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The *Navbelt* - A Computerized Travel Aid for the Blind

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ABSTRACT

This paper presents the *Navbelt* - a new travel aid for the blind. The device consists of a portable computer, ultrasonic sensors and stereophonic headphones. The computer applies navigation and obstacle avoidance technologies that were developed originally for mobile robots. The computer then uses stereophonic imaging techniques to process the signals arriving from the ultrasonic sensors and relays them to the user by stereophonic headphones. The imaging techniques produce several informative parameters, which provide the user with an acoustic "picture" of the surroundings, or, depending on the operational mode, with the recommended direction of traveling. The acoustic signals are transmitted as discrete beeps or continuous sounds. Each of the operational modes requires different levels of attention, thus allowing different degrees of assistance. In the *Navbelt*, adaptive control methods are combined with optimization techniques to minimize human workload and to reduce the user's conscious effort during travel.

1. BACKGROUND

The most widely used travel aid is the *long cane* which can detect obstacles on the ground, uneven surfaces, holes, steps, and puddles [1]. The cane can detect obstacle only within its reach (3-4 feet) and therefore it provides only limited information about the environment. Furthermore, the traveler is required to constantly scan the surrounding with the cane, a time and effort-consuming process.

During the past 20 years a number of *Electronic Travel Aids* (ETA's) have been developed. Best known are the *Laser-cane*, the *Mowat Sensor*, the *Russell Pathsounder,* and the *Binaural Sonic Aid (Sonicguide)*. While all these devices improve the detection range of the long cane, they still require active scanning of the environment by the user. Furthermore, once an obstacle is detected, the user is required to perform further measurements in order to avoid the obstacle, again a process that requires time and conscious effort.

Another type of assistive devices is called *Global Navigation Aids* (GNAs). GNA systems are not concerned with local obstacle avoidance but rather with globally directing the user toward a desired target. These devices aim at providing the absolute position of the user (e.g., an intersection of two streets, an entrance to a building, a bus stop), or directional information (e.g., "go straight 30 meters," "turn left," "go up the stairs"). Examples for GNAs are the *Talking Signals,* the *Sona System*, the *Freeston device,* and the *Gilden device*. Since these devices were not designed to perform local obstacle avoidance tasks, travelers had to use additional assistive devices which complicate the traveling process.

2. THE GENERAL CONCEPT OF THE *NAVBELT*

In order to overcome the shortcomings of existing travel aids, we have transferred an obstacle avoidance technology, originally developed for mobile robots, to a portable device - the *Navbelt* [2]. The *Navbelt* consists of a belt, a small computer, and ultrasonic sensors. Applying the obstacle avoidance system, the computer processes the signals arriving from the sensors and relays them to the user by stereophonic headphones, using a stereo imaging technique. The concept of the *Navbelt* design is illustrated in Figure 1. The electrical signals which originally guide the robot around obstacles are substituted by acoustic (or tactile) signals. However, the computation of the free path and the sensing techniques are similar in both applications.

