Personal Guidance System for the Visually Impaired*

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Abstract

We outline the design for a navigation system for the visually impaired and describe the progress we have made toward such a system. Our long-term goal is for a portable, self-contained system that will allow visually impaired individuals to travel through familiar and unfamiliar environments without the assistance of guides. The system, as it exists now, consists of the following functional components: (1) a means of determining the traveler's position and orientation in space, (2) a Geographic Information System comprising a detailed database of the surrounding environment and functions for automatic route planning and for selecting the database information desired by the user, and (3) the user interface.

1 Introduction

Finding one's way through the environment depends on two distinct processes: navigation through large-scale space and the sensing of the immediate environment for impediments to travel, such as obstacles and drop-offs. Navigation, in turn, involves updating one's position and orientation during travel with respect to the intended route, and, in the case of becoming lost, reorienting and reestablishing a route to the destination. Methods of updating position and orientation can be classified on the basis of kinematic order: position, velocity, and acceleration. Position-based navigation (called *pilotage* or *piloting*) relies on external signals indicating the traveler's position and orientation [1]; such signals would include those from visible, audible, tactual, or odorous landmarks known to the traveler and those provided by electronic navigation aids, such as the Global Positioning System (GPS). Velocity-based navigation (called *dead reckoning* or *path integration*) depends upon external signals indicating the traveler's velocity of travel [1, 2, 3]; linear and rotary displacements relative to the starting position and orientation are computed by integrating the linear and rotary components of the traveler's velocity. External signals of potential use for dead reckoning by humans include optical and acoustic flow. Acceleration-based navigation (called *inertial navigation*) involves the sensing of linear and rotary accelerations and doubly integrating these values to obtain translational and rotational displacements relative to the starting position and orientation [3]; inertial navigation has the virtue of not depending upon external signals but acceleration signals provided by the vestibular sense probably contribute little to human navigation through large-scale space.

Obviously, a traveler lacking vision is at a considerable disadvantage, for the traveler has no remote landmark information for position keeping and for route selection during travel, and obstacles and other hazards may be encountered with little

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[*] This research was supported by grant R01 EY09740 from the National Eye Institute.

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ASSETS 94- 10/94 Marina Del Rey, CA, USA

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advance warning. The seeing-eye dog, the long cane, and a number of electronic travel aids (e.g., the laser cane and ultrasonic sensors) assist the blind traveler with the local aspects of wayfinding, such as obstacle avoidance [4]. In contrast, navigation aids do not exist, except for a few in the experimental stage (e.g. the "talking signs" of Loughborough [5]). This article briefly outlines a project, the goal of which is to contribute toward development of a practical navigation aid for the visually impaired, as conceived by Loomis [6] and, independently, by Collins [7]; more recently, Urdang and Stuart [8] have proposed something quite similar. The aid we are working toward, which we call a Personal Guidance System, will inform a traveler of his or her current position and orientation with respect to the environment being navigated, will provide information about the immediate surroundings, and, if desired, will guide the traveler along a route selected either by the traveler or by the computer. This idea of a navigation system for the blind is now the focus of research and development by a number of groups around the world, including several commercial firms. Indeed, one of them, Arkenstone of Sunnyvale, California, is planning to put a product on the market in the very near future.

The research system we have developed is intended as a test bed for trying out different design options, for assessing the potential of such an aid, and for identifying potential problems. The hardware currently consists of a laptop computer and peripherals, all of which are worn in a backpack. Miniaturization will eventually reduce its size so that most of it can be worn in a small waistpack, as depicted in Fig. 1. Functionally, the system consists of three modules, shown in Fig. 2. The first module determines the position and orientation of the traveler. The second module is software implementing a Geographic Information System (GIS), which includes a spatial database of our test site organized in terms of different layers (buildings, walkways, trees, etc.). The third module is the user interface, which includes a virtual acoustic display [9, 10]. Our preferred design at this point is to have the navigation system indicate the positions of environmental landmarks and choicepoints along a route by having their labels, spoken by a speech synthesizer through earphones, appear as virtual sounds at the correct locations within the auditory space of the traveler (see Fig. 1). The current implementation approaches but does not quite attain this level of functionality, as will be discussed later.

