

Remote mobility and navigation aid for the visually disabled

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ABSTRACT

Outdoor tests of a system for remote guidance of the blind are reported in the paper. The main idea of the system is to transmit a video stream from a camera carried by a visually impaired user to a remote assistant that navigates the blind by short spoken instructions. The communication link is established over the GSM network within the High-Speed Downlink Packet Access (HSDPA) communication protocol. Mobility trials of the system were carried out with a mobile prototype and three blind volunteers in the university campus. The aim of the study was to test the overall tele-assistance concept including: communication link efficiency and reliability, influence on mobility and safety, and the improvement of operator-user interaction. Tests, albeit performed on a small group of volunteers, clearly show an objective performance increase when traveling with the remote guide. This is evident primarily in increased travel speeds and decreased occurrences of missteps and collisions.

1. INTRODUCTION

Blindness deprives humans of their most important sense and the primary source of information about the environment. In Europe 3-4 persons in every 1000 are visually handicapped. This statistic is going to worsen, chiefly due to the aging demographic. The number of the blind in the world is foreseen to increase by 20% within the next 50 years (European Blind Union).

A blind person has to count on a sighted guide's help or use specialized aids that compensate for the lost vision. There are a numerous technical aids that have been developed through recent decades that make the lives of the blind easier. Braille monitors "print" the text that is legible for the blind. Sound synthesizers convert text into speech. Braille typewriters or electronic voice recorders facilitate the blind in tasks of storing text or spoken messages. Also, special software packages are being developed that make computers and mobile devices more friendly for the blind user. Hence, the communication barrier that the blind is confronted with is steadily being overcome. The blind, however, rank the lack of independent and safe mobility as the most important impairment that deprives them of normal everyday life, both social and professional wise.

There has been a long lasting research record on electronic travel aids (ETAs) helping the blind in obstacle avoidance and navigation. The idea of sensory substitution, i.e. replacing lack of stimuli from one sense by appropriate stimuli for another sense is in fact the operation principle of all ETAs for the blind (Bourbakis, 2008).

Among the reported ETA devices (some commercially available) one could indicate UltraCane (Sound Foresight), LaserCane (Nurion-Raycal), Sonic Pathfinder (Perceptual Alternatives), NavBelt system (Shoval et al, 2003), vOICe (vOICe), EAV (Espacio Acustico Virtual), Tyflos (Bourbakis, 2008), and our system based on stereovision and spatialized sounds for presentation of obstacles (Strumillo et al, 2006; Pec et al, 2006; Bujacz and Strumillo, 2006). However, none of these systems have found ubiquitous acceptance among the blind community, mainly due to high costs and long learning curves.

Another line of research on ETA devices that we have commenced a few months ago is aimed at navigating the blind by a remote sighted guide (Naviton). The underpinning idea of this study 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. We have constructed an early prototype system comprised of a notebook worn in a backpack designed for mobility, a standard wireless LAN connection, a digital webcam mounted on a chest-strap, and a headset. Existing commercial software – Skype was used for audio and video streaming between the user and the operator. Results of tests that have been carried out indoors with three blind volunteers were reported in (Bujacz et al, 2008) and can be summarized as follows:

- contrary to their expectations, the blind participants retained better orientation when using the remote guide, than when walking unguided or with a human guide,
- average travel speeds were 20-50% better than following the paths unguided,
- the blind participants pointed out the psychological comfort and confidence brought by the contact with the remote operator.

In this communication we report results of implementing the concept of the remote navigation system for outdoors trials. Several field test scenarios were carried out on the university campus. The prototype was replaced by an ultraportable Flybook laptop and augmented with a GPS sensor. A new software package for streaming video, audio and GPS readouts over the GSM channel has been developed and tested. The trials were conducted with participation of the same three blind persons that earlier took part in the indoor tests.

Tele-assistance is a new concept to navigating the blind. Although, another person is still involved in the guidance, this idea has a number of advantages (e.g. increased user privacy and independence) over traditional guidance by a sighted person. Current and upcoming advances in information and telecommunications technologies offer platforms for efficient implementation of such systems.

