ECE 445 Team 2 Project Proposal: Seeing-Eye Hat

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1. Introduction

1.1 Problem

Individuals with visual impairments encounter difficulties in independent navigation of their surroundings, causing lowered spatial awareness and concern with their personal safety. While there are solutions such as canes or seeing eye dogs, there is an issue with detecting range for objects further than a meter out. Seeing eye dogs only take the owner into a certain direction and are used to make sure the user stays in a straight line from their directions. Dogs can unfortunately become distracted by things like food or children petting them, even with training. Also, there are likely people allergic to dogs or with traumatic experiences that wouldn't want one, while the dog requires being taken care of constantly as a pet.

1.2 Solution

We want to make a hat designed to empower blind individuals by offering a 360-degree field of view. It will use advanced LiDAR sensors for wayfinding and dead reckoning, and Doppler RADARs for collision detection. This technology translates the surrounding environment into real-time spatial data, allowing users to navigate their surroundings with newfound independence. The hat also includes vibration motors strategically placed to indicate the direction of the nearest objects, aiding users in easily navigating their environment.

1.3 Visual Aid

The main body of the device is a standard baseball cap, and a small PCB fitted with a microcontroller will be embedded into the brim of the hat. This microcontroller will process data and generate haptic stimuli. A brushless motor and a Lidar Sensor are mounted to the top of the hat, where the brushless motor rotates the LiDAR sensor to process a 360 degree view of the surroundings. This data is sent to the microcontroller, which processes the distances between the user and surrounding objects. The inside of the cap will be lined with vibrating motors that will function as haptic stimuli. The microcontroller will activate these motors at different strengths depending on the distance between the user and an object in that direction. Additional sensors, such as the accelerometer, will be embedded into the brim or placed around the outside of the hat as required.
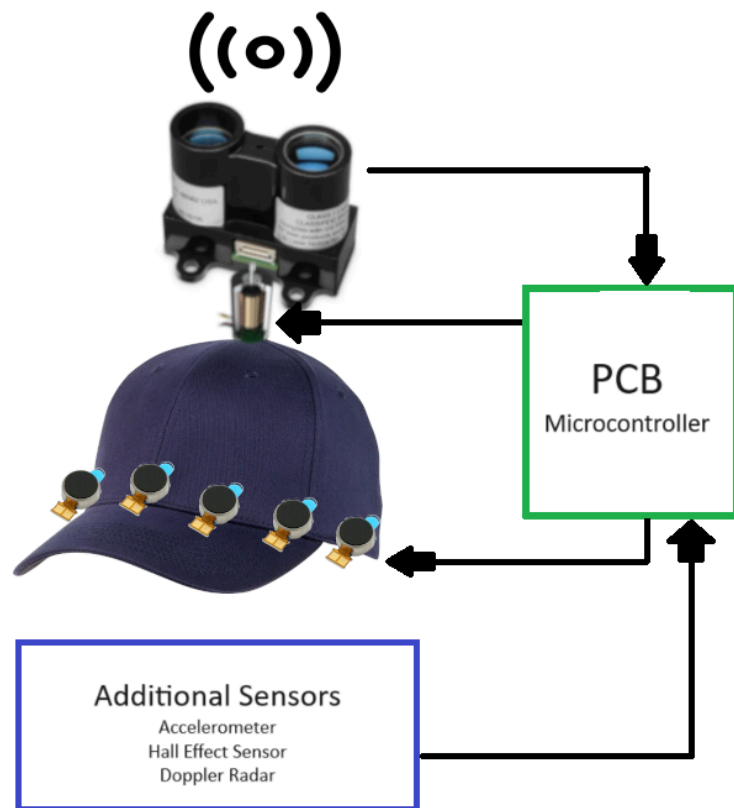
1.4 High Level Requirements

1. Able to image a room, such as ECEB 2072, from the center at resolution of at least 0.5 meters using haptic feedback and with a monitor for others' viewing as a diagnostic tool with a 360 degree range with an angular resolution and accuracy of up to 25 degrees.
2. Able to detect objects approaching the user from front, back, below, and both sides within 2 seconds.
3. Navigational Success: The hat must detect and produce stimuli to inform the wearer of a wall that is up to 5 feet away from them in all directions.

