

The GuideCane — A Computerized Travel Aid for the Active Guidance of Blind Pedestrians

by

Johann Borenstein and Iwan Ulrich

The University of Michigan, Advanced Technologies Lab, 1101 Beal Avenue, Ann Arbor, MI 48109-2110.
Ph.: 313-763-1560, fax: 313-944-1113, email: johannb@umich.edu; iwan@umich.edu

ABSTRACT

This paper introduces the *GuideCane*, a novel device designed to help blind or visually impaired travelers to navigate safely and quickly among obstacles and other hazards faced by blind pedestrians. The *GuideCane*, currently under development at the University of Michigan's Mobile Robotics Lab, comprises of a long handle and a "sensor head" unit that is attached at the distal end of the handle. The sensor head is mounted on a steerable but unpowered two-wheeled steering axle. During operation, the user pushes the lightweight *GuideCane* ahead of him/herself. Ultrasonic sensors mounted on the sensor head detect obstacles and steer the device around it. The user feels the steering command as a very noticeable physical force through the handle and is able to follow the *GuideCane*'s path easily and without any conscious effort.

I. REVIEW OF EXISTING DEVICES

The most successful and widely used travel aid for the blind is the *white cane*. It is used to detect obstacles on the ground, uneven surfaces, holes, steps, and puddles. The white cane is inexpensive, and is so lightweight and small that it can be folded and tucked away in a pocket. However, users must be trained in the use of the white cane over periods of 100 hours – a substantial "hidden" cost. More high-tech devices, discussed next, have been on the market for many years but appear to lack utility, and, consequently, are not widely used [Blasch and Long, 1989].

1.1 Conventional Electronic Travel Aids

In the past three decades several *electronic travel aids* (ETAs) were introduced that aimed at improving their blind users' mobility in terms of safety and speed.

The *C-5 Laser Cane* – was introduced by Benjamin et al. [1973]. It is based on optical triangulation with three laser diodes and three photo-diodes as receivers. The *Laser Cane* can detect obstacles at head-height, drop-offs in front of the user, and obstacles up to a range of 1.5 m or 3.5 m ahead of the user.

The *Mowat Sensor* – is a hand-held ultrasonic-based device that informs the user of the distance to detected objects by means of tactile vibrations [WORMALD]. The frequency of the vibration is inversely proportional to the distance between the sensor and the object.

The *Nottingham Obstacle Detector (NOD)* – is a hand-held sonar device that provides an auditory feedback, in which eight discrete levels of distance are distinguished by different musical tones [Bissit and Heyes, 1980].

The *Binaural Sonic Aid (Sonicguide)* -- comes in the form of a pair of spectacle frames, with one ultrasonic wide-beam transmitter mounted between the spectacle lenses and one receiver on each side of the transmitter [Kay, 1974]. Signals from the receivers are frequency shifted and presented separately to the left and right ear. The resulting *interaural amplitude difference* allows the user to determine the direction of an incident echo and thus of an obstacle. The distance to an object is encoded in the frequency of the demodulated low-frequency tone.

Three fundamental shortcomings can be identified in all ETAs discussed in the foregoing sections:

1. The user must actively scan the environment to detect obstacles (no scanning is needed with the *Sonicguide*, but that device doesn't detect obstacles at floor level). This procedure is time-consuming and requires the

traveler's constant activity and conscious effort.

2. The traveler must perform additional measurements when an obstacle is detected, in order to determine the dimensions of the object. The user must plan a path around the obstacle) Again, a time-consuming, conscious effort that reduces the walking speed.
3. One problem with all ETAs based on acoustic feedback is their interference (called *masking*) with the blind person's ability to pick up environmental cues through hearing [Lebedev and Sheiman, 1980; Kay, 1974; Brabyn, 1982].

1.2 Mobile Robots as Guides for the Blind

In general terms, one could argue that *any* mobile robot with obstacle avoidance can be used as a guide for the blind. However, mobile robots are inherently unsuited to the task of guiding a pedestrian. The foremost limitation of mobile robots is that they are large, heavy, and incapable of climbing up or down stairs or boardwalks.

1.3 The NavBelt

During the past six years we have conducted active research in applying mobile robot obstacle avoidance technologies to assistive devices for the handicapped. In 1989 we developed the concept of the *NavBelt*. The *NavBelt* is a portable device equipped with ultrasonic sensors and a computer. A prototype of this system was built and tested in our lab (see Figure 1) [Shoval et al., 1994].

