A Pocket-PC Based Navigational Aid for Blind Individuals

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Abstract *– This paper describes a Pocket-PC based Electronic Travel Aid (ETA) that helps a blind individual navigate through indoor environments. The system detects surrounding obstacles using ultrasonic range sensors and the travel direction using an electronic compass. The acquired information is processed by a Pocket-PC to generate a virtual acoustic environment where nearby obstacles are recognizable to the user. This virtual environment is played back through stereo headphones, so that the user can perceive surrounding obstacles and the direction of the Earth's magnetic North, using spatialized 3D sounds. The paper describes the instrumental and computational aspects of the design and presents the results, demonstrating the improvement in blind travel achieved with the system.*

Keywords *– Pocket-PC, Electronic Travel Aid, Spatialized Sound, HRTF, Navigation Aid, Ultrasonic range sensor, Embedded microcontroller.*

I. INTRODUCTION

Developing an Electronic Travel Aid (ETA) for blind individuals presents two major challenges - information must be presented in a non-visual form and the navigational information must be updated in real time to ensure user confidence. In addition to this, the device needs to be lightweight, portable and must have low power consumption. Many electronic interfaces for blind assistance utilize an acoustic presentation method. However, in such systems, an additional challenge is to develop an acoustic information presentation method that does not interfere with the user's normal hearing activities. The flow of information needs to be such that the requirement for user attention is minimum. The target of this project is to present a blind traveler with real-time obstacle and heading information using a 3D spatialized virtual sound environment [6] that is natural and comfortable for the user.

Currently, most instrumentation applications utilize Digital Signal Processing to some extent. A variety of real-time digital signal processors are available for these purposes. However, in many cases such design solutions do not provide a low cost, versatile end-product. The Personal Computer (PC) has also been popularly employed as a signal processing and integrating instrument, utilizing its standard multimedia capability, but the bulk size, weight and power requirements of most Personal Computers have discouraged portable applications. However, in recent years, handheld, general purpose computing devices have become increasingly affordable to the consumer. Many of these computing devices offer adequate speed, performance and resources for real-time instrumentation and human-computer interface applications. This project explores the possibility of utilizing such a device for sensor data processing and a human-computer interface application, specifically designed for blind navigation.

II. SYSTEM DESCRIPTION

The system performs two major functions in real time – information gathering and information display. To reduce the latency in the cyclic process, these two functions are performed in parallel, by two independent platforms: i) The Sensor Control Unit (SCU), and ii) the pocket-PC based 3D Sound Rendering Engine (3DSRE). Figure 1 shows an outline of the system components.

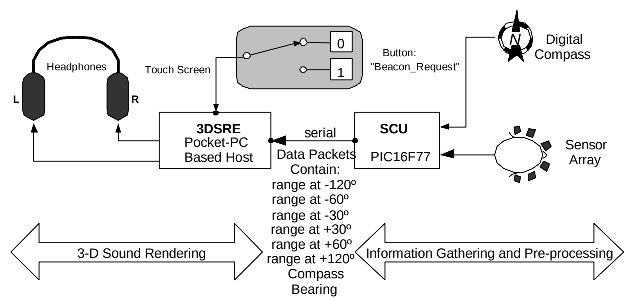

Fig. 1. Layout of the different functional blocks of the navigational system.

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) support available to the developer.

III. SENSORS

It was determined that an accurate range reading of up to 10 feet would be adequate for a blind person to navigate efficiently in an indoor environment. The Devantech SRF04 Ultrasonic range sensor [1] was selected for the indoor obstacle detection system because of its small size, lightweight and low power requirements. The SRF04 was found to have a low power ultrasonic transmitter with a high sensitivity receiver. This minimizes multiple reflections that may cause crosstalk between sensors in an indoor environment. As illustrated in Figure 2, six ultrasonic range sensors are arranged in an array to measure obstructions from +120º (right) to -120º (left). The array is mounted on a headgear, which is worn by the user.