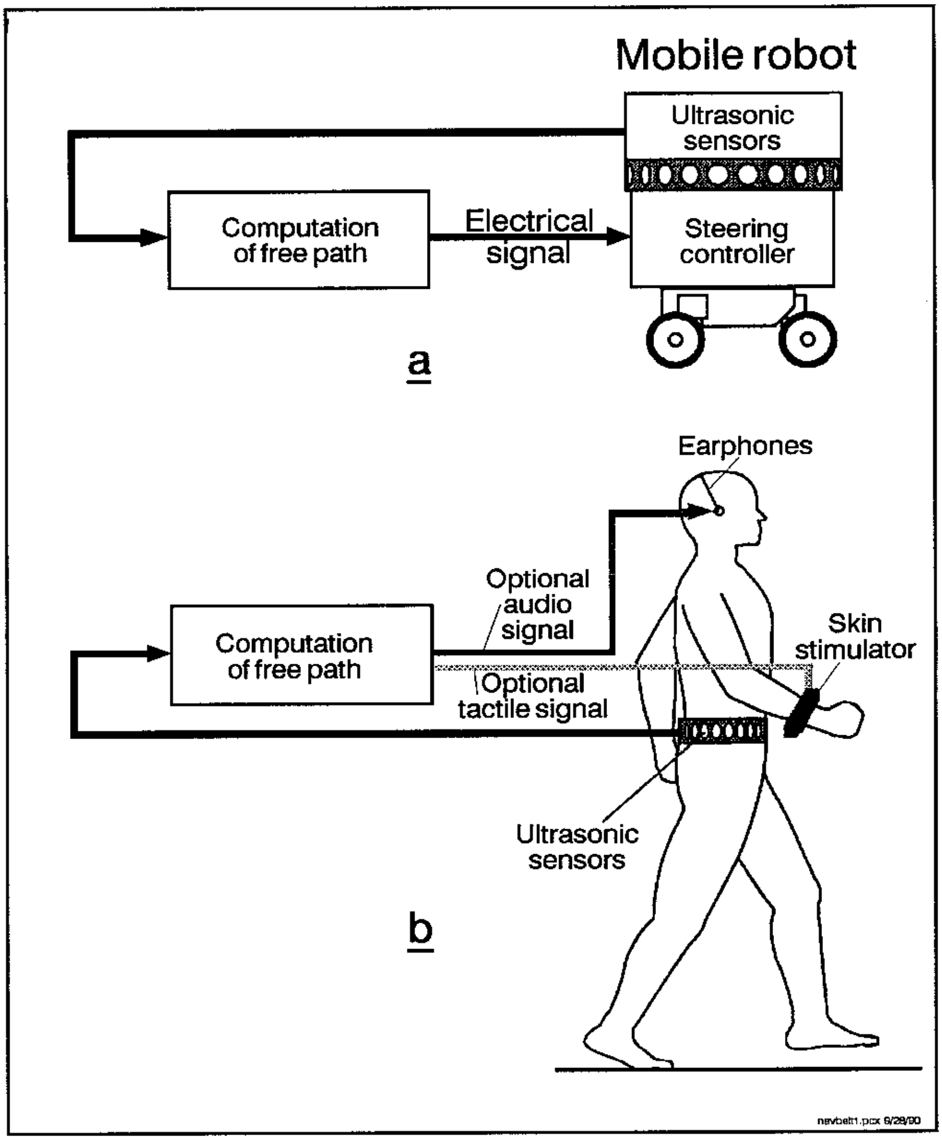

Figure 1: The concept of the *NavBelt*.

The obstacle avoidance system (OAS) [3] scans the environment with several sensors simultaneously and employs a unique real-time signal processing algorithm to produce active guidance signals. The strength of the OAS is based on its gradual reduction of data complexity (from multiple sensors) to a level suitable for real-time guidance of robots or humans. The sensors' data is stores in a world model, and is updated continuously in real-time. The OAS computes the recommended traveling direction according to the user's current position, target location and the obstacles in the surroundings. In the absence of obstacle, the recommended direction is simply the direction toward the target. If, however, obstacles block the user's path, the OAS computes an alternative path which safely guides the user around it.

An additional algorithm generates acoustic signals for the user. Part of this algorithm is a sophisticated optimization odel based on a *human's performance model*. The model reflects the user's ability to perceive and analyze the signals, and is continuously adjusted according to the up-to-date performance of the user.

3. DESIGN

The user wears the *Navbelt* around the waist like a "fanny pack." In our first prototype, the user must also carry a portable computer as a backpack. Further developments will reduce the size and weight of this computer considerably. Eight ultrasonic sensors, each covering a sector of 15°, are mounted on the front pack, providing a total scan sector of 120°. More sensors will be installed in the future for more complete coverage.

Small stereophonic headphones provide the user with the auditory data without precluding perception of acoustic signals from the environment. A binaural feedback system (BFS) based on internal time and amplitude difference (phase and volume difference between left and right ear) creates a *virtual direction* (i.e. an impression of directionality of virtual sound sources).

The *Navbelt* is designed for four operational modes, which offer different levels of assistance to the user.

1) **Guidance Mode** - The acoustic signals actively guide the user around obstacles in pursuit of the target direction. The signals carry information regarding the recommended direction and speed of travel and proximity to obstacles.

2) **Image Mode** - This mode presents the user with a panoramic *acoustic image* of the environment. A sweep of stereophonic sounds appears to "travel" through the user's head from the right to the left ear. The direction to an obstacle is indicated by the spatial direction of the signal, and the distance is represented by the signal's volume.

3) **Directional Guidance Mode** - The system actively guides the user toward a temporary target, the location of which is determined by the user. The user indicates this location with a joystick, and when the joystick is not used, the target is located five meters in front of the user. In case an obstacle is detected, the *Navbelt* provides the user with information to avoid it with minimal deviation from target direction.