The *NavBelt* provided two modes of operation:

1. In the *image mode* the *NavBelt* produced a 120°-wide view of the obstacles ahead of the user (similar to a radar screen image). This image was then translated into a series of directional (stereophonic) audio cues through which the user could determine which directions were

blocked by obstacles and which directions were free for travel. The problem with this method lay in the fact that a considerable conscious effort was required to *comprehend* the audio cues. Because of the resulting slow response time our test subjects could not travel faster than roughly 0.3 m/sec (1 foot/sec). And even this marginal level of performance required hundreds of hours of training time.

2. Another mode of operation was called *guidance mode*. In this mode it was assumed that the system knew the traveler's momentary position and the traveler's desired target location. Under these conditions, the *NavBelt* only needed to generate a single (thus, low-bandwidth) signal that indicated the recommended direction of travel. It was much easier to follow this signal, and walking speeds of 0.6 - 0.9 m/sec (2 - 3 feet/sec) were achieved. The great problem was that in reality the system would not know the user's momentary position, as required by the guidance mode.

II. THE GUIDECANE

In this section we describe in some detail the components of the *GuideCane* system, and how these components are used to provide the desired functional capabilities.

2.1 System Description

Figure 2 shows a blind user walking with the *GuideCane*. Much like the widely used *white cane*, the user holds the *GuideCane* in front of him/herself while walking. The *GuideCane* is quite a bit heavier than the white cane, but it rolls on wheels that support *the GuideCane's* weight during regular operation. At the distal end of the *GuideCane* is a pair of *guide wheels* (see Figs. 2 and 3). A steering servo motor, operating under the control of the *GuideCane's* built-in computer, can steer the guide wheels left and right, relative to the cane. An array of ultrasonic sensors is mounted in a semi-circular fashion above the guide wheels (see Figs. 2 and 3). Additional sonars are facing



Figure 1: Grad. student Shraga Shoval demonstrates the *NavBelt*.

upward and sideways. A digitally controlled fluxgate compass is also mounted above the guide wheels. Attached to each guide wheel is an incremental encoder, and the “onboard” computer uses the data from these encoders and from the fluxgate compass to compute (i.e., by means of odometry) the relative motion of the traveler, as well as the momentary travel speed. A miniature joystick that can be operated with the thumb allows the user to specify a desired direction of motion (see Fig. 2).

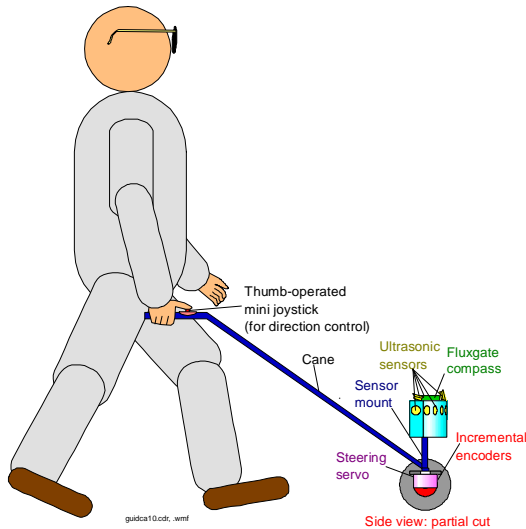


Figure 2:
A blind person walks with the GuideCane.

2.2 Functional Description

During operation, the user holds the *GuideCane* in one hand, so that the guide wheels contact the ground right in front of the user (possibly offset slightly to the side of the hand that holds the cane). The user prescribes a desired direction of motion with the miniature joystick. This direction command is understood to be relative to the current absolute direction read off the fluxgate compass. For example, if the compass is facing straight north and the user indicates the direction to be “forward” (by pushing the joystick forward), then the system would lock into “straight north” as the desired direction of travel and steer the guide wheels so that the compass is always facing north. As another example, let us consider the case where the user indicated “right” as the desired direction of travel. Then the computer would add 90° to the current direction of travel (say, north) and steer the guide wheels to the right until the compass was facing east.

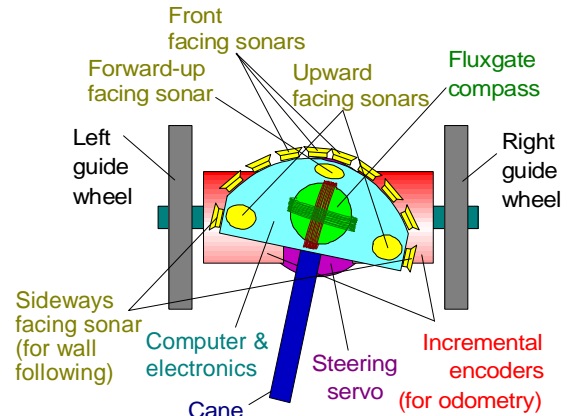


Figure 4: The GuideCane sensor-head.