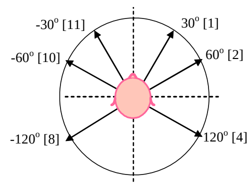

Figure 1. The physical layout of the six ultrasonic transducers (top view). Note that the sonar directions have been marked as clock positions for reference.

The ultrasonic sensor beam-spread specification [1] (Figure 3) shows the possibility of a beam overlap between adjacent sensors in this particular geometry. To eliminate co-channel interference, two types of triggering sequence modes were tested [2]. 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 4, two groups of non-adjacent sensors are triggered in an alternating fashion.

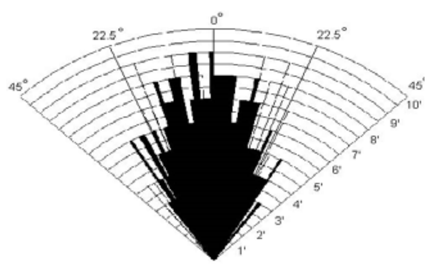

Figure 2. The Devantech SRF04 beam pattern [1].

The interlaced mode was found to require 40% less time than the sweep mode to acquire a complete panoramic range reading.

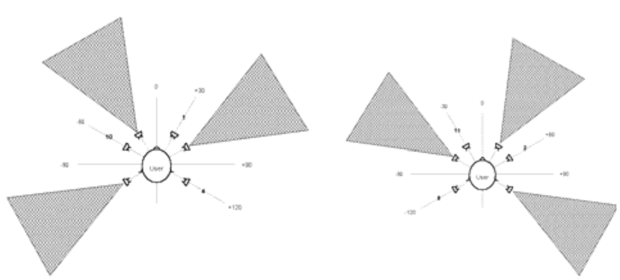

Figure 3. Illustration of the two interlacing sonic fields in the interlace mode.

The headgear worn by the user also incorporates a Devantech CMPS01 Magnetic Compass module [5]. This module is based on two Philips KMZ51 magnetic field sensors, which are sensitive enough to detect the Earth's magnetic field. The sensors are mounted at right angles, with respect to each other. The orthogonal components of the Earth's magnetic field are recorded with respect to the sensor reference direction. This direction is continuously updated and made available to the SCU as a 1-byte, 255-step compass reading, which can represent up to 360º of deviation between the compass reference direction and the North direction (1 full revolution). This 1-byte value is included as the last data item in each packet sent from the SCU to the host computer.

IV. SENSOR CONTROL UNIT

The Sensor Control Unit (SCU) is designed around an OOPIC-II [3], which is a single board microcomputer based on a Microchip PIC16C77 microcontroller [4], featuring 24 bit digital I/O, serial and I^{2}C interfaces [10]. The functions of this unit includes: sensor interface, data pre-processing, communications with the host system, command interpretation and command execution.

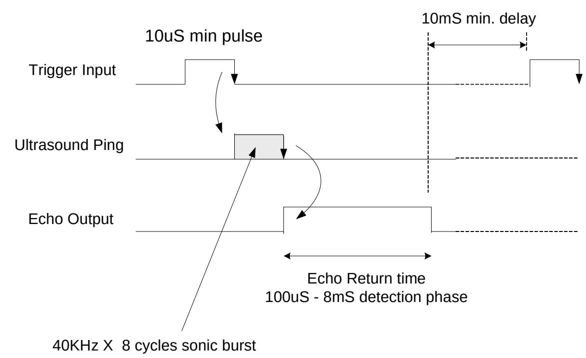

Figure 4. The Devantech SRF04 control protocol [1].

The SRF04 module contains a Trigger input and an Echo output. 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 pulse, 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.