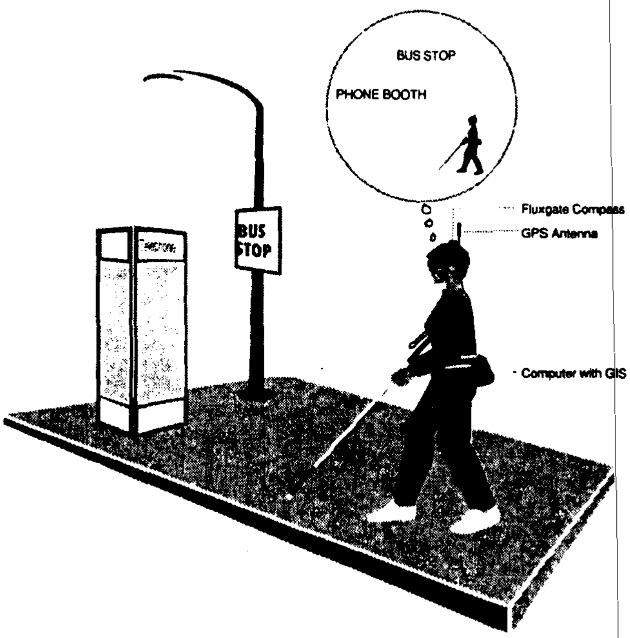

Fig. 1: Depiction of a blind traveler using the navigation system, as we envision it in miniaturized form. The person is wearing the computer and ancillary hardware in a pack at her waist and earphones, a fluxgate compass, and a GPS antenna on her head. In this implementation using a virtual acoustic display, she would hear the names of landmarks, spoken by speech synthesizer, appearing at the proper locations within her auditory space.

Because the navigation aid we ultimately foresee is not intended to replace mobility aids for sensing the near environment (e.g., long cane, ultrasonic sensor, seeing-eye dog), the traveler will still need to make use of such aids for avoiding obstacles, keeping on paths, and the like. However, if a successful implementation does involve the use of earphones, the inclusion of signals for detecting obstacles from an ultrasonic sensor might be feasible, and indeed, might promote greater use of ultrasonic sensors by the blind.

Our hope is that if such a navigation aid ever becomes practical, it will allow blind users to travel without assistance over unfamiliar territory and will instill in them feelings of independence and confidence that are lacking in all but the most adventurous of blind travelers. We also hope that, because of the manner in which it informs them of the layout of surrounding space, such an aid will make it easier for blind travelers to develop mental representations of the environments through which they are traveling. However, we are cognizant of a number of potential negatives as well. Aside from the obvious ones, such as cosmetic undesirability, unreliability, and the risks associated with faulty operation, there is the likelihood that travelers will become dependent upon the aid and allow their normal travel skills to languish, so that they are actually worse off when the aid is unavailable.

2 System Description

2.1 Module I: Determining Position and Orientation

The function of this module is to provide the computer with orientation and location information, which can then properly locate the traveler within a spatial database of the environment. The primary means of determining position is, and will probably continue to be, a GPS receiver (with differential correction). The possibility of using GPS in a navigation aid for the blind was first proposed by Collins [7] and by Loomis [6]; Brusnighan, Strauss, Floyd, and Wheeler [11] were the first to actually experiment with GPS with this purpose in mind.

The full complement of 21 GPS satellites (and 3 backups) is now in orbit, thus allowing localization of a GPS receiver with near uniform accuracy over the earth's surface. Currently, commercially available hand-held GPS receivers provide a localization accuracy of about 100 m when Selective Availability (the US military's deliberate perturbation of the satellite signals) is in effect. A means of obtaining much higher accuracy is differential correction, whereby one uses a base receiver, with fixed and known coordinates, in addition to the receiver carried by the traveler. Errors in the signals arriving at the base receiver are computed for each satellite and then transmitted by radio link to the mobile receiver. If the mobile receiver is not too distant, the errors to which it is subject correlate almost perfectly with those at the base; thus, the base receiver errors can be used to correct the computed position of the mobile receiver. With Differential GPS (DGPS) it is now possible to obtain submeter accuracy within many miles of the base station.