To the authors' best knowledge, the system developed at the Brunel University, UK was the first reported system for remote guidance of the blind (Garaj et al, 2003). The system offered the tele-assistance service by implementing GPS and GIS technologies and transmission (voice, video, other data) over the 3G network. First successful guidance results were reported in an outdoors trial. A French company Ives Interactivity Video & Systemes has announced a device called Visio.assistant (Ives). It underwent preindustrial tests. In that solution the webcam and the wireless transmitter are mounted in a case resembling hand hair dryer and the transmission link is established over the WiFi network. Yet another tele-assistance system for remote guiding of the blind is the MicroLook, that is under development by a Polish company Design-Innovation-Integration (Microlook). MicroLook integrates a webcam with a headset and a mobile telephone platform. The project is at the stage of a prototype under tests and was not published in any scientific literature; however, it has won a Brussel Eureka 2007 trade fair award.

2. PROTOTYPE DESCRIPTION

The prototype device consisted of an ultra mobile laptop computer (Flybook) worn in a shoulder bag, a digital webcam and a GPS receiver attached to the shoulder strap, and a single-ear head-phone with a microphone. The Flybook was equipped with a built in UMTS/HSDPA modem and a large touch screen. The digital webcam was a high-end Logitech camera, modified with a wide-angle fish-eye lens from a CCTV camera. The GPS receiver used Bluetooth to connect to the Flybook.

Using the ultra mobile laptop allowed the prototype to be both functional and easily modifiable, retaining access to all PC transmission protocols and codecs. The computer operated by the assistant who remotely aids the visually impaired person, can be any PC with a public IP address. A link is established over the Internet and GSM network using the HSDPA protocol.

2.1 *Modifications from the Previous Prototype*

The main modifications from the trials described in (Bujacz et al, 2008) were the change of the base platform from a laptop to an ultra-mobile laptop and the implementation of new software written for minimized delay of audio and video transmissions and quick automatic connections and reconnections. There also were a few smaller problems that were fixed or improved on. The camera was fitted with a fish-eye lens to broaden the operator's field of view. The audio headset was replaced by a single earphone-microphone set. During preliminary trials the camera's oversensitivity to sunlight turned out to cause many difficulties to the operator. This was solved by replacing the camera with a newer model that had the ability to automatically adjust exposure time.

2.2 User-operator Connection

In the prototype, the connection can be invoked both by the operator and the blind user. The link is established through TCP/IP packets that guarantee information delivery. The status of the connection process is accompanied by appropriate auditory icons, i.e. calling in progress, connection established, connection failure, broken connection. The connection details are presented in Figure 2. The two feedback loops at the bottom of the schematic serve to calculate packet delays and trigger pauses in transmission if the network is too congested.



Figure 1. Trial participant wearing the prototype for communication with a remote assistant: A – earphone, B - microphone, C – Bluetooth GPS receiver, D – webcam with a fish-eye lens, E – Flybook laptop with built-in UMTS/HSDPA modem and touchscreen.

