

S.I.G.H.T.
Smart Integrated Guidance & Haptic Technology
Wearable Smart Shoe for the Visually Impaired

120 Page Final Report
EEL4914 – Senior Design I
Group 5



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Chapter 1 Executive Summary

The Smart Integrated Guidance and Haptic Technology (S.I.G.H.T.) project is an innovative wearable shoe designed to enhance the accessibility, safety, and independence of individuals who are visually impaired or blind. In order to offer real-time environmental awareness and obstacle detection, this smart shoe combines several sensor systems, a microprocessor, haptic feedback, and wireless communication technologies into a durable and user-friendly design.

The need for this device stems from the daily challenges faced by individuals who suffer from a visual impairment. One of our team members has a family member with a visual impairment and every day for her is a challenge, especially to navigate in different environments. Although tools like the white cane can provide essential assistance, they have their restrictions. In today's rapidly evolving world of technology there is a strong opportunity to create something more effective. While advanced assistive devices do exist, many are very expensive and out of reach for those who need them the most. Our goal is to design a solution that is not only innovative and functional but also affordable and accessible to the visually impaired community.

With the S.I.G.H.T. shoe, it will include multiple hardware components such as a microcontroller which will be the ESP32-CAM for data processing and control, 3D light structure that will map a grid out of the environment detected, haptic motors for directional vibration feedback, ultrasonic sensors to measure distance when an obstacle is detected, and audio feedback to alert the user also when an obstacle is detected by giving direction movement. This system will be powered by a 5V rechargeable battery, and with the camera module that comes with the ESP32-CAM, it will provide image processing that will work with lasers and the 3D structure to detect an environment. We will also include an LCD screen display that will show distance readings to make sure that the ultrasonic sensors are working. All these features will be able to detect up to 2 meters of range and will work with a 100% accuracy to ensure the safety of the user. Furthermore, the shoe's durable and modular design is further enhanced by including a custom PCB board for power management as well as making wiring less and easier to implement.

A comprehensive review of existing products along with user feedback helped shape our design process. This research was very important as this guided us to establish different types of achievable goals to ensure that accurate obstacle detection and dependable feedback systems were in place. Measurable performance objectives, including detection range, battery life, response time, and overall durability were outlined in a detailed engineering specification table. This table will be used at the end to make sure that we met our goals and that the final design worked as intended during final testing. The team also developed block diagrams that show our task distribution, and status for both hardware and software design steps. All of the main components and systems are then combined into a prototype that will create the S.I.G.H.T. wearable shoe.

In summary, the Smart Integrated Guidance and Haptic Technology (S.I.G.H.T.) shoe project shows a great dedication to practical problem solving. Our approach offers a clear

path to the development of a fully functional prototype for our final product that will also balance innovation, cost, and make it user centered.

Chapter 2 Project Description

In this chapter, we will discuss the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.) shoe project. This smart shoe is designed to assist individuals with visual impairments by identifying obstacles and giving turn left turn right directions. This will make navigation more secure. We will discuss the project's background, objectives, and features. In addition to system requirements, important engineering parameters and detailed hardware and software designs are provided. This chapter will also highlight the proposed prototype of how our final shoe will look.

2.1 Project Background and Motivation

Navigating daily life independently can present considerable challenges for people who are blind or visually impaired individuals. Traditional white canes provide tactile feedback, meaning they allow users to detect obstacles by touching them. While the white cane can be helpful and is a standard tool for navigation, it limits the user to only sense what is in front of them. This can lead to accidents with changes in the ground or dangerous conditions like busy streets. In a rapidly increasing world with advanced technologies, we have an opportunity to rethink and improve this important mobility device through wearable innovations.

The goal of the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.) is to move beyond the limitations of the traditional white cane by introducing a smart shoe designed for enhanced safety, navigation, and user independence. The S.I.G.H.T. offers a wearable solution that has essential features like obstacle detection, vibration and audio haptic feedback, a rechargeable battery, and water-resistant material, making it suitable for everyday use.

According to the World Health Organization, approximately 2.2 billion people worldwide experience vision impairment or blindness [4] . Many individuals could benefit from assistive devices designed for modern needs. Individuals with blindness and visual impairments of all ages who aspire for greater independence and enhanced safety on their daily travels will be among our target audience.

Real-world experiences and user feedback reveal the drawbacks of the conventional mobility aids which inspired this project. Users express that they need better obstacle awareness, more information about their surroundings, and guidance tools that do not interfere with the ease of comfort. This project also carries personal significance. A close relative of one of our team members has a visual impairment and uses a traditional white cane to get around daily. Seeing the difficulties she encounters, especially in new or crowded settings, stressed the flaws of the cane and inspired our commitment to this project. The Smart Integrated Guidance & Haptic Technology shoe aims to close those gaps and provide improved independence, safety, and navigation by combining modern technologies into a wearable alternative aid.

2.2 Goals and Objectives

The primary goal of the S.I.G.H.T. shoe project is to create a wearable assistive shoe that will improve mobility and obstacle awareness. The team has established goals that will adhere to the SMART acronym, Specific, Measurable, Achievable, Relevant, and Time Bound, this will guarantee significant development as well as place a strong emphasis on timelines, performance standards, and well-defined targets for both hardware and software.

2.2.1 Goals

The Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.) shoe project will aim to overcome the challenges that the cane faces by incorporating emerging technologies to enhance user awareness, safety, and independence into a wearable shoe.

Shown in Table 1 are the following goals that are organized into three tiers, basic, advanced, and stretch. Each level builds on the previous, leading to a final prototype of the S.I.G.H.T. shoe, that not only satisfies practical needs but also demonstrates the potential of technology-driven mobility solutions.

Table 1: Project Goals Overview for the S.I.G.H.T Shoe

Goal Type	Description
Basic	• Design a smart shoe system that detects obstacles within a 2-meter range with 100% accuracy. • Operating continuously for a minimum of 6 hours on a single charge using a rechargeable battery that will guide visually impaired users. • Implement one 3D light structure sensor and two ultrasonic sensors to enable multi-directional detection, providing real time guidance alerts with <250ms latency to facilitate the users' use when walking. • Develop the S.I.G.H.T system as a strap on attachment that houses all core components, allowing users to easily wear it over different types of shoes within in 30 seconds.
Advanced	• Enhance the user experience by incorporating a forward-facing camera module capable of capturing real time environment mapping and identifying at least four object categories (wall, door, person, and tree) using lightweight materials by the end of week 13. • Implement haptic feedback using a vibrational motor and a speaker, providing directional alerts with a <250ms delay, and verify functionality under wet conditions allowing visually impaired users to receive clear navigation alerts in real time and rely on the device in various weather conditions. • Incorporate a voice guidance system that delivers clear, spoken navigation instructions (e.g., Turn left, right, Obstacle detected) using audio output, with latency under <1 second. • Optimize system performance for both indoor and outdoor use by calibrating sensors and audio output to adapt to different lighting

	and ambient noise levels (up to 60dB), ensuring consistent detection for indoor, outdoor, and low light with background noise.
Stretch	• Expand shoe accessibility by supporting voice feedback in at least two languages (English and Spanish), with a language selection menu available through an app. • Implement fall detection using an accelerometer, with the system triggering emergency alerts via Bluetooth or SMS within 10 seconds of detecting a fall. • Integrate GPS based navigation support using a GPS module, enabling users to navigate to five saved destinations with the user's preference, with audio guidance and <5-meter location accuracy. • Design and implement an SOS alert feature activated by a double tap pressure sensor within the insole, to allow visually impaired users to quickly signal for help by sending their location to an emergency contact in <15 seconds.

A successful design of the S.I.G.H.T. shoe will result in a fully working prototype that detects obstacles within a 2-meter range and notifies the user in real time with less than 250 milliseconds of latency. The final prototype will operate continuously for 6 to 10 hours on a single charge. Key success criteria include reliable performance by doing multiple tests, ease of use and comfort by completing navigation tasks, and measurable improvement in avoiding obstacles over walking without assistance. Overall project success will be measured by these specifications and completing prototype testing by the end of the development timeline.

2.2.2 Objectives

The objective of the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.) shoe aims to provide functional and user-friendly mobility assistance for those with visual impairments.

The system's main function from the basic level will be to use two ultrasonic sensors to measure and detect obstacles within a 2-meter range. An LCD screen to display distance measured to make sure that the ultrasonic sensors are working properly. This will help identify the object's detected distance and provide real time feedback in the form of vibration and audio alerts within 250 milliseconds of detection. We will also use a 3D light structure to detect obstacles in a frame. The shoe also needs to run continuously for six to ten hours to support daily use from the rechargeable battery powered in a single use. System performance will be evaluated through indoor and outdoor tests. The device will be designed as a strap on module that can be put on or taken off, of various shoe kinds in less than 30 seconds, making it easy to use every day without requiring the user to change their footwear.

For the advanced level, the shoe's enhanced capabilities will include a speaker and vibrational motors that will both provide multidirectional haptic feedback. Voice navigation will also be implemented, allowing the system to provide spoken commands

like “Turn left” or “Obstacle ahead” with less than one second delay allowing users to receive clear navigation information. The system will also be adjusted to work well indoors, outdoors, and at low light levels, with ambient noise levels of up to 60dB, to guarantee dependable use in a range of settings. The system will also be able to differentiate between at least four obstacles, wall, person, tree, and door with at least 95% or higher recognition. This will be possible because the camera module will enable object recognition and environmental mapping. All hardware will be enclosed in a water-resistant box.

As part of the stretch objectives, if time permits, the team will want to expand the shoe safety and accessibility features. These include an accelerometer for detection of fall. If a fall is detected, an emergency GPS alert will trigger within 10 seconds. Another feature we want to incorporate is a GPS navigation system that will allow the user to pre-define five destinations using audio-based directions. In addition, a double tap pressure sensor built into the insole will trigger the SOS alarm system, which is an extra safety feature that enables users to call for help in an emergency. Additionally, the system will offer voice feedback in at least two languages (English and Spanish), with the ability to select a language through a mobile app. These features are explained more in section 2.8 Prototype Illustration.

Below are a few figures showing the components of the optical design aspect of the project. Included are the laser module, a collimating lens, and a diffractive optical element.

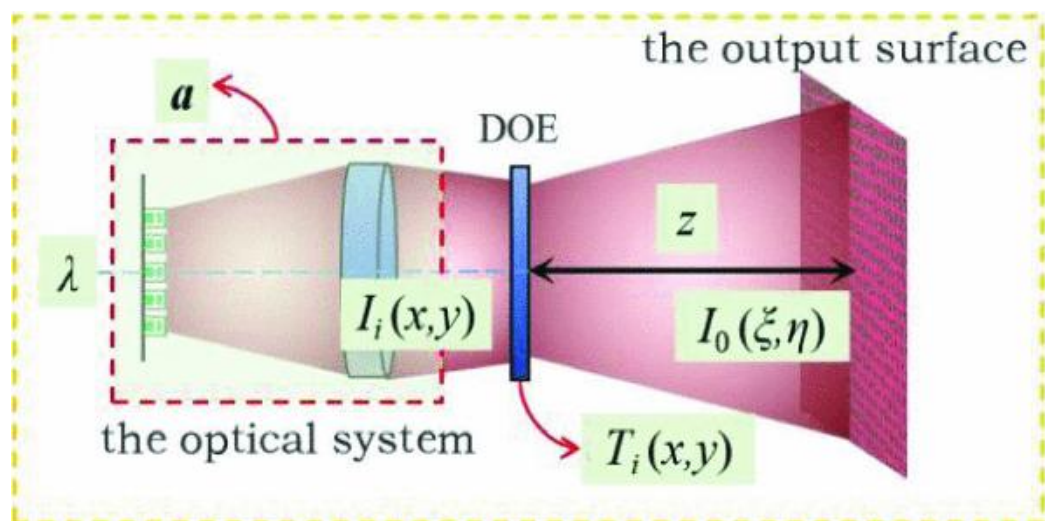


Figure 1: Shows optical system used by S.I.G.H.T. project

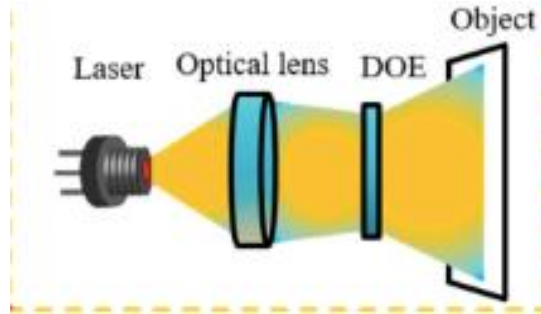


Figure 2: Another illustration of laser diode module, collimating lens, and DOE.

An overview of the structured light system that will be used in the final design of the S.I.G.H.T. is presented in the figure below. The system includes the projector that is explained in the prior figures, while also including the camera module that will be used to capture the images needed to calculate the distortion of the projected pattern.

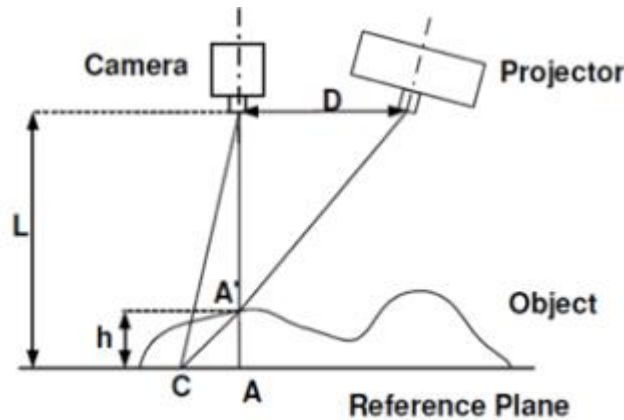


Figure 3: Structured light system that is used with projector, camera, and the baseline used for depth mapping

2.3 Features and Functionality of Final Product

The features of our S.I.G.H.T. system are its wearable and compact design, a fusion of a structured light projection system and ultrasonic sensor for reliable obstacle detection, onboard processing, low power consumption, and environmentally robust use in ambient and low light settings. The system will be small enough in design to mount on a shoe and allow for hands free operation. The final design will enable a comfortable, low profile, and unobtrusive ease of use in everyday life. The user to test the final product will be visually impaired, so ease of use is very important for the final product. The structured light projection system will enable reliable obstacle detection through pattern distortion measurements. This distortion will enable a depth mapping as well as the shape of the object or obstacle. Any distortion in the stripe pattern will be observed and the signal will be given that an object is in the way of the user. When the path is clear, we will not have any distortion pattern. An ultrasonic sensor system will also be implemented in the design. This is another sensor for the S.I.G.H.T. that will detect obstacles and objects in the path of the user. The combination of different sensors will allow for overlap in detection zones,

which ultimately lead to the same goal of reliable obstacle detection for the user. There will be onboard processing done using the microcontroller for the system, which will be done on an ESP32-CAM. The S.I.G.H.T. system will be able to have low power consumption as a feature as well. All the components used are optimized for low current, low power, and an all-day use. This is important in case the user of the product needs to use the S.I.G.H.T. all day. This project needs to be environmentally robust in the way that it can be used and operated indoors and outdoors. The laser projection pattern will be visible in all light settings, which include both ambient and low light.

