

## **Portable 3D Sound / Sonar Navigation System for Blind Individuals**

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### **Abstract**

This paper describes the development of a system that uses a portable Pocket PC to generate 3D spatialized sounds, based on the readings from a multidirectional sonar system that detects obstacles around a blind person. The distances from the user position to the closest objects in six directions are continuously determined using six sonar range meters. The information is used by the Pocket PC to create a 3D sound environment that represents the obstacles in these directions through the simulation of six spatialized sound sources. The dynamic spatialization of the sounds is achieved through the use of previously computed Head Related Transfer Functions, taking into consideration the distance to the obstacles, and the direction the person is heading. The paper explains the process followed by the Pocket PC to acquire the signals from the sonar system, and the real-time creation of the 3D sound environment that would help a blind person locate nearby obstacles in his or her navigation environment. This system may facilitate the navigation of blind individuals through indoor environments, since it provides the user with information that is different from that collected through the use of a cane. This system explores the presence of obstacles in all six directions around the user simultaneously, and it can provide an indication of obstacles even if they are farther away from the user than the radius covered by the reach of the cane.

### **Keywords**

Assistive Technologies, Travel Aids for the Blind; Navigation Aids, 3D Sound, Sonar.

### **1. Introduction**

Visually impaired individuals have relied on a variety of techniques to actively participate in society. With today's advancements in technology, it is possible to design devices that could allow these individuals to overcome some of the limitations they face, to facilitate the tasks they have to accomplish in their everyday life. One of the key needs for visually impaired individuals is to navigate safely through environments such as their workplace. With today's technology, relying on digital signal processing, and the use of a Pocket PC, it is possible to design such a system in a portable fashion.

To navigate safely through an environment, the individual must continuously identify the positions of obstacles around him/her, in order to develop a mental map of the surroundings, in which a safe route can be planned and followed. Therefore the first goal of an assistive system for navigation is the detection of obstacles, which must be followed by the non-visual communication of the detected layout of the

surroundings, to the user. The system developed employs a device that the user wears on the head, which measures the distance to the obstacles around, with the use of ultrasound. Then, the acquired information is processed to create 3D a sound environment around the user, using Head Related Transfer Functions, which allow for the projection of three-dimensional sounds delivered through stereo headphones.

## 2. Objectives

The objective of this project is to explore the potential of a technological alternative to the cane, which is currently the device most commonly used by blind individuals to navigate in closed environments. This overall goal, in turn, defined some of our engineering design goals, in terms of the required portability and lightweight of the system, so that the user can wear it without having to sacrifice on mobility, or having to carry cumbersome equipment. In order to accomplish this mobility, a Pocket PC was chosen as the platform for the 3D Sound Rendering Engine, which provides sufficient amount of processing power, an acceptable battery life, while simultaneously fostering user mobility, as required. A second consideration would be to develop software for the system, which must be efficient enough to run on the limited resources provided by the Pocket PC, without sacrificing much on the final result. It is pertinent to keep in mind that the system should require as little attention as possible from the user, since it could be used for prolonged periods of time. And finally, it is also important to take simplicity into account, to create a dependable solution. A picture of the resulting system is shown in Figure 1.



**Figure 1. A Picture of the System**

## 3. Scope of Work

The system is basically conformed by two modules that interact with each other. The first one is the Sonar and Compass Control Unit (SCCU), which is a hardware subsystem for the management of commands to the sensors and collection of data received from them (Choudhury and Barreto, 2003). The second module in the system is the 3D Sound Rendering Engine (3DSRE), which is mainly a program developed to run on a Pocket PC. This paper focuses mainly on this second component of the system, where the data acquired from the SCCU is processed, and the corresponding sound environment is created for the user, in near real-time. These two parts are interconnected using an RS232 serial interface, and the communication employs a proprietary protocol with the objective of having a simple and fast response (Barreto and Choudhury, 2004).

## 4. Methodologies

The following subsections provide further details about the two modules of the system.

#### **4.1. The Sonar and Compass Control Unit**

This hardware subsystem employs six Devantech SRF04 ultrasonic range sensing modules to measure the distance (range) from the user to the nearest objects in the six radial directions around the user. In addition this system pre-processes the range and user bearing data forming the data transmission packets that are transmitted serially to the 3DSRE. As explained by Choudhury (Choudhury and Barreto, 2002) this module is built around the Microchip™ PIC16F77-based microcontroller board computer called OOPIC™, which features a resident operating system with the support for an object-oriented language. (Choudhury and Barreto, 2004).

Each of these sensors emits a 10  $\mu$ S ultrasonic ping, and measures the return time, by activating an 8 bit counter, with a clock calibrated at 6.85 KHz, which would provide a final result of 1 bit per inch to the obstacle, after the clock is stopped when the corresponding ultrasound burst returns.