While traveling, the ultrasonic sensors detect any obstacle in a 120° wide sector ahead of the user. Using UM’s previously developed, patented obstacle avoidance technique called “Vector Field Histogram” (VFH) in combination with UM’s patented “Error Eliminating Rapid Ultrasonic Firing” (EERUF) method for firing the sonars, allows for travel at fast walking speeds [Borenstein and Koren, p16, p32]. These techniques

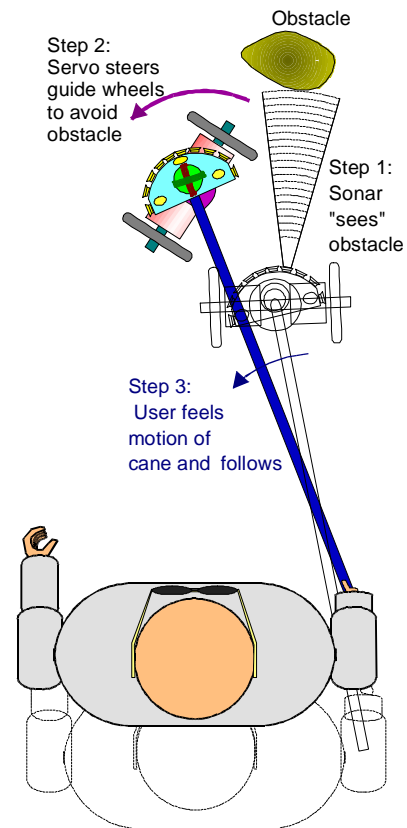


Figure 3: The GuideCane guides a user around an obstacle.

enable the system to instantaneously determine an optimal direction of travel even among densely cluttered obstacles. For example, if the system was “locked” into a desired travel direction of north, but an obstacle blocked the way (see Step 1 in Figure 3), then the obstacle avoidance algorithm would prescribe an alternative direction that would clear the obstacle but would be facing north as close as possible (see Step 2 in Figure 3).

Once the guide wheels begin to move sideways to avoid the obstacle, the user feels the resulting horizontal rotation of the cane (see Step 3 in Figure 3). In a fully intuitive (i.e., there is virtually no training time required) response, the traveler changes his/her orientation to align himself/herself with the cane at the “nominal” angle. In practice, the user’s walking trajectory follows the trajectory of the guide wheels similar to the way a trailer follows a truck. Once the obstacle is cleared the guide wheels steer again in the original desired direction of travel. The new line of travel will be offset from the original line of travel. Depending on the circumstances, the traveler may wish to continue walking along this new line of travel, or, the system can be programmed to return to the original line of travel. This latter option is made possible by the full odometry capability provided by the guide wheels and their attached encoders.

One particularly difficult problem for blind pedestrians is that of stairs. The GuideCane offers separate solutions for down-steps and up-steps. Down-steps are detected in a failsafe manner: when a down-step is encountered, the wheels of the GuideCane drop off the edge — without a doubt a signal that the user can’t miss. Up-steps are potentially more difficult to detect. The height of the main array of front-facing sensors is such that the first step of the up-steps is detected just like an obstacle (see Figure 5). However, higher up on the GuideCane and mounted at a different angle is one additional sensor, called the “forward-up” facing sensor. This sensor “looks” above the bottom step and detects the presence of the second step at distance R_2 . The difference between R_2 and R_1 is com-

puted and, if it meets a pre-programmed criterion for stairs, then the GuideCane identifies the object as stairs. If R_2 and R_1 are almost equal, then the object is treated as a wall. If R_2 is much larger than R_1 , then the GuideCane interprets the object as an obstacle that needs to be avoided.

2.3 Additional Functions

The utility of the GuideCane can be further enhanced by a variety of other advanced features:

Brakes – Computer-controlled brakes attached to both wheels can increase the resistance that the user feels when the GuideCane avoids obstacles nearby. Similarly, the user may have walked into a dead-end where no avoidance maneuver is possible. Again, this condition can be signaled immediately and intuitively by applying the brakes.

