EYE FOR THE VISUALLY IMPAIRED

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Abstract

The Robotic sonar stick is a novel device designed to help blind or visually impaired users navigate safely and quickly among obstacles and other hazards. During operation, the user pushes the lightweight Robotic sonar stick forward. When the Robotic sonar stick's ultrasonic sensors detect an obstacle, the embedded computer determines a suitable direction of motion that steers the Robotic sonar stick and the user around it. The steering action results in a very noticeable force felt in the handle, which easily guides the user without any conscious effort on his/her part .

I. INTRODUCTION

Many of the visually challenged persons use the white cane – the most successful and widely used travel aid for the blind. This purely mechanical device is used to detect obstacles on the ground, uneven surfaces, holes, steps, and other hazards. The inexpensive white cane is so lightweight and small that it can be folded and slipped into a pocket. The main problem with this device is that users must be trained in its use for more than 100 hours – a substantial "hidden" cost. In addition, the white cane requires the user to actively scan the small area ahead of him/her. The white cane is also not suited for detecting potentially dangerous obstacles at head level. Guide dogs are very capable guides for the blind, but they require extensive training. Fully trained guide dogs cost between $12,000 and $20,000, and they are only useful for about five years Furthermore, many blind and visually impaired people are elderly and find it difficult to care appropriately for another living being.

During the past three decades, several researchers have introduced devices that use sensor technology to improve the blind users' mobility in terms of safety and speed. Examples of these devices, collectively called Electronic Travel Aids (ETAs), are the C-5 Laser Cane, the Mowat Sensor, the Nottingham Obstacle Detector, and the Sonicguide.

These ETAs, however, have not found wide use among their targeted users, likely because the utility of this group of systems is limited. In particular, conventional ETAs suffer from the following three fundamental shortcomings:

1) The user must actively scan the environment to detect obstacles (no scanning is needed with the Sonic guide, but it does not detect obstacles at floor level). This procedure is time-consuming and requires the user's constant activity and conscious effort.

2) The user must perform additional measurements when an obstacle is detected in order to determine the dimensions and shape of the object. The user must then plan a path around the obstacle. Again, a time-consuming, conscious effort that reduces the walking speed.

3) Another problem with all ETAs based on acoustic feedback is their interference (called masking) with sound cues from the environment, reducing the blind person's ability to hear these essential cues .

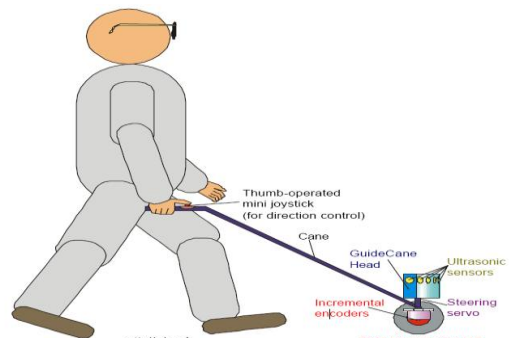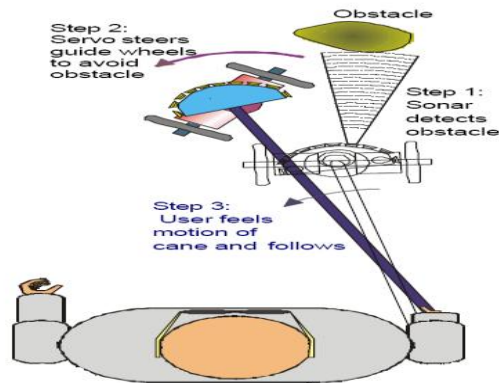## II. THE ROBOTIC SONAR STICK CONCEPT

Figure 1: Functional components of the GuideCane.

Figure 1 shows a schematic view of the Robotic sonar stick and its functional components. Much like the widely used white cane, the user holds the Robotic sonar stick in front of himself/herself while walking.

The Robotic sonar stick is considerably heavier than the white cane, but it rolls on passive wheels that support its weight during regular operation. Both wheels are equipped with encoders to determine the relative motion. A servomotor,

controlled by the built-in computer, can steer the wheels left and right relative to the cane. To detect obstacles, the Robotic sonar stick is equipped with ten ultrasonic sensors. A mini joystick located at the handle allows the user to specify a desired direction of motion.