Our project uses a Trimble Navigation real-time DGPS configuration, consisting of a GPS base station, a portable GPS receiver, and a spread spectrum radio link between them. The current configuration provides a positional accuracy on the order of 2 to 5 m (the radius of a circle within which 50% of the observations are located); however, the configuration is being upgraded so that it will provide an accuracy of about 1 m. The differentially corrected coordinates currently serve as the only basis for position determination.

A major limitation of GPS for pedestrian travel is the loss of satellite visibility produced when nearby buildings and dense foliage block a substantial part of the sky. For GPS to be useful in pedestrian travel within urban environments, it will have to be supplemented by some other means of position determination. One possibility is to use some type of non-contact sensor, such as a downward-pointing video camera or ultrasonic transceiver, to measure the person's velocity (direction and speed) over the ground and then to integrate this velocity signal to obtain the traveler's displacement subsequent to the last GPS fix; such dead-reckoning navigation is commonly used in vehicle navigation systems, where differential odometry and a fluxgate compass provide vehicle speed and heading [12, 13]. Along this line, Milner and Gilden [14] reported an evaluation of an ultrasonic sensor as part of a dead-reckoning aid for the blind. Another possible adjunct to GPS is an inertial navigation device that doubly integrates the signals from accelerometers to obtain displacement subsequent to the last GPS fix. Still another possibility is to dispense with GPS altogether and to use in its place a local Loran-type system of low power transmitters placed throughout an urban environment. If these signals were to penetrate buildings more effectively than do GPS signals, signal availability might be much more widespread.

The traveler's orientation, which must be known if the traveler is to know the bearings to surrounding landmarks, is currently being provided by means of a fluxgate magnetometer (electronic compass). For a conventional synthetic speech display, knowing just the orientation of the traveler's body is sufficient; in this case, a single compass mounted on the torso will do. In the case of the virtual acoustic display, head orientation is required, in which case the compass must be mounted on the head. Currently, we have one attached to the strap of the earphones worn by the traveler. Because problems associated with local

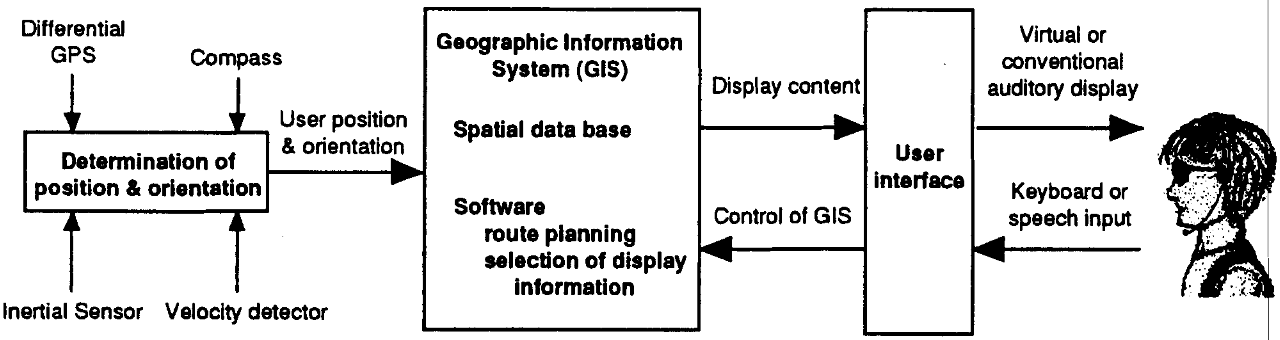

Fig. 2: Schematic diagram showing the functional components of the navigation system.

distortions of the earth's magnetic field may arise, it may be necessary to resort to mechanical or optical gyroscopes as supplementary or alternate orientation sensors.