Global Navigation – The GuideCane can be equipped with a *Global Positioning System* (GPS). Outdoors, commercially available GPSs (which cost less than \$1,000) can provide global positioning information to within 20 meters accuracy. This makes it possible for the blind individual to prescribe a desired target location (for example, the supermarket or the post office) to the system and to have the GuideCane automatically guide the user to that location. Alternatively, the system could learn a desired path by recording path segments during an initial “lead-through” run with a sighted person. Indoors, where GPS is not effective, the same path programming or lead-through techniques can be used to have the GuideCane automatically guide the user to a desired location, using dead-reckoning based on encoder and compass readings. This latter method is not suitable for long distances because of the unbounded accumulation of odometry errors, but it is suitable for shorter indoor paths.

Speech input/output –

A large variety of functions can be implemented with the help of speech output and/or input modules attached to the onboard computer. One useful function could be the instant presentation of exact location and orientation data.

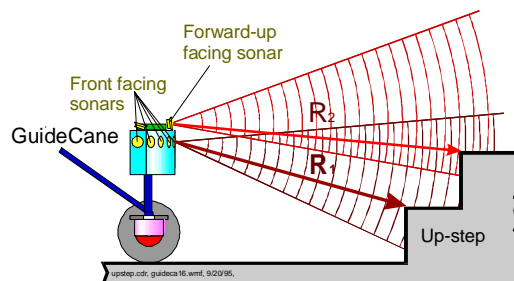


Figure 5: How the GuideCane identifies up-steps. An up-step is distinguished from a vertical wall by the forward-up facing sensor.

3. EXPERIMENTAL RESULTS

A prototype of the *GuideCane* is currently being built at our lab, as shown in Figure 7. As an initial test, before obstacle avoidance was implemented, we installed a radio-control joystick receiver inside the sensor head, which allowed a sighted assistant to steer the *GuideCane* remotely. A sightless subject would then walk with the *GuideCane*, “steered” by the assistant. As expected, the subject could easily follow even complex maneuvers. With this test we verified the key-hypothesis, namely, that following the *GuideCane*’s path was completely intuitive, even at fast walking speed.

About one week before this paper went to press we completed the implementation of basic obstacle avoidance with the onboard sonars. In our first experiments with the functional obstacle avoidance system our subject was able to traverse densely cluttered obstacle courses (see Fig. 7) at 0.5 - 1.0 m/s (depending on obstacle density). We expect that extensive tuning and iterative improvements during the next six months will yield safe travel speeds of 1.0 to 1.5 m/s (i.e., fast walking speeds).

IV. DISCUSSION

The *GuideCane* is unique in its ability to physically direct the user around obstacles and toward a user-prescribed target. Indeed, the uniqueness is thus twofold:

4.1 Guidance Signals versus Obstacle Information

Existing ETA’s are designed to notify the user of obstacles (usually requiring the user to perform some sort of scanning action). Then, the user must evaluate all of the obstacle information, which comprises of the size and proximity of each obstacle and decide on a suitable travel direction. In sighted people such relatively high bandwidth information is processed *almost reflexively*, usually without the need for conscious decisions. Nature had millions of years to

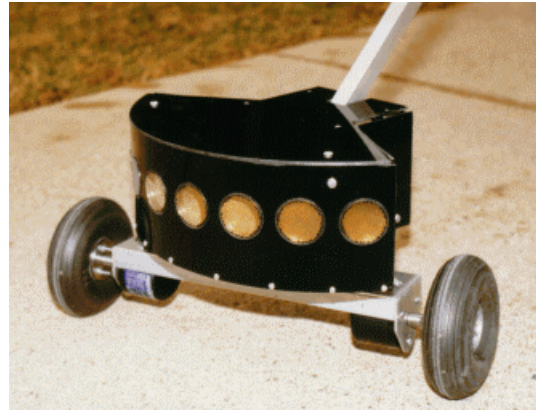


Figure 6: The GuideCane sensor head.

perfect this skill. However, the evaluation of obstacle information presented acoustically is a new skill that must be acquired over hundreds of hours of learning. Even then, exercising such a skill will take a great deal of conscious effort, and thus processing time. The required effort further increases with the number of obstacles found.

The *GuideCane* is fundamentally different from other devices in that it “views” the environment and computes the momentary optimal direction of travel. The resulting guidance signal is a single piece of information — a direction — which means that the bandwidth of the information is much smaller. The consequence is that it is far easier, safer, and faster to follow the low-bandwidth guidance signal of the *GuideCane* than to follow the high-bandwidth information of other existing systems.