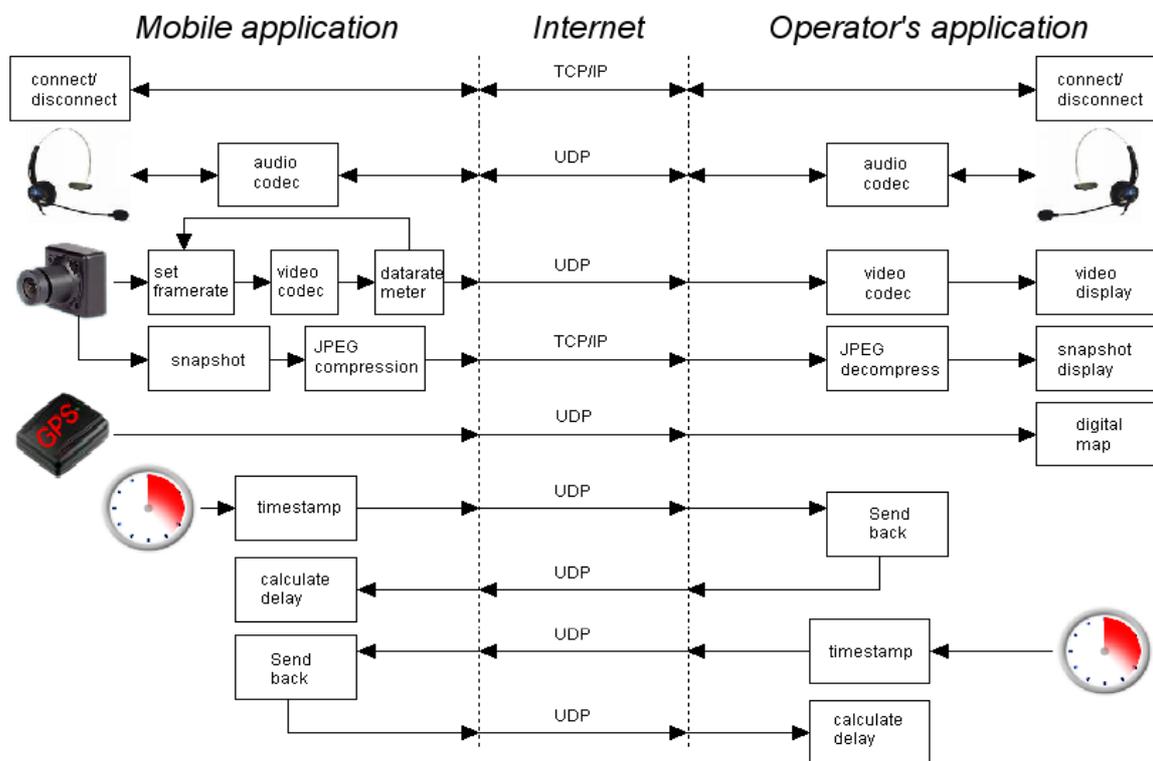


Figure 2. The connection schematic and protocols used.

The operator and the blind person establish a two way voice communication. Voice is sampled, 8-bit encoded and divided into appropriate data packets. The counterpart system receives the voice packets and decompresses them. Voice samples make their way to the destination by UDP packets that are devoid of any additional wrap-up data (compared to TCP/IP packets). Voice packets are made as compact as possible to arrive at the destination with minimal delay. In the current version silent samples are also transmitted, but an algorithm that skips such packets is in the works, as it will allow us to conserve a lot of bandwidth. The audio stream currently occupies approximately a constant bandwidth of 6 kB/s. Lost audio packets were not retransmitted. Packets' delay is kept at minimum mainly by a roundtrip packet monitoring procedure which is discussed thereafter.

The blind person wears a digital USB camera. The acquired video sequence is compressed using the MPEG2 codec. The paramount issue of concern here is to fit the resultant stream (video and audio) below the canal throughput. Otherwise, packets are queued at the internet provider and in consequence the delivery is deferred. As mentioned before, the audio stream is constant. Hence, the video stream is the one modified not to exceed a given bandwidth. The volume of the compressed video stream depends on the dynamics of camera movements and scene complexity, thus it varies greatly and a mechanism for controlling the video data rate had to be implemented. The amount of compressed video data is averaged over 1 second, using both key and differential video frames in the calculations. Under default settings, when the average data rate exceeds 25kB/s, the number of coded frames per second is decremented, otherwise it is incremented. In consequence, the resultant video stream is squeezed into fewer than 25kB/s, always at the highest possible frame rate. The compressed video is sent to the operator in UDP packets.

The snapshot option is initiated by the operator through a small TCP/IP packet. This is not depicted in Figure 2 for the sake of simplicity. A picture is captured from the camera and undergoes lossless JPEG compression. It is relayed to the operator by TCP/IP packets and displayed. The delay is not an issue in this case.

The GPS receiver returns coordinates (longitude and latitude) once every second. This data is then transmitted by UDP packets. Longitude and latitude are converted into the Cartesian coordinate system and the blind person's position is plotted on the digital map in the operator's computer. A screenshot of the operator's application is seen in Figure 3.