2.2 Module II: Geographic Information System

The second module provides a spatial database of the environment, information from which can be communicated to the traveler by means of the user interface. Its supporting software provides for the computation of optimal routes of travel and for accessing of information within the database, as desired by the traveler. Research on this component is linked to studies of the cognitive processes involved in navigation, which constrain and direct the nature of the information and how it is retrieved and presented.

This second component is a Geographic Information System (GIS), for it links spatial data about objects, such as their shapes and locations, to nonspatial attributes such as the object's category or its properties (e.g., surface trafficability). A GIS can be used to provide spatial layout information to a user or to compute information such as the number of objects of a given type within a given region (e.g., the number of restaurants of a given type within some radius of the traveler). As this example indicates, a GIS allows data to be retrieved by spatial or semantic cues relative to the traveler's current position and orientation.

We have developed a spatial database for our test site, the campus of the University of California, Santa Barbara, and for the surrounding area [15]. The database consists of a number of layers, corresponding to entities such as walkways, buildings, and large permanent obstacles. Our software accepts other spatial databases created by any CAD program, provided that they are in DXF format. However, CAD maps constructed for other purposes usually do not contain sufficient information at the scale necessary for walking without vision, such as the location of trees and planters. Also, most CAD maps do not allow attribute tables or analytical data to be directly linked to geocoded data.

Our GIS module is intended to provide functions different from those in most existing GIS's and to do so in support of real-time navigation. Types of functions the database should support can be seen by considering an apparently simple task: directing the traveler along a predetermined route.

In a particularly simple version of the task, the traveler is led along the predetermined route by a succession of virtual auditory beacons, sounds that are presented through earphones but appear externalized within the auditory space of the traveler. For travel along linear segments, virtual beacons are positioned at waypoints defining the intersections of two segments. By homing to each beacon, the traveler can walk to the end of that segment, at which point a new beacon is activated. Obviously, for this implementation, the spatial database must include possible routes as well as objects. The current implementation of our GIS keeps track of the traveler's position with respect to the intended route, determines when the traveler has arrived at the current waypoint, and then determines the next waypoint and its associated beacon.

The task of following a route becomes considerably more complex when we consider alternative means of directing the traveler along the route, such as the use of natural-language commands (e.g., "go five paces forward, turn right 30 degrees") rather than homing. In this case, the functions required to monitor the traveler's position are the same as previously, but new functions are required to generate the appropriate linguistic description. Research is needed to determine the spatial language that will be most effective in this situation.

More complex still is a situation in which the traveler is to be informed about landmarks in surrounding space. This would occur, for example, if the traveler had a "mental model" of the space and wished to pursue some trajectory that was defined in terms of known landmarks. The spatial database must now perform functions that select a group of items to display and determine the sequence of item presentations. This application will be advanced by research on human working memory for item locations and the extent to which it competes with the cognitive demands of travel per se.

2.3 Module III: The User Interface

The user interface provides the user with two-way communication with the GIS module. In our research, we will be comparing two display alternatives, namely, conventional speech display through earphones (or speaker) and a virtual acoustic display through binaural earphones. The virtual display will indicate the positions of landmarks by having their labels, spoken by a speech synthesizer, appear as virtual sounds, including speech, at the correct locations within the auditory space of the traveler. In contrast, the conventional display will provide spoken instructions for guiding travel and spoken descriptions of the traveler's surroundings. The use of either display expands the potential range of transmitted data beyond position information; for example, the function or occupancy of a nearby building could be provided. For the virtual display, we have been using the analog hardware developed at UCSB [9], which implements an approximation of the head-related transfer function [10]. However, an alternative is to use one of the commercial virtual acoustic displays, such as the Convolvotron from Crystal River Engineering [10], a digital signal processing board that does high-speed convolution of the full head-related transfer function with the signal from a monaural input source.

The function of the input component of the user interface is to allow the traveler to select a destination, add landmarks to the database, change the display mode (e.g., from auditory beacons to the spoken names of landmarks), and change display parameters, such as map scale. This part of the interface, which we have yet to develop, will probably be implemented using either a small keypad or voice input in conjunction with limited-domain speech recognition.