4.2 Information Transfer

In our own prior research with the NavBelt, we tested different methods of using binaural (stereophonic) signals to guide the user around obstacles. We found that it is generally extremely difficult to recognize and react to such signals at walking speed. Even after nearly 100 hours of training (and many more hours of optimizing the system itself), the Ph.D. student who conducted this research could not walk safely at walking speed. By contrast, when we tested the guidance capability of



Figure 7: Blindfolded grad. student and co-author Iwan Ulrich walks through an obstacle course.

the *GuideCane* (by having a sighted person steer the guide wheels via remote control), we found that *any* subject could *immediately* follow the *GuideCane* at walking speed and among densely cluttered obstacles.

This success can be credited to another unique feature of the *GuideCane*: Information transfer through direct physical force. This process is completely intuitive, which means that any user can use the system immediately and without learning how to interpret artificially defined acoustic or tactile signals (as with existing ETAs). Furthermore, yielding to external forces is a reflexive process that does not require a conscious effort. In the *GuideCane* there are actually two different forces noticeable to the user:

Even though the *GuideCane* is basically unpowered (except for the small amount of power needed for steering), it can apply a substantial amount of physical force on the user if the user fails to respond to a change of direction prescribed by the device. This force is the result of the sideways motion of the guide wheels when avoiding an obstacle. The resulting rotation of the cane forces a clearly noticeable rotation of the hand that holds the proximal (near) end of the cane.

A second force, immediately noticeable after the guide wheels change their orientation (but even before the user feels the rotation of the cane), is the increased reaction force that is opposed to pushing the cane forward. We will not analyze this second force in detail but in essence it can be understood as follows: When walking while the cane and the guide wheels are aligned, the user must only overcome the reactive force resulting from the friction in the bearings and the roll resistance of the wheels. Let's say this force was equivalent to one pound. Now, suppose the guide wheels steered 60° in either direction. Then the traveler would have to push the cane with a force of $1/(\cos 60^\circ) = 2$ pounds in order to overcome the 1 pound reactive force of the guide wheels. This change in reactive force is immediately felt by the user and prepares him immediately for an upcoming steering maneuver.

Acknowledgment:

This research was funded by the Whitaker Foundation.

V. REFERENCES

- Benjamin, J. M., Ali, N. A., and Schepis, A. F., 1973, "A Laser Cane for the Blind." *Proceedings of the San Diego Biomedical Symposium*, Vol. 12, pp. 53-57.
- Bissitt, D. and Heyes, A. D., 1980, "An Application of Biofeedback in the Rehabilitation of the Blind." *Applied Ergonomics*, Vol. 11, No. 1, pp. 31-33.
- Blasch, B. B., Long, R. G., and Griffin-Shirley, N., 1989, "National Evaluation of Electronic Travel Aids for Blind and Visually Impaired Individuals: Implications for Design." *RESNA 12th Annual Conference*, New Orleans, Louisiana, pp. 133-134.
- Borenstein, J. and Koren, Y., 1991, "The Vector Field Histogram – Fast Obstacle-Avoidance for Mobile Robots." *IEEE Journal of Robotics and Automation*, Vol. 7, No. 3., June, pp. 278-288.
- Borenstein, J. and Koren, Y., 1995, "Error Eliminating Rapid Ultrasonic Firing for Mobile Robot Obstacle Avoidance." *IEEE Transactions on Robotics and Automation*, February, Vol. 11, No. 1, pp. 132-138.
- Brabyn, J. A., 1982, "New Developments in Mobility and Orientation Aids for the Blind." *IEEE Transactions on Biomedical Engineering*, Vol. BME-29, No. 4, pp. 285-289.
- Kay, L., 1974, "A Sonar Aid to Enhance Spatial Perception of the Blind: Engineering Design and evaluation." *Radio and Electronic Engineer*, Vol. 44, No. 11, pp. 605-627.
- Lebedev, V. V. and Sheiman, V. L., 1980, "Assessment of the Possibilities of Building an Echo Locator for the Blind." *Telecommunications and Radio Engineering*, Vol. 34-35, No. 3, pp. 97-100.
- Shoval, S., Borenstein, J., and Koren, Y., 1994f, "Mobile Robot Obstacle Avoidance in a Computerized Travel Aid for the Blind." *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, San Diego, CA, May 8-13, pp. 2023-2029.
- Wormald International Sensory Aids, 6140 Horseshoe Bar Rd., Loomis, CA 95650.