2. Design

2.1 Block Diagram
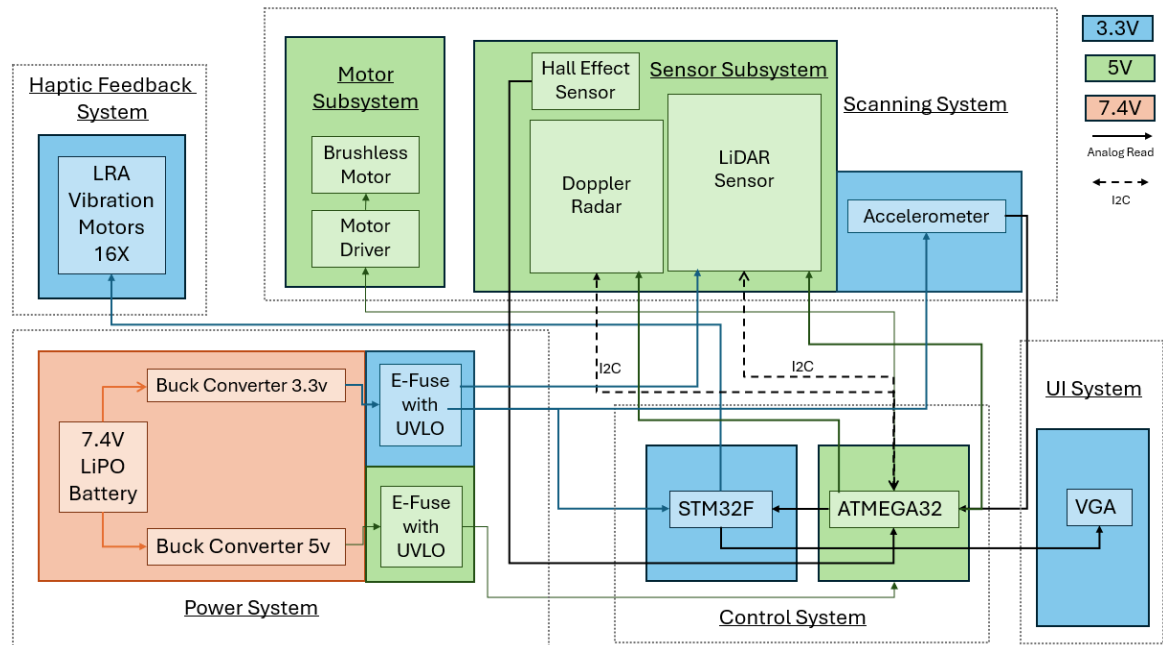
2.2 Subsystem Overviews

Control Unit Subsystem

The control unit will consist of either one or two microcontrollers. The primary function of this system is to read data from the Imaging and Sensing System, and to activate the motors in the Haptic Feedback System accordingly. The microprocessor will utilize the I2C protocol to interface with the LiDAR and Doppler Radar sensors, and analog input pins will be used to take measurements from the accelerometer [1] and the Hall Effect Sensor [2]. Internal calculations will be performed to determine which of the 16 LRA Motors should be on at any given time, and 16 analog output pins will be used to provide signals of different strengths to each LRA Motor. The microprocessor will control the motor driver as well. During testing, this unit will be responsible for generating LED Flags and VGA output for the UI Unit. Ideally, the control unit will consist of just one STM32 microcontroller, but if the singular STM can not support all of the required functionality, an ATMEGA32 [3] will be added, and a serial connection will be established between them.

Imaging and Sensing Subsystem

This subsystem focuses on capturing real-time spatial data. The keystone of the system is the LiDAR Sensor [4]. It utilizes 'time of flight' measurements in order to determine the distance between itself and any forward facing obstacle, and will be rotated about its y-axis by the scanning mechanism subsystem. The LiDAR Sensor has its own internal microcontroller. The distance measurement will be stored in an internal register and sent to the control unit over I2C, which will also be utilized by the Doppler Radar to send its own proximity information to the same unit. The accelerometer will be read by the control unit to compensate for the user moving while the LiDAR is active. The Hall Effect Sensor will measure the angular position of the scanning mechanism's brushless motor, and the microcontroller will read this data and use it to select the appropriate LRA motor to associate a LiDAR Measurement to.