The S.I.G.H.T. functionalities include obstacle detection in real time, 3D depth estimation from the ground level, enhanced spatial awareness for visually impaired users, hands free and passive operation, and haptic feedback. The key function of the S.I.G.H.T. will detect objects and elevation changes such as curbs, walls, or furniture. Through this object detection, trips, falls, and collisions will be avoided by the user. 3D depth estimation through the structured light system will be available from the ground level. Object distance will be calculated from deformations of the projected stripe patterns on the object. This will work on textured and nontextured surfaces. The use of our S.I.G.H.T. project will enhance spatial awareness for the visually impaired. This project is intended to supplement the use of a cane or other mobility aids used by visually impaired individuals. This device will also be hands free and used passively by the user. This project should be able to be used with no user interaction and fully automated once the system is turned on and engaged. The use of haptic feedback will warn the user of an obstacle. This can be done through a speaker giving instructions or a series of buzzers and beeps. The use of the ultrasonic sensor will give distance detection for obstacles and inform the user of changes in the distances of obstacles.

2.4 Existing Products / Past Projects /Prior Work

In researching the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.) project, several existing smart shoe products and wearable mobility aids were analyzed to guide the design process. These prior efforts illustrate the potential and limitations of integrating sensing and feedback technology directly into footwear to assist the visually impaired.

One notable example is the Le Chal smart shoe, developed in India [5]. This product embeds vibration motors in the shoe soles, which respond to GPS navigation directions and obstacle proximity. The shoe is paired with a smartphone app, allowing users to set destinations and receive turn-by-turn haptic cues. While the Le Chal shoe demonstrates the viability of combining location-based services with wearable feedback, its reliance on GPS alone limits its effectiveness for real-time obstacle avoidance in dynamic environments.

Another example is the Shoe Integrated Navigation System (SINS), a prototype system developed for real-time guidance [6]. This design uses ultrasonic sensors mounted at the front of the shoe to detect nearby obstacles and trigger vibration feedback at varying intensities based on proximity. The sensors detect obstacles within a range of 0.5 to 2 meters, while microcontrollers process input and control the vibration patterns. The system is effective for low-level obstacle avoidance but lacks extended features like object classification or indoor mapping.

Research presented in a 2023 review by Joseph et al. in *Sensors* outlines several additional smart shoe prototypes [7]. These systems typically integrate low-power microcontrollers (e.g., NodeMCU or ESP32), ultrasonic or infrared sensors, and vibration motors. In some designs, sensors are placed on the toe or sides of the shoe to increase coverage for ground-level hazards, curbs, or stairs. Feedback is delivered either through vibration actuators in the insole or via wireless connection to a smartphone. A few models even incorporate piezoelectric energy harvesters that generate power from foot movement to extend battery life.

Some smart shoe systems go beyond obstacle detection. For example, a prototype cited in the review includes moisture sensors to detect wet or slippery surfaces, while another tracks foot pressure distribution to detect falls. Although most of these systems remain in prototype stages, they highlight the growing interest in footwear-based assistive technology as a supplement or enhancement to the traditional white cane.

These existing products and research studies provide a strong foundation for the S.I.G.H.T. project. Our smart shoe aims to combine the strengths of previous designs such as reliable low level obstacle detection and intuitive haptic feedback while addressing their limitations. Key goals include extending sensing range, improving environmental adaptability (e.g., operation in bright light or wet conditions), increasing power efficiency, and ensuring comfort and ease of use in everyday wear.

2.5 Engineering Specifications Table

This project requires the design and realization of the Smart Integrated Guidance & Haptic Technology, which will detect obstacles and give real time feedback for blind/visually impaired people. For this project to be successful, certain specifications will need to be met. These can be found on the table below.

Table 2: Requirement Specifications for the Final Product

Smart Integrated Guidance & Haptic Technology Specification Table		
Parameter	Specification	Engineering Requirement
Obstacle Detection Range	2.0m	The operating distance for obstacle detection.
Battery Life	6 to 10 hours of continuous use	It is important that S.I.G.H.T. has long battery life.
Weight	5 lb. (+-.5lb)	Product needs to be light weight.
Accuracy	Zero Errors in obstacle detection	Accuracy and reliability are key for use by visually impaired person.

Detection Response Time	>150ms (+-50ms)	Product needs to have real time response to avoid objects.
Sensor Field of View	60°	Field of View needed to ensure proper range for obstacle detection.
Daylight and Low Ambient Light Operation	SIGHT obstacle detection will work in daylight ambient and low light situations.	Obstacle detection system needs to work without interference from daytime ambient light and low light.

2.6 Hardware Block Diagram

The diagram below outlines the design and functional flow of the obstacle detection system for visually impaired users, with individual responsibilities color-coded by each team member. At the core of our system is the Microcontroller Unit (MCU), which interacts with all major modules and components. The programming of the MCU is handled by Johan (red), ensuring that data from input devices like the Ultrasonic Sensor and Obstacle Detection Module are processed efficiently. Ana (blue) is responsible for the User Interface, including the ON/OFF button, as well as the LCD Display and the Ultrasonic Sensor. Giovanni (green) oversees the Obstacle Detection Module and the Ground Drop-Off Detection Module, which uses an IR LED and photodiode with a collimated lens to identify ground-level hazards. Jasmine (yellow) handles the power system, including the Battery/Rechargeable power source and the Vibration Motor, as well as ensuring the system can be recharged via a Charging Port. She also manages the Audio Feedback component. The team jointly contributes to the prototyping phase and focuses on maintaining shoe usability regardless of the integrated modules. Together, this system enhances situational awareness for users through multiple sensory feedback mechanisms.

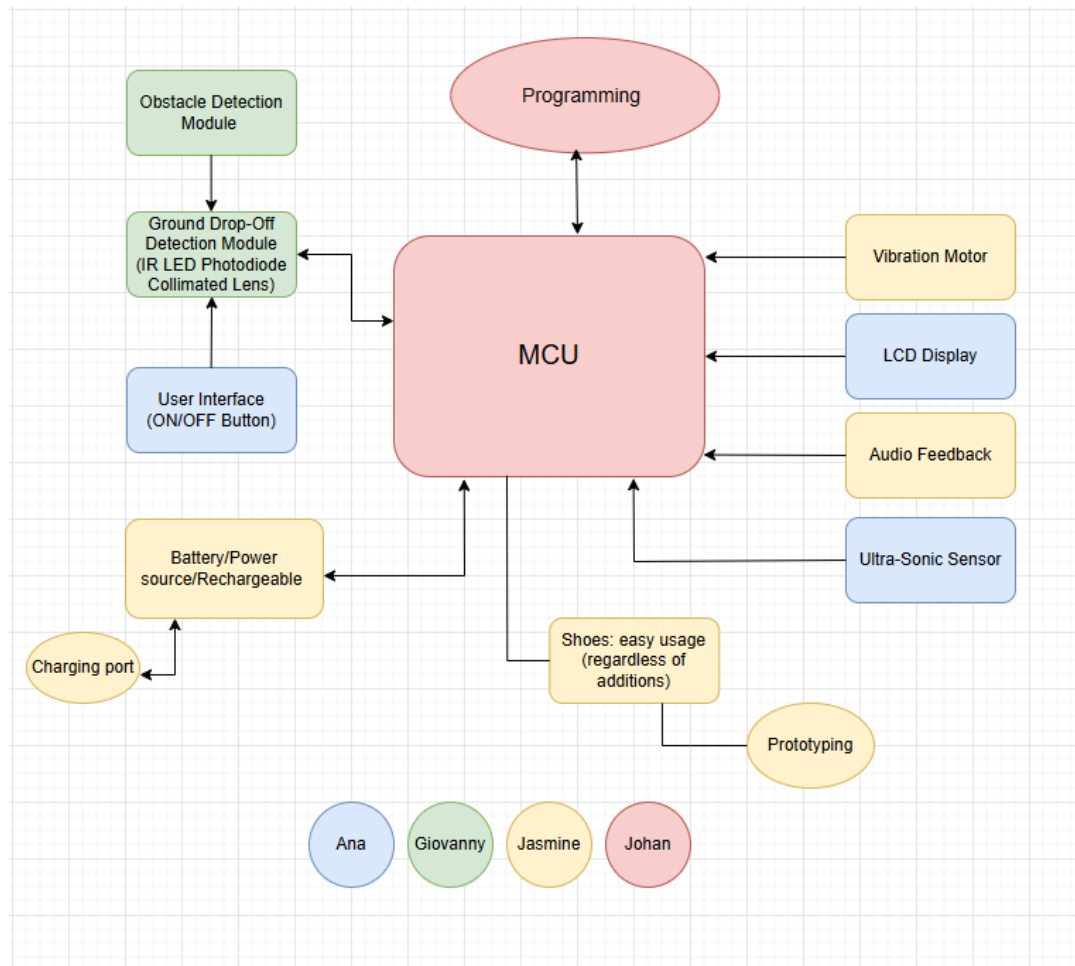


Figure 4: Hardware Block Diagram for Project

2.7 Software Diagram / Flowchart

This software diagram illustrates the operational logic of a wearable obstacle detection system using an ESP32 microcontroller, with each team member's contribution color-coded. The process begins with initializing the ESP32, followed by setting up essential components: the ultrasonic sensor, camera module, vibration motor, and speakers, most coordinated by Jasmine (yellow) with help being given by Ana (blue). The core functionality checks for obstacles within 2 meters using the ultrasonic sensor, an area managed by Ana (blue). If an obstacle is detected, the system triggers the vibration motor and speakers which are programmed by Johan, in (red) to alert the user. The vibrations indicate proximity, while audio feedback specifies whether the object is to the left or right. Giovanni (green) handles camera-based object recognition, which detects more specific obstacles and sends additional signals to enhance feedback accuracy. The system loops continuously until either a shutdown is triggered, due to low battery, manual power-off, or sleep mode, or no obstacles are detected. This software architecture ensures real-time responsiveness and layered sensory alerts for improved navigation and safety.

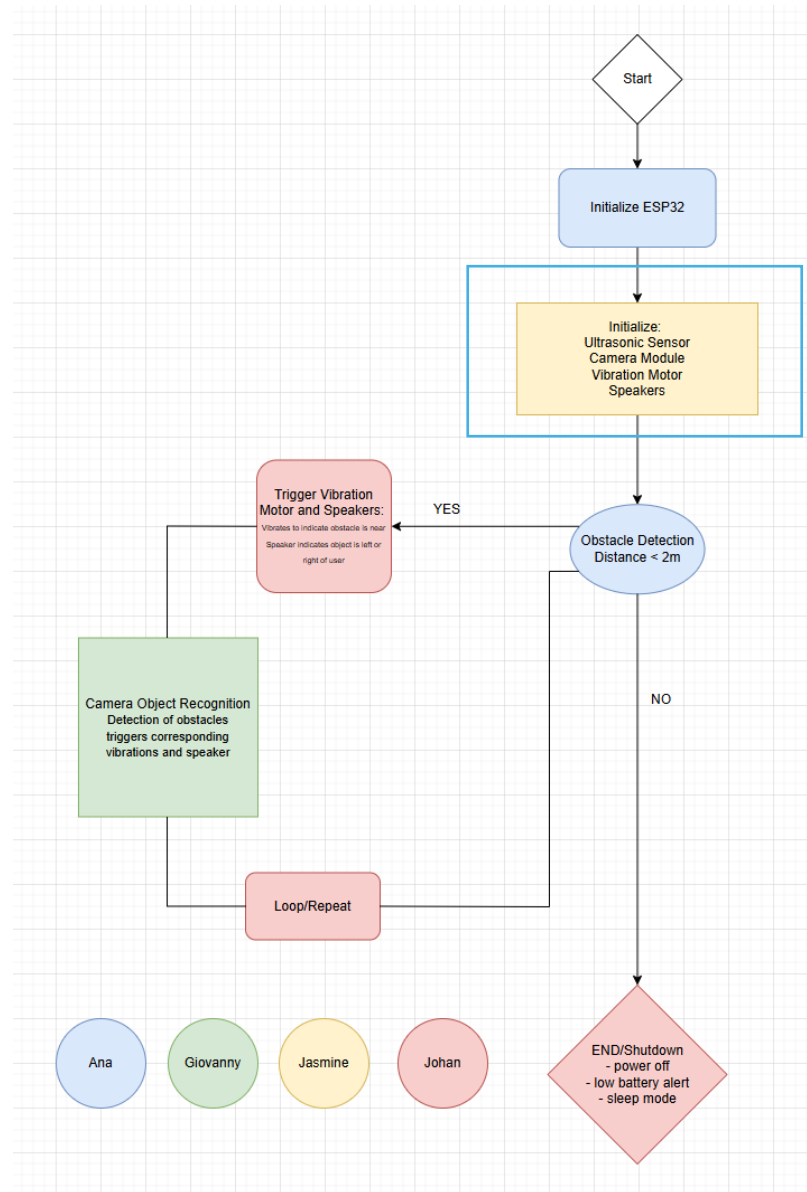


Figure 5: Software Flow Chart

2.8 Prototype Illustration / Blueprint

The following illustration demonstrates a visual representation of the S.I.G.H.T. design, highlighting the integration of key hardware components. It also illustrates the placement of our key features.



