DESIGN OF A MULTI-SENSOR SONAR SYSTEM FOR INDOOR RANGE MEASUREMENT AS A NAVIGATIONAL AID FOR THE BLIND

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ABSTRACT

This paper reports the methodology for the design of a sonar-based ranging and guidance system. The intended application of the system is to help a blind person avoid obstacles as he/she navigates his/her environment. Six sonar transceivers are arranged radially on a headgear worn by the user. The transceivers detect discrete range data at discrete-time sampling instances. A panoramic map of the environment is generated from the discrete-space sensory data. The paper emphasizes the challenges faced during the measurement of omni-directional ranging information in indoor environments. Situations have been identified where erroneous range readings are generated due to channel cross talk caused by echo bouncing off multiple surfaces. Several sonar control and measurement schemes were developed and tested to avoid these situations. The results and performance of these different control schemes are compared in this paper. A microcontroller-based system commands the sonar ping sequences, acquires the echo return times and computes the ranges. The set of range data is transmitted to a PC, which utilizes the information to build a spatialized audio map of the surrounding obstacles. The hardware and software layout for the system are described in this paper.

INTRODUCTION

In attempting to navigate through his/her environment, a blind person faces two main types of challenges: 1) Identify the exact location of obstacles, and 2) Figure out a safe route through the obstacles, in reference to his/her position. Electronic systems commonly known as Electronic Travel Aides (ETA's) assist visually impaired people in improving the performance in both of these tasks. Several devices have been developed in the past as an electronic replacement of the guide dog. The Personal Area Locator (PAL) [1] designed primarily for outdoor navigation applications, utilizes GPS (Global Positioning System) and RDS (Radio Data Services) in addition to a compass for directional orientation detection. The 'Navbelt' [2] utilizes sonar technology to evade obstacles in indoor environments. Similarly, the system described here utilizes sonar technology to estimate the distances between the subject and the closest obstacles in his/her surroundings, creating an estimated panoramic map of those surroundings.

Our system has been designed to continuously monitor and report sets of six range measurements, which are communicated to the user as spatialized sound by a 3-D sound rendering system [3], also developed in our laboratory [4]. The 3-D sound rendering engine has been implemented in Matlab and runs on a

Personal Computer (PC) platform. Therefore, the tasks required from the omni-directional range-finding system are as follows: 1) Control six sonar transceiver modules, triggering them in a prescribed sequence; 2) Record the echo return obtained in each sonar module; 3) Calculate object distance from the time delay; 4) Store all ranging information in a defined sequence; 5) Apply an error detection mechanism on the data, to ensure its validity, and form a data transmission packet; 6) Serially transmit the range data to the PC via a serial link (COM port). The major part of the development work involves the design and integration of appropriate hardware and software into a Sonar Control Unit (SCU), capable of performing the functions mentioned above. In addition, a program module was developed under Matlab that performs the following tasks: 1) Controls the COM port of the PC to communicate with the mobile SCU; 2) Identifies and handles errors; 3) Extracts the raw data from received packets; 4) Transfers the ranging information to the 3-D sound rendering engine.

During the testing process for the omni-directional ranging system in indoor environments, some measurement challenges were found that seemed to depend on the sequence used to obtain measurements from the different sonar channels. Situations have been identified where erroneous range readings are generated due to channel cross talk caused by echo bouncing off multiple surfaces. Several sonar control and measurement schemes were developed and tested to avoid these situations. The system modifications needed and the results obtained from two fundamentally different triggering strategies are presented.

METHODS

The omni-directional ranging system utilizes six Devantech SRF04 sonar modules to retrieve ranging information in six directions around the subject. These sensor modules are set in a headgear worn by the user (Figure 1). They are intended to sense obstacles in the following azimuthal directions +30^o, +60^o, +120^o, -30^o, -60^o, and –120^o, (where 0^o azimuth indicates the direction straight-ahead with respect to the user and 90^o azimuth is directly to the right of the subject), as shown in Figure 2.