Functional Description

During operation, the user pushes the Robotic sonar stick forward. While traveling, the ultrasonic sensors detect obstacles in a 120o wide sector ahead of the user (see Step 1 in Figure 2). Based on the sonar and encoder data, the embedded computer instantaneously determines an appropriate direction of travel. If an obstacle blocks the desired travel direction, then the obstacle avoidance algorithm prescribes an alternative direction that clears the obstacle and then resumes in the original direction (see Step 2 in Figure 2). Once the wheels begin to steer sideways to avoid the obstacle, the user feels the resulting horizontal rotation of the cane (see Step 3 in Figure 2). In a fully intuitive response, requiring virtually no training time, the user changes his/her orientation to align him/her with the cane at the "nominal" angle. In practice, the user's walking trajectory follows the trajectory of the Robotic sonar stick similar to the way a trailer follows a truck. Because of the handle's short length, the user's trajectory is very close to the Robotic sonar stick's trajectory. Once the obstacle is cleared, the wheels steer back to the original direction of travel. The new line of travel will be offset from the original line of travel. Depending on the circumstances, the user 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 Robotic sonar stick's dead-reckoning capability.

The user can prescribe a desired direction of motion with the thumb-operated mini joystick. This directional command is discretized into eight directions and is understood to be relative to the Robotic sonar stick's current direction of motion. For example, if the user presses the button to the left, then the computer adds 90° to the current

direction of motion and, as soon as the new desired motion of travel is free of obstacles, steers the wheels to the left until the 90° left turn is completed. It is important to note that the user can usually indicate a new direction well before the change of direction should occur. In the case of a corridor, if the user presses the button to the left, then the Robotic sonar stick will continue down the corridor until it reaches an intersection or an open door where it can turn to the left. The ability to indicate a desired direction of motion in advance significantly enhances the Robotic sonar stick's ease-of-use.

The detection of stairs is a particular problem for most ETAs. The Robotic sonar stick offers separate solutions for down steps and up-steps. Down-steps are detected in a fail-safe manner: when a down-step is encountered, the wheels of the Robotic sonar stick drop off the edge until the shock-absorbing bottom hits the step – without a doubt a signal that the user can not miss. Because the user walks about 60 cm behind the Robotic sonar stick, he/she has enough time to stop. Up steps can be detected by additional front-facing sonars as described in; = however, this method has not yet been implemented in the Robotic sonar stick. Because the Robotic sonar stick is compact and lightweight, it can easily be lift up whenever the user needs to cope with stairs

Conventional ETAs are designed to notify the user of obstacles, usually requiring the user to perform additional scanning once the obstacle is detected. The user must evaluate all of the obstacle information, which comprises of the size and proximity of each obstacle, and then 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 of evolution to perfect this skill. However, the evaluation of obstacle information presented by acoustic or tactile signals is a new skill that must be acquired over hundreds of hours of learning. Even then, exercising such a skill requires a great deal of conscious effort, and thus processing time. The required effort further increases with the number of detected obstacles. The Robotic sonar stick is fundamentally different from other devices in that it first analyzes the environment and then computes the momentary optimal direction of travel. The resulting guidance signal is a single piece of information – a direction – which substantially .consequence, it is far easier and safer to follow the low-bandwidth guidance signal of the Robotic sonar stick than to follow the high-bandwidth information of other existing systems. However, reducing the high-bandwidth obstacle information to a momentary optimal direction of travel requires

the implementation of a reliable obstacle avoidance system.

Information Transfer

This advantage can be credited to another unique feature of the Robotic sonar stick: information transfer through direct physical force (also called "haptic display" in the scientific literature). This process is completely intuitive so that everybody can use the system right away without learning how to interpret artificially defined acoustic or tactile signals, as with conventional ETAs. Yielding to external forces is a reflexive process that does not require a conscious effort. Moreover, many blind persons are accustomed to being guided by sighted people in a similar fashion.

III. THE ROBOTIC SONAR STICK SYSTEM

The Robotic sonar stick is a fully embedded system, implementing all components on-board. The main constraints in the mechatronic design of the Robotic sonar stick are size and weight. The mechanical hardware must be as compact and as lightweight as possible so that the user can easily lift the Robotic sonar stick, e.g., for coping with stairs and access to public transportation. For the same reason, the electronic components should require minimal power in order to minimize the weight of the batteries. In addition, both the mechanical and electronic hardware must be designed to facilitate the software's task, allowing real-time performance with limited on-board processing power.

A. Mechanical Hardware

The Robotic sonar stick consists of three main modules: housing, wheelbase, and handle. The housing, made of acrylic, contains and protects most of the electronic components. The current prototype is equipped with ten Polaroid ultrasonic sensors that are located around the housing. Eight of the sonars are located in the front in a semi - circular fashion with and reduces the information bandwidth. As a Robotic sonar stick with a total angular spacing of 120°. The other two sonars face sideway and are useful for following walls and for going through narrow openings, such as doorways. The sonars are close to the ground so that the Robotic sonar stick can also detect obstacles that protrude only slightly above the ground. One disadvantage of this location is that the sonars sometimes detect minor irregularities in the ground, which erroneously trigger an avoidance maneuver). By placing the sonars at a small upward-looking angle, we hope to eliminate this potential problem with the next prototype.