3 Our Experience to Date

Our system, with all of its hardware and GIS software, has been functional since October of 1993. The GIS module now incorporates the spatial database of the UCSB campus, but can work with any spatial database in DXF format, as noted above. One of us (Golledge) is visually impaired and has accrued the most experience with the 28 lb system, mainly in conjunction with informal pilot work and two public demonstrations on campus. In addition, four other individuals, three sighted and one blind, have tried out the system. In all of this work, the only mode of operation so far has been walking along routes defined by linear segments. The waypoints specifying the endpoints of these segments are presented through the virtual display as stationary auditory beacons--the speech synthesizer produces the spoken labels of the numbered waypoints, and the virtual display hardware then transforms the monaural speech signals into binaural signals appropriate to the different waypoint locations.

For all of these occasions, we selected times of day for which satellite availability was high. Four satellites are needed to obtain a three-dimensional fix; we carried out all of this informal work when 6 to 8 satellites were to be within range. We also selected campus locations where buildings and dense foliage were less likely to block visibility of the satellites. Even under these optimal conditions, there were moments when too few satellites were being received by the mobile receiver to obtain a DGPS fix. As is to be expected of the DGPS configuration we were using, positional errors exceeding 10 m did occur. On the other hand, we also observed exceedingly stable performance where positional errors remained less than 2 m for periods of more than 30 minutes. In one demonstration, Golledge twice traversed a route of four linear segments with remarkable repeatability; on both replications his turn points, as defined by the virtual auditory beacons he was hearing, were centered in the sidewalk intersections. His exceptional performance and that by a sighted individual with no prior experience indicate that the various system components were functioning properly. In particular, the difficulties reported with the fluxgate compass in earlier work on homing to virtual sounds [9], difficulties which were subsequently traced to a programming error, were not present here. The signals from the compass are stable and distortion free, providing an azimuthal accuracy estimated to be 1 deg. Once acclimated to the display, our observers have had no difficulty in orienting immediately toward the target and then walking without any obvious veering tendency.

Besides the problem of DGPS signal loss, we have identified one other major problem to be reckoned with. In the current implementation of our system, the virtual sounds are most definitely internalized within the head. In our earlier published research [9], we had reported that the virtual sounds produced by our display were experienced by most observers as externalized and we presented this as evidence that a detailed implementation of the head-related transfer function is not a necessary condition for externalization. This is an issue that has been much discussed in recent years (e.g., [10, 16]). We stand by our earlier claim and present as additional evidence our observations with a binaural listening device we have assembled. The device consists of (1) in-ear earphones, (2) a sound-attenuating hearing protector worn over the earphones, and (3) microphones mounted on top of the earcups of the hearing protector, and (4) a battery-operated stereophonic amplifier. A person wearing this device hears environmental sounds indirectly through the microphones, amplifier, and earphones. Even though this indirect sound is being heard with a drastically altered head-related transfer function, all observers have reported unmistakable externalization of sound with eyes closed.

Why then are we not obtaining the externalization with our current display that we did in our earlier research? We think that the critical difference is in the nature of the reverberation we used then and are currently using. In the earlier work, we used a high-quality but non-portable digital reverberation unit to provide reverberation; in addition, some of our demonstrations were done using sound picked up by a microphone within a reverberant room. We speculate that these two sources of reverberation contributed greatly to the impression of externalization reported in the published article, for reverberation is generally recognized to be an important factor in the externalization of earphone sound [16, 17]. Our portable system, however, makes use of a lightweight, battery-operated reverberation unit that we suspect fails to produce natural-sounding reverberation. If we are correct, externalization should improve with our display when we add a higher-quality reverberation unit that provides more authenticity.

While it is true that externalization is not essential in order for a person to home to a virtual sound [9], and, thus, a person could navigate along a route of linear segments without externalizing the virtual beacons, our desire for externalization is more than aesthetic. We strongly believe that a person using a navigation system equipped with a virtual acoustic display is much more likely to be able to develop an internal representation of the surrounding environment if the virtual sounds representing environmental objects and landmarks are externalized than if they are internalized.

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