A Sonar-Based Omni Directional Obstacle Detection System Designed for Blind Navigation

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Abstract: - A blind navigational aid has been implemented that utilizes a multi directional sonar system for obstacle detection and an electronic compass for traveler heading detection. The system controls and gathers information from the sensors in real-time and presents the navigational information using a 3D audio interface based on Head Related Transfer Functions. This paper describes the hardware and software design for this real-time system.

Key-Words: - Sonar, Disabilities, 3D Sound, Electronic Travel Aid (ETA), HRTF, Ranging, Real-time DSP.

1 Introduction

Electronic devices developed for blind navigation basically perform two functions: i) Gather information about the user's orientation and surrounding environment, ii) Present the information to the blind user utilizing a non-visual medium. The blind navigational aid described in this paper has been developed specifically for indoor applications. The system uses a method of auditory presentation of the surrounding environment, called Head Related Transfer Functions. The system has been designed to minimize delays in information gathering, post processing and presentation [13].

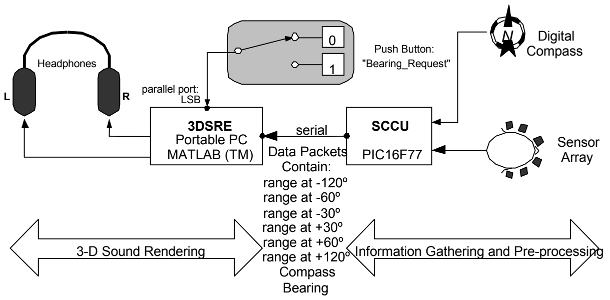

Figure 1. Layout of the different functional blocks of the navigational system.

2 System Outline

The overall layout of the system is shown in Figure 1. The two key computational components are the 3-D Sound Rendering Engine (3DSRE) and the Sonar and Compass Control Unit (SCCU). The components used in the system fall into three categories: 1) sensors, 2) control and computation, and 3) communications and sequencing. The following issues were considered while selecting the components, 1) simplicity of design, 2) ease of integration, 3) configurability, 4) low power, 5) size, 6) detail in documentation, and 7) developer support.

2.1 Sensors

The range detection system is designed for indoor range measurements. Therefore, special considerations are required for the ultrasonic sensor characteristics. Six ultrasonic sensors are arranged in an array to measure obstructions from +120º (right) to -120º (left). The configuration of the array is illustrated in Figure 2. The physical arrangement of the ultrasonic sensors suggests that the sensors ideally have a beam spread of no more than ±15º. The physical dimensions and weight of the sensor modules are also important, because they are mounted on a headgear worn by the user.

The ultrasonic power emitted by the transmitter must be comparatively low, with a high sensitivity receiver, to ensure minimizing multiple reflections that may cause crosstalk between sensors. It was determined that an accurate range reading of 10 feet would be adequate for a blind person to walk freely in an indoor environment.

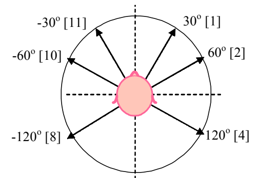

Figure 2. The physical layout of the six ultrasonic transducers. Note that the sonar directions have been marked as clock positions for reference.

The Devantech SRF04 ultrasonic range sensing module has been chosen as the range finding sensor for the application because of its compact construction and comparatively narrow beam pattern. The sensor operates at an ultrasonic frequency of 40KHz with a maximum supply current of 50mA. The manufacturer specified range is from 3cm to 3m [1].

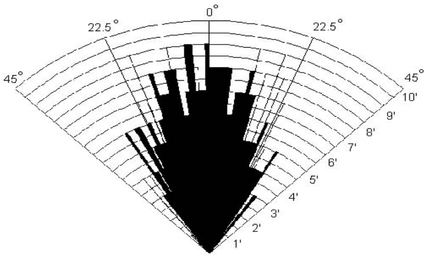

Figure 3. The Devantech SRF04 Beam pattern

The Devantech module shows a beam spread of less than ±22.5º at a distance of 10 feet. The beam spread widens to about ±30º at about 5 feet (Figure 3). Even though this does not meet the beam-spread requirement defined by the array geometry, a technique has been developed to compensate for the beam overlap on neighboring sensors [2].

The Devantech CMPS01 compass module was selected for orientation detection in the system. This module features an I^2C interface [10] at a maximum bus speed of 1MHz. The angular resolution of the compass module is 3º. The compass measurements are read as an 8 bit binary number [3].

