Auditory Spatial Awareness Device for the Visually Impaired

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1 Introduction

1.1 Objective

There are 36 million people who suffer from blindness around the world, and require mobility aids to help them effectively navigate their surroundings and avoid obstacles [1]. The most common tools used by victims of blindness include white canes and guide dogs [2]. However, both of these tools are problematic for the following reasons:

1) White canes are cumbersome to use in environments with many obstacles. The user may knock down precariously placed items indoors, accidentally hit pedestrians on a crowded sidewalk, etc. These canes only provide information about the environment within a tight radius.

2) Guide dogs require intensive training and a substantial amount of maintenance, so they may not be affordable to all victims of blindness.

Consequently, we aim to develop a cost effective electronic tool that can be intuitively used by blind people to navigate their surroundings. We propose a two-part device consisting of a headset and a handheld device. The handheld device will resemble the body of a flashlight and will use an ultrasonic sensor to detect objects up to 3 meters away from the user. A 3D audio signal (a short beep) will be transmitted to the user via the headset to indicate the presence of an obstacle, and will be varied based on two factors: the distance of the object from the sensor and the angle (horizontal and vertical) of the device relative to the user's head. The distance of an object from the sensor will determine the speed of the signal; shorter distances will result in more frequent beeps. The horizontal and vertical angles of the device will be used to determine a filter that will be applied to the audio signal, so that the source appears to match the physical position of the obstacle.

Since blind people rely heavily upon hearing to create a mental image of their environment, we hope that a 3D audio feedback will enable users to navigate their surroundings in a more natural manner [3]. Moreover, the usage of this device will be similar to that of a white cane so it will be relatively easy for users to learn how to use the device. Its operation is analogous to navigating a dark room with a flashlight.

1.2 Background

In general there are more products utilizing advanced technologies to aid the hearing impaired then there are for the visually impaired. Blind people have a harder time navigating their surroundings than the deaf and there are very few products that offer a solution beyond walking sticks and guide dogs. The proposed solution is inspired by the flashlight and the ability it provides for the user to navigate a dark room by only illuminating a section of the room at a time. The images of the previously illuminated sections are burned into the memory of the user. For the blind, their whole world is one dark room, and we believe that the concept of a flashlight can be ported over to the auditory domain.