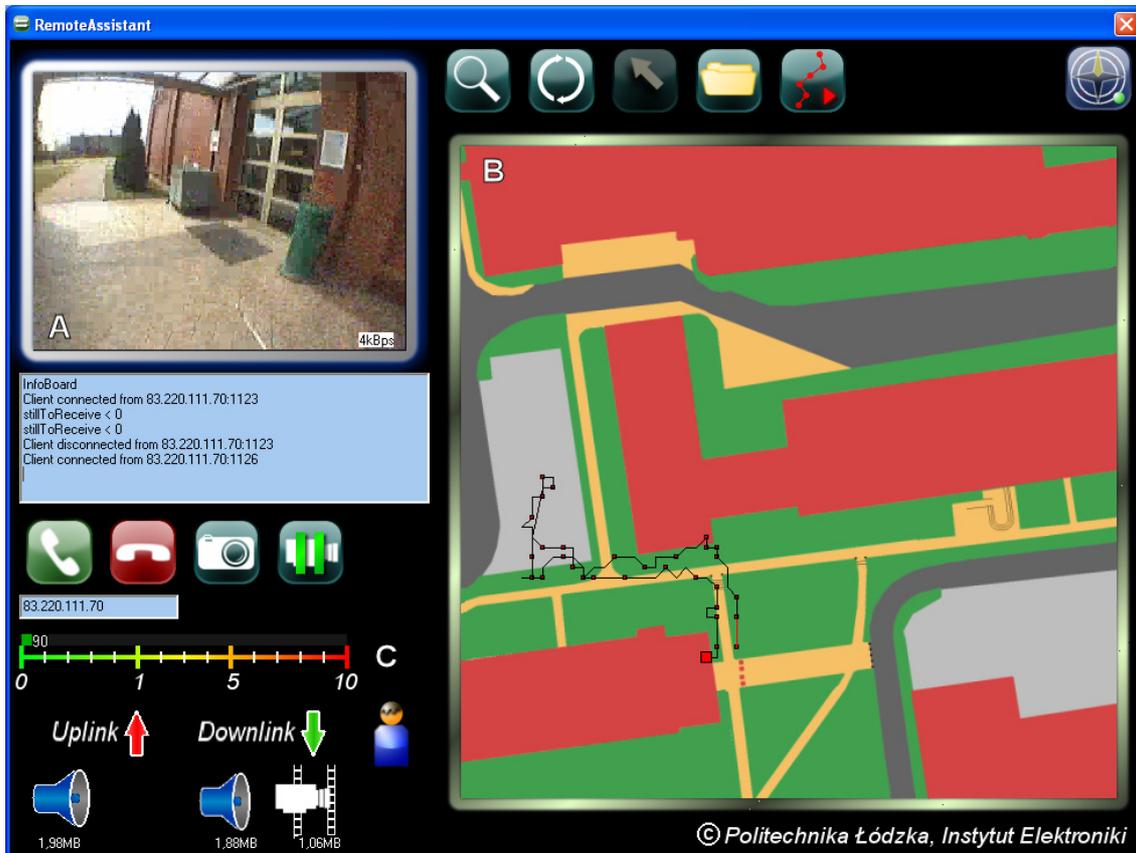


Figure 3. Screenshot of the operator's application: A) The video stream, B) Digital map with GPS readouts, with small markers every 5 seconds, C) Connection controls and parameters.

2.3 Anti-congestion Measures

The GSM connection is subject to the problems of congestion and poor link quality stemming from unfavorable locations (radio related phenomena, buildings, weather). This entails limited throughput and transmission lags. In order to detect and correct this problem, a special mechanism is implemented. At short intervals, default every 2 seconds, a time-stamped UDP packet is sent from the blind user's computer to the operator, where it is sent back. The packet roundtrip time and loss ratio are measured. These parameters reflect the network's condition. In the event of a compromised connection quality, the video frame rate is reduced to one frame per second. If the problem persists, the audio and video streams are put on hold to avoid further worsening of the situation. As soon as the connection improves, the audio stream is resumed. The video stream starts from a low frame rate (1 per second) and is slowly increased by the mechanism balancing the video bandwidth described previously.

A poor link is signalized to the blind person by special sound cues. This is to prepare the blind person to be more vigilant as the operator might answer with much greater delay or even be disconnected. When a disconnection occurs, the blind user hears a special alarm and can try to reestablish the connection by pressing a large button on the touch-screen.

The operator has the ability to manually suspend and resume the video stream to spare the bandwidth when video is not needed, for example during a lengthy conversation, or to avoid congestion when the signal strength is very poor.

3. FIELD TRIALS

The goals of the trials were to confirm the prototype's usefulness in real world navigation, reveal possible problems with outdoor use and determine future directions for development. The main problem with objective verification of outdoor path navigation is the fact that the efficiency and safety of a blind person traveling pre-defined paths is mainly dependant on the experience the person has with the route. This can be avoided by randomizing a selection of artificial paths as it was done in our previous experiment (Bujacz et al, 2008); however, this introduces a new problem. With random paths, the effectiveness of navigation chiefly depends on the orientation and mobility (O&M) skills of the blind person. To get rid of both these problems, we decided to observe the learning curve of navigation for multiple repeated runs of a path.

3.1 Trial Description

Three blind volunteers participated – all male, aged 25-45, two blind since birth, and one for the last 17 years. One of the participants retained marginal light sensitivity, which was however not useful for mobility. Every participant was taught to navigate two paths (approx. 150m and 190m long) on the university campus. Each was then asked to repeatedly transverse these paths, alternating navigation by a remote assistance and independently. The attempts were recorded, and the number of missteps and accidental collisions counted.