Figure 6: Boot Prototype with all components



Figure 7: ChatGPT Prototype of the Camera and all other components are inside the pack



Figure 8: Chat GPT photograph of shin guard possibility including all other components

Below is a breakdown of each component shown in the first illustration above and its function:

Basic:

- Rechargeable battery: This will power the entire shoe, it needs to last between 6-10 hours on a single charge, ensuring the shoe remains reliable and convenient for extended daily use.
- Laser Projector: Will emit a structured light to generate a depth map of the area.
- Camera Sensor: Will measure the depth of the maps and blur.
- Ultrasonic sensors and LCD screen: Will help the laser measure and display the distance from an obstacle.

Advanced:

- Camera: Camera will act as a sensor for object recognition and be able to classify objects.
- Vibration and audio feedback: Will provide cues to the user through vibration patterns and audio support in the shoe. These vibrations and audio will signal objects, direction, and or proximity of obstacles and guide the user.
- Water-resistant design: Ensure that all electronic components, including sensors and wiring, are protected against water, making the shoe durable and able to use the shoe in various outdoor conditions.

Stretch:

- SOS alert system/ button: Activated by a discreet pressure sensor or tap pattern to allow visually impaired users to quickly signal for help in emergencies

Chapter 3 Research and Investigation

This chapter presents the detailed investigation and analysis conducted to select the most suitable components and technologies for the S.I.G.H.T. smart shoe. Each subsystem, ranging from sensing, processing, power, and feedback, was studied against multiple alternatives to balance performance, cost, and integration ease. The research also explores algorithms, structured light sensing techniques, and prior literature to provide foundational knowledge that supports design decisions.

3.1 Part Selection and Relevant Technologies

To make our project, the S.I.G.H.T, a working functional and reliable shoe for the visually impaired, we put a lot of thought into choosing the right components and technologies for developing a working product.

The primary function of the S.I.G.H.T. shoe is to detect obstacles in the user's path and provide real time haptic and audio feedback. We will need to ensure that accurate distance measurement through sensors, real time processing with a microcontroller, and feedback via vibration and the speaker all must work together to finalize our final product to help the visual impaired community.

We first started off with, defining requirements and constraints. Figuring out what our prototype system needed to do, things like sensing, processing data, communicating, and providing real time feedback. Then this is where we looked at and researched different components that could handle each of these jobs. When picking parts, we focused on what mattered the most, factors such as power efficiency, ease of programming, whether the components would work well together, and overall cost efficiency. Our team compared our options in each area to make sure we ended up with a design that would work and wouldn't be too expensive or complicated to build and if we wanted to scale it up this could also be done in the future.

Each subsystem in this chapter also has specific performance criteria that needs to pass in order for our final design to be able to work and be safe for the users. For more information, please visit chapter 9.

This section is divided into two main categories, the hardware components and software selection. For the hardware portion we will discuss and compare two to three of the same part and compare them to choose the best option out of the two or three that will work best for our project. On the software side we will cover our programming setup, why we chose the program, and how it will be implemented onto the board for this project. All of these choices will work together to create the foundation for our final prototype.

3.2 Hardware Selection

In this section, we will walk through the hardware selection process. We will explain why we chose each component, their role within the overall system, and how they all connect together. We will also pay close attention to power efficiency, size and weight constraints and if the shoe will be functional and comfortable for the visually impaired users to use.

3.2.1 Shoe Selection

The S.I.G.H.T. shoe system is built around a wearable platform that integrates electronics into everyday footwear to make walking for the visually impaired easy and reliable. The person who will be testing our shoe prototype will be the relative of one of our team members who has a visual impairment, so this became our first step in the hardware selection process. Since she is also diabetic, we had to carefully assess various shoe types, such as sneakers, Crocs, and boots, to determine the most suitable base for embedding our components.

When choosing our shoes, as mentioned above, there are multiple factors that we need to take into account. The first being what type of shoe can hold the most without messing with our components like falling apart. This means we need something sturdy to hold everything together. The next factor would be weight, which shoe can hold the most weight without it being too heavy on the user. Another factor to consider is wiring, what shoe can be easy to wire to install all our components.

Looking at sneakers, we see that they are a good option. We can add our necessary camera to the top of the shoe as well as the ultrasonic sensors. All other components will be placed on the sides or at the bottom of the shoe. The bad thing about sneakers would be the lack of space that will be needed to implement the rest of our components, thus having no room or, in other words, being too compact. Overall, the sneakers will be sturdy and not heavy, but the wiring will be difficult to work with.

Looking at our second option, Crocs, the camera and ultrasonic sensors will be at the top, and everything else will be on the sides and bottom of the shoe, like the first option. Right away we see that the Crocs will not be sturdy enough to hold our components in place like we wanted. The weight will be a bit heavy on the Crocs because the shoe overall is light, so adding the weight of the components will be a little too much. For the wiring portion, these shoes will be the best to wire because of the holes already in the shoes, so wiring and the implementation of the rest of the components will be so much easier than the sneakers.

For the final option we have some type of boots; to be more specific we will look at rain boots for this project. This shoe is perfect for all our factors we specified above. It will be sturdy, where all our components will be held up correctly to have perfect use of the camera, we will have weight distribution for all our parts needed, making our final prototype lightweight and wiring is possible because everything will be spread out and easier to read and demonstrate. Table 3 summarizes the key differences between the three shoe options we researched.

Table 3: Comparison of Shoe Types

Parameters	Sneakers	Crocs	Rain Boots
Sturdy	Moderate	Low	High

Weight	Moderate	Moderate	High
Implementation	Low	Moderate	High

Key: Low = Weak/Less Suitable – difficult to work with, Moderate = Average/Acceptable – in the middle, High = Strong/Ideal – highly suitable for this project

Out of the three shoe types we decided to go for the rain boots to meet the requirements for this project. There were two options of rain boots to decide from, which were the Women's Chelsea Rain Boots and the Dunlop Protective Chesapeake plain toe boots. The following table shows the comparison between both boots regarding ease of integration of the electrical components for the visually impaired users.

Table 4: Boot Comparison for the S.I.G.H.T. shoe

Feature	Dunlop Chesapeake Plain Toe Boots	Women's Chelsea Rain Boots
Space for Electronics	Spacious inside and higher ankle design allows room for wiring, speakers, sensors, LCD, and battery	Limited space and lower ankle design reduces camera view visibility
Material Suitability	Made from thick PVC which is ideal for securing components onto the boot.	Thinner material makes it harder to securely mount the components along with wearing overtime.
Structural Stability	The durable material prevents components from moving or slipping.	The flexible material may cause the material to fall off or slip.
Waterproof	Made from 100% PVC which is a proven waterproof material.	Made from 70% PVC and 30% Polyester means that it has a lower waterproof rating.
Weight Support	Supports the extra weight of the battery and other components thus making it equally distributed across the boot	Due to the boot being smaller, the weight of the components will be concentrated on one part of the boot
Ease of Mounting Components	High	Low

Durability	Strong enough to keep everything together while walking	May be harder to walk in without suffering wear and tear
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The other criteria to consider is the comfortability and accessibility of the boots for the visually impaired. Not only do we want a boot that is compatible with our electrical components, but we also want a boot that will be a perfect fit for our target demographic. The following table compares the boots based on the value for our intended users.

Table 5: Comparison of Two Boot Types

Category	Dunlop Chesapeake Plain Toe Boots	Women's Chelsea Rain Boots
Ease of Slip On and Off	Wide opening and tall structure make it easy to slide foot in	Tighter ankle fit makes it more difficult to put on
Grip and Slip Resistance	Slip resistant bottoms make it ideal for safe walking on slippery or uneven surfaces	Non-slip resistant bottoms increase the risk of falling due to their basic design
Water Protection	Protects the foot and leg from watery conditions up until the mid-calf	Lower ankle height reduces protection and can only tolerate light rain
Support and Stability	Sturdy sole and rigid sides provide ankle support and balance, reducing risks of falling	Less support and structure due to its lower ankle height
Comfort for Long Use	Lightweight but may feel rigid over time	Softer more flexible materials that provide comfort for daily walking
Durability over time	High	Low
Tactile Feedback	Low	High

After comparing both types of boots we went for the Dunlop Chesapeake Plain Toe Boots because they offer greater value and accessibility for visually impaired individuals as well as safely securing our electrical components to the boot.

3.2.1.1 Shin Guard and Socks

In the initial design phase of the Smart Integrated Guidance and Haptic Technology (S.I.G.H.T.) shoe, our team explored a variety of footwear platforms in order to accommodate and support our electrical components which include the microcontroller, ultrasonic sensors, LCD display, vibration and audio haptic feedback, and the battery. As

we mentioned in the sections above, we researched and evaluated the following footwear, sneakers, crocs, and boots before deciding on the Dunlop Chesapeake PVC boots because of their durable, waterproof, and large inside space. But after further discussions with the family member who has a visual impairment, we realized that the boots were not a great choice for comfort and daily usefulness.

Wearing bulky, enclosed boots may not be suitable for all users, especially the users that our product is intended for. It might be difficult for those with restricted movement, of old age, or physically disabled individuals to put on and take off rubber rain boots. Our design philosophy then changed to emphasize comfort and ease of use, which resulted in the creation of a different solution. A system that is based on sock and shin protection.

For right now though, we will continue to work with the boot design, implement all hardware components and make sure we get a functioning working prototype of the S.I.G.H.T. shoe. Once this is done, and we hope to get this up and running by early October we will then implement the concept of a strap on shin guard with an integrated sock layer underneath. The goal with this new idea is to maintain the same functional capability which is obstacle detection with haptic and audio feedback while improving wearability. Once everything is working, we will mount the electronics directly onto the sides of the shin guard and will be worn on the lower leg with Velcro straps. This will make taking off the final product easier to take off and put on. To provide comfort and stability and to prevent the guard from slipping or irritating the skin, a soft, breathable compression sock will be worn below. Overall, with this new concept we introduced we improved ergonomics, easy to use, and comfortable to wear. Our ultimate goal is to develop a final product that seamlessly integrates into users' lives without placing any restrictions.

3.2.2 Microcontroller Unit (MCU) Selection

The most important component for the S.I.G.H.T. shoe is the selection of the microcontroller unit (MCU), which will serve as the central processor that will manage and control all inputs, outputs, sensors, communications tasks and our other key features. When picking the right MCU, we looked for things like processing power, easy for us to work with, whether it can connect wirelessly, size, low cost, and power efficiency. In this section, we will discuss our top choices and the option we went for at the end.

The first option we researched was the Raspberry Pi 4 Model B [8]. This board is a complete desktop computer designed for desktop-class computing. Some of the features this board has to offer are its quad-core 1.5GHz processor, memory up to 8GB, dual displays, multiple USB ports, and gigabit ethernet. Other things are its 40-pin GPIO pins, Bluetooth, and high-power supply. While this is an excellent choice for image processing, which will be good for this project, it consumes significantly more power, it will be harder to code as the group lacks python expertise, its large size, and a bit expensive which is around \$40, which makes the Raspberry Pi not an ideal candidate.

The second option we looked at was the commonly known MSP430FR6989 board [9]. This board was mostly used in our classes at UCF, especially for the embedded systems class, making this board an easy option to use. The MSP430FR6989 is a low-power MCU

that is developed by Texas Instruments, known for its 128KB FRAM memory and minimal energy consumption. This board includes a 16MHz processor, 83 GPIO pins, advanced sensing, a real-time clock, and a 12-bit ADC, and optimized for sensing. On the other hand, this board lacks wireless connectivity, camera support, and processing power needed for the shoe project. While very good for low-power environments, and a price of \$24 which is lower than the Raspberry Pi, coding for this project will take a while as coding in C is a bit much since we will need more lines of code to do one task. This makes the MCU also not an ideal candidate.

Our last option was the ESP32-CAM Development Board [10]. This board is compact and cost-effective at \$15. This microcontroller has key features such as Wi-Fi, Bluetooth, and a built-in camera option. It has a dual-core processor that goes up to 240MHz, plus it supports various communication protocols like UART, SPI, PWM. This board is ideal for our S.I.G.H.T. shoe because of its small size, wireless connectivity, and does not use much power. This board also makes it easy to code and implement in Arduino as the team has a background in it. The only downside to this board is that it has only 10 GPIO pins to use. All in all, the size and efficiency of the ESP32-CAM makes it a great match for what we need.

The table below summarizes the options we have researched for our needed microcontroller board that will make our shoe project for visually impaired individuals possible.

Table 6: Microcontroller Comparisons

Specifications	Raspberry Pi 4 Model B	MSP430FR6989	ESP32-CAM
Processor	Quad-core 1.5 GHz	16MHz	Dual core up to 240MHz
Memory	Up to 8 GB RAM	128KB FRAM	520 KB SRAM + 4MB Flash
Wireless Connectivity	Wi-Fi + Bluetooth	Not Included	Built in Wi-Fi and Bluetooth
Camera Support	Optional	Not supported	Built in camera
GPIO Pins Available	40	83	10
Power Consumption	High	Very Low	Low
Ease of Coding	Low	Moderate	High
Size	Large	Compact	Very Compact
Cost	~\$40	~\$24	~\$15

After evaluating all of our options for the three microcontrollers, we decided to go with the ESP32-CAM [11] for the S.I.G.H.T. shoe project as it made the most practical and efficient choice for our wearable design.