The housing and wheelbase are about 43 cm (17") wide, 25 cm (10") high, and 23 cm (9") deep. The current Robotic sonar stick prototype weighs about 4 kg (9 lbs). However, we expect that a commercial version can be built that weighs only 2.5 – 3 kg (5.7 – 6.8 lbs).
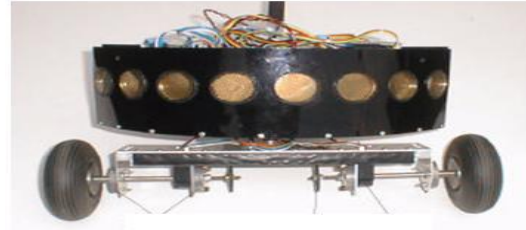

Fig 3: *Our Practical Implementation*

As shown in Figure 3, the wheelbase uses ball bearings to support two unpowered wheels. To perform odometry, both wheels are equipped with lightweight quadrature encoders. Using full quadrature decoding, the resolution of the encoders is 2,000 pulses per revolution, resulting in more than 5 pulses for a wheel advancement of 1 mm. The Robotic sonar stick's odometry equations are the same as for a differential drive mobile robot. However, because the wheels are unpowered, there is considerably less risk of wheel slippage.

The wheelbase is attached to the housing with a pivot angular spacing of 15°, covering the area ahead of the push-rod couples the wheelbase to the servo, which is fixed to the housing bottom. Because the servo shaft is rigidly linked to the wheelbase, the built-in computer can access the potentiometer inside the servomotor to determine the relative angle between the wheelbase and the housing. This information is important for correctly updating the local map based on the sonar and the odometry data.

The handle serves as the main physical interface between the user and the Robotic sonar stick. It consists of an extruded aluminum bar with a square-shaped profile. A square shape is better than a circular shape as it allows the user to determine the handle's orientation through tactile contact. The handle is attached to the housing with a hinge, whose angle can be adjusted to accommodate users of different heights.

B. Electronic Hardware

The electronic system architecture of the Robotic sonar stick is shown in Figure 4. The main brain of the Robotic sonar stick is an embedded PC/104 computer, equipped with a 486 microprocessor clocked at 33 MHz. The PC/104 stack consists of four layers. Three of the modules are commercially available, including the motherboard, the VGA utility module, and a miniature 125-MB hard disk. The fourth module, which we custom-built, serves as the main interface between the PC and the sensors (encoders, sonars,

and potentiometer) and actuators (main servo and brakes). The main interface executes many time-critical tasks, such as firing the sonars at specific times, constantly checking the sonars for echoes, generating PWM signals for the servos, and decoding the encoder data. The main interface also acts as an asynchronous buffer for the sonar data. Although the Robotic sonar stick currently uses only ten sonars, the main interface provides hardware and software support for up to 16 sonars.

The main interface is connected to the PC's bi-directional parallel port. The interface preprocesses most of the sensor data before the data is read by the PC. In addition, all communications are buffered. The preprocessing and buffering not only minimize the communications between the PC and the interface, screw and can be rotated by a small servomotor. A PC to control the sensors and actuators. Because the main interface completes all the low-level tasks, almost all of the PC's computational power can be dedicated to medium and high-level tasks. The interface consists mainly of three MC68HC11E2 microcontrollers, two quadrature decoders, a FIFO buffer, and a decoder.

The embedded PC/104 computer provides a convenient development environment. For stationary development, the system is connected to a regular keyboard and a CRT mo nitor. For mobile tests, the PC is connected to a smaller keyboard and a color LCD screen that is attached to the handle below the developer's hand. The entire system is powered by rechargeable NiMH batteries, allowing mobile testing for several hours. The Robotic sonar stick is thus fully autonomous in terms of power and computational resources.

While the current prototype consists of four PC/104-sized modules, only two of them are required for the final version. While the VGA module is very useful for visual verification and debugging, it is no longer needed after development. In addition, the hard-disk module can be eliminated in the final product, because the final software can be stored in an EPROM on the motherboard. This solid-state solution also eliminates potential problems with the moving parts of the hard-disk, which is sensitive to shocks and vibrations.