Since cross talk may exist between adjacent ultrasonic beams when the angle between the sensors is near or less than 30°, a method had to be implemented to avoid a misleading result. A first possibility would be to only use one sensor at the time, allowing for an “environment settling time” after activating any of the sensors and before activating the next one. This “sweep” pinging sequence, however, requires a long time to complete a full round of activation of all the sensors to yield a complete map of the surroundings. A solution that is very close in performance but requires much less time to complete a pinging sequence was found by activating the sensors in two alternating groups, such that no two adjacent sensors are active at the same time, which was designated as “interlaced” pinging.

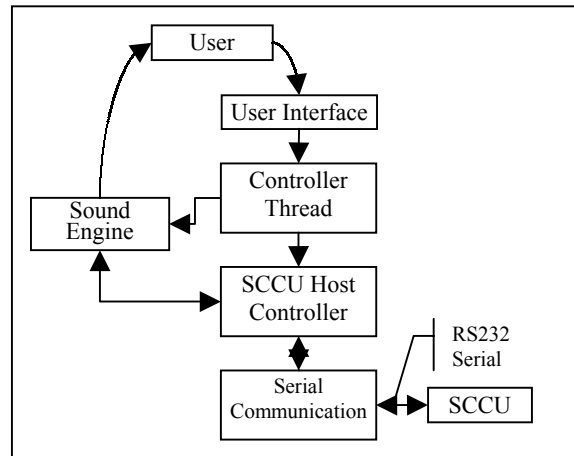
Once the SCCU has gathered all this information, and also the compass information regarding to the direction the person is looking at. A nine-byte response packet is generated. This packet includes two bytes that identify the sequence number, and the command, followed by six bytes with the distance to the obstacles, and one final byte with the bearing information. The complete packet is sent through a RS232 serial interface to the Pocket PC, where the 3DSRE execution takes place based on these nine values. It is important to note that once the current data packet is sent the SCCU will immediately re-start its acquisition cycle by commanding a new pinging sequence. Therefore, at this point in the process an “acquire-while-display” methodology is being implemented, to minimize the latency in the periodic updates of the virtual auditory scenario that will be presented to the user, in a recursive fashion.

#### **4.2. The 3D Sound Rendering Engine**

The 3D Sound Rendering Engine (3DSRE) is responsible for synthesizing six binaural sounds that appear to the user as if emerging from six phantom sound sources located at the distance to the closest obstacle in each one of the directions explored by the sonar elements controlled by the SCCU. The emulation of these six phantom sound sources aids the user in creating a mental map of the layout of his/her surroundings, so that obstacles can be avoided and open passages can be considered for path planning and navigation. Initially, these functions were implemented with a Matlab® script, for initial verification, but later needed to be ported to the Pocket PC, to fully meet the portability requirements introduced before. Therefore, an application had to be designed to run on the Pocket PC device, to complete the final stage of the system. For this stage of development, Microsoft Embedded Visual C++ 3.0 was used, since it compiles to native code that can run on the Pocket PC's MIPS processor. In fact, the application provides two operating modes. The first mode, called “Obstacle Map” mode, creates the 3-dimensional sound environment shaped by the surrounding obstacles, as detected by the ultrasonic sensors. The second mode, called “North Beacon” mode, produces a single spatialized sound that is emulated to appear as if coming from the North direction, which can be achieved due to the availability of bearing data from the digital compass, also controlled by the SCCU. The “Obstacle Map” mode is the default mode of operation, but

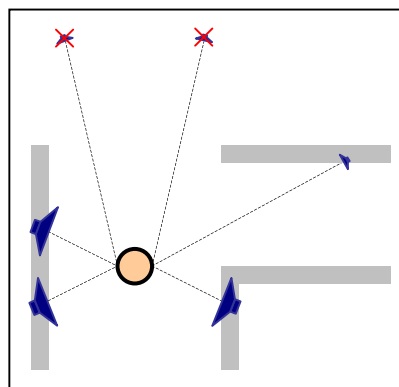
the user can make the system switch to the “North Beacon” mode, temporarily, by pressing a button on the Pocket PC.

Internally the application employs four main components: 1) the Controller Thread, which interprets the user mode selection and actively queries the other components to produce the results, 2) The SCCU Host, which interprets the communication packets and provides the application a more intuitive control over the hardware, 3) The Serial Communication class, which handles the lower level serial port communication with the operating system, and 4) The Sound Engine, which loads, and mixes the sounds for the final result. This architecture can be visualized using the diagram shown on Figure 2.