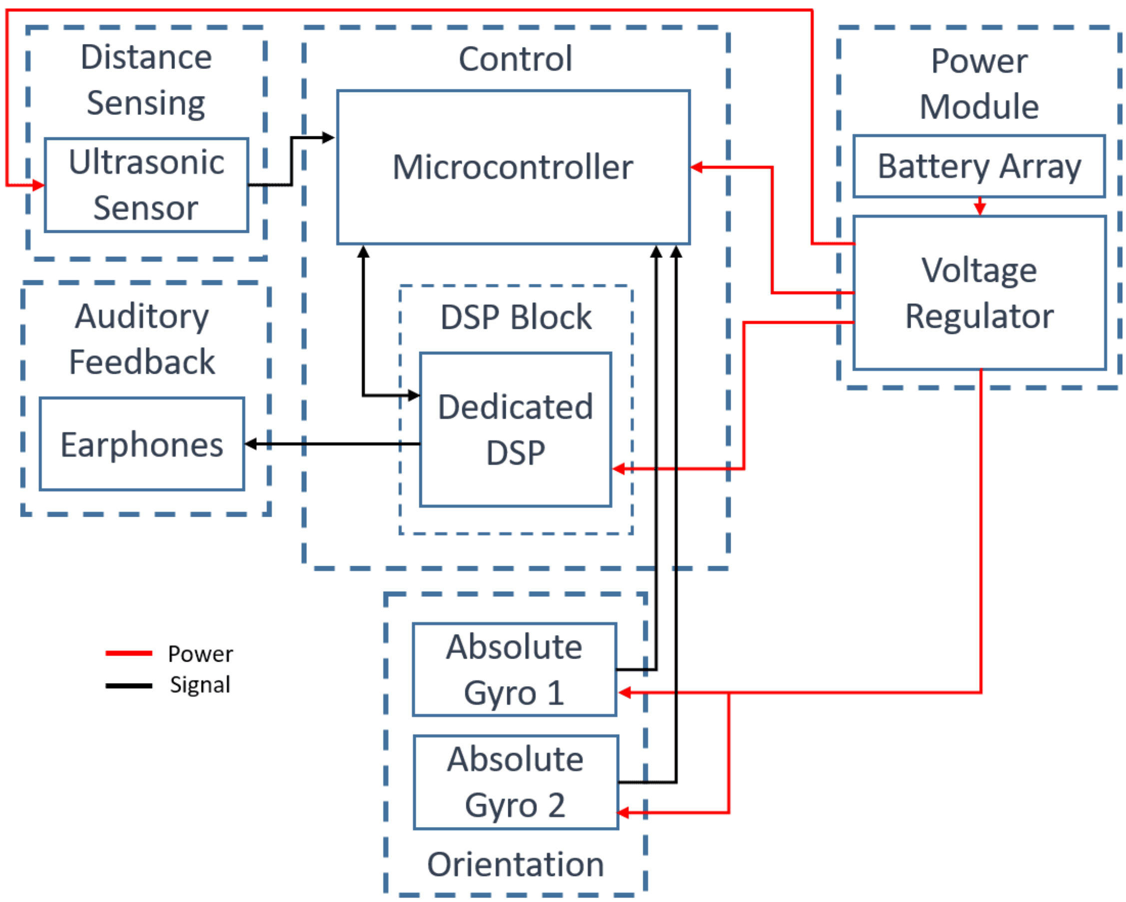
A solution proposed and completed in the Spring 2017 semester took a different approach to solve the problem of environment navigation for the visually impaired. That solution involved a series of ultrasonic sensors placed around a belt that the user would wear. The belt would provide haptic (vibrational) feedback based on the distances read by each sensor. We believe this solution is not intuitive to use and is not comprehensive enough for the user to navigate their environment. In addition, it uses multiple ultrasonic sensors and vibration generators and therefore is not cost effective. Our proposed solution uses just one ultrasonic sensor, a pair of earphones, and two gyroscopes. The user has full control over where they're pointing the device, and the operation should be as natural as using a walking stick. We also believe that using 3D audio feedback will help create a mental image in the user's head with unquantifiable value.

1.3 High-Level Requirements

- The handheld component of the device should be lightweight and portable.
- The sensor should never fail to detect the presence of an object.
- The source of the audio feedback should appear to align with the physical location of the object.

2 Design

2.1 High Level Design



2.2 Control Unit

A microcontroller will be a part of the handheld device. It will process the ultrasonic sensors data as well as the gyroscope's data from the handheld device. A wire will carry the gyroscope signals from the headset to the microcontroller, where it will compute the 3D sound data. This will be sent through a wire to the headset.

Requirement 1: Must be powered by a minimum of 5 V.
Requirement 2: Must input signals from both gyroscopes and the ultrasonic sensor.
Requirement 3: Must have bichannel communication with DSP functions loaded into memory.
Requirement 4: Must output final stereo signal to headphones.

2.3 Power Source and Management

A rechargeable battery will be placed in the handheld component and the headset and upper gyroscope will be powered through a tethered connection. A voltage regulator may be required to sustain sufficient voltage from the battery modules for input to the microcontroller, sensor, and other sub-components.

Requirement: Batteries must apply sufficient voltage for all sub-components of the device.

2.4 Object Location Detector

2.4.1 Gyroscope

Gyroscopes are placed on both the headset and the handheld device so that a coordinate system can be created for the 3D audio relative to the direction the user is facing. The difference in angular (including azimuthal) orientation between the handheld device and headset will give the origin of the sound source for the 3D audio generator.

Requirement 1: Gyroscopes must send reliable and accurate signals to the microcontroller.
Requirement 2: They need to be properly fixed onto the devices.

2.4.2 Ultrasonic Sensor

An ultrasonic sensor is a cheap way to provide distance data to the microcontroller. It has a beam spread angle that provides some leniency for the user when they're scanning such that they don't need to sweep everywhere in front of them to get the general layout of their environment.

Requirement: Must be able to quickly and accurately measure the distance of objects in front of it.