The Robotic sonar stick is a semi-autonomous system, providing full autonomy for *local* navigation (Obstacle avoidance), but relying on the skills of the user for *global* navigation (path planning and localization). Combining the skills of a mobile robot with the existing skills of a visually impaired user makes this particular application feasible at the current stage of mobile robotics research. While reliable global navigation systems might be available in the future, they are not essential for the Robotic sonar stick. Although visually impaired people have difficulties performing fast local navigation without a travel aid, they are in most cases perfectly capable of performing but also minimize the computational burden on the desired direction of travel. To achieve safe travel at fast walking speed through cluttered and unknown environments, the Robotic sonar stick employs several mobile robot obstacle avoidance technologies that were developed earlier at the University of Michigan's Mobile Robotics Lab, as explained next. The ultrasonic sensors are controlled by the *Error Eliminating Rapid*

Ultrasonic Firing (EERUF) method. EERUF allows sonars to fire at rates that are 5-10 times faster than conventional methods. Each of the 10 sonars is fired at a rate of 10 Hz, so that the Robotic sonar stick receives 100 sonar readings per second. However, fast firing with multiple sonars can result in crosstalk, a phenomenon in which one sensor receives the echo from another sensor.

By employing alternating delays before firing each sensor, EERUF is able to detect and reject crosstalk. The faster firing rate improves the reliability of the Robotic sonar stick's obstacle avoidance performance and is necessary for allowing safe travel at fast walking speed. Based on the sensor data, the Robotic sonar stick uses *histogramic in-motion mapping* (HIMM) to build a local map of its immediate surroundings. The map is represented by a two-dimensional array, called *histogram grid*, which is based on the concept of *certainty grids* pioneered by Moravec and Elfes. HIMM produces high certainty values for cells that correspond to obstacles and keeps low certainty values for cells that were increased because of misreading or moving objects. In the current implementation, the dimensions of the local map are 18 m 18 m with a cell size of 10 cm 10 cm. The map requires less than 32 kilobytes of memory. A discrete scrolling algorithm is implemented so that the finite dimensions of the local map do not limit the Robotic sonar stick's workspace. Based on the information contained in the local map, the local obstacle avoidance algorithm determines an appropriate instantaneous direction of motion. Using the information in the local map instead of solely the current sonar readings, a better obstacle avoidance performance is achieved than with a purely reactive system. The task of the obstacle avoidance algorithm global navigation. The main task of the Robotic sonar stick is to steer around obstacles and to proceed toward the direction of travel. This direction is then used to send the appropriate steering signal to the Robotic sonar

stick's servomotor. Originally, the *vector field histogram* (VFH) obstacle avoidance method was implemented in the Robotic sonar stick. During the Robotic sonar stick development, the original VFH method was successively improved, resulting in the VFH+ and VFH* algorithms .The improved algorithms are more robust by taking into account the width and the trajectory of the Robotic sonar stick, and less likely to direct the Robotic sonar stick into local dead-ends.

IV. FUTURE IMPROVEMENTS

Sonars – The next version of the Robotic sonar stick prototype will be equipped with 13 sonars located in the front in a semi-circular fashion, covering 195ahead of the Robotic sonar stick. Three additional sonars will be placed on top of the housing to detect overhanging obstacles.

Brakes – Both wheels can be equipped with brakes that can be activated by the onboard computer, for several purposes. In densely cluttered environments, the user can be slowed down if his/her speed is too fast. Or, when the user walks into a dead-end where no avoidance maneuver is possible, e.g., a closed door at the end of a corridor, the system can immediately signal this condition by fully applying the brakes. Brakes can be implemented using off-the-shelf, servo-actuated disk brakes used in model race cars. These brakes are powerful and their dimensions are suitable for the Robotic sonar stick.

Speech output – Speech output could be a very helpful feature if used appropriately. It would allow the Robotic sonar stick to not only guide the user to a desired location, but also to provide additional information about the environment. One useful function could be the instant presentation of location and orientation data. Another useful function would be to warn a user if he/she gets too close to an obstacle, and even telling him/her on which side the obstacle is. Speech output could also be used instead of the brakes to ask the user to slow down or stop.

V. CONCLUSION

The Robotic sonar stick offers innovative solutions for the three fundamental shortcomings of conventional is to determine a suitable direction of motion, i.e., one that is free of obstacles but close to the user's desired ETAs:

1. Because of the sensor array comprising of multiple sonars, the user no longer needs to actively scan the area ahead of him/her. Although not yet implemented in the experimental prototype described in this paper, upward-facing sonars should be relatively easy to implement to detect overhanging obstacles.

2. When the user approaches an obstacle, the Robotic sonar stick does not communicate everything it
Knows about the obstacle to the user. Instead, it analyzes the situation, determines an appropriate direction to avoid the obstacle, steers the wheels in that direction, and thus guides the user around the obstacle without requiring any conscious effort on his/her part. This is possible because a coarse representation of the obstacle's contour is formed in the Robotic sonar stick's local map.

3. The Robotic sonar stick does not use acoustic feedback, so that there is no masking of audio cues on which many   blind persons rely heavily.
As a consequence of these advantages, the Robotic sonar stick is intuitive and easy to use. In addition, because the Robotic sonar stick takes care of the local navigation task, it allows the user to fully concentrate on the global navigation task.

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