2.2 Sonar and Compass Control Unit (SCCU)

The Sonar and Compass Control Unit (SCCU) communicates with the host system (the 3DSRE). Based on the commands sent by the host system, the SCCU triggers the ultrasonic sensors according to a set of predefined sequences. The SCCU integrates the range and compass readings and prepares a data packet to deliver to the host computer. The platform selected for the SCCU is a Microchip™ PIC16F77-based microcontroller board [4]. This single board computer called the OOPIC™, also features a resident operating system to interpret instructions written in an object oriented language [5].

The logic circuitry designed to interface the six ultrasonic sensors to the OOPIC board, provides flexibility in the control and sequencing of the six range measurements. The Devantech SRF04 control interface is fairly simple [6]. The protocol shown in Figure 4, requires the *Trigger* input of the sensor module to be pulsed high for a minimum duration of 10µS. At the falling edge of the *Trigger*, the module emits a burst of ultrasonic energy – known as the "ping". Immediately after the ping emission, the *Echo* output of the sensor goes into a high state and remains high until the receiving circuit detects the echo. The instrumental challenge is essentially to measure the duration of the *Echo* pulse, since the detected range is proportional to the Echo detection time.

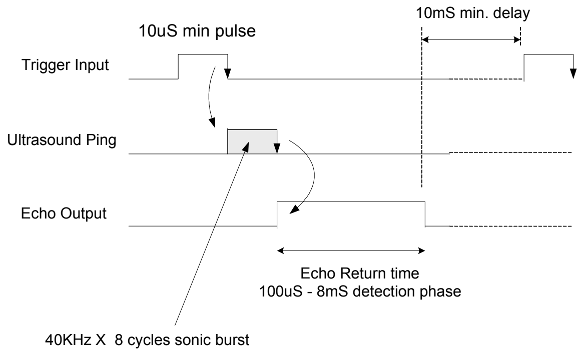

Figure 4. The Devantech SRF04 control protocol

The ranging sensor interface uses a calibrated clock reference for registering the echo detection time. Figure 5 shows the schematic diagram of the logic circuit for the six-sensor interface. Each sensor controls an independent 8-bit counter for registering the time delays. All counters are driven by a clock calibrated at 6.85KHz. This provides a count value of 1bit per inch of detected obstacle range.

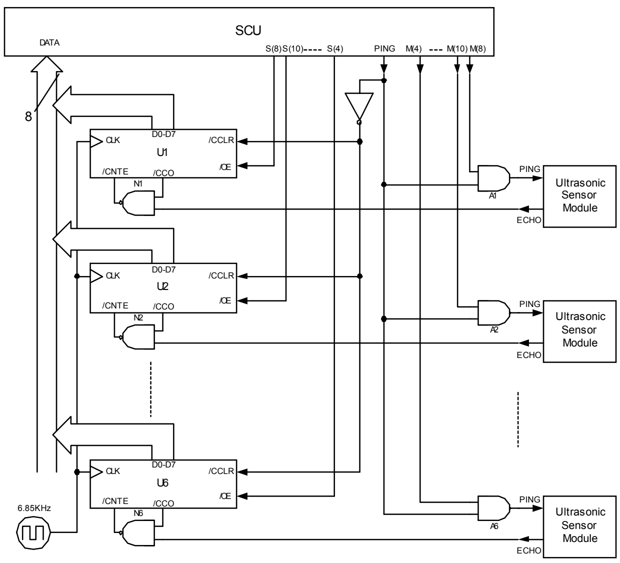

Figure 5. Schematic diagram of the SRF04 interface to the OOPIC board.

The maximum recordable range is therefore 255 inches or 21.25 feet. This "time-delay to distance conversion" implemented in hardware reduces post processing functions typically performed by the CPU and enables the SCCU to provide a meaningful output, directly. The OOPIC provides a single ping control, which is routed to the sensors via individual gating circuits *(A1…A6)*. The Masking bits *M(n)* control the respective gating circuits, providing a software selectable ping for individual channels. The echo output of each sensor is routed to the respective pins through a NAND gate. The carry out signal from the counter inhibits the count enable operation using this gate. This mechanism ensures roll-over prevention and pauses the count operation at 255.

After all the range values have been recorded in their respective counters, each counter can be selected using the *S(n)* bits to transfer the values to the OOPIC board. In summary, this design ensures complete autonomy in individual or group measurements, which is software selectable.