The paths on the university campus were chosen to provide multiple obstacles, such as stairs, trash cans, park benches, lamp posts and fire hydrants. Every blind volunteer used his long cane during the tests. The paths had only limited turns to be easily remembered. One of the experimenters accompanied the blind volunteers at all times, should an unexpected or dangerous situation arise.

Each path was completed in three different "modes":

- a) *walk with a human guide* – the first walk on each path was in the company of a human guide, who explained the turns in the path and any dangers along it. All three participants claimed that one run was sufficient to learn each simple path, and most of the obstacles on it.
- b) *remote guidance* – the blind participant wore the earpiece, chest-camera and the Flybook. The operator provided remote guidance on the base of the real-time video transmission and observed the volunteer's positions thanks to GPS readouts displayed on his digital map.
- c) *independent walk* – the participants relied only on themselves to navigate the paths, they were warned when in danger or when they lost their way

3.2 Data Collection

During each path attempt the volunteer was closely followed by a sighted observer who took notes on the following occurrences during each path navigation attempt:

- *time* – Each path lead from a building door to another and back. The time was measured from the moment the volunteer let go of the doorknob, to the time until he touched it again after reaching the destination door.
- *missteps* – These were noted every time the blind participant slightly stumbled (without falling) or stepped onto the grass.
- *minor collisions* – These were noted when the blind volunteer collided with an obstacle, but only with his white cane, thus not endangering himself. This was usually occurring when the participant hit thrash cans or park benches slightly off the path, on the grass.
- *major collisions* – These were mostly avoided at the last moment thanks to warnings or support from the sighted observer. They were noted when the participant was about to collide with an obstacle with his body or has tripped hard enough to almost fall. The most frequently collided with obstacles were columns near the building entrances and short posts from a chain along the path.

The collected data is presented in Table 1 and the total results, summed for the three participants, on all repeated attempts are shown in Figure 4.

The GPS position readouts were recorded once every second. The experiments were recorded and later replayed so that the participants' positions at 5 second intervals could be plotted.

At the end of the experiment, all participants provided feedback about the proposed system, their experiences from the trials, and expectations from the developed device.

Table 1. Trial data summary for the three blind volunteers.

Path I		Time			Missteps			Minor Collisions			Major Collisions			Lost Way		
		JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP
Assisted	1	03:27	03:58	04:06	2	1	2	-	1	1	-	1	-	-	-	-
Independent	2	03:31	04:00	03:50	2	2	2	-	2	2	-	1	1	-	1	2
Assisted	3	02:57	03:44	03:18	-	3	1	-	2	1	-	-	-	-	-	-
Independent	4	03:06	03:20	03:53	-	1	2	-	3	-	-	-	1	-	-	1
Assisted	5	02:58	03:06	02:55	-	3	1	-	1	1	-	-	-	-	-	-
Independent	6	03:05	03:30	03:10	-	3	1	-	-	-	-	-	-	-	1	-
Assisted	7	02:55	03:08	02:55	-	-	1	-	-	-	-	-	-	-	-	-
Independent	8	03:00	03:08	03:03	-	3	2	-	1	2	-	1	2	-	-	-

Path II		Time			Missteps			Minor Collisions			Major Collisions			Lost Way		
		JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP	JM	MM	RP
Assisted	1	03:21	06:00	04:00	-	3	-	-	4	-	-	-	-	-	-	-
Independent	2	04:02	06:41	04:40	2	1	1	-	3	2	-	1	2	-	2	2
Assisted	3	03:06	05:09	03:50	-	1	-	-	1	1	-	1	-	-	-	-
Independent	4	03:50	05:15	04:09	2	1	3	-	5	1	-	1	-	-	1	1
Assisted	5	03:58	03:58	03:37	-	2	-	-	1	-	-	-	-	-	-	-
Independent	6	03:17	04:41	03:51	-	3	1	1	4	-	1	2	1	-	-	-
Assisted	7	03:40	03:20	03:26	-	-	-	-	2	-	-	-	-	-	-	-
Independent	8	03:20	04:32	03:29	-	4	2	-	2	-	-	1	-	-	1	-