4) **Selected Image Mode** - In this mode the user is presented with a selectable section of the environment, as with the image mode. However, unnecessary information is suppressed and only the most important section of the environment is transmitted to the user.

4. ADVANTAGES OF THE *NAVBELT* OVER EXISTING DEVICES

- The *Navbelt* not only detects obstacles but can also guide the user around them. This combination of obstacle detection and avoidance reduces the conscious effort required from the user.

- Continuous scanning of the environment relieves the user from additional actions, therefore reducing the required physical and mental effort.

- The *Navbelt* can provide the user with a panoramic view of the environment, covering a sector of 120°.

- The *Navbelt* can automatically guide the user alongside walls. Consequently, the traveler can easily detect corners of buildings or rooms, doorways, windows etc.

- Using the *Navbelt*'s computer as a training device reduces training cost significantly. A computer-based simulator can systematically train the user in various types of environments and circumstances with absolutely no danger to the user's safety, requiring only limited assistance from a professional trainer.

- The *Navbelt* adjusts itself to changes in the environment and to the user's needs. It suppresses insignificant information and transmits only the most relevant and crucial data so that the user can react with only a minimal conscious effort.

- In a commercial product based on the *Navbelt*'s design, the portable computer can be used just like a conventional computer, making the purchasing cost of more economic.

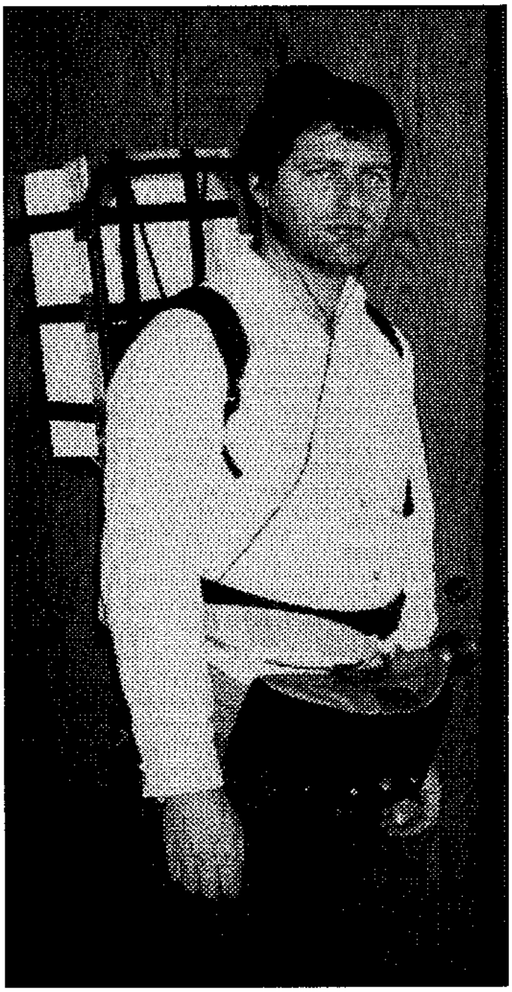

Figure 2: The *NavBelt* prototype.

5. IMPLEMENTATION

We have built a prototype of the *Navbelt*, which comprises of an IBM PC 486 33 MHz computer, 8 ultrasonic sensors and stereophonic headphones (see Fig. 2).

Five programmable timers produce the binaural feedback, allowing control over the signal wave form for the stereophonic effects. The ultrasonic sensors are controlled by an I/O board via interrupt handler for efficient utilization of CPU time. A joystick attached to the computer allows the user to specify directional commands to the computer while traveling. Out of the four modes of operation listed in Section 3, we have currently implemented only the image mode and the directional guidance mode.

6. SIMULATOR EXPERIMENTAL RESULTS

A simulator, based on the same hardware as the *Navbelt*, assists the user in the training procedure. The same acoustic signals that guide the user in the real *Navbelt* are used in the simulator. The user's response to these signals are relayed to the computer by the joystick. Several maps are stored in the computer representing different types of environments.

We conducted initial experiments with the *Navbelt*'s simulator to asses the performance of the binaural feedback system, different formats of acoustic signals, and the user's ability to react quickly to such inputs. In the first experiment the image mode was tested. Acoustic images were created continuously, with a sweep-time of 0.55 sec. After 20 hours of training, users could "travel" at an average speed of 30 cm/sec.
Next, the guidance and directional guidance modes were tested. The test persons were able to "travel" (again using the joystick) among different types of obstacles toward a pre-defined target (guidance mode) or a user's specified temporary target (directional guidance mode). Depending on the user's experience and the type of the environment, test persons moved through the simulated environment based only on the acoustic guiding signals. Figure 3(a) illustrates an experiment using real sensor data while the experiment in figure 3(b) is based on computer generated obstacles. In both experiments the dots represent obstacles while the continuos curve is the user's traveling path. In Fig. 3(a) the user traveled at an average speed of 0.75 m/sec and in Fig. 3(b) at an average speed of 0.54 m/sec.