The range sensor interface circuitry (Figure 5) features highly flexible configurability, which allows triggering and range recording of any desired combination of the six ultrasonic range sensors. Six independent 8-bit up-counters have been assigned so that each ultrasonic range sensor records the echo detection time with reference to a time-base. All counters are reset when the master ping (PING) signal is activated. The master ping signal is gated through a set of AND gates which are controlled by the six ping mask signals M(*n*) for each channel. The bit pattern on these signals determines which sensors are activated when the PING signal is triggered. Upon receiving a trigger, the 'Echo' output of each sensor enables the count operation on its associated counter. Count operation is suspended immediately after the ultrasonic echo is detected by the related sensor and the Echo output is deactivated. The S(*n*) selection lines are used to sequentially transfer the counter values into the microcontroller through an 8-bit data bus. The count values are held in each counter until reset during the next ping cycle. Counter roll-over prevention has been implemented by a set of NAND gates that disable the count-enable signal of each counter when the count value reaches 255.

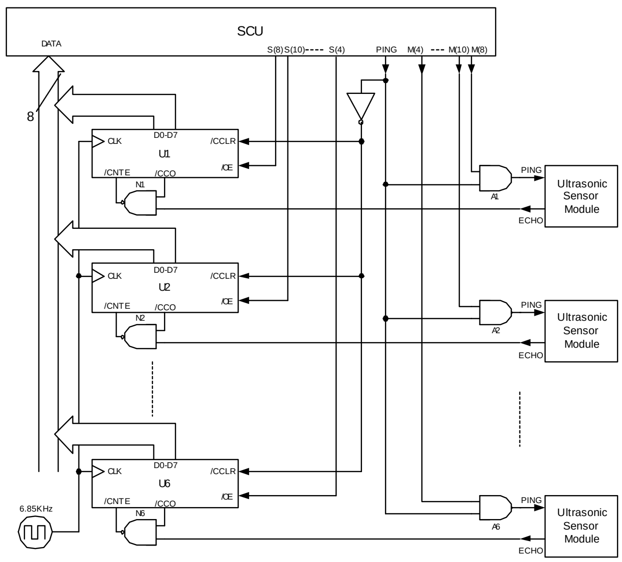

Figure 5. Schematic diagram of the SRF04 interface to the OOPIC board.

The interface circuitry converts the echo detection time into inches in real time, without any computational efforts by the microcontroller. This is possible by calibrating the period of the time-base to be exactly equal to the echo detection time for a distance of one inch. Therefore, the count values registered by each counter represents the detected range readings in inches. The clock frequency was calculated to be 6.85KHz. The maximum recordable range is 255 inches or 21.25 feet.

The SCU interfaces with the Devantech CMPS01 compass module using the I^2C interface and collects compass readings during every ping cycle at a bus speed of 1MHz. The angular resolution of the compass module is 3º. The compass measurements are read as an 8 bit binary number.

The SCU is designed to communicate with a host computer through an RS232 interface at a speed of 9600 bps. The host computer acts as a master and sends commands to the SCU to execute some predefined sequence of operations. The SCU can store multiple sets of these sequences, which are selectable by decoding the commands sent by the host.

V. REAL-TIME 3-D SOUND SPATIALIZATION

The 3-D sound spatialization scheme is based on Head Related Transfer Functions (HRTF) [9]. Head-Related Transfer Functions (HRTFs) 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 or outer ears [7]. The HRTFs capture the nature of these modifications. The left and the right HRTFs contain all the information required by the listener to localize the source of the sound. Conversely, a single-channel digital sound can be processed by these HRTFs to generate left and right audio signals that will make the listener believe that the sound emanates from the corresponding virtual source location. For an acoustic point source placed in a certain position, the HRTF models the binaural spectral modifications in phase and amplitude, caused by the facial and ear geometry of the listener. These spectral modifications may be emulated by 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 such as the AuSIM3D® HeadZap system [8]. 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.