3.2.3 Laser Selection

For our S.I.G.H.T project, the laser diode module is one of the key components needed for the structured light system used for depth mapping and object detection. The ideal laser would have a stable output, with a narrow beam capable of being used with a diffractive optical element for beam shaping to create a stripe pattern. The laser must also be compatible with the embedded system used to control the system. To find out which laser would be best to use for our project, the laser diode modules were evaluated based off the wavelength needed to match the D.O.E. needed which is at 650nm, the output optical power, which cannot pass a certain threshold or additional safety considerations would need to be taken. Beam profile and intensity are compared, as well as uniform beam is essential for projection of the stripe profile. The use of a built-in driver circuit is also essential in this project because of the space constraints of the design being on a shoe and not wanting to give unnecessary work to our electrical engineers as the summer semester shortens development time. Because this student funded project, the price of materials and ease of sourcing were prioritized. Because of the low power requirements in the design, all components need to be able to be powered off a 3.7V battery. Based off these criteria, three laser diode modules were compared from trusted distributors such as Amazon, Thorlabs, and Lasermate. The following table compares laser diode modules.

Table 7: Comparison of Laser Modules

Part Name	Wavelength (nm)	Output Power	Beam Shape	Driver Included	Price
Lasermate LDM-655-04	650nm	4mw	Elliptical	Yes (TTL Modulated)	\$42.00
Amazon Red Laser Module	650nm	5mw	Circular	Yes	\$10.99
Thorlabs CPS635R	635nm	0.6mw	Circular	Yes	\$78.00

For prototyping, the amazon laser will be used, for its low cost and ease of shipping. Eventually, the laser mate laser diode module will be the preferred choice, because of its more uniform output and beam shape. All the information found in the charts was taken from data sheets from the respective websites and sellers [2] [1] [3].

3.2.4 Lens Selection

The optical lens is a crucial component in the structured light system used for our project. The lens is responsible for shaping the laser beam as well as manipulating how well the camera sensor captures the striped light pattern. Choosing the correct lens to incorporate to achieve necessary resolution, field of view, and minimal aberration is crucial. To choose the proper lens compatibility with the existing laser diode module and D.O.E. is necessary.

The lens needs to have a short focal length to achieve a wider field of view needed for short range object detection. The lens needs to have proper aperture and lens diameter with minimal distortion and other aberration. The size and mounting are important as standard sizes can use an m12 or m9 mount. The preferences for the lens are affordability and that they are readily available.

Table 8: Comparison of the Lens

Lens	Focal Length	Field of View	Mount Type	Lens Type	Distortion	Cost
2.1 mm Wide angle M12	2.1mm	160 degree	M2	Wide angle glass	High barrel distorton	\$12.00
6 mm M12 Standard	6.0 mm	60 degree	M12	Glass, multi element	moderate	\$10
Plano Convex	8.0 mm	na	Lab mount	Single element pcx	minimal	\$18

Option 1 is the best for the space constraint of the boot design. The wide field of view comes with barrel distortion, which is an issue for object detection, as this could impact the image of the striped output projection. The second lens is good for testing in a controlled environment with better image quality and sharpness, which will improve the imaging of the striped design. Lens 3 is used for ensuring the laser path remains collimated through the D.O.E. and the information from the chart was provided by the websites and distributors and can be found in the reference section [12] [13] [14].

3.2.5 Structured Light Camera Selection

After testing with the ESP32-CAM, the team transitioned to the ThorLabs CS165CU. This industrial-grade USB 3.0 camera offers key advantages in terms of sharpness, gain control, manual white balance, and frame stability. The CS165CU also provides raw Bayer output for pixel-level processing, which is critical when identifying slight distortions in projected grid lines.

The decision was based on experimental evidence. While ESP32-CAM frequently dropped frames and suffered from compression artifacts, the CS165CU allowed our team to capture crisp, full-frame images with consistent exposure. This was essential for thresholding algorithms and edge detection later in processing. The CS165CU's compact form factor and USB compatibility also made it simple to mount inside the shoe and interface with an external processor.

Though it lacks onboard processing or wireless transmission, the camera's superior imaging quality allows for more accurate detection of object-induced grid warping. Our early tests show that it significantly improves the precision of grid point tracking compared to prior modules.

3.2.5.1 Grid Distortion Algorithm Design

With the camera selected, the next step was to evaluate how to analyze the projected light grid for signs of environmental obstruction. The approach consists of three key stages:

1. Preprocessing: Convert the image to grayscale and normalize brightness to reduce ambient light interference.
2. Grid Point Detection: Use Hough Line Transform or custom edge detection kernels to identify projected grid lines.
3. Distortion Analysis: Detect uneven spacing, line bending, or gaps in the grid pattern to infer physical obstacles.

We considered more complex algorithms like stereo vision or depth-from-focus, but they were deemed unnecessary and computationally heavy. The grid-warp detection algorithm, by contrast, runs efficiently and requires only a single image. It also works under partial occlusion since line deformation is usually visible even when only a portion of the pattern is blocked.

Threshold tuning was key to reducing false positives. Through trial and error, we established optimal spacing and angle variation tolerances, reducing misfires from textured floors or shadows. This image-based module acts as a supplement to the ultrasonic sensor, allowing for richer spatial awareness and improved user safety.

3.2.5.2 Environmental Tuning & False Positive Reduction

A common issue with embedded sensors is misinterpretation of environmental data, leading to false alerts or missed obstacles. This was particularly relevant for our project, where uneven terrain, wet surfaces, or bright sunlight could affect sensor input.

For the structured light module, we addressed this by capturing image datasets under different lighting conditions: indoor fluorescent, outdoor sunlight, and dim hallway settings. Our algorithm was refined to adapt thresholds dynamically based on local contrast and grid density, significantly reducing error rates.

For ultrasonic sensors, averaging filters and redundancy checks helped to validate object presence before feedback was triggered. We also introduced logic to ignore objects that appear for less than 100 ms, preventing misfires from thin poles, leaves, or surface reflections. These refinements were the result of careful field testing and iterative firmware improvements.

3.2.5.3 Event Patterns

As part of our structured light distortion analysis, we documented and categorized the most common types of grid deformation patterns encountered during environmental testing. Each distortion type provides specific visual cues that can be mapped to likely real-world obstacles or terrain changes. This mapping enables the system to trigger different feedback intensities tailored to the urgency of the hazard. The table below summarizes the most frequently observed distortion events, their likely causes, and the corresponding system responses designed to alert the user effectively.

During our preliminary distortion classification tests, we observed recurring visual anomalies in the gridded light pattern that could be systematically linked to common environmental obstacles. By defining these visual signatures and their likely causes, we established an early decision framework for the system’s real-time response logic. The table below summarizes four of the most distinct distortion types we recorded, along with their expected triggers and the system responses programmed to alert the user accordingly. These classifications will serve as the foundation for future refinement and expanded detection accuracy.

Table 9: Comparison Pattern Type

Pattern Type	Visual Signature	Likely Cause	System Response Triggered
Bent Lines	Curved horizontal or vertical segments	Wall, leg, or pole	Short pulse + audio alert
Gaps/Broken Lines	Missing sections in the grid	Edge of step, object in path	Stronger vibration
Blurred Grid	Soft, smeared edges	Water, fog, transparent barrier	Audio only (non-urgent)
Angled Skew	Tilted or diagonal line deformation	Slope or hill	Mild haptic warning

Test examples:

To validate system performance, we will conduct multiple trials simulating real-world walking paths with embedded obstacles. Currently, we have saved two reference images from the gridded light system. One showed an undistorted pattern projected onto a flat surface and another displaying visible distortion caused by an obstacle. Our detection algorithm was able to accurately distinguish between the distorted and undistorted images, confirming the basic functionality of the structured light analysis module. This distinction then allowed the code to output “Object Detected” and “Detecting...” depending on whether the gridded light system was distorted or not respectively.

The figure below illustrates the gridded light system projected onto a flat, unobstructed surface. This undistorted pattern serves as a visual baseline for our structured light detection algorithm. Because the lines remain evenly spaced, parallel, and symmetrical, the system can use this reference to detect any deviation or distortion caused by nearby obstacles. Establishing this clean grid projection is critical for calibration and allows our code to reliably differentiate between normal terrain and potential hazards during real-time operation.

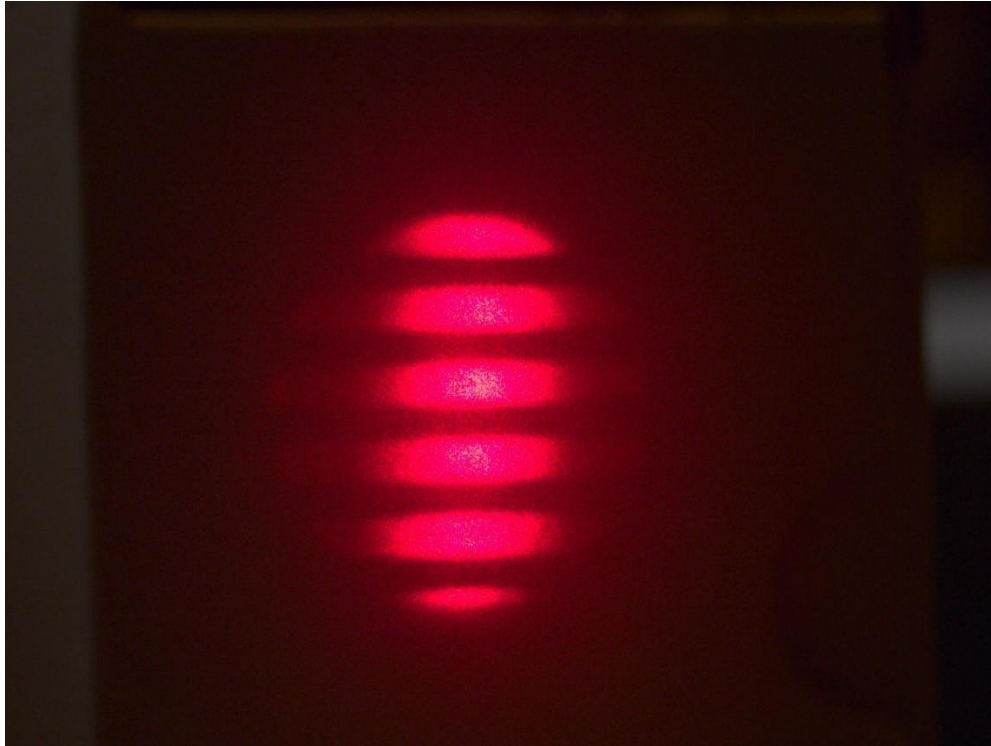


Figure 10: Undistorted gridded light system

The figure below displays a distorted version of the gridded light system caused by the presence of an object within the projected area. Unlike the uniform pattern seen on flat surfaces, this image shows gaps in the lines that indicate a disruption in the light path. These distortions provide essential visual cues for our obstacle detection algorithm, allowing the system to identify the presence, shape, and approximate location of nearby hazards. This type of deformation is what triggers the feedback mechanisms in the S.I.G.H.T. smart shoe, such as vibration or audio alerts.

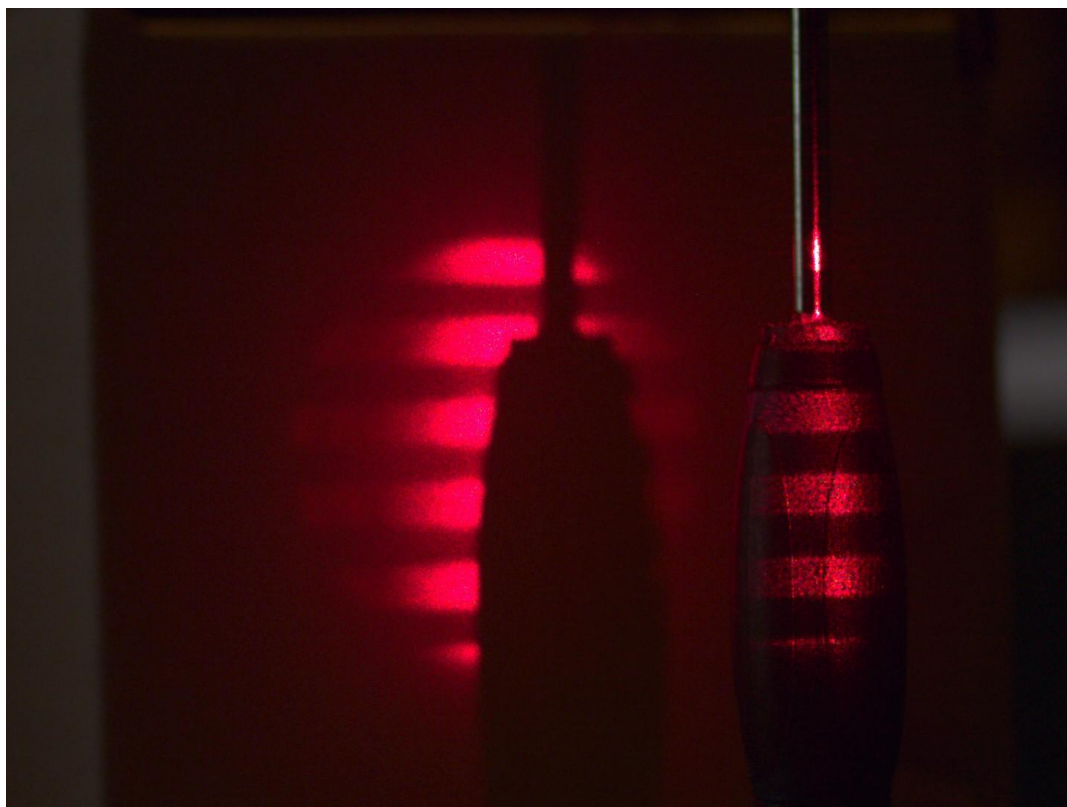


Figure 11: Distorted gridded light system

The figure below shows the current output of our distortion detection algorithm. The output prints “Detecting” while looking at figure 10 to signify that it is still looking for a distortion in the gridded light system. Later the output prints “Object Detected” to show that it sees a distortion in the gridded light system as shown in Figure 12. This algorithm is a current baseline for our distortion detection algorithm. As we move forward in Senior Design 2, we plan to work towards allowing the code, camera, and gridded system to be able to work effortlessly to signal audio and vibrational cues to show an objects distance from user and direction so that users with visual impairment can navigate effortlessly through various environments.

```
>> distortiondetection
Detecting
Object detected
>> distortiondetection
Detecting
Object detected
```

Figure 12: Distortion Detection Output distortion

In one planned scenario, the user will walk toward a recycling bin positioned approximately 1.2 meters ahead on a flat sidewalk. We anticipate the projected grid will show a horizontal compression pattern upon approach, which should trigger a high-priority alert. The system is expected to activate the vibration motor at full intensity for 500 ms, followed by a distinct audio tone to notify the user.