The SCCU interfaces with the Devantech CMPS01 compass module using the I^2C interface and collects compass readings during every query cycle [11]. The SCCU communicates with the 3DSRE using an RS232 interface.

2.3 3D Sound Rendering Engine (3DSRE)

The 3D Sound Rendering Engine (3DSRE), based on a portable PC, continuously interacts with the user. The system runs a Matlab™ [12] based program. It acts as a host system for the SCCU, communicating with it through the serial port. In addition the program polls data bit 0 of the parallel port (designated "bearing request") for user input, once every cycle. Normally the 3DSRE functions in the "Obstacle Map Mode". In this mode the detected six range readings modulate the amplitude of six individual phantom sound sources placed in their associated angles. This makes the phantom sources appear closer or farther away in the virtual environment (Figure 6).

When the user presses the *bearing request* button the 3DSRE switches to North Beacon mode. In this mode a single virtual sound source is placed at the angular direction of the earth's magnetic North, relative to the user's heading direction. This is shown in Figure 7.

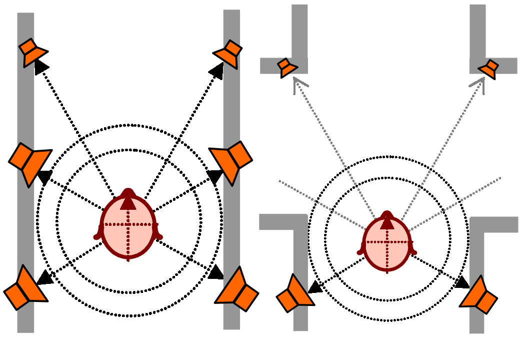

Figure 6. The speaker sizes indicate the magnitude of the phantom sound srouces. The sound sources are placed at the position where the obsticle are detected.

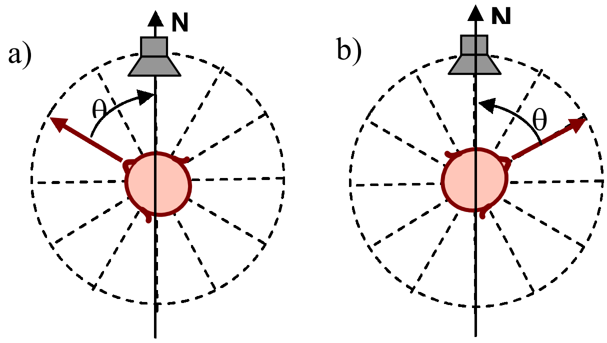

Figure 7. Sound sources placed in virtual environment in the North Beacon mode operation

3 HRTF Implementation

The 3DSRE utilizes Head Related Transfer Functions (HRTF) to generate a virtual 3D sound environment [7]. Head-Related Transfer Functions are widely used for the synthesis of binaural sound, which can produce in the listener the illusion of a sound that originates at a virtual location around him/her. Sounds traveling from a physical source to the listener's eardrums undergo modifications due to reflections and interactions with the listener's torso, shoulders, head and the pinnae (outer ears). For an acoustic point source placed in a certain position, the HRTF models 3 parameters [8]: a) the inter aural time delay (ITD), which is a small but significant time delay between the two ears of the listener; b) the Inter aural Intensity Difference (IID), which is the magnitude difference of the sound source felt between the two ears of the listener; and c) the binaural spectral modifications caused by the facial and ear geometry of the listener.

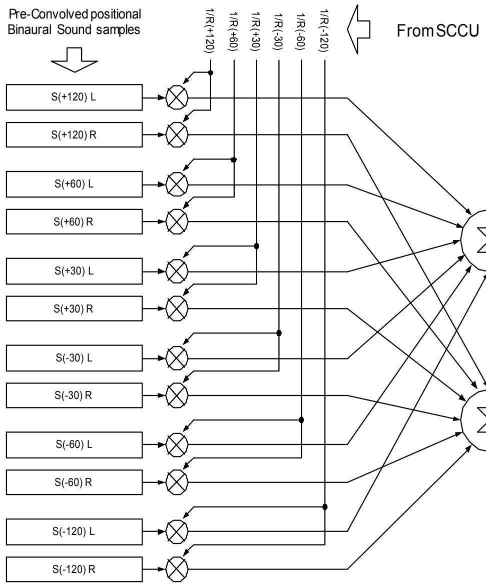

Figure 8. Schematic diagram HRTF implementation in the system.

