Eyeris: Ultrasonic/Haptic Device for the Visually-Impaired

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1 Introduction

1.1 Objective

With 40 million legally blind people in the world and the most popular blind mobility aids having never improved past white canes and guide dogs [1], it seems natural that we should improve the mobility aids with the technology we have today. The most common solution today is the white cane, which only provides extremely localized feedback at the tip of the cane for the low price range of $20 to $50 (from single length to adjustable length) [2]. It moreover requires the user to physically manipulate the device with one hand, which prevents them from using that hand for other purposes (i.e. using the cellphone, carrying groceries bags in more than one hand, using more than one crutch/walking cane, etc). Finally, it requires a certain of dexterity to use well and effectively, which is a deterrent to being mobile for many people [3].

We envision an affordable solution that will address these weaknesses by being a hands-free wearable that provides a more complete understanding of the user's immediate surroundings. Unlike the white cane, this device would provide continuous sensing of obstructions in multiple directions (at a fixed elevation angle projecting from the torso), while leaving the user's hands free. While having multiple elevation angles covered would be a more complete solution and have the ability to supplement the white cane, it adds much more complexity; we will focus on satisfying the current conditions and leave that for future work. This project is thus supplementary to the white cane.

Our proposed solution is a 360-degree ultrasonic sensor system with haptic feedback: it will continuously calculate the distances of the surrounding objects through sonar technology, and relay information to the user through haptic feedback located on a belt (to model the 360-degree environment for directional feedback). The information will be encoded as higher intensity modulated vibrations for closer objects, and lower intensity modulated vibrations for farther objects. In addition, our solution will aim to help the user navigate more easily to their destination, and so the haptic belt will also provide information about cardinal direction: the haptic belt will produce continuous vibrations in the north direction when the user switch on the cardinal mode.

1.2 Background

The World Health Organization estimates that 285 million people worldwide are visually impaired, 40 million of whom are totally blind. About 90% of visually-impaired people live in low-income settings, meaning that a distributive solution must be low-cost and reliable [4]. Additionally, most blind people require a way to be mobile and independent to some degree.

The two major mobility aids for the visually-impaired currently are white canes and guide dogs. White canes has a restricted range as well as inability to detect over-the-knee obstacles that could cause collisions and injuries. Moreover, they require certain levels of dexterity to use well, which is an deterrent for many blind people to be mobile [3]. Guide dogs primarily fulfill three specific assistance functions: grasping (picking up objects), physical support, and pulling (wheelchairs). There is no additional understanding of one's environment through the use of guide dogs, and in fact most users supplement guide dogs with the white cane as well [5]. On the technology side, there also exists use of miniguides, which are sonar or laser-based pointers that give either haptic or audio feedback; however, their limitation lies in being just as localized as the white cane [6]. There is, then, a market niche for providing a more useful, informative feedback device to the visually-impaired user about the state of their environment.

Research on current assistive technologies show that existing electronic devices have not seen widespread use. According to a 2016 publication in Neuroscience and Biobehavioral Reviews, one limit of existing "technological canes" is that they have a limited spatial range (only give feedback in one direction at a time) [7]. Likewise, they do not give feedback about global spatial information, only about immediate surroundings, which we believe our integrated cardinal direction feedback would help to address.

Additionally, we reached out to a member of one of our teammate's family who is legally blind as well as hearing-impaired, and asked for her opinion of a device that gave haptic feedback through a belt. As she is losing her hearing as well as her sight, audio feedback is useless for her; she is therefore a proponent of haptic feedback. Additionally, haptic devices have so far been a popular choice as feedback solutions for the blind through as evident through other solutions [8, 9]. We hope to reach out to more visually-impaired people over the course of this project to adjust our design to better suit their needs.

1.3 High-Level Requirements

1. The sensor system must also have an effective range of at least 2 meters and accuracy of +/- 20 centimeters[1].

2. The haptic feedback must be intuitive for the user to easily understand and act upon; additionally, the differences between the proximity and cardinal information must be distinguishable.

3. The device must be able to be powered for an 8-hour day; the power module must also be completely safe for the user.

[1] White canes typically range from 110 to 150cm [10]; moreover, average walking speed is 1.5m/s [11], and so 2 meters translates to 1.3 seconds of reaction time. That is sufficient as average human reaction time is 279 milliseconds [12].