Benefits of Structured Light Pattern Analysis:

By translating optical distortion into categorized alerts, we enable the shoe to function not just as a binary obstacle detector, but as a spatial awareness tool. Over time, we plan to expand the pattern database and train the system to auto-calibrate thresholds based on user walking style, environmental lighting, and grid projection angle. These insights will support improvements in both reliability and user trust, especially in outdoor environments where unexpected terrain can pose serious hazards to visually impaired individuals.

3.2.5.4 Comparison to Other Wearable Vision Systems

Wearable computer vision systems typically fall into two categories: obstacle avoidance aids and navigation aids. Our S.I.G.H.T. shoe aligns more with the former but introduces a unique structured light approach, unlike conventional camera or LiDAR setups.

Most available systems rely on cameras mounted on glasses or belts, which can be invasive or require directional orientation. In contrast, S.I.G.H.T. projects light downward from the foot, avoiding the need for directional calibration. The depth feedback is locally processed and fed back to the user in real time without requiring internet or cloud services.

Some vision-based smart canes rely on infrared structured light or stereoscopic lenses, but these are bulky, expensive, and often unreliable in bright light. Our laser grid design is compact and can be tuned to visible red light, which performs well under various ambient conditions. While not as advanced as full 3D reconstruction, our implementation balances simplicity and real-world usability. We expect future iterations to improve even further with the integration of lightweight processors and more adaptive vision algorithms.

3.2.6 Camera Selection

The camera sensor is an integral part of the structured light system because it captures the distortion and deformation in the projected pattern, which is used to generate a depth mapping using spatial geometry. The system used for our S.I.G.H.T. project needs to be low power, and small in spacing, but able to identify distortions in the projected pattern in real time. To choose the best camera module for our project, the key characteristics to be considered include resolution as adequate pixel density is needed to capture the stripe patterns. The frame rate needs to be high enough that objects can be detected, and the user can be notified in real time. Without this feature, the product would not be useful. The selected camera module must also be compatible with the microcontroller used for the project. Again, the form factor is key, because the S.I.G.H.T. is a boot design with limited space for components. The lens mount should support customizable lenses, and the system is designed to run on low power. Cost and availability are crucial because this is a self-funded student project. The camera comparison will be shown in the table below.

Table 10: Comparison of the Camera Types

Camera	Resolution	Interface	Lens Mount	Operating Current	Cost
ESP32_CAM	1600x1200	Wi-Fi, UART	Fixed M12	160mA	\$7.00
Arducam Mini 2mp	1600x1200	SPI	M12 swappable	140mA	\$15.00
Raspberry Pi Camera Module 3	4608x2592	CSI	M12 or CS mount	250mA	\$25-\$35

The ESP32-CAM was selected as the primary imaging sensor used for the imaging system for several reasons. The low power consumption and native Wi-Fi capability enable easy programming integration. The camera unit we chose has sufficient resolution to be able to detect the distortion in the striped patterns for the structured light system, which will detect objects at a short range of 2 meters. The low cost and affordability make it ideal for a student-led project like our own. The camera module is easily integrated with the microcontroller and supports basic image processing where Matlab can be used to calculate distortion. The raspberry pi camera module offers higher resolution but was not chosen due to the need for a dedicated pi host board. The Arducam offers flexibility but falls short in real time object detection and the information found in the table can be found in the reference section [15] [16] [17].

3.2.7 Ultrasonic Sensor Selection

For our S.I.G.H.T. shoe we will work with ultrasonic sensors for part of our obstacle detection and distance measurement feature. To determine the best sensor for our design, we compared three commonly used ultrasonic sensors based on range, accuracy, and ease of integration with the ESP32-CAM.

The HC-SR04 is the first option we examined since it is a very popular sensor, and we also used this component as part of our Junior Design course at UCF. This ultrasonic sensor is low-cost with a detection range of 2cm to 400 cm and accuracy that can reach 3mm. It uses it's I/O pins to produce accurate distance measurements and runs as 5V. However, the ESP32-CAM uses 3.3V, but this can be fixed through using a simple boost converter. All things considered, this is the best choice due to its small size and reliable performance, which make it a good fit for obstacle detection for our shoe project.

The next ultrasonic sensor we looked at was the JSN-SR04T-3.0 [18]. This sensor ranges from 21cm to 600cm. It has a precision that can reach as high as 3mm and even though this is a longer distance from the HC-SR04, [19] this sensor has a slower response time. It is also a waterproof version of the ultrasonic sensor, which is a good feature, especially to have for outdoor use like what is needed for our shoe. This sensor also operates at 5V and requires more space and power making it less ideal for what we need.

The last option was the RCWL-1601 ultrasonic sensor which is a smaller sensor compared to the rest. It is compatible with 3.3V and 5V and the 3.3V can work with the ESP32-CAM. It offers a shorter range and only goes up to 2-400cm for 3.3V and 2-450cm for 5V [20]. This sensor results in less accuracy. This ultrasonic sensor has some difficulty in troubleshooting and integration thus making this ultrasonic sensor also not a reliable option. The table below summarizes our comparisons between the three ultrasonic sensors modules based on key performance, compatibility, and integration for the S.I.G.H.T shoe.

Table 11: Sensor Comparison Table

Feature	HC-SR04	JSN-SR04T-3.0	RCWL-1601
Voltage Operation	5V	5V	3.3V – 5V
Range	2-400cm	20-400cm	2-440cm
Accuracy	~3mm	~5mm	~5-10mm
Waterproof	No	Yes	No
Size	Compact	Heavy and Large	Small
ESP32-CAM Compatibility	Needs boost converter	Needs boost converter	Yes
Cost	~\$3	~\$8	~\$3
Best Fit for Shoe Project	Yes	No	Maybe

After comparing our three options, the HC-SR04 ultrasonic sensor was selected for our S.I.G.H.T. shoe due to its reliable performance, range, compact, and cost-effective design. While it requires 5V, we will implement a boost converter to allow smooth integration with the ESP32-CAM.

3.2.8 LCD Screen Display Selection

Another hardware component we plan to add to the S.I.G.H.T. shoe is the liquid crystal display or LCD. This component is a flat panel display screen that is used in embedded systems and is known for its low power consumption, compact size, and cost efficiency as well as they come in different dimensions. For the Smart Integrated Guidance and Haptic Technology (S.I.G.H.T.) shoe, the LCD screen will help us as engineers to verify outputs, calibrate sensors, and to make sure that the final product is functioning as expected. This feature can provide critical information to caretakers or users on obstacle detection alerts, this will work alongside the vibration and speaker components, give the battery level of the shoe, and for the future to possibly give status during new software updates. But for

now, the LCD screen will help us make sure that the S.I.G.H.T. shoe is working during prototyping by working with the ultrasonic sensors and displaying distance readings. Below we will discuss three different types of LCD displays and compare each one to find the right fit for the final design of our product.

The first option we investigated was the OLED 0.96" I2C Display. This screen comes in a compact design that supports a 128x64 pixel grid [21]. It also does not need any backlight, and it uses less power than the classic LCD screens. It operates at 5V and comes with its own voltage regulator, which is good because it can be compatible with a 3.3V. It uses the SSD1306 driver and works with via the I2C communication. This makes integration easier to work with. The issue with this board is that it is more complex to program rather than the text only LCDs. This option is not ideal for our wearable shoe product as it will be harder to read and work in bright outdoor settings.

The next option is the LCD1602 display screen. This LCD display screen is the most widely used in embedded systems. This one is the one that the team is most comfortable with because we have used this screen in the Junior Design course offered at UCF. This blue screen offers two rows of 16 characters each with a parallel interface that is controlled by the MCU [22]. This screen operates at 5V and is composed of a 5x8 dot matrix for good character representation [22]. This screen also has the option of a backlight that can connect with a potentiometer that can help with adjusting the contrast of the display for best viewing. This LCD display is cost effective, easy to use with any microcontroller but will be best with the ESP32-CAM that we are using. However, this screen only works with text and no graphics, but it works since that is not what we intended to use.

The last and final option we researched was the 1.44" TFT Color Display. This LCD screen is a full graphical 128x128 pixel resolution [23]. It uses the DT7735 driver and connects via the SP1 to offer a vibrant color display. However, because of these advanced features it requires higher power consumption, will require more GPIO pins and programming is more complex than the other two options above.

After analyzing the three options, the LCD1602 is chosen as the ideal LCD screen display for the S.I.G.H.T. shoe, due to its simplicity, low power needs, and ease of use. While the OLED and TFT displays offer enhanced capabilities, they create more complex problems with their advanced features. The table below shows the comparison of each option and their features they have to offer as well as a summary of which LCD screen display we chose.

Table 12: Comparison of LCD Displays

Feature	OLED 0.96" (SSD1306)	LCD1602 (16x2)	TFT 1.44" Color (ST7735)
Display Type	Monochrome Graphics	Text only 2 lines	Full Color Graphics
Interface	I2C	I2C or Parallel	SPI

Resolution	128x64 pixels	16x2 characters	128x128 pixels
Cost	~\$8	\$3.50	~\$8-\$12
Power Consumption	Low	Low	High
Ease of Use	Moderate	Low/Easy	High

3.2.9 Vibration Motor Selection

The S.I.G.H.T. shoe system is designed to make every day walking a more comfortable and easy experience for the visually impaired. This means that any features we add to the shoe need to be safe for human interaction on an everyday basis. A key feature for this system is the vibration motor that will assist the user by vibrating when an obstacle is detected in its path. When selecting a vibration motor there were many to choose from that would be considered adequate for this system, but ultimately, we can only choose one. Below are three potential vibration motors and an explanation into why one is selected.

Seed 316040001:

The Seed 316040001 is a brushed DC eccentric mass (ERM). It has a voltage of 2.5-3.5V and an expected current is <80mA typically. It is ideal for compact DIT electronics and the coreless DC allows bidirectional mounting. These features could make this motor ideal for our project. However, all ERM's have a coarse vibration (buzziness) which means it will have an uncontrolled frequency. This is not ideal since we would like the vibration motor to be strong and have a clear frequency level that skin-to-skin contact will allow. This motor does, however, run on a classic DC voltage input which is an important factor to consider when choosing a motor. This means that there will not need to be any other additions to the PCB. This product is meant to be worn daily and needs to be the most stable and have a strong vibration, we will not be choosing this device for our product.

DFRobot FIT0774:

The DFRobot FIT0774 is a brushed DC eccentric mass (ERM). It has a voltage of 1.5-4.2V DC(3V rated) and a typical 50mA at 3V current. It has a RPM of $11,00 \pm 2,500$ and is an ideal small form factor for wearables. As stated above in the Seed vibration motor, ERM's have a buzziness to their vibration, which is not ideal when we would like a very clear sensation when letting the user know there is an obstacle in its path. However, this motor runs directly from a DC voltage source which is easier and can be then run on a battery of our choosing rather than needing any other additional inputs to the PCB. Similar to the Seed above, we need to have the safety of the motor against the skin and although this can be done with this device, we would like to be able to have control over the frequency and precision on the motor which is not applicable when it comes to this motor.

Vybrionics VG0840001D:

The Vybronic VG0840001D is a Linear Resonant Actuator (LRA) AC type. It has a voltage of about 2VAC sine drive at 170Hz but does require a LRA drive circuit. This vibration motor has a crisp haptic response and has a low latency, but it will require a dedicated driver IC. The downside to this device is that it does require an AC sine wave driver. This is a downside since it will mean adding this component to the PCB. An AC sine wave driver (like the DRV2605) is meant to help the LRA with waveform library and auto-resonance tracking. As per its description from Texas Instruments “The DRV2605 device is designed to provide extremely flexible haptic control of ERM and LRA actuators over a shared I2C-compatible bus. This control relieves the host processor from ever generating pulse-width modulated (PWM) drive signals, saving both costly timer interrupts and hardware pins”. This is a vital part of the design of our board but it will be necessary when initializing this motor. This motor provides the most accurate and clear vibrations and is optimized for skin contact and because of the consistent resonant frequency it is easier to feel on the skin and should be quieter. The life span is also significantly longer than the ERM devices and will benefit our product.

Ultimately, for this product we will be choosing the Vybronic VG0840001D for our vibration motor. It provided the best capabilities out of the chosen vibration motors regardless of the additional features needed to be added to the PCB design.

Table 13: Comparison of Vibration Motors

Parameters	Seed 316040001	DFRobot FIT0774	Vybronic VG0840001D
Size	D: 9.91mm, Thick: 2mm	D: 10mm, Thick: 2.7mm	D: 8mm. Thick: 4.05mm
Weight	0.9g	1.82g	1.27g
Freq.& Sensitivity	Uncontrolled frequency	Uncontrolled frequency	~170Hz (consistent resonant frequency) Optimized for skin contact, commonly used in wearables
Price	\$1.20 (in bulk)	\$0.99 (each)	\$5.39 (each)
Durability	N/A	~100k cycles	Excellent longevity/consistent response
Requirements	None	None	Requires a LRA driver circuit

3.2.10 Vibration Motor Driver Selection

For the S.I.G.H.T. shoe, we will need a vibration motor driver that will control the vibration required for this project. This driver will need to produce minimal vibrating sensations that will not affect the user through skin interaction. It will need to provide tactile feedback so it can allow users to feel alerts when an obstacle is detected 2 meters away. It also needs to use less power, so it doesn't drain the battery right away. Below we will discuss three types of vibration motor drivers and then choose the best fit that will work for our final product.

The first option we researched was the DRV2605L by Texas Instruments. For this vibration motor driver, we see that it is both a Linear Resonance Actuator (LRA) and an Eccentric Rotating Mass (ERM) motors [24]. This means that both are capable of producing complex and subtle vibration effects. This driver supports a voltage range of 2V to 5.2V, and it communicates with the microcontroller via I2C interface. This will help with enabling control over motor operation. This driver also includes over 100 licensed effects, six ERM and one LRA library as well as audio-to-vibe features [24]. The DRV2605L vibration motor driver is a strong choice because of its drive capability and integrated feedback loop. This will give accurate vibration strength. However, the cons of this device are that it is too complex when it comes to programming, the I2C feature will require more wiring, and its advanced features can cause problems for simple vibration needs.