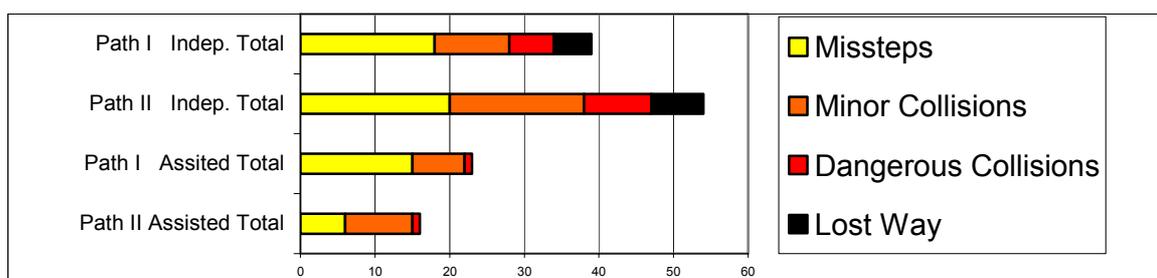


Figure 4. The comparison of the total number of unfortunate event occurrences for assisted vs. independent trials totaled for all participants on all attempts.

4. DISCUSSION AND FUTURE WORK

Comparing the performance between the three participants listed in Table 1 clearly shows their strongly differing O&M skills. The oldest participant – JM, most experienced in independent travel, had almost no collisions and never lost his way. The two younger participants had considerably slower times and more accidents. Despite these big differences in skill, it is clear that the use of the remote assistance resulted in a significant reduction of missteps and collisions for all participants as seen in Figure 4. None of the subjects lost their way when assisted and there were only two potentially dangerous collisions noted, both for the same participant who blamed them on his overconfidence.

The increase in travel speed when assisted, which in the previous indoor trials reached 50%, was not as significant in the outdoor attempts, only 15-20%. This is primarily due to the real-world environment in which the trial participants were experienced in navigating. The trials were constructed in such a way as to quickly familiarize the blind volunteers with the paths, leading them to reach quickly a similar safe top speed.

4.1 Participants' and Operator's Conclusions

The operator's adjustment to each blind user's needs seemed to be a key parameter in providing effective navigation. When encountering obstacles, short and simple commands e.g. "park bench on your left, a doorway on half right" were far more welcome to most users than precise maneuvering instructions. To ensure the blind persons maintain a proper walking direction it was advisable to find a travel boundary e.g. „walk along the left curb". From the psychological point of view operator-user communication should be settled individually with every blind user. Some participants only wanted short navigating instructions and obstacle warnings; others felt more comfortable and safe after a more detailed description of the environment. The trial participants all proposed of their own accord that even if an operator service was never put into life, the constructed device would be of great help if the connection could be established with family members at home.

4.2 Improving GPS Navigation

One of the problems encountered during the outdoor trials was that in the presence of high buildings GPS readouts could err by over 30 meters. This can be seen on Figure 3, where the route constructed out of the GPS readouts seems to indicate the blind participant walked onto the parking lot, while in reality he stayed on the path. The workaround for this problem is to combine the data from the GPS receiver with data from additional sensors – accelerometers, gyroscopes and/or a digital compass.

4.3 Target Platform

The solution used in the prototype consisting of an ultra-mobile notebook PC and a modified webcam is a plausible, but probably an overly large and expensive target platform. Interviews with the blind volunteers concluded that the price, size and appearance of any electronic aid is of great importance to them. The target device must be small enough to fit in a pocket or a light shoulder bag. It cannot be overly exposed and too expensive, as all three trial participants have been victims of cell-phone theft.

The target platform remains undetermined and will depend on further trials with mobile phones and microcontrollers. A likely solution might be using a mobile phone to maintain the user-operator connection, while an external microcontroller circuit handles the more resource consuming tasks of voice and video compression.

5. SUMMARY AND CONCLUSIONS

The results of outdoor trials of a prototype tele-assistance system for the blind are presented in the paper. The system consists of an ultra portable Flybook laptop with a built-in HSDPA modem, a GPS sensor, a wide-angle camera and an earpiece. A software package for streaming video, audio and GPS readouts over the GSM channel has been developed and proven efficient and reliable.

The results from trials with participation of blind volunteers showed improved travel speeds and greatly increased safety when compared to unaided travel. The trials were conducted in a way to observe the changes in blind participants' mobility with growing familiarization with a route, both when navigating independently and with remote assistance. When utilizing the help of the remote guide the blind persons traveled 15-20% faster, did not lose their way, almost never endangered themselves with major collisions and approximately

halved the number of missteps and minor collision. Work on the system will continue with the aim of development of a commercial application.

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- Perceptual Alternatives: the domain of the Sonic Pathfinder and an increasing number of other things, website: www.sonicpathfinder.org/
- SOUND Foresight Ltd website: www.soundforesight.co.uk/
- The vOICE, Vision technology for the totally blind website: www.seeingwithsound.com/