2 Design

2.1 Block Diagram

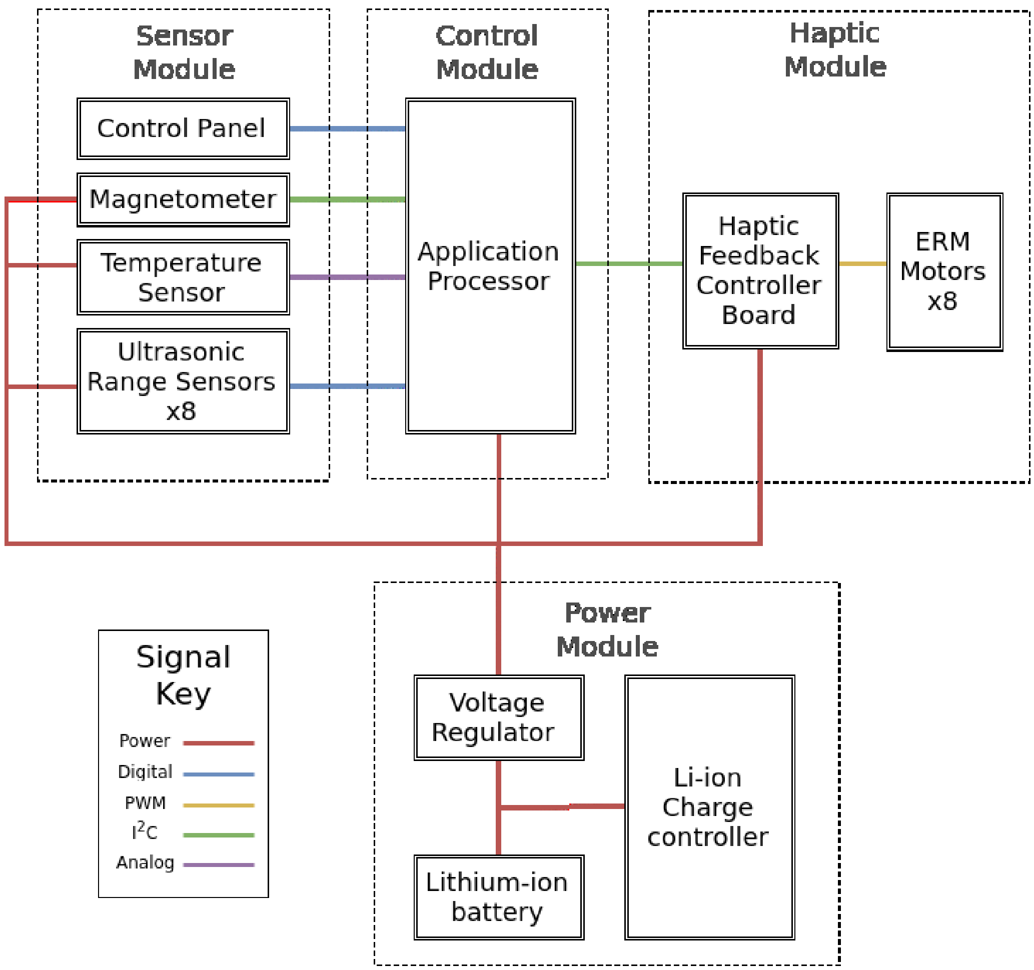

Figure 1: Block Diagram

The ultrasonic range sensors will talk to the application processor, which will process the data and send it to the haptic module. The haptic module will process this data and use it to make the ERM motors vibrate at various intensities using different patterns. The magnetometer will also transmit data to the application processor, which will perform the mathematical calculations to determine where magnetic north is. The data will be sent to the haptic controller, which will in turn tell the appropriate ERM to vibrate with a given pattern. The control panel will interact with the application processor, which will turn on/off the proximity or cardinal feedback system by not giving the appropriate commands to the haptic module. These three modules will interact together to fulfill the first two high-level requirements. The power module will provide enough juice to keep the device going for the whole day, as well as regulate voltage for the boards and check for power hazards (i.e. overheating). That will fulfill the last high-level requirement.