The next option we looked at was the SparkFun Electronics 14538 Vibration Motor Driver. This is very similar to the DRV2605L, this is because the DRV2605L is the actual motor driver chip, and the SparkFun 14538 is a breakout board that includes this chip and all necessary components. It is simple compared to the first option, and it specializes in Eccentric Rotating Mass (ERM) [25]. It also functions at 2V to 5.2V and uses a pulse width modulation input with a 0-100% duty cycle to regulate vibration intensity [26]. This vibration motor is easy to use and has basic speed control, compact size, and affordable. This is an ideal choice as this fits the criteria that we are looking for in a vibration motor driver.

The last option we looked at was the Adafruit DRV8833 Dual Motor Driver. This driver is a general-purpose dual motor driver that is capable of controlling two DC motors. It supports a wide power supply voltage range of 2.7V to 10.8V [27]. It can also deliver current up to 1.5A per channel. This also can be controlled via PWM to signal for speed and direction. While this is good, this causes more complex programming because it has the power to control multiple motors instead of one, if we only stick to vibration motors. The DRV8833 does not have the features of haptic effects or any specific vibration types. This driver is considered larger than the SparkFun 14538, it also may cause an overkill for simple vibration. Thus, not making this a good option.

After comparing these three vibration motor drivers, the SparkFun 14538 is the best choice to go with as it prioritizes simplicity, cost efficiency, and reliable control. While the DRV2605L is the runner up because of its advanced features we did not go with this option as its complexity and higher cost make this driver less suitable. The Adafruit DRV8833 is also great for dual motor setups but lacks specialized vibration motor control and it is also larger than the rest. The table below summaries all three vibration motor drivers.

Table 14: Comparison of Vibration Motor Drivers

Feature	SparkFun 14538	DRV2605L Texas Instruments	Adafruit DRV8833 Dual Motor Driver
Motor Type Standard	ERM vibration motors	ERM and LRA vibration motors	DC motors and vibration motors

Control Interface	Simple PWM control (1 pin)	I2C communication	PWM speed and direction control
Voltage Range	~2V – 5.2V	~2V - 5.2V	2.7V – 10.8V
Current Capability	Works well with small vibration motors	Integrated current feedback control	Up to 1.5A per channel
Built-in Vibration Effects	No	Yes, over 100 pre-programmed effects	No
Ease of Use	High	Low	Moderate
Size	Compact	Small but still needs extra components	Larger
Cost	Cost effective	Higher cost	Cost effective
Best For	Simple vibration	Advanced vibration	Dual motor control

3.2.11 Rechargeable Battery Selection

The core value of this product for the S.I.G.H.T. shoe is to be an easy and helpful guide for anyone who is visually impaired. That being said, one of the key features for this project will need to be the rechargeable battery. The rechargeable battery is arguably one of the most important parts of this project since it will provide power to all components. Without a perfectly working battery this project will not be able to run at the desired efficiency that the product is looking for. This includes easy recharging and a long battery life. After researching rechargeable batteries, three have stood out as potential options for our device. We will break these down and explain our selection.

Before we begin our explanation of the three possible batteries, there is one battery that met almost all product requirements and would have been chosen for our product had it been in production or sold in the United States during the time of our project. This rechargeable battery is the Panasonic NCR18650B. This would be the ideal battery simply due to its capacity capabilities which are far greater than any of the other batteries listed. In the table below, I have added this as a comparison to the other batteries, since this would have been the ideal choice.

Adafruit 2011 Li-Ion:

The Adafruit 3.7V 6600 mAh LiPo battery is an excellent choice for this project due to its high capacity, built-in protection, and compatibility with typical wearable electronics. It has a large 6600 mAh capacity which provides longer runtime, making it ideal for our project, which will need to operate continuously for many hours without recharging. To be precise, if we assume our product consumes 200mAh, we can use the formula $6600\text{mAh}/200\text{mAh} = 33$ hours before the battery needs to be charged. this would exceed our goal by 23-27 hours, which is a significant upgrade. The integrated protection circuit ensures safe operation by guarding against overcharging, over-discharging, and short circuits, which is especially important in portable applications. Additionally, its standard JST-PH 2.0mm connector makes it easy to integrate with power management boards and is compact and lightweight. This battery strikes a great balance between performance,

safety, and ease of use—making it a reliable power source for embedded and wearable systems.

Adafruit 150 mAh:

The Adafruit 150 mAh is a Li-Po Pouch or Lithium Polymer. This type of battery is flexible and lightweight and comes in customizable sizes. It is ideal for small wearable products. But the battery is more fragile and is sensitive to overcharge (discharge). This battery has a voltage of ~3.7V and a capacity of 150mAh. This is a significantly lower capacity compared to the other two batteries listed. As stated in the Dantona L37A26 battery example, to find the duration of a battery, we will divide the given 150mAh by an estimated consumption (using the same from above 200mAh), $150\text{mAh}/200\text{mAh} = 45$ minutes. This means the user would need to charge the shoes every 45 minutes and therefore it is not practical. A benefit to this battery, however, is the flat pouch form and the easy to use plug in wires and is incredibly lightweight. This makes the battery easy to install. A significant downside is that this type of battery is typically made for small low-power devices and not typically used in large main power systems. This is not an ideal candidate for our battery options.

SparkFun 2.6 Ah:

The SparkFun 2.6 Ah is a 18650 Li-Ion or Lithium-Ion Cylindrical Cell. Lithium-ion cylindrical cells (as stated in the Dantona L37A26 battery) are widely available, have a high energy density, have a robust casing, and thermal stability. But they are ridged and are heavier than pouch cells. This battery has a voltage of ~3.7V and has a capacity of 2,600mAh. This battery does not have simple easy to use wires but rather requires a holder and protection for battery stability. Without circuit protection this could be very dangerous, which will mean another part will need to be installed. This battery does have the same capacity as the Dantona L37A26, which means it should have a similar runtime. Which means it should reach our duration goal of 6 - 10 hours of power. This battery does meet the specifications we are looking for but we will need to add protection, which would provide overcharge, over-discharge, and short-circuit protection to ensure safe charging (and discharging) for the battery, as well as a battery holder. This is not an ideal candidate for our battery options.

After careful consideration of the parameters of all three batteries, the best fit for the S.I.G.H.T. shoe will be the Adafruit 2011 Li-Ion. Due to its popularity, stability, simplicity, and its capacity which will help us reach our longevity of daily use.

Table 15: Comparison of the Rechargeable Batteries

Parameters	**Panasonic NCR18650B (This would be the ideal candidate but is out of stock, this is a comparison)	Adafruit 2011 LI-ION 3.7V 2AH	Adafruit 150 mAh	SparkFun 2.6 Ah

Battery Type	18650 Li-Ion Cylindrical Cell	Lithium Polymer rechargeable	Li-Po Pouch Cell	18650 Li-Ion
Voltage	3.7V	3.7V	3.7V	3.7V
Capacity	3,400 mAh	6,600 mAh	150 mAh	2,600 mAh
Current	~2-3 A (continuously)	Up to ~1-2 A (continuously)	~200 mA	~2-3 A
Protection Circuit	No: would need to add separately	Yes: built-in	No	No
Connector	No	JST-PH 2.0mm 2-pin	JST-PH 2-pin	Bare terminals
Price	~\$11.00	~\$12.50	~\$5.95	~\$11

3.2.12 Battery Charger Selection

For this selection we will need a battery charger that charges the battery we chose from above in the Rechargeable Battery Selection. The specifications for this part are to safely and efficiently replenish the energy stored in a rechargeable battery. It will also need to control the voltage and current delivered to the battery, to ensure that charging is done within safe limits to prevent overheating, overcharging, or damage. This is important to research due to the wearable device of our S.I.G.H.T. shoe, since it will need to be safe for the user and have battery longevity. Below we will discuss and compare three battery charging modules to determine which is the best suited for the smart shoe. Each option will be evaluated on features such as size, safety, current, and compatibility with the shoe.

The first option we will look at is the SparkFun LiPo Charger Basic (PTH08080) Micro USB. This charger is based on single cell lithium, it uses the MCP73831 chip but has fewer integrated features. It provides charge current from 15mA to 500mA [28] and comes in a small breakout form. The pros for this charger is that it is compact and micro-USB input. On the other hand, this charger lacks advanced protection circuitry and has no onboard status indicators. This charger is a good option but not ideal choice for the S.I.G.H.T. shoe. The second option for the battery charger we looked at was the TP4056 charging module. This module is a low-cost lithium battery charger, it can provide 1000mA of charge current over micro-USB and includes protection circuitry [29]. While this battery charger has high charging current the TP4056 board is often heavier, lacks quality assurance, and may be too much for small batteries. Thus, this is also not a great choice for the S.I.G.H.T. shoe.

The last option we researched was the Adafruit Industries LLC 4410. This battery charger is a compact and efficient lithium-ion/polymer battery charging module that is based on the MCP73831 chip. This charger is also designed for single cell batteries and is ideal for low power systems which would work greatly for this project. This device offers minimal external components making this battery charger lightweight and easy to use. It also

provides automatic charge termination and status indication. The Adafruit 4410 is perfectly suited for the final design that works for safety, reliable, and efficient charging.

The table shown below shows the three different types of battery chargers and compares each feature to find the right one. The team went with the Adafruit 4410 battery charger selection because of it of its compact size, safety, current, and compatibility with the S.I.G.H.T. shoe.

Table 16: Comparison of Battery Charger

Feature	SparkFun LiPo Charger Basic (PTH08080) Micro USB	TP4056 charging module	Adafruit Industries LLC 4410
Charging chip	MCP73831	TP4056	MCP7381
Charging current	500mA	1A	500mA
Input interface	Micro-USB	Micro-USB	Micro-USB
Protection circuitry	None	Built in	Built in
LED indicators	No	Yes	Yes
Board Size	Compact	Large	compact
Ease of use	Low	Moderate	High
Cost	\$4.95	\$3	\$5.95

3.2.13 Speaker Selection

To make absolutely certain the S.I.G.H.T. shoe will function at the highest level, installing another obstacle alert sensor is imperative. Similar to how the vibration motor will vibrate when an obstacle is within a certain distance from the boot, the speaker will alert the user whether an object is on the left- or right-hand side of the user. This gives the user double the amount of coverage (Vibration motor and Audio speaker) and makes sure that the user has as much time to avoid possible collisions. This project will only require one type of speaker. Below we have listed three possible speakers and reasons as to why or why not the item was chosen.

Same Sky CDS-15158-SMT-TR:

The Same Sky CDS-15158-SMT-TR speaker has a Sound Pressure Level (SPL) of 87dB, a power of 0.3W, a size of 15x15mm, and a frequency range of 800 Hz - 20 kHz. Breaking this down, the SPL is at 87dB which although is not bad at all and in reality is a very good volume level, it is not as loud as the other speakers selected. The power is 0.3W which is a lower power and although suitable for small rooms or lower volume listening, this is not an ideal choice when it comes to this product. This shoe will require to be worn in all types of settings, meaning a speaker best at low volumes will not be applicable to the daily life

of the user. Another issue with this potential speaker is its size. This speaker is on the smaller size compared to the other two speakers and it may not produce sound loud enough for outdoor usage. And lastly, the frequency range is perfectly acceptable for outdoor usage, other speakers have a wider range. Another small but important factor about this speaker is the fact it is not weather resistant. This is a very good speaker but arguably not the right fit for this project.

Same Sky CDS-20144:

The Same Sky CDS-20144 speaker has an SPL of 92dB, a power of 1W, a size of 20x14.4mm, and a frequency of 800 Hz - 20 kHz. Breaking this down, the SPL is at 92 dB and when compared to the other speakers listed is the loudest. This is a very important feature since it will allow for us to input a much louder sound and make sure the user can hear the alert in a noisy area. The power is 1W, which is again a very good characteristic since the more power the speaker has the more the user can hear it in noisy areas. This is yet another benefit to choosing this speaker. The size, however, is not as good as other speakers. Although the size of this device is 20x14.4 mm and is decent in a general sense it would have been more beneficial to have a larger speaker that could generate sound to higher places (the users' ears above). Lastly, this device has a frequency of 800 Hz - 20 kHz. This is not a huge loss in terms of outdoor use; however it is not as wide a range compared to other speakers in this comparison. For a few side comments about this device, it is not weather resistant and the mounting aspect of this could be a particular challenge for the shoe itself. For this project device is a high contender in terms of valuable characteristics for this project.

PUI Audio AS02708CO-WR-R:

Lastly, the PUI Audio AS02708CO-WR-R, has an SPL of 88 dB, a power of 0.5W, a diameter 27mm, and a frequency of 300 Hz - 20 kHz. What does this mean? With an SPL or Sound Pressure Level of 88 dB we can say that this speaker can produce a decent level of noise - although comparing it to the Same Sky CDS-20144 it is not as loud and therefore loses some credibility in the selection. Nevertheless, the speaker should be loud enough to produce loud sounds or alerts. The power is 0.5W and although not bad, the more power the object has, the louder the speaker can produce noise. A key feature is the actual size of the device. The diameter is 27mm and therefore is the largest speaker in this list. This is arguably the best speaker to choose from given this characteristic since it will be able to project farther. Lastly, the frequency being from 300 Hz - 20 kHz is a huge advantage. This is the widest frequency range in this list and therefore produces a better low-end response - which means it will produce more perceptible tones outdoors. An added bonus to this speaker is the easy mounting capabilities and the weather resistance. Easy mounting makes for less issues in the installation process and less mistakes. The weather resistance is a huge bonus. This could be the determining factor in choosing this speaker since this is to be placed on a shoe and needs to withstand the outside world for the user's everyday use.

After comparing the speakers selected in this list. We ultimately ended up going with the PUI Audio AS02708CO-WR-R for its weather resistance, frequency range, size, and easy mounting capabilities.