All three parameters are integrated into a pair of FIR filters for the left and right channels. Appropriate FIR coefficients are derived experimentally, for each spatial position (azimuth, elevation, distance) of the sound source, using specialized measurement equipment called the AuSIM3D HeadZap system [9]. Any sound sample convolved through a pair of these FIR coefficients appears to the user at the spatial direction preset by the FIR filter pairs.

Six pairs of FIR coefficients are implemented in the design, representing their associated sensor directions (+/-30º, +/-60º, +/-120º) in the horizontal plane. To reduce the processing time for the spatial sound generation, six individual 0.4 second sound samples (16bit, 44.1KHz) representing the obstacles in the six associated sensor directions are pre-convolved with the corresponding FIR pairs to generate binaural cues.

These six stereophonic sound samples are stored in different memory locations of the 3DSRE CPU. The six range measurements acquired from the SCCU attenuate the corresponding stereo sound samples to adjust the distance of the spatialized sounds in the virtual sound environment. The process of real time spatial sound environment generation is shown in Figure 8. The acquired range readings are truncated at 10 feet or 120 inches, before processing the HRTF rendering.

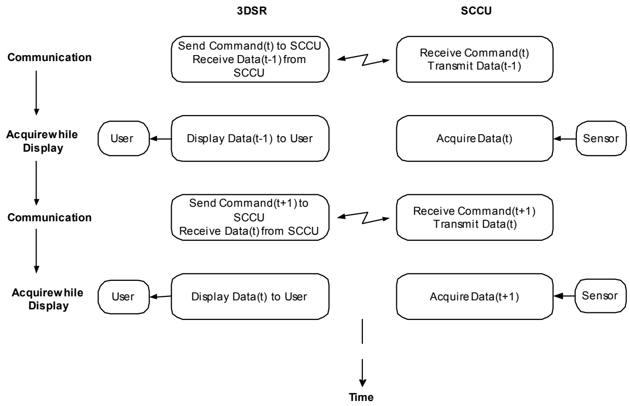

Figure 9. Diagram showing inter-process communications and operation synchronizing.

4 Inter-process Communications

The navigational system is composed of 2 autonomous computing platforms. Inter-process communication plays a key role in synchronizing the operations of these two units, so that information can be delivered to the user with minimum latency.

After power-up, the SCCU initializes all its peripherals and waits for a command from the host system. The 3DSRE, which acts as the host system, initializes communication with the SCCU by sending a 2-byte command packet. Upon receiving the command packet, the SCCU transmits the most recently acquired data packet to the 3DSRE. At this point both platforms perform autonomously – the SCCU interprets the command and acquires data from the sensors accordingly. Then it generates a 9 byte data packet and waits for the next command packet from the 3DSRE. Depending on the command type, the data acquisition process takes 0.4 to 0.75 seconds. While the SCCU is gathering and compiling the data, the 3DSRE generates the 3D sound map based on the data packet it just received from the SCCU. At this point the "Bearing Request" button status is polled. Depending on the status of this button the 3DSRE displays acquired information either in the *Obstacle Map mode* or the *North Beacon mode*. The Data display process for the 3DSRE takes approximately of 0.8 seconds. After completing this "acquire while display" phase, the system switches back into the communication phase. This cycle is repeated continuously as explained in Figure 9. The protocol designed for inter-process communication also includes functions to detect and eliminate errors and maintain a proper sequence of transactions.

5 Sonar Triggering Modes

Three types of sonar triggering modes were implemented and evaluated in the system: 1)flood; 2)sweep and 3) interlaced. The sensor control sequences for all three modes are stored in the SCCU memory. The command packet transmitted by the 3DSRE contains one byte that indicates the desired sonar triggering mode. Upon receiving the command packet the SCCU interprets this mode byte and runs the corresponding sequence to acquire the information. The flood mode triggers all six sonar channel at the same time. This mode requires the shortest time to gather omni directional range information.

The sweep mode triggers and records distances one channel at a time, starting from -120º to the +120º direction. This mode takes the maximum amount of time. In the interlaced mode illustrated in Figure 10, sensors in alternating positions are triggered in two groups.