2.2 Physical Design

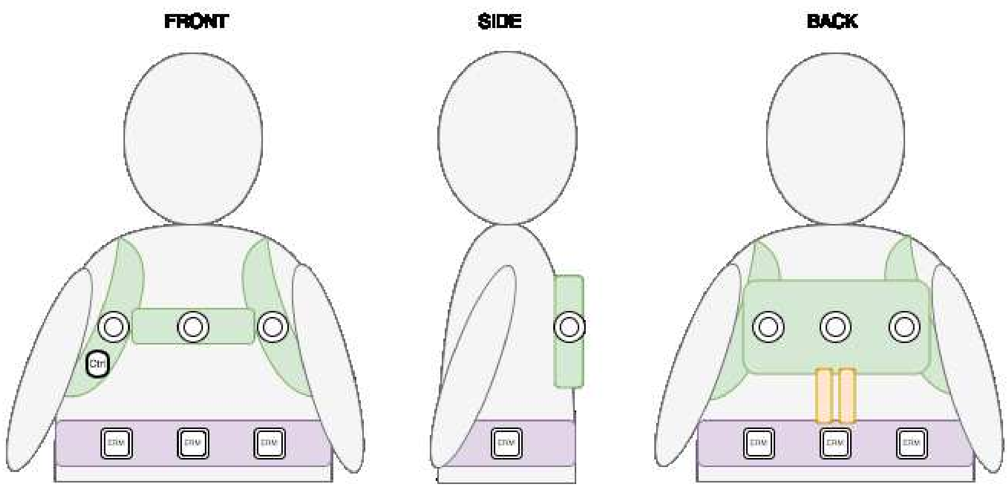

Figure 2: Physical Design

The device will be composed of a harness, which will be the mount for the sensors, and the haptic belt, which will be the mount for the ERMs. They will be joined together via military grade cabling to protect the power and I2C wires as well as provide structural rigidity. This design aims to be intuitive and hassle-free to put on: the user will first slip on the the harness through the arm holes, clip on the front-facing strap, then clip on the belt dangling from the harness. The power module will be integrated into a slim, rigid form factor on the back of the harness, and will deliver power to the rest of the modules. The main board will be integrated in the rigid pack, and connected to the rest of the peripherals through rigid cabling to prevent the wiring from being easily breakable. The ultrasonic sensors will be mounted externally on the harness on the front, sides, and back, such that arm movement will not block the sensors. The control panel for proximity/cardinal mode-activating will be positioned on the lower half of right arm strap for convenient access. The haptic belt will have the 8 ERMs affixed around the circumference and also hold the haptic controller board.

2.3 Functional Overview

2.3.1 Sensor Module

The sensor module includes all devices that provide inputs to our system. This includes 8 ultrasonic range sensors, a temperature sensor, a 3-axis magnetometer, and a control panel.

Ultrasonic Sensors Our design includes 8 ultrasonic range sensors to measure the distance to nearby obstacles. To reduce interference between sensors, the controller will sample one sensor at a time. Each sensor has a two-wire digital interface with active high 5V signaling: one wire for controlling ultrasonic transmission, and the other for detecting a response. To perform a distance measurement, the transmit pin is pulsed for $10\mu s$ to send out a short ultrasonic chirp. The sensor drives the receive pin high when an echo is detected. By measuring the delay between the chirp and echo, distance can be measured.

Requirement 1: Ultrasonic sensors must be accurate to within 20cm

Requirement 2: All 8 ultrasonic sensors must operate independently and simultaneously

Requirement 3: Ultrasonic sensors must have an effective range of 2m

Temperature Sensors Because the propagation delay from the sensor to object depends on the air temperature, we also include an analog temperature sensor. This will be read by the application processor using an integrated analog-to-digital converter.

Requirement 1: Must be able to sense from -10°C to 30°C with a 1°C accuracy.

Magnetometer Using a three-axis magnetometer IC enables our device to give absolute orientation feedback to the wearer. The magnetometer will communicate to the application processor using an I2C bus. Because we only include 8 haptic ERMs in our design, our detection of geomagnetic north needs to be accurate to within 10°.

Requirement 1: Must be able to sense geomagnetic north within a 10° accuracy.

Control Panel The control panel will contain the master power switch, allow the user to adjust the range sensitivity of the ultrasonic sensors, and allow the user to control the mode of operation. The control panel will have three switches: one for the power, one to enable geomagnetic feedback, and one for proximity feedback. The panel will also contain a rotary dial to control the sensitivity of the proximity sensors. The switches will connect to GPIO inputs of the application processor, and the sensitivity potentiometer will be sensed using the integrated ADC.

Requirement 1: Must provide three on/off switches (power, and mode select), and a potentiometer for intensity section.

2.3.2 Haptic Module

ERMs The haptic module is responsible for generating all haptic feedback to the user. There will be 8 eccentric rotating mass (ERM) modules arranged around a belt worn around the midsection. Each ERM will be driven using an ERM controller IC that takes as input a PWM signal encoding the intensity and direction of rotation. A 50% duty cycle corresponds to no vibration, 0% to full reverse, and 100% to full forward. The haptic microcontroller will have 8 PWM outputs so that all ERM's can be controlled simultaneously. We will define 5 distinct intensity levels corresponding to each 40 centimeter increment of distance, which the user will be able to distinguish clearly. Having finer increments will necessitate more intensity levels that the user may not be able to meaningfully distinguish.