Scanning Mechanism Subsystem

This subsystem focuses on the rotation of the scanner and the associated motor controls. It consists of a motor driver which is responsible for controlling the rotational speed of the scanner using PWM input from the microcontroller. The main mechanical power source for this system is a DC brushless motor, and to physically rotate the LiDAR, the system will make use of a slip ring that will work in conjunction with 3D printed parts.

Haptic Feedback Subsystem

This subsystem consists of vibration motors [5] responsible for providing haptic feedback to the user. 16 LRA vibration motors will be evenly distributed within the hat, and they will be turned on to indicate the direction of the nearest objects. The number 16 was chosen to provide precise information without overstimulating the user with excessive haptic feedback. As for determining the strength of motors, multiple options will be explored to determine the best fit. One potential option is the use of demultiplexers. These motors will receive analog inputs from the Control Unit that determine the strength of the motor.

Power Subsystem

To ensure a uniform voltage supply, boost/buck converter circuits will be utilized for power supplies. The batteries chosen for this system needed to be stable, rechargeable, light and small, so LiPO Batteries were selected due to their increased stability over lithium ion batteries. Every component in each of the other systems operates at either 5V, 3.3V, or 3V. Given that LiPO Batteries measure in intervals of 3.7V, a 7.4V battery was subsequently selected. The battery voltage needs to be stepped down to both 3.3V and 5V, so two buck converter ICs will be used.

Each buck converter is protected by an E-Fuse with Undervoltage Lockout, which will enforce an adjustable current draw limit on the rest of the device. The maximum current will be determined by the properties of the buck controller.

2.3 Subsystem Requirements

Control Unit Subsystem

1. Must activate the motors with strengths proportional to the closeness of the obstacle, where a closer object corresponds to a stronger haptic feedback signal.

Imaging and Sensing Subsystem

1. The LiDAR and Doppler sensors must provide distance measurements that have an accuracy within ±5%.
2. The LiDAR sensor should be able to detect objects at a maximum distance of 2 meters.

Scanning Mechanism Subsystem

1. The slip ring and brushless motor should be able to rotate the LiDAR continuously for half an hour.

Haptic Feedback Subsystem

1. Whenever the user is within 2 feet of any wall, the nearest haptic motor to the wall should activate at full strength.
2. Whenever the user is within two feet of any wall, the motors adjacent to the closest motor should activate at lower strength.
3. The haptic feedback provided by said motor should have an intensity strong enough to be picked up by the user.

Power Subsystem

The power systems requirements center around protecting the rest of the device from excessive voltages and currents.

1. The power system must output two power buses at 5V +/- 0.2V and 3.3V +/- 0.1V.
2. The 5V line supports a maximum current draw of 0.5A. This is based on the sum of constant current draws by each sensor and microcontroller.

3. The 3.3V line must support a maximum current draw of 1.5A. This calculation is based on the 16 LRA Motors, which are rated for 60mA.
4. If either of the maximum current thresholds are reached, the e-Fuse will safely disconnect the battery from the other systems. This feature also protects the components from short circuits, and from backfeeding.

2.4 Tolerance Analysis

One important point to consider in our design is how we would handle the worst case power draw situation. Our maximum pack voltage is 7.4V, and many of our components, particularly the haptic motors, operate off the 3.3V line. If all 16 haptic motors were on at the same time, they would draw a rated current of 0.96A. Our team settled on an estimate of 1.5A maximum draw limit for the e-Fuse component. The power dissipated in a hypothetical linear voltage regulator would be represented by the following formula.

$$P_D = i_{out} * (V_{in} - V_{out}) = 1.5 * (7.4 - 3.3) = 6.5W$$

The lower bound of the temperature of a component dissipating a quantity of power can be represented with the following equation. We will assume this device has a perfect heat sink. The TPS7A53B Linear Regulator from Texas Instruments lists a thermal resistance of 46.5 (°C/W) [6].

$$T_{ja} = P_D * (\Theta_{jc}) = 6.5 * 46.5 = 302.25 \, ℃$$

This temperature is certainly not viable for any electrical component. Therefore, a buck converter has been chosen for the 3.3V line.