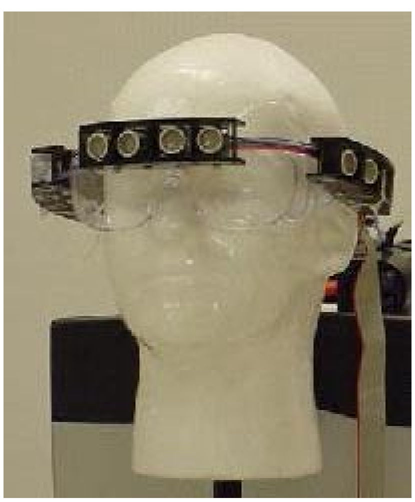

Figure 1. Headgear housing the six sonar modules

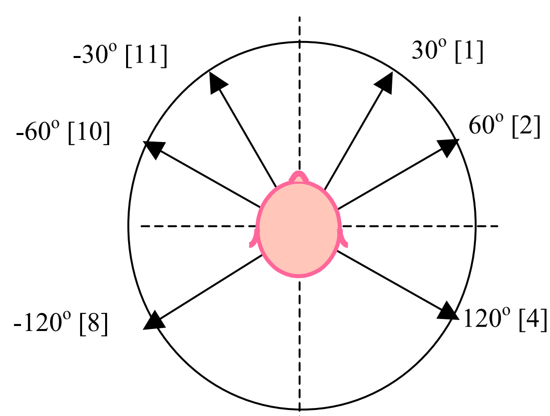

Figure 2. Main azimuthal directions explored by the system

Sonar Module Characteristics

The Devantech SRF04 sonar module transmits an ultrasonic frequency of 40 KHz, and has a guaranteed range of operation from 3 cm to 3 meters. Its sensitivity is such that it detects a 3 cm diameter stick at 2 m range. Triggering the sonar requires a TTL-level pulse of a minimum duration of 10 microseconds. After it has been triggered the SRF04 will provide a TTL-high level in its "Echo output", until the ultrasonic echo has been detected. At that time, the "Echo output" will switch to TTL-low. The complete timing sequence for this sonar module is shown in Figure 3. Figure 4 shows the nominal beam pattern for this sonar module [5].