2.5 Audio Feedback System

2.5.1 Stereo Sound for Headphones

This component serves as the "eyes" of the user by providing 3D audio feedback which allows the user to generate a mental picture of their environment with sounds and relative locations. Real-time audio feedback is a comprehensive way to navigate the world as a blind person.

Requirement: Headphones must accept right and left audio signals from the microcontroller after DSP calculation.

2.5.2 DSP Software

As stated in Section 1.1, the audio feedback system will be a series of pulses that will be dependent on the distance of an object from the sensor and the device's angle relative to the user's head.

The distance will affect the rate of the pulses - the pulse rate will increase as the distance between the object and sensor decreases. This will be accomplished by generating a simple square wave, with a frequency that is dependent on the distance, and multiplying it with the signal that we want to transmit to the user.

The source of the audio signal should appear aligned with the physical location of the object. Consequently, we will use the angle of the sensor relative to the user's head to generate a pair of head-related transfer functions (HRTF) to apply to a pure tone and generate a binaural audio signal. HRTF's are filters that characterize how sound waves from a point in space are received by human ears, which allows humans to localize a virtual sound source. Large collections of HRTF's have been compiled by various research groups and are available online and are free to use [4]. We plan to store these HRTF's in the microcontroller's memory and fetch the appropriate functions based on the measured angles. By applying two HRTF's (one for each ear) on a pure tone, the tone will appear as though it is originating from a point that corresponds to the detected object's position.

A block diagram of the process we plan to use to generate the audio feedback is shown below in Figure 2.

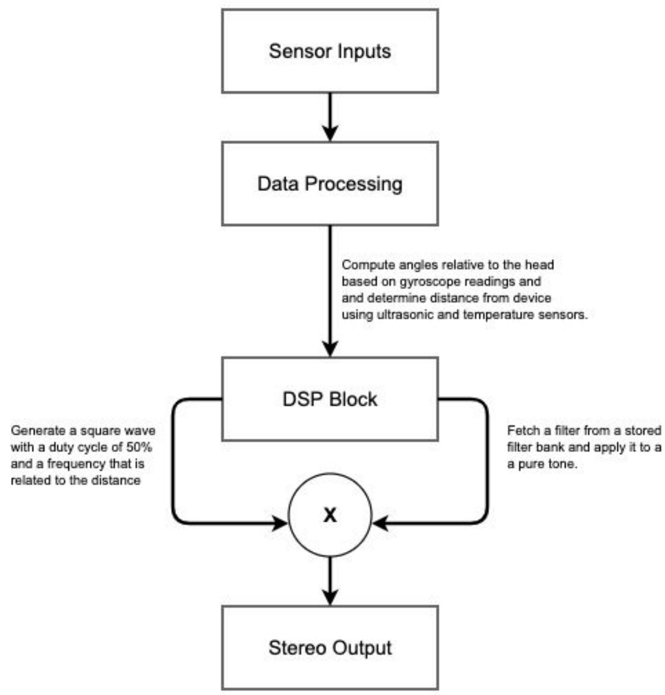


Fig. 2 High Level DSP Pipeline

Requirement 1: DSP module is stored on the microcontroller's memory.

Requirement 2: DSP module inputs gyroscope data and sensor distance data from microcontroller and outputs stereo signal.

2.6 Risk Analysis

Risk involved in the proposed product is generally derived from user safety. If the device doesn't correctly identify an object in close proximity to the user, that object has serious potential to harm the user. One method of risk mitigation is through the use of an ultrasonic sensor as the main sensor. This type of sensor has a large beam angle compared to other types of proximity sensors (infrared, LIDAR, etc.) and therefore gives a buffer for the user to identify all objects incident upon that beam. The tighter the beam angle, the more the user has to sweep the device to get a reading and consequently the more likely they are to miss a fine detail that may pose danger to the user.

3 Ethics and Safety

Since the device we propose is intended to be used as a primary source of navigation, malfunctions in the device could seriously harm the user. As such, thorough testing of the object sensors and the audio feedback system is necessary in order to ensure that the device never fails to detect the presence of an object and provides accurate feedback to the user. It is paramount for us to be forthcoming about any potential bugs or limitations in the device to make sure that our product will not result in any injuries, in accordance with Rules #3 and #9 in the IEEE Code of Ethics [5].

4 References

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