The secondary 5V power bus is only expected to draw 0.5A of power.

$$P_D = i_{out} * (V_{in} - V_{out}) = 0.5 * (7.4 - 5) = 1.2W$$

$$T_{ja} = P_D * (\Theta_{jc}) = 1.2 * 46.5 = 55.8 \, ℃$$

While this heat is survivable for an electrical component, this estimate assumes a perfect heat sink is in place. Even the ideal situation could reasonably prove to be uncomfortable for the users or cause damage to the hat the device is embedded in. Therefore, a Buck Converter was selected for this line as well.

3. Ethics and Safety

As engineers, we are acutely aware of our responsibility to support the betterment of humanity in the safest and most respectful way possible. Our project aims to use emerging technology in order to alleviate the struggles of people with disabilities. We selected a humanitarian project because we believe that everyone should lead lives that are as fulfilling as possible. We, Section 1.1 of ACM Ethical Code, and Section 1.1 of the IEEE Ethical Code, all consider this to be a noble goal. However, we recognize that good intentions can easily yield poor results.

3.1 User Risk

This product is inherently risky. The Seeing Eye Hat is an Independent Living Aid for people who are blind, and potentially have other sensory issues as well. Despite our intentions to minimize environmental risks, malfunctions could lead the user directly into harm's way. Errors could arise from many different sources, including design oversights, improper use, physical hardware damage, environmental conditions, and the battery running out at inopportune times. These concerns are a part of why this product is being explored within the context of a university design course, instead of directly in real world applications. As a team, our goal is to assess the feasibility of implementing this concept, rather than develop a commercial product.

Above all else, it is our duty to address all minute concerns with the product's functionality to ensure maximum safety for users. This project requires meticulous attention to detail for successful completion. Additionally, it is essential to communicate to users that this product is not a substitute for general precaution.

As discussed in Sections 2.1-2.6 of the ACM Code of Ethics, this product would need to undergo extensive testing and professional review. In the context of this course, this would likely come from the university faculty, course staff, and other students. Outside of this course, there are many regulatory agencies that would need to thoroughly investigate this product before it is approved for testing with the target audience. As a team, we wholeheartedly welcome and seek out this accountability. The FDA regulates personal medical devices including hearing aids, so they may potentially have jurisdiction in our case. The FDA's Electronic Product Radiation Control Program might govern our sensors. Our team has contacted the FDA for more information, but we have not heard back from them at the time of submission.

3.2 Laser Safety and Regulation

An early concern about the product is that the LiDAR Sensors utilize lasers. These sensors use sources between 905 nm and 1550 nm, within the infrared part of the electromagnetic spectrum [7]. These values specifically fall under a class known as near infrared light, which can penetrate the eye through to the retina, so a strong enough beam or long enough

exposure could cause damage [8]. However, these adverse effects do not generally apply to low powered lasers such as those used in LiDAR Sensors. The IEC 60825 standard states that Class 1 lasers are "eye-safe at all times … A Class 1 laser can never exceed the [threshold for biological damage within a 10 second exposure]". Sensors using 1550 nm lasers pose even less risk. Our team will heavily consider this in our component selection, and if further research suggests that LiDAR may be unsafe in populated areas, we will change primary sensors.

The FDA Center for Devices and Radiological Health primarily governs demonstration lasers and laser pointers [9]. Our project is out of their general purview, but it would be wise to consult them anyway. The laser is too weak to impact any FAA regulations. The State of Illinois requires registering lasers above Class 3B; this project only utilizes Class 1 lasers, which are free for unregulated use.

3.3 Data Processing and Privacy

This project collects information about the user's surroundings, which can pose an ethical concern. As it stands, no data is stored for longer than a few seconds or transmitted off of the device in any form. This protects the privacy of the users, as per the ACM Code of Ethics section 1.6. The data that is currently collected only measures the distance between the user and surrounding undefined objects, which is not comprehensive enough to be invasive. This stage of the project does not intend to include image processing or location data of any kind, however it could be a potential future feature if this project were to continue past this course. If the project were to go in that direction, we would enforce that the data collected is later discarded and never transmitted off the device.

3.4 Personal Responsibility

As team members, we must each hold each other accountable to maintaining good ethical practices. Because this project mostly exists in an academic setting, this means that we can never allow the pressure of finishing tasks to result in cutting corners or compromising the quality or safety of the project. In addition, we must never fabricate data or manipulate test results, as it will affect the credibility of the final product.

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