Table 17: Comparison of Speakers

Parameters	Same Sky CDS-15158-SMT-TR	Same CDS-20144	Sky PUI Audio AS02708CO- WR-R
Size & Weight	15x15mm (rectangle) 2.1g	20x14.4mm (rectangle) 1.3g	27mm (circular) 4.5g
SPL	87dB @10cm	92dB @ 10cm	88dB @ 10m
Mount Type	Surface	Surface	Through-hole
Frequency	800 Hz - 20 kHz	800 Hz - 20 kHz	300 Hz - 20 kHz
Weather Resistant	No	No	Yes
Power	300mW	1W	0.5W
Impedance	8 Ω	4 Ω	8 Ω

3.2.14 Speaker Amplifier Selection

Now that we have our speaker chosen, we will need to decide which amplifier is needed to fit this speaker so that it can boost low power audio signals from the microcontroller to a higher power level that can work with the speaker and produce sound that is not too loud but loud enough for the user to hear the alerts. Below we will discuss three choices to see which amplifier will fit best with the PUI Audio AS02708CO-WR-R speaker.

We will begin with the Adafruit 2130, also known as the PAM8302A Mono Class D Audio Amplifier. This device is super small and capable of delivering 2.5W into a 4-8 ohm impedance speakers [30]. Taking a look at the chip inside of this amplifier we can observe that it runs on 2.0V-5.5V DC voltage supply. With the class D chip, the Adafruit 2130 is very efficient which can go over 90% efficient when using an 8ohm speaker [30]. This device also is ideal for low voltage battery powered systems, which is perfect when working with the S.I.G.H.T. shoe. This module counts on a fixed gain of 24dB making this amplifier a great choice for its clean audio output with minimal distortion, small size feature, and easy to implement. It also generates low electromagnetic interference (EMI). Even with its mono output only and fixed gain this speaker amplifier makes a great choice for our final design.

The next option we researched was the PAM8403 Stereo Class D Amplifier. For this amplifier it is a very popular choice for speaker amplifiers. It provides two 3W channels into a 4-ohm load and 5V power supply [31]. This module also falls into class D which means that its efficiency can go up to 90% making this amplifier efficient. Another feature that this module has is that it can also produce low EMI as the first option as well, it has very low noise and is easy to control volume with its two-channel stereo output which makes controlling the volume easier for the user to adjust in different environments. On the other hand, this amplifier is larger compared to the Adafruit 2130 and it requires extra wiring thus not making it user-friendly. This option is great but not for what we need for our final design.

The last option is the LM386 Analog Audio Amplifier, which is another option that everyone uses. This amplifier operates at a voltage range from 4V to 12V or 5V – 18V [32]. It outputs around 0.5W of power which is lower than the two options above. The LM386 requires external components like resistors and capacitors to set gain and filter the output, which makes implementation more complex. When we consider the pros and cons for this amplifier the pros of this device are its simple analog design but for the cons we see that it has poor efficiency compared to the first two choices, requires more components, distortion, on the bigger side and does it generates more heat and is less power efficient which is not good for the wearable shoe.

After comparing all three speaker amplifiers, the Adafruit 2130, also known as the PAM8302, was selected as the most suitable amplifier for the S.I.G.H.T. shoe. The table below summarizes these three options and demonstrates why we chose the Adafruit 2130 for its performance, simplicity, and reliability.

Table 18: Comparison of Speaker Amplifiers

Feature	Adafruit 2130 PAM8302A Mono Class D Amplifier	PAM8403 Stereo Class D Amplifier	LM386 Analog Audio Amplifier
Type	Class D Mono	Class D Stereo	Analog
Output Channels	1	2	1
Max. Output Power	2.5W at 4-8 Ω	3W at 4 Ω	~0.5W
Voltage Range	2-5.5V	5V	4-12V or 5-18V
Size	Compact	Big	Larger
Efficiency	High	High	Low

For the battery we selected, Adafruit Industries LLC 2011, we need to regulate the voltage to different components that require different voltage levels. Since the battery we have chosen has a nominal voltage of 3.7V, we will need to use a voltage booster and a buck-converter to help regulate the voltage from 3.7 volts to 3.3 volts or 5 volts respectively. In the next two sections we will be giving a detailed explanation into which booster or buck-converter we selected, other options we considered, and why or why not we choose our specific component.

3.2.15 Battery Buck Converter Selection

In this section we will be discussing which buck-converter we selected for our battery. Like we stated earlier, our battery produces a nominal voltage of 3.7V but some components require a lower voltage. Below we will compare 3 different buck converters and select one for our final product.

SparkFun 5V to 3.3V 2A Synchronous Buck Converter (AP63203):

The SparkFun buck converter is a high-efficient and compact module. It is designed to step down voltages from a broad range of 3.8-32 volts to a stable 3.3-volt output. It uses a synchronous switching regulator - AP63203, which will allow it to reach high efficiency and can support up to 2A of continuous current. It is a key feature that this converter is able to deliver a high maximum current (up to 2A) while maintaining a steady output of 3.3V. This converter was typically built for small portable systems since it leads high on both reliability and compact size. It includes very essential features like the thermal shutdown and short-circuit protection. It also has an enable pin (EN) for power control from the microcontroller, like the ESP32-CAM. For our project which has multiple components - the camera, ESP32, ultrasonic sensor, laser module, speaker, amplifier, and vibration motor - having more space to move around in terms of current is essential. This ensures that we avoid voltage drops and power instability. This converter is a reliable and robust power delivery system for a multi-load product.

Pololu 3.3V Step-Up/Step-Down Regulator (S8V9F3):

The Pololu S8V9F3 is a buck-boost converter which is capable of stepping up and stepping down the input voltage to a regulated 3.3V. It can adjust a wide range of inputs from 1.4V to 16V, which makes it an ideal candidate for our battery of choice since our battery could drop below the output voltage during discharge. The regulator supports up to 1A of output current and produces a high efficiency of about 90%. It includes a thermal shutdown and overcurrent protection. This is a key feature since thermal shutdown prevents overheating, extends product lifespan, reduces risk of fires, and ensures safe operation. Overcurrent protection protects against short circuits and overloads, prevents equipment damage, reduces fire risks, and ensures electrical safety. These are both extremely important factors to consider when selecting a buck converter. Another feature of the Pololu converter is its compact design, its size makes it extremely appealing in terms of PCB compatibility in comparison to other products. Since it has a large versatility in handling its low input voltages for battery systems, its maximum output current is less ideal. Our power system is demanding and with low current flexibility, devices such as the camera and audio amplifier can typically create spikes in the current. This 1A converter might not be able to handle this load under a sustained load. Since our system will be using a stable 5V input from a regulated booster we will no longer need the step-up capability. This means that although this is a useful regulator for our product it is too complex and does not provide enough benefits compared to other converters.

Pololu 3.3V 500mA Step-Down Regulator (D24V5F3):

This step-down regulator is highly compact and efficient for converting voltages down to 3.3V. It supports 500mA of current and has an input range of ~6.6-36V. Due to its input range it is typically suited for high-voltage sources and because its efficiency lies between 80%-93%. Similar to the other two converters, it includes protections like thermal shutdown and over-current limits. Its size is ideal since this will need to be easily adapted onto a PCB. However, regardless of its efficiency it is underpowered for our product. The 500mA current limit could work for one or two components but it will not be sufficient for the entire system we are running simultaneously (ultrasonic sensor, camera, speaker, vibration motor, ex.). Even if certain components can operate at low power, the

simultaneous operation may easily exceed the converter's capabilities. This will lead to undervoltage and system resets. Comparing this to other converters which have four-times the current, this is not an ideal choice for our product.

Table 19: Comparison of Battery Buck Converters

Parameters	SparkFun AP63203	Pololu S8V9F3	Pololu D24V5F3
Input Range	3.8-32V	1.4-16V	~6.6-36V
Output Voltage	3.3V (fixed)	3.3V (fixed)	3.3V (fixed)
Maximum Output Current	2A	~1A	0.5A
Efficiency	High	~90%	80-93%
Protections	Thermal, Short Circuit	Thermal, Over-current	Thermal, Over-current
Size	~1" x 1"	0.4" x 0.65"	0.5" x 0.4" x 0.1"

For our product we have selected the SparkFun AP63203, which offers a reliable and strong power delivery solution for our system which has dynamic load demands. This converter is the best choice for ensuring a consistent performance across all systems in our design.

3.2.16 Battery Boost Converter Selection

Adafruit PowerBoost 500 basic:
The Adafruit PowerBoost 500 basic is a 5V boost converter module built from the TI TPS61090 IC. It was designed for LiPo batteries and can convert 3.7V(our battery voltage) to a regulated 5V output at 500mA. It has a synchronous design, this helps reduce energy waste and heat generation, which helps with wearable electronics for safety. The board has an enable pin functionality and a low battery indicator pin which will be incredibly helpful for the user to determine if the battery needs to be charged. It is a compact layout and for the PCB offers clean solder pads to make for easy integration on our PCB customs. Although it doesn't offer the highest current capacity, 500mA is sufficient for many 5V components (LCD display, ultrasonic sensor, audio amplifier). A bonus is the Fusion/Eagle files that are available for the Adafruit products. Overall, this module is ideal for our 5V power demands due to its reliability, safety features, and ease of integration.

QWinOut Synchronous 1S LiPo Booster:

The QWinOut 1S LiPo Boost Converter is a cost-efficient, compact module designed specifically for converting 3.7V LiPo battery to 5V. It is a synchronous step-up design which enhances efficiency and reduces heat. This is extremely beneficial in wearable application since both space and thermal buildup are major concerns. The module supports up to ~1A of current output which makes it suitable for moderate loads (sensors, LED indicators, speakers). Its design is simplistic, making it ideal for beginners. Another

advantage is its easy PCB integration. The module includes through-hole solder pads that make it organized and clean to attach to a custom board. It is also low cost and suited to a LiPo battery. Although it does lack the enable pins and low-battery detection it is still an excellent choice for powering a 5V system and can typically be paired with a buck-boost converter for 3.3V.

Readytosky 5V UBEC (3A):

The Readytosky UBEC (Universal Battery Elimination Circuit) is a strong voltage converter that can step-up from LiPo inputs (as low as 3.7V) to a solid 5V output at up to 3A. It was designed initially for applications that require higher current loads. However, this includes so many components that the UBEC can provide enough power to all of these without being phased. The output is clean and consistent, which is ideal for digital devices and control. It is slightly larger than the other options, however, is still compact enough for small portable projects, such as ours. It includes convenient through-hole solder pads which make it adjustable and adaptable for PCBs. An added bonus is its tolerance for field use, which means our system will have a greater tolerance against voltage spikes and thermal variation. For multiple 5V applications this is the ideal choice.

Table 20: Comparison of Battery Boost Convertors

Parameters	Adafruit PowerBoost 500	QWinOut Booster	Readytosky UBEC
Max Output	500mA @ 5V	~1A @ 5V	3A @ 5V
Size	50 x 22 mm	~30 x 15 mm	RC
Efficiency	Synchronous with low noise	Synchronous - good for wearables	RC style
Ease of Use	Easy	Through-hole	Good
Footprint	PCB available	Compact	Moderate

For our project the Adafruit PowerBoost 500 is the easiest option with good documentation, ideal for small to moderate loads (under 500mA), a clean 5V output and safety features like an enable pin and low-battery indicator.

Once all hardware components are bought, we will start prototyping by using a breadboard, wires, and other components to make sure that all hardware parts are working properly before implementing on a printed circuit board (PCB) and onto the final design. The PCB board will serve as the central platform that connects all electronic components that are apart of the S.I.G.H.T. shoe. This will help the shoe by minimizing weight and size that are crucial to maintaining user comfort. It will also facilitate stable connections to each hardware component to make sure everything looks clean and not crowded. Careful consideration will be given to make sure that power distribution and signal routing are done correctly. Further technical details can be found in chapter 8.

3.3 Software Selection

The software platforms and tools selected for the S.I.G.H.T. shoe were chosen based on their compatibility with the hardware, ease of development, support for real-time processing, and low memory usage. Since the development is embedded in a wearable device and operates autonomously, all software components need to be lightweight, efficient, and compatible with the ESP32-CAM microcontroller.

Arduino IDE:

The Arduino Integrated Development Environment (IDE) was selected as the primary development environment for firmware programming. The IDE provides extensive support for ESP32-based devices and simplifies integration with sensors, actuators, and Wi-Fi/Bluetooth communication modules. Its large ecosystem and open-source libraries accelerated development, particularly for prototyping sensor logic, motor control, and state machine implementation.

Language: Arduino

Purpose: Embedded firmware development and sensor integration

Justification: Lightweight, ESP32-compatible, and open-source with strong community support

ESP32 Board Support Package (BSP):

To support the specific hardware features of the ESP32-CAM, such as dual-core processing and built-in Wi-Fi, the ESP32 BSP for Arduino was installed. This allowed developers to use GPIO pins, timers, camera functions, and wireless communication protocols seamlessly.

Purpose: Low-level hardware abstraction and peripheral control

Justification: Required for camera, PWM (vibration), and network features
Visual Studio Code

For more advanced debugging and code management, Visual Studio Code (VS Code) will optionally be used with the PlatformIO extension. This provides Git integration, IntelliSense, and project-level dependency management during collaborative phases of the project.

Purpose: Code versioning and debugging support

Justification: Enhanced productivity in multi-developed environments

Graphing and Simulation Tools:

To design and simulate software behavior, canva.com was used for flowcharts, state diagrams, and use case diagrams.

3.3.1 Software Challenges and Mitigations

UART Overflows: Caused intermittent freezing; resolved via `Serial.flush()` and reduced output frequency.

Stack Overflow in Recursion: Sensor polling routines restructured to iterative loops.

Camera Buffer Crashes: Limited image resolution to avoid heap fragmentation.

PWM Distortion: Fixed by adjusting timer resolution and switching speaker mounting position.

These refinements helped stabilize the system, especially under continuous runtime testing.