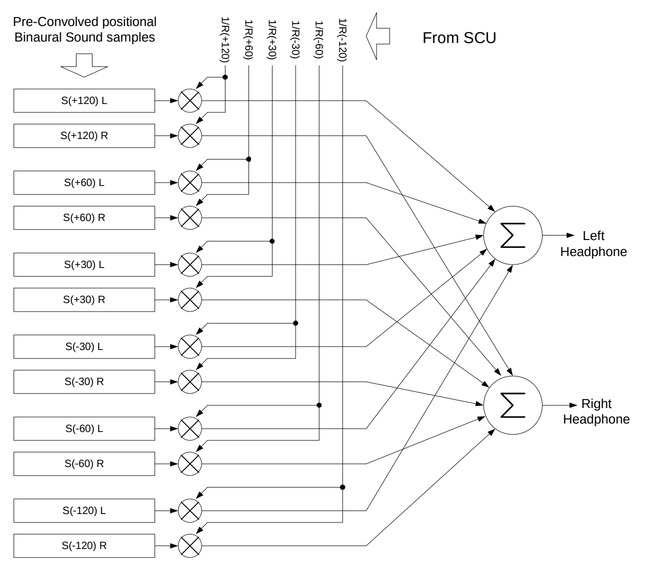

Figure 6. Schematic diagram HRTF implementation in the system.

The sound spatialization scheme is executed in real-time by the 3D Sound Rendering Engine (3DSRE), in the Pocket-PC, acting as a host system. 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, as shown in Figure 7. These six stereophonic sound samples are stored in different memory locations in the 3DSRE. The six range measurements acquired from the SCU are used to scale the corresponding stereo sound samples to adjust the simulated radial distance of the spatialized sounds in the virtual sound environment. The process of real time spatial sound environment generation is shown in Figure 7. The acquired range readings are truncated at 10 feet or 120 inches, before processing the HRTF rendering.

VI. HOST SYSTEM

In the tested prototype, the host system is implemented on a Cassiopeia E-125 Pocket-PC. This unit, based on a 150MHz MIPS processor, features an RS232 interface and a 16-bit, 44.1KHz stereo codec. These functionality was programmed for the Pocket-PC using Microsoft Embedded Visual tool [12]. This unit also functions as the 3DSRE, which performs the task of presenting the data to the user. A GUI provides a ‘beacon request’ button on the touch screen that allows the user to switch between ‘Obstacle Map Mode’ (OMM) or ‘North Beacon Mode’ (NBM).

Normally the 3DSRE functions in OMM. 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 to correspond to physical distances in the real world (Figure 8).

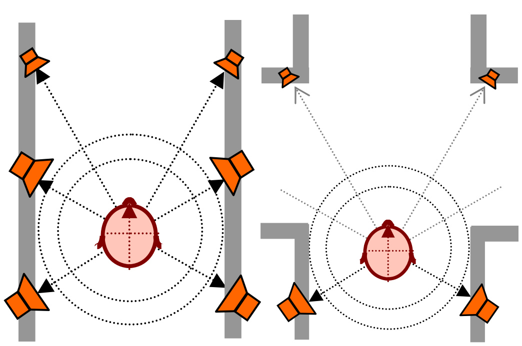

Figure 7. Obstacle Map Mode. The speaker sizes indicate the magnitude of the phantom sound sources. The sound sources are placed at the position where the obstacles are detected.

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 9.

To ensure swift real-time performance, the tasks of data acquisition and data presentation are distributed between two independent platforms – the SCU and the host computer. 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. The parallel architecture ensures the utilization of CPU resources on both units at any instance by altering between the ‘communication phase’ and the ‘Acquire-while-display’ phase, as shown in Figure 10.

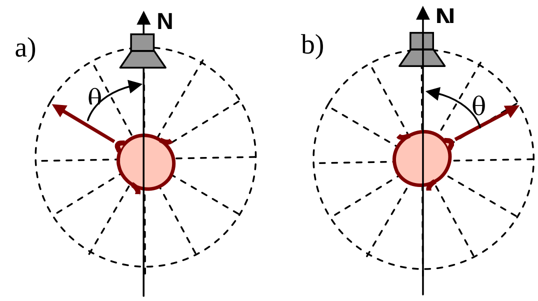

Figure 8. Sound sources placed in virtual environment in the North Beacon mode operation.