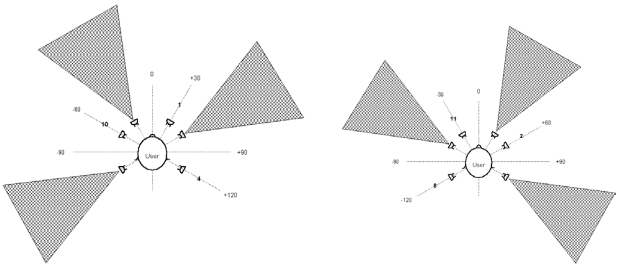

Figure 10. Illustration of the two interlacing sonic fields in the interlace mode.

5 Evaluation

A portable prototype of the system has been assembled for evaluation (Figure 11). A 9.6 V Ni-MH, 1600 mAh rechargeable battery (Radio Shack 23-3318) is used to power the SCCU.

The three triggering modes were compared in terms of accuracy and timing. The flood appeared to have generated range readings with minimum latency. However, The flood mode showed a ±30% measurement error, attributed by co-channel interference. Compared to the flood mode, the sweep mode requires 89% more time to generate an omni directional range reading, while the interlace mode requires 20% more time. The measurement error in the interlace mode was approximately ±17%, which is comparable to that of the sweep mode. The interlace mode was found to be an effective method to compensate for the wide sensor aperture and minimize co-channel interference, while providing fast data updates.

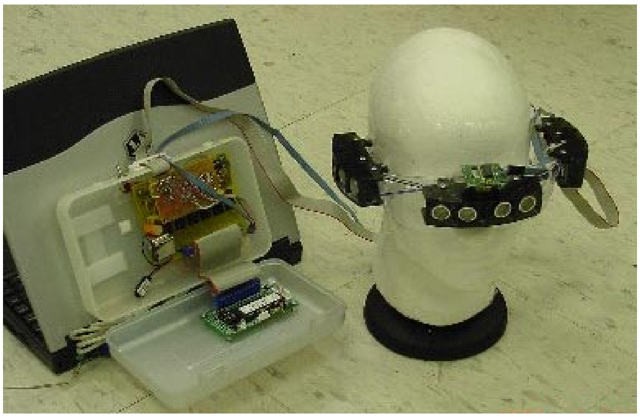

Figure 11. Photograph of the fully constructed prototype

Four fully-sighted individuals employed the system to navigate the hallways of the third floor of the FIU Engineering Center (FIU-EC), while blindfolded. These subjects were placed at the South end of the FIU-EC 3rd floor, and asked to progress to the North as far as they could go in an interval of 10 minutes. During the timed trials, subjects were followed by one of the authors, who videotaped their navigation, maintaining a distance of no less than 10 feet from them. The videotape was later played back to approximate the trajectory of the subject through linear segments in an Autocad® blueprint of the FIU-EC third floor. This enabled the assessment of the total trajectory traveled by each subject (along a real path) and the total effective displacement to the North achieved (as if measured over a hypothetical straight South-to-North trajectory). Table I shows both measurements for each subject and the corresponding average values. The navigational efficiency ratio (Table 2) compares the actual path traveled to an equivalent ideal path. In an average the subjects achieved an efficiency ratio of 0.93.

Table 1. Experimental Results showing effective North displacement verses Traveled distance

Subject No.	Trajectory Traveled	Effective Disp.North
1	212	203
2	362	308
3	417	336
4	386	367
Average	*344.3*	*303.5*

In an average, subjects were able to navigate, avoiding obstacles and finding the points where turns were required, at an approximate rate of (344.3 ft / 600 sec) = 0.57 ft/second. The actual paths observed deviate from the ideal path because of meandering due to hesitation and, in some cases, making a wrong turn and then having to correct the course.

Table 2. Navigation Efficiency

Subject No.	Actual Path	Ideal Path	Efficiency Ratio
1	212	209	0.986
2	362	325	0.898
3	417	353	0.847
4	386	383	0.992
Average	*344.3*	*317.5*	*0.931*

6 Conclusions

This paper reported the design, implementation and preliminary evaluation of a system that uses multiple computing platforms interacting in real time to aid a blind user in the navigation of indoor environments. The Digital Signal Processing scheme employed in 3D sound generation has been designed so that the computational demand is minimized during run time. The system speed, accuracy and ease of use was found to be acceptable for smooth and unhindered blind travel in indoor environments. The data presentation method, as a virtual acoustic environment, is natural and intuitive, requiring minimum attention from the user.

7 Acknowledgements

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