobility, such as the walking speed or the continuity of progress (Heyes, Dodds, Carter & Howarth, 1983).

In the first session, when travelling unguided, the blind participant committed five errors (Figure 5). The points on the route where the errors were committed are marked with numbers 1 to 5. On three occasions, the blind participant missed the correct turn and as a result, diverted off the route (Points 1, 4 and 5). Twice, he attempted to enter the wrong building entrance (Points 2 and 3), due to misjudging the end-point of the route. Following the last error, the participant felt frustrated and hence incapable of proceeding with the walk; he gave up, thus concluding the session without completing the route. In the second session, while the blind participant was remotely guided, there was no need for the intervention. The blind participant diverted off the route on two occasions (Figure 6, Points 1 and 2). However, both times the error was identified by the remote guide, who subsequently rerouted the blind participant in the right direction. The session ended with the blind participant locating the correct door and entering the building, thus successfully completing the route.

Post-trial interviews

Following the trial, interviews were conducted with both the blind participant and the guide in order to obtain their subjective feedback on the difficulty of the trial tasks, usability of the system and suggestions for improvement.

According to the blind participant, the main reason for not being able to conclude the walk in the first session was unfamiliarity with the route, even though the provided description gave him the initial confidence and enabled him to create a mental map of the route. After he first lost the way (Figure 5, Point 1), he had difficulties in relating the map to the actual environment in the remainder of the journey. At some point, he incorrectly assumed that he was approaching the end of the route while actually being much further away. At this point, following the usual practice of the collaboration, he ordered the guide dog to find the entrance to the building. Consequently, the dog located the incorrect door. Similar mistakes were repeated twice (Figure 5, Points 2 and 3). After being corrected by the experimenter on those two occasions, he lost his way twice again (Figure 5, Points 4 and 5) and decided to give up on the walk. The blind participant expressed high contentment with the efficiency of the provided guidance service in the second session, emphasising the contribution of the micro-navigational assistance in locating and entering the correct building entrance at the end of the route in this session.

The main problem experienced by the sighted participant who undertook the role of the guide was being unable to precisely establish the changes of the blind participant's heading in relation to the route/digital map as they were occurring. Perceiving the change of heading based on the video image and the GPS position increased the response time and caused an occasional confusion in the directions he was providing to the blind participant. He suggested that having the real-time change of heading displayed on the screen along with the position and video image might improve the guidance effectiveness.

In addition, having had the knowledge of the environment in which the trial took place, the guide expressed a concern that his performance might have been poorer if he was unfamiliar with the environment, because some of the decisions he made were based on previous knowledge rather than the system inputs solely.

Despite being satisfied with the success of the second session, both participants agreed that an additional training and fine-tuning of the communication protocols, particularly in terms of verbalising of the navigation instructions, would improve the performance even more.

Discussion

In the given trial conditions, while travelling unguided in an unfamiliar area, the blind participant achieved a very poor level of mobility despite familiarisation with the route by verbal description before the journey. The mobility level significantly increased in the second session, when the blind participant travelled in the similar travel environment supported by the use of the system for remote sighted guidance. Moreover, the use of the system had a positive impact in tasks of micro and macro-navigation.

Albeit general conclusions regarding the contributions of the system to the mobility of visually impaired pedestrians cannot be made before more advanced evaluation trials are conducted, the results and the participant's feedback obtained in this preliminary trial lead to a belief that a remote sighted guidance is potentially a very usable mobility aid.

In addition, the use of the video image as a tool to enhance the precision of the GPS positioning was demonstrated in the trial. As depicted in Figure 6, the accuracy of the GPS positioning decreased significantly when the blind participant was walking along the tall building in the second half of the route. The blind participant's position in this section of the route, as traced by the GPS and presented on the guide's display, fell within the area of the building on the map; this information is ambiguous and untrue. The reduction in the GPS accuracy occurred because the building was obstructing the line of sight to some of the GPS satellites that were visible in the preceding part of the route situated in the area of lawn, which was free of obstruction. In this situation, the guide used the video image (Figure 7) to determine the true position of the blind participant.