Requirement 1: ERM's must provide 5 distinct levels of intensity that can be easily distinguished by the wearer.

Requirement 2: ERM's must not draw more than 150mA when driven to maximum power.

Haptic Controller The vibration pattern and intensity of each ERM will be controlled by a microcontroller on the belt, which will receive haptic feedback commands from the application processor over an I2C bus. When the application processor needs to change the vibration intensity of a particular ERM, it will send a message on the I2C bus.

Requirement 2: Haptic feedback must have different vibration patterns for different types of information (i.e. proximity vs. cardinal)

2.3.3 Control Module

The control module is responsible from reading all data from the sensor module, interpreting the data, and sending haptic commands to the haptic module. It consists of an application processor and board, as well as the software to convert sensor data into haptic responses. The mode switch on the control panel will tell the control module whether it should provide feedback for obstacle detection, cardinal direction, or both. The control module will read the intensity adjustment knob on the control panel and adjust the haptic commands sent to the haptic module accordingly. The application processor will control the rangefinders through a multiplexer/demultiplexer pair using its GPIO pins. In order to get accurate time-of-flight measurements, interruptible timers integrated into the application processor will be used.

Requirement 1: Must warn user when battery reaches 20% or overheats

Requirement 2: Control panel must be able to turn proximity and direction functionality on/off

Requirement 3: Must be able to read all ultrasonic sensors, magnetometer, and temperature sensor every 100ms.

Requirement 4: Latency between receiving sensor data and sending output commands is less than 10ms

Requirement 5: Must ignore obstacles within 20cm from body (chairs, etc)

2.3.4 Power Module

The power module comprises of the voltage regulator, the controller, and the battery.

Voltage Regulator The voltage regulator will deliver low-voltage DC power to the various parts of the two PCBs.

Requirement 1: Must maintain supply voltage of 4.8 to 5.2V for digital logic components.

Charging Controller The controller will control the recharging of the Lithium ion batteries, by converting the wall port 5V AC to the current needed (0.5 C, according to Digikey [13]), as well as prevent overcharging and undercharging the Li-ion battery. Likewise, the controller will detect overheating, overcharging or overdischarging, or low-power states; it will deliver warning signals to the haptic belt through the main board. It will also cut off the power supply to the rest of the device if necessary.

Requirement 1: Must charge batteries at 0.5C from a 4.8-5.5V supply.

Requirement 2: Must prevent charging when charging supply polarity is reversed.

Requirement 3: Must stop charging if battery temperature exceeds 50°C.

Lithium-ion Battery The battery pack will have sufficient power to last for 8 hours of continuous use. Requirement 1: Battery must last 8 hours when all ERM's are driven at 40mA.

Requirement 2: Battery must be rechargeable

Requirement 3: Must weigh less than 5 lbs

2.4 Risk Analysis

The ultrasonic sensors comprise the riskiest module for our project. If we cannot find ultrasonic sensors with enough range and accuracy at a low enough cost, it would harm the performance of our project. Additionally, variability in the reflectivity of objects in the path of the user might give inconsistent or unpredictable responses.

The power module also comprises another risky module. This is due to the fact that it is the most unfamiliar area for all three of our team members.

3 Ethics and Safety

Our project will provide a tool to be used as a means to assist independent living and safety of the visually impaired. While this is an ethically sound idea, there are some implications that come with it. If this tool is used as an aid, we have to take into account for the potential of the tool to mislead the user into a dangerous situation. The IEEE Code of Ethics Code 3 claims that we must be honest and give realistics claims about the capabilities of our device [14].

In order to prevent accidents and to be in accordance with the IEEE Code of Ethics, we must make it clear that this product, at this stage, is by no means a replacement for a white cane. It is to be used only as a supplement to existing tools so as not to introduce any insecurities into the daily routine of the user. We must not overstate the capabilities of it to ensure no more trust is invested in it that it deserves.

Additionally, there are components of our design that can be physically dangerous to the user, namely the battery pack. According to IEEE Code 1, we must accept responsibility for the safety of the users of this device, and we must make clear any factors that may be dangerous [14].

In order to properly protect the user from potential malfunctions of the battery pack, we will ensure that it has Ingress Protection (IP) 63 [15]. This will prevent spraying water from entering into the battery pack and compromising the battery. We will also incorporate a temperature sensor in order to detect if the battery is reaching unsafe temperature levels.

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