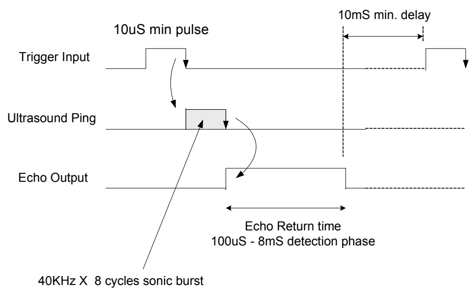

Figure 3. Timing diagram for the Devantech SRF04

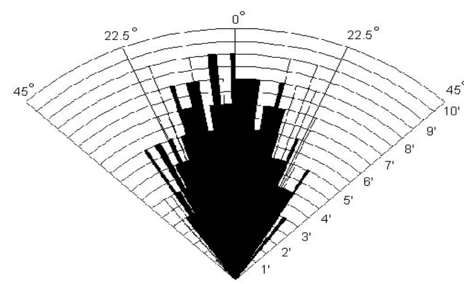

Figure 4. Beam pattern for the Devantech SRF04 sonar

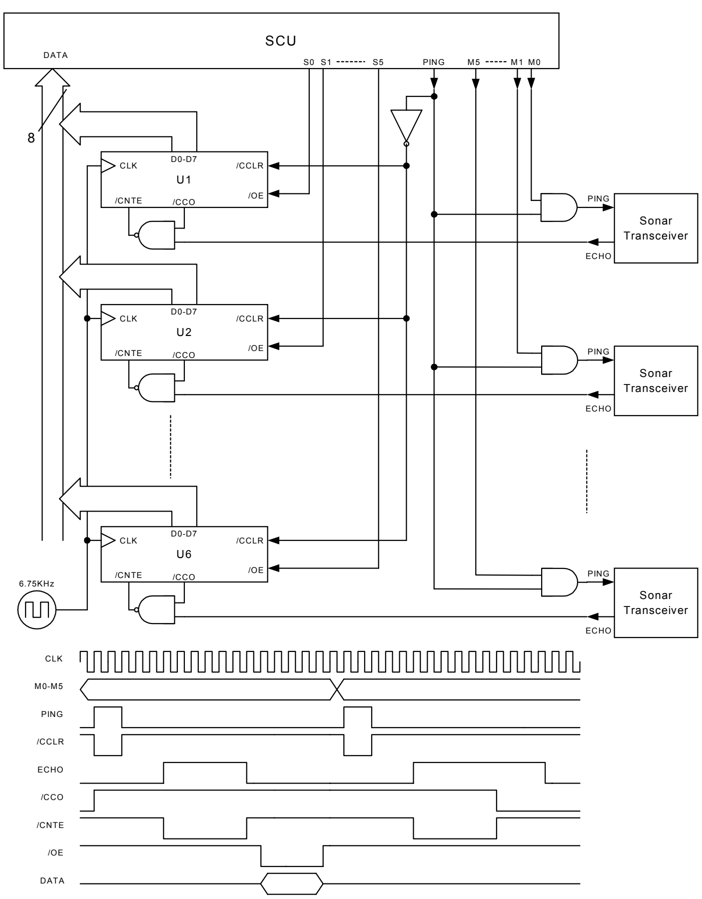

Figure 5. SCU schematic and timing diagram describing the sonar module interface technique

Sonar Module Triggering

The triggering of the sonar modules and the acquisition of the ranging information obtained from each one of them are under the control of the Sonar Control Unit (SCU). The microcontroller selected for the SCU implementation is the OOPIC (Object Oriented Programmable Integrated Circuit)[6]. This is a Microchip PIC16F77-based microcontroller [7] running a real time Operating System (OS). In addition to the SCU, the hardware for the system includes an 8-bit counter for each of the sonar moudules. Each one of these counters is enabled/disabled by the "Echo output" line form the corresponding sonar module and driven by a 6.75 KHz clock, in such a way that the maximum count reached in the counter represents the range, in inches, detected by the associated sonar module. The clock period is approximately 148 μS, which represents the echo return time for a distance of one inch. The 8 bit counters therefore can effectively measure up to a distance of 255 inches. An over-range prevention scheme employed in the logic circuit suspends the count operation of an individual counter when it reaches a count of 255. A block diagram of the system is presented in Figure 5. The architecture of the system is designed to allow complete freedom in the temporal relationships between triggers on different sonar modules. In this paper we analyze the results obtained in two particular modes: *a) "Sweep Mode",* in which the individual sonar modules are triggered in sequence, and *b) "Flood Mode",* in which all the modules are triggered simultaneously, and each module count is latched according to the earliest echo sensed by the modules. The Flood mode presents to the host PC a panaromic range reading approximately every 0.9 seconds. The Sweep mode requires approximately 1.5 seconds to generate the same amount of data.

RESULTS

Several range measurements were taken in the Flood and Sweep modes inside an office building. The static range measurements obtained by both triggering mechanisms are compared in Figure 6. This figure also shows the effective location of the obstacles around the system. In all cases it is apparent that the Sweep mode produces a more accurate range reading. However, it was also observed that using the Sweep mode while the system was in movement introduced erratic fluctuations in the readings. On the other hand, the Flood mode readings appeared to be steady, even as the sensor array was displaced, yielding a lower but acceptable range of accuracy.

DISCUSSION

The SCU design was tested in both Flood and Sweep modes to identify the performance characteristics of the two triggering methods. Notice that the Flood mode readings are in most cases shorter than the actual physical dimension. This may be caused by co-channel cross talk. All channels emit ultrasonic signals at the same time and the beam spread eventually causes cross talk at a distance where co-channel signals converge. The advantage of the Flood mode is that it generates quicker snapshots of the surroundings. The apparent drawback of this mode is its reduced accuracy. However, the results show that in the Flood mode, the sonar is active within a reasonable range suitable for our application. Furthermore, the 3-D sound rendering mechanism produces best spatialization effects with range estimates that do not exhibit abrupt changes.