ThorCam Integration for Structured Light Capture

For structured light detection, we evaluated ThorLabs' CS165CU USB 3.0 CMOS camera. This camera worked extremely well in calibration and algorithm testing stages on our laptop

Purpose: Capturing high-resolution frames of the projected grid and performing distortion mapping in MATLAB or OpenCV

Resolution Advantage: 1440 x 1080 sensor resolution enabled clean visuals of diffraction in the horizontal laser from our DOE projector

We plan to migrate some image recognition methods developed through ThorCam into future embedded-compatible formats for SD2

To ensure efficient development, integration, and visualization throughout the S.I.G.H.T. project, a variety of software tools were selected based on their compatibility with the ESP32-CAM microcontroller and their ability to support real-time processing and embedded system design. Table 21 provides a summary of the primary software platforms used in this project, outlining each tool's role and the reasoning behind its selection. These tools enabled streamlined firmware development, hardware interfacing, system debugging, and the creation of visual representations essential for documenting and communicating software logic.

Table 21: Summary of Software Tools

Software Tool	Purpose	Reason for Selection
ThorCam	Image capture for testing	Calibrating distortion patterns with DOE projection
Arduino IDE	Firmware development	ESP32 compatible, easily documented
ESP32 BSP	GPIO, camera, and network support	Hardware abstraction
Visual Studio Code	Advanced code editing and debugging	Debugging support
Canva.com	Diagram generation	Flowcharts, State diagram, Use Case Diagram
GitHub	Version control	History tracking, feature branching
PlatformIO	Advanced build system	Supports multiple targets and CI/CD-like builds

To enable efficient hardware-software interaction within the S.I.G.H.T. smart shoe, our development leveraged a variety of embedded software libraries. These libraries provided essential functionality for handling sensor inputs, managing actuators, processing serial communication, and maintaining real-time responsiveness. By integrating well-supported and lightweight libraries, we were able to reduce development time, improve code stability, and ensure seamless compatibility with the ESP32-CAM platform. The table below

outlines the core libraries used, their purposes, and the specific features they enabled within our firmware.

Table 22: Core Software Libraries Used in Embedded Development

Library Name	Purpose	Relevance to Project
NewPing.h	Ultrasonic distance reading	Reads and averages data from HC-SR04
ESP32CAM.h	Camera management	Accesses frames from Thorlabs module
Wire.h	I2C communication	Interfaces with DRV2605L motor driver
Adafruit_DRV2605.h	Vibration motor control	Controls haptic feedback vibrations
tone()	Built-in function for audio feedback	Generate alerts using speaker

3.4 Requirements and Specifications for Optical Components

For our project the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.), which is a wearable smart shoe for the visually impaired, a structured light sensing system will be used to detect objects and obstacles. For this system to be accurate and reliable, the optical components chosen need to be able to achieve certain specifications and requirements. In the following section, the optical components chosen specifications will be written in table format. Calculations will be done with the chosen components and will be compared to see if they fall within the chosen parameters. This is an important aspect of the research done for this project to confirm that the chosen components will be able to successfully detect objects and obstacles through our structured light sensing system.

3.4.1 Component Specification

The optical components chosen for the structured light system used in our S.I.G.H.T. project include a diffractive optical element or DOE, aspheric plano convex lens, camera lens, and laser diode module. The table below will give the specifications of the components chosen. All these are key components needed in the stripe projection process and taking measurements of the distortion in the stripes to get a reliable depth mapping and to identify potential obstacles and objects in the user's way.

Table 23: Optical Component Specification

Component	Parameter	Specifications	Unit
Aspheric Plano Convex Lens	A) Focal Length B) Diameter C)Coating D)F/#	A)3 to 15 B)2 to 6 C)650 D)F/2 to F/4	A) mm B) mm C)Nm D)-

Diffractive Optical Elements	A) Wavelength B) Pattern Type C)Field of View D)Projection Distance	A)650 B) Linear Stripe C)60 to 80 D)2	A) Nm B)7x7 C)Full angle D)Meters
Camera Lens	A) Focal Length B) Field of View C)F/#	A)2 to 4 B)70 to 120 C)f/2 – f/3	A) mm B) Degree diagonal C)-
Laser Diode Module	A) Wavelength B) Output Power C)Operating Voltage/Current	A)650-660 B)3-5 C)3.3 @ 25mA	A) nm B)mW C)V/A

3.4.2 Chosen Engineering Requirements

For the Smart Integrated Guidance and Haptic Technology (S.I.G.H.T.) to achieve the goals listed in chapter 2, certain system requirements must be met. This includes a fast, almost real-time response to objects detected. The distance that will be in the range of detection must go up to 2 meters. These are the basic requirements and more will be shown in the table below. These are the requirements chosen for our project and achieving these requirements will be the final goal of our sight project and ensure that the user has a successful and safe experience while using the product. User safety is the most important factor in our project, because ultimately the goal of the S.I.G.H.T. is to improve user independence and as an aid to walking around for the visually impaired.

Table 24:Chosen Engineering Requirements

Engineering Requirements	Requirements Specifications	Unit
Latency (Camera to Vibration) ensures a fast response time.	≤ 150	ms
Obstacle Detection Range to give adequate distance to stop or redirect.	≥ 2	meters
Maximum power consumption enables multiple hours of use.	≤ 1.5	Watt

Depth accuracy to distinguish curbs, potholes or ditches, and steps.	≤ 7	cm
Minimum field of view required to capture sufficient scene width for SLS.	70	degrees

3.4.3 Details of Design Calculation

Based off the specifications given by the data sheets of the chosen optical elements, calculations can be derived to express if these specifications fall within the chosen specifications for the S.I.G.H.T. This is a crucial step in component selection, because the calculation of the components should fall within the specified specifications of our project.

The first calculation shown will be for the “detection box” created by the diffractive optical element. Based off the height and width, and angle of the element, we can get the exact size of the “detection box” created by the DOE. This detection box will be the area of the fanned-out region of the laser beam where the projected horizontal lines will be visible. The area of this detection box will be for objects within 2 meters. Any object that is detected in this area will be seen as an obstacle and will let the user know, and when the path is clear, the user will also be notified.

Equation 1: Detection Box of Diffractive Optical Element

Detection Box at 2 meters

$$Width : 2 \times D \times \tan\left(\frac{\theta_H}{2}\right) = 2 \times 2 \times \tan(20^\circ) = 1.46 \text{ meters}$$

$$Height : 2 \times D \times \tan\left(\frac{\theta_V}{2}\right) = 2 \times 2 \times \tan(10^\circ) = 0.7 \text{ meters}$$

The calculated width for the detection box is 1.46 meters wide by 0.7 meters high. These calculations will be referred to later in the chapter to compare with the horizontal scene width of the camera module.

The laser diode module that will be used for the project is a 650nm “dot” laser beam. The overall power output with the operating current will be shown in the equation below.

Equation 2: Shows Output Power @ 3.3V and 25mA

$$Output \text{ Laser Power} = V \times I = 3.3 \times .025 = 82.5 \text{ mW}$$

The optical power output of the laser used in the experiment was measured in the lab to 4mW. The output power calculated above is taken from the operating current and voltage of the laser diode module. The laser diode module on the data sheet reads that it is a 5mW laser which is class 2 or 3R which with proper classification can be safe if it is not viewed

directly. With the calculated output power of 82.5mW, the laser diode module falls into the category of low power components needed for the S.I.G.H.T. project.

The camera module that will be used for the structured light system will be used for object detection. By taking the pixel count and pitch, the field of view of the camera can be calculated. Having sufficient field of view to be able to capture the area where curbs or drop offs will be crucial to the success of the final design. The figure below will show the calculations for the field of view. The camera module used will be the OV2640 found on the ESP32-CAM. The camera module has an active pixel array of 1600 x 1200 pixels, and 2.2 μm pitch.

$$\begin{aligned}
 \text{width } 1600 \times 2.2\mu\text{m} &= 3.52 \text{ mm} \\
 \text{height } 1200 \times 2.2\mu\text{m} &= 2.64 \text{ mm} \\
 \text{diagonal } \sqrt{3.52^2 + 2.64^2} &= 4.41 \text{ mm} \\
 FOV &= 2 \arctan \left(\frac{\text{sensor size}}{2f} \right) = 2 \arctan \left(\frac{4.41}{22.6} \right) = 81^\circ
 \end{aligned}$$

Figure 13: Field of View Calculation for OV2640 Camera module

The final calculated value of 81 degrees will fall within the necessary range for accuracy and success of the structured light system for the S.I.G.H.T. project and meets the 60 degrees field of view that is a minimum requirement for the project. With the field of view meeting the requirements, the next step is calculating if the camera module will be able to get a full image of the projected striped light pattern given by the diffractive optical element. The equation given below will give the measurement for the horizontal scene width.

Equation 3: Horizontal Scene Width of OV2460 Camera Module

$$2 \times \tan \left(\frac{62^\circ}{2} \right) = 2 \times \tan (31^\circ) \times 2 \times 0.6018 = 1.2 \text{ meters}$$

This horizontal scene width falls comfortably within the 1.4-meter detection box created by the diffractive optical element that was calculated earlier in the chapter. This detection box needs to be captured by the camera module to calculate distortions in the projected light pattern of stripes that will detect objects and obstacles. A table will be given below to tabulate the chosen engineering requirements and the calculated specifications.

Table 25: Engineering and Calculated Specifications

Parameter	Chosen Specification	Calculated Specification	Meets Requirement
Detection of Obstacles within “detection box” @ 2 meters	$\leq 1.4\text{m}$	1.2m	yes
FOV (Horizontal)	$\geq 60^\circ$	81°	yes
Laser Power consumption	$\leq 1.5\text{W}$	82.5mW	yes
Frame Rate	$\geq 15\text{fps}$	15-20fps	yes

The camera module detection area falls within the “detection box” created by the diffractive optical element. This means that any object within that detection area that will cause distortion will be captured by the camera module. This will alert the user that an object or obstacle has been detected.

The field of view of the camera module was also calculated and has exceeded the required specifications needed for the structured light system used by the S.I.G.H.T. project.

Laser power consumption wanted to be kept below 1.5W as a specification chosen by the S.I.G.H.T. team to keep power consumption as low as possible. With an output power of 82.5mw while operating at 3.3 V and 250 mA, this falls below the 1.5W specified by the team. An engineering design constraint for this project includes using low power components to maximize power and battery life of the final product.

For real time object and obstacle detection to occur without the user having to adjust for gate and walk in a regular motion, the camera module should operate at least 15 frames per second, and off the spec sheet for the ESP32-CAM, the frames per second are from 15 to 20.

3.4.4 Optical Design Trade Offs

During the initial testing process, it was determined that improvements in certain design parameters could give drawbacks to other parameters. Examples of this include the field of view versus resolution, optical power versus eye safety, and resolution versus dynamic range. A higher degree field of view increases how much of the field that the camera sensor can see, but as it increases, distortion also increases. There is also a lower pixel density per degree. With increased distortion, this will negatively affect the performance of the obstacle detection system, because we want a clear projection of the vertical stripes. Any distortion from an increased field of view will negatively affect the distortion measurement of the projected stripes. For eye safety, the S.I.G.H.T. shoe will use a laser diode module

below 5mW optical output. It can be thought that perhaps by increasing the power of the optical output of the laser diode, the distance for obstacle detection can be increased. If a more powerful laser diode module were to be used, the increased power would make it not possible to use in public. The distance in mind for obstacle detection was 2 meters. This means that the angle of the projection fan out from the diffractive optical element must match with the focal distance and field of view of the camera module. If the projection does not match the camera distance and field of view, the structured light system will not be reliable and accurate. Finally, the biggest optical tradeoffs in our S.I.G.H.T. project include resolution versus dynamic range, for example, a low-cost sensor may miss low light projections in a brighter ambient light setting. One of the designs constraints we have is the overall cost of the project. There are cameras and lenses available that would cover the budget of the entire project for S.I.G.H.T. and the same can be said for other components on the project, but for structure light, the camera sensor is crucial in the success of 3D scanning.

3.5 User Interface Design Calculations

Designing an assistive device for visually impaired users demands a unique approach to user interface (UI) development. While typical graphical interfaces are not applicable, the S.I.G.H.T. smart shoe leverages multimodal feedback mechanisms to communicate with the user. These mechanisms serve as the equivalent of a traditional interface, providing real-time alerts and intuitive guidance through vibration and audio cues.

The user interface is minimal by design but highly responsive. For instance, different vibration patterns correspond to specific distances detected by the ultrasonic sensor. A short pulse indicates a distant object, while continuous pulses suggest immediate danger. Similarly, audio tones differ in pitch and volume depending on proximity. These settings were chosen after internal testing among team members and reflect human-centered principles for accessibility.

3.6 Calibration and Tuning

To ensure accuracy and consistency across different environments and use cases, the S.I.G.H.T. shoe undergoes a series of calibration and tuning procedures. These are essential to align sensor outputs, feedback thresholds, and detection logic with real-world use. Calibration protocols include:

Ultrasonic Sensor Range Tuning: The HC-SR04 sensor is tested against flat walls and various obstacles at measured distances (from 5cm to 400cm) to determine a reliable detection range.

Feedback Intensity Profiling: The DRV2605L motor is calibrated for three vibration levels using a linear ramp-up voltage pattern. Team members evaluated each setting for comfort and perception.

3.7 Mechanical Mounting and Enclosure Design

The physical integration of electronic components within footwear presents mechanical challenges that impact sensor performance and user comfort. Our team selected the Dunlop Chesapeake boot for its wide toe area, water resistance, and interior mounting volume.

Components are mounted using Velcro, zip ties, and foam padding to minimize vibration transfer and physical discomfort.

Sensor Mounting: Ultrasonic sensors are recessed into 3D-printed brackets near the toe for forward-facing detection.

Vibration Motor: Placed under the heel, where pressure transfer is optimal for tactile feedback.

Speaker Mounting: Affixed inside the boot collar, projecting upward to the ear while remaining discrete.

We used conformal coating and sealed JST headers to improve water resistance. The enclosures are rated approximately IP44, providing protection against splashing water and dust.

3.8 Structured Light Grid Testing Setup

In anticipation of future upgrades, the S.I.G.H.