VII. REAL-TIME OPERATION

During the communication phase, The host system transmits a 2-byte command packet to the SCU. This packet contains a 1 byte ‘Query ID’ and a 1 byte ‘Command code’ indicating the requested ping mode. A data packet compiled by the SCU is transmitted to the host immediately after receiving the command packet.

The system subsequently switches to the ‘Acquire-while-display’ phase. While the SCU is gathering and compiling the data, the 3DSRE generates the 3D sound map based on the data packet it just received from the SCU. At this point the “Beacon Request” button status is polled. Depending on the status of this button the 3DSRE displays acquired information either in the OMM or NBM. The Data display process for the 3DSRE takes approximately 0.8 seconds.

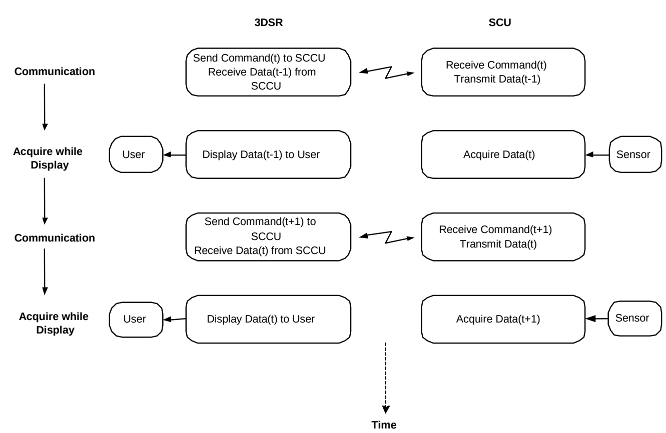

Figure 9. Inter-process communications and synchronization scheme.

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.

VIII. 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 SCU.

Figure 10. Photograph of the fully constructed prototypes: The Pocket PC based system (top) and its precursor, a laptop PC based system (bottom). The photographs show the host computer, SCU and the sensor array.

Different triggering modes were compared in terms of accuracy and timing. Initially the system was tested with a 'flood mode', in which, all range sensors were triggered at the same time. The flood mode appeared to have generated range readings with minimum latency. However, the flood mode showed a ±30% measurement error, attributed to co-channel interference. Compared to the flood mode, the sweep mode requires 89% more time to generate an omni directional range reading, while the interlaced mode requires 20% more time. The measurement error in the interlaced mode was approximately ±17%, which is comparable to that of the sweep mode. The interlaced 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.

Human subject tests were conducted with a precursor to the Pocket-PC based host system [11]. This system was built on a laptop Personal Computer (PC). 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 I. Experimental results showing effective North displacement versus 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 II. Evaluation of 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*

IX. CONCLUSIONS

This paper reported the implementation of a blind navigation system that employs a Pocket-PC device as an instrumentation, signal integration and auditory display component of the system. The system architecture ensures satisfactory real-time performance, which contributed to the improvements achieved towards smooth and unhindered blind travel in indoor environments. The sound spatialization scheme was tailored to match the computation and signal processing capabilities of a handheld computer. This project also proposed a suitable scheduling approach in the triggering of the multiple sonar range sensors used. This was useful to overcome the inaccuracies first observed in the range measurements due to limitations in the sensor specifications (broad beam pattern). Further, the proposed interface to the sonar elements was designed with the goal of allowing full versatility in commanding arbitrary ping sequences and in providing the capability of individual range measurement results from any of the sonar sensors, at any time. Flexibility was also achieved in terms of enabling the future addition of more sensors, of similar or different types.

ACKNOWLEDGMENT

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