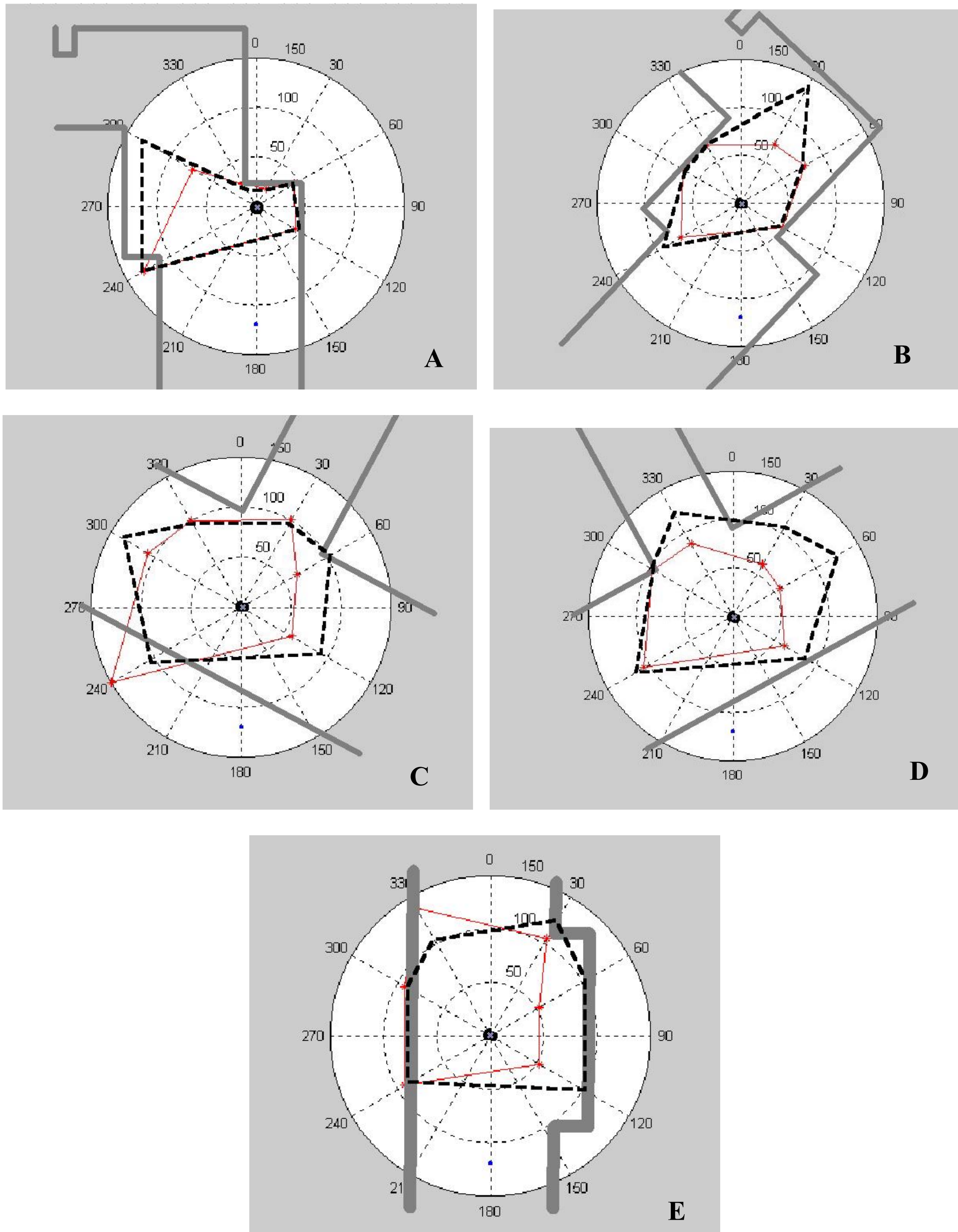

Figure 6. Omni-directional range measurement results for 5 different indoor scenarios (A – E). The thick and continuous gray lines represent wall boundaries in the test environment. The thick dotted lines represent range measurements acquired with the Sweep mode. The thin continuous lines represent range measurements acquired with the Flood mode. The three concentric circles represent 50-, 100- and 150-inch ranges.

CONCLUSIONS

Conventionally, ETAs feature an obstacle avoidance system that merely acts as a warning for blind individuals to steer away into safety. The navigation aid for which this sonar system was developed not only offers this warning, but also tries to present a spatial acoustic environment representative of the physical world around the person in an easy-to-comprehend, intuitive manner. To make this possible, it is not only required to detect the closest objects, but also objects that are relatively distant, as well as openings and pathways. This requires reproduction and measurement with considerable dynamic range and stability in measurement. We estimated that an acoustic representation of 120 inches would be adequate for a blind individual to perform normal pace maneuvers. The results of both the Sweep and the Flood modes, illustrated in Figure 6, show that the system described here satisfies those performance requirements.

ACKNOWLEDGMENTS

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