A self-training computer program which includes 10-20 hours of training with the simulator (for the directional guidance mode only) gradually and systematically exercises the user for safe and quick travel. Furthermore, an adaptive user's-model and optimization algorithm enable the training procedure to be adjusted to the user's individual progress. Additional experiments to be conducted in the future will investigate the effect of the adaptive training on human performance.

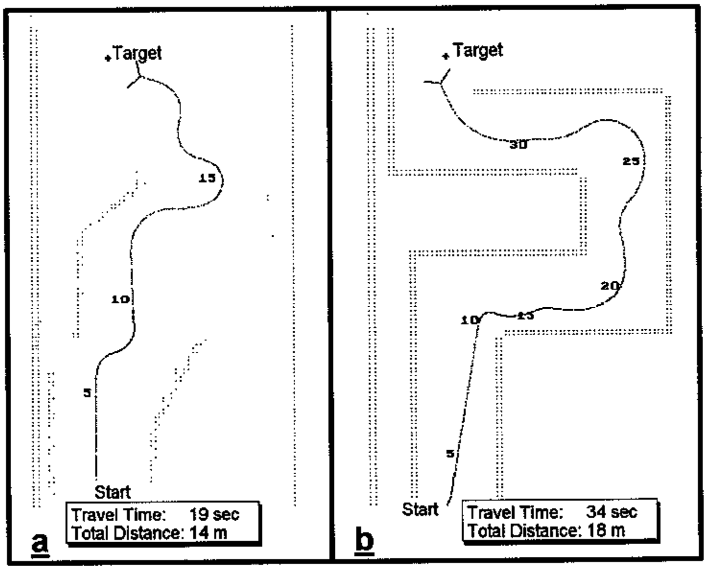

Figure 3: Simulation results with
(a) real sensor data and (b) computer generated data.

7. EXPERIMENTAL RESULTS WITH THE *NAVBELT*

The experiments with the *Navbelt* prototype included investigation of the *Navbelt*'s ability to detect obstacles and construct an environment map. We also observed the reaction to the acoustic signals in a real environment. Test persons were asked to travel through an unknown environment in a pre-defined direction using the directional guidance mode without using the joystick. Subjects were able to travel in cluttered environments, avoiding obstacles as small as 10 cm in diameter. Classifying human performance in term of their walking speed, deviation from recommended direction and ability to avoid obstacle, we found that training has the dominant effect on performance. Subjects with more experience traveled faster and generally were more comfortable while traveling. A subject with 10 hours experience with the simulator and 10 hours of practical experience traveled at an average speed of 0.6 m/sec while a subject with 20 hours of practical experience traveled at 0.8 m/sec.

8. CONCLUSIONS

We have built and tested a new travel aid for the blind - the *Navbelt*. The device, based on technology originally developed for mobile robots, integrates fast and reliable obstacle detection with obstacle avoidance technology. The *Navbelt* is designed to offer four operational modes, each requiring a different level of conscious effort from the user. Adaptive information transfer and optimization techniques adjust the signals transmitted to the user according to changes in the environment. Signals are also adjusted according to the user's skills and requirements to improve human and machine integration.

The *Navbelt*'s built-in simulator can train the user systematically and independently according to the individual progress. after 10-20 hours of self training users were able to travel with the *Navbelt* at 0.6-0.8 m/sec while avoiding obstacles as small as 10 cm in diameter.

9. REFERENCES

1. Barbin J. A., "New Developments in Mobility Aids for the Blind", *IEEE Transaction on Biomedical Engineering*, Vol. BME-29, No. 4, April 1982

2. Borenstein J., "A Computerized Multi-Sensor Travel Aid for Active Guidance of the Blind", CSUN's Fifth Annual Conference on Technology and Persons with Disabilities, Los Angeles, California, March 21-24, 1990.

3. Borenstein J., Koren Y., "The Vector Field Histogram - Fast Obstacle-Avoidance for Mobile Robots." *IEEE Journal of Robotics and Automation*, Vol. 9, No. 5, June 1991.