Figure 7: The camera view

Further work

Future work on the system will concentrate on the twin aspects of further technical development and system evaluation. The major change to be implemented in the system is the integration of the system's communication channels. A high-bandwidth telecommunications network, such as the Universal Mobile Telecommunications Service (UMTS), will be utilised for the integrated voice and data communication between the user's and the guide's terminals. UMTS is the third generation of the mobile telecommunications systems (3G) that is currently under development for the world market. It will support simultaneous multi-channel data transmission of the capacity up to 2Mbit/s, including multimedia content such as digital video (Korhonen, 2001). The application of the standardised 3G-telecommunication network will enable full operability of the system in a wide geographical area of the network coverage.

An electronic compass will be added to the user's terminal to perform the function of a heading sensor. The user's heading in the form of the data acquired by the electronic compass will be transferred along with the GPS data and the video image to the guide's terminal and presented on the digital map. Knowing the user's heading in addition to the position will enable the guide to acquire better understanding of the user's whereabouts and orientation in the related environment. Hence, the guide will be able to achieve a quicker response to the user's accidental departures from the planned travel route and provide more precise guidance instructions.

One could argue that the system for remote sighted guidance in its present form may not be economically feasible in real-life conditions as it may require a large number of staff in the navigation centre to be continuously engaged in the process of navigation, if more users are to use the system at the same time. In addition, the constant engagement of a sighted guide in the micro-navigation may not be necessary as the visually impaired pedestrian can deal with many micro-navigational tasks by using a cane or a guide dog. In order to enable a single guide to assist more than one user at the same time, an automated navigation option will be added to the existing system configuration. In the automated navigation mode, the intelligent navigation module will automatically generate macro-navigational instructions based on the user's position and the heading and present them to the user as synthesised voice messages. If granted permission by the user, the guide will be able to switch the system to automated guidance prior to, for instance, the user approaching less demanding sections of the journey. Nevertheless, the user will retain the option to request the sighted guidance at any time. The system will also alert the guide and automatically switch to the sighted guidance mode in, for example, situations whereby the availability of the GPS is significantly reduced.

A portable and mobile prototype of the guide's terminal will be developed using a Personal Digital Assistant (PDA) as a technological platform. Such a version of the guide's terminal will be used to explore the scenario in which the remote guidance service is provided to the visually impaired pedestrian by a relative or a trusted friend. If this concept is proved successful, a remote sighted guidance function could be implemented to any standard 3G-enabled mobile phone in the future as a cost-effective alternative to the navigation centre. All the proposed technological changes are summarised in the scheme of the advanced system architecture in Figure 8.

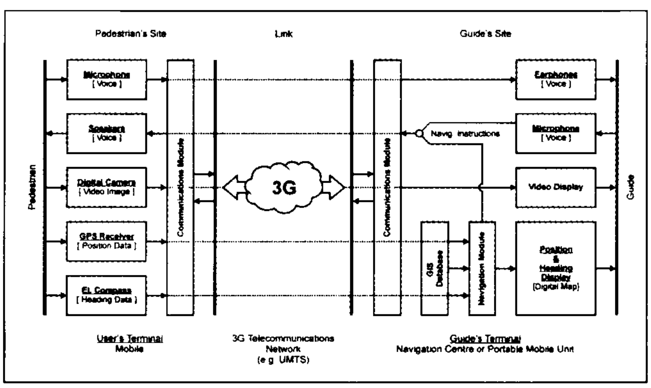

Figure 8: The architecture of the future system

The additional system evaluation will aim to establish broader conclusions regarding the usability of the system. The system will be tested in different travel environments and the trials will include a cross-section of potential visually impaired users and sighted guides.

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