**Figure 2. 3DSRE Components Diagram**

The effective 3D sound-rendering task is accomplished by the Sound Engine, which creates a mixture of six previously computed binaural sounds. These binaural pairs of signals are obtained off-line by application of the Head Related Transfer Functions (HRTFs) associated with the directions explored by the six sonar sensors (Kendall, 1995; Cheng and Wakefield, 2001). Therefore, this set of binaural sounds gives the user the illusion of having six separate sound sources coming from those directions. The Sound Engine loads each one of those, multiplies them by a gain factor, and adds one sixth of the result to a separate output array. Since the objective is to produce a louder sound when the obstacle is closer to the subject, the gain factor for each binaural sound is determined by subtracting the corresponding ranged value (in inches) measured by the sonar associated to the corresponding direction from the maximum measurable distance, i.e., 60 inches. The final step of this stage is to send the output sound to the operating system, to be played to the user through stereo headphones, producing the illusion of a virtual six speaker environment that will aid his/her navigation, as illustrated on Figure 3 below.



**Figure 3. Environment Generated With the Spatialized Sounds**

Clearly, it is important to continuously update the acoustic environment delivered by the system to the user as the physical environment surrounding him/her changes during the navigation process. To increase the pace of those updates, avoiding silent gaps in the operation of the system, an “acquire-while-display” strategy was implemented, supported by the independent (but coordinated) operation of both modules of the system: The 3DSRE sends the command to start scanning for obstacles, while the sounds for the previous measurements are computed and played, so that the rendering of these values will be immediately followed by the rendering of the next batch of range measurements.

The North Beacon operating mode consists of a single sound, which appears to come from the north. In effect, when the system operates in this mode it only needs to select one of 12 pre-recorded binaural sounds that are associated with positions all around the listener, separated by 30° intervals. The selection of the pre-recorded direction that is currently closest to the North (given the current orientation of the user’s head) is made on the basis of the bearing value reported by the digital compass, whose reference direction points “straight-ahead” from the users point of view.

## 5. Results

The potential navigational value of the system has been tested by having four blindfolded individuals use the Matlab implementation of the system to navigate in the 3<sup>rd</sup> floor of the Engineering Center at Florida International University (Choudhury and Barreto, 2004). Each blindfolded subject was placed at the South end of the third floor and asked to use the system to proceed as far north as possible in an interval of 10 minutes. While the subject navigated through the hallways one of the experimenters followed at a distance of at least 10 feet (to avoid interfering with the range measurements obtained with the sonar sensors), and videotaped the navigation of the subject. Playback of the resulting videotapes allowed tracing and measuring the actual path followed by each subject during the experiment. The actual path was then compared with an “ideal path”, which would be followed to reach the same final spot avoiding any wrong turns, hesitation or meandering, to yield a navigation “efficiency ratio” for the particular experimental run. The results found for the four subjects tested appear in Table 1.

**Table 1. Navigation Efficiency Results**

Subject	Actual Path (ft)	Ideal Path (ft)	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

The values in Table 1 indicate that, although different subjects reached different total traveled distances, all of them navigated with similarly high levels of efficiency (between 84.7% and 99.2%), as determined by the calculated ratios. These results seem to indicate that the hesitation and meandering that would be commonly associated with blind navigation might have been reduced by the additional remote obstacle detection provided by the system. On the other hand, the average navigation speed recorded is only 34.43 ft/min. This slow navigation speed may be attributable to the lack of familiarity with the system and to the small delay that still precedes the rendering of an acoustic environment that corresponds to the physical obstacles around the user.

## 6. Conclusion

This paper reported the design and implementation of a portable system that assists blind navigation through indoor environments by sampling the user's surrounding with six ultrasonic range sensors and delivers this spatial information to the user as a synthetic acoustic environment, through stereo headphones. The requirement for near-real-time operation was fulfilled by designing the system on the bases of two independent, but coordinated, modules that simultaneously perform their designated tasks: SCCU: sensor management and data acquisition, and 3DSRE: data interpretation and 3d sound environment generation. Furthermore, the function of the 3DSRE module was, in turn, parallelized, by the use of multiple concurrent threads. The encouraging results obtained in the experimental evaluation of the proposed concept show that this method of blind navigation assistance has a clear potential to be useful to blind users.

## 7. Recommendations

In spite of the simplicity of the design, users sometimes reported a level of confusion of sounds coming from a given direction with other from different directions when both were played simultaneously. This was particularly likely to occur when the subject navigated through narrow corridors. To relieve this potential confusion the following approaches are being considered:

1. Use of different pitch sounds associated with the front, and the sides, to give the user an additional directional clue for distinguishing the sources.
2. Use of a sequential rendering approach in which the binaural sounds associated with different directions are not played simultaneously, but in one at a time (although this would result in correspondingly longer sweeps).
3. Implement two different sound decay profiles: one for narrow spaces, and the other for broad spaces, which could be automatically selected according to the average range value measured.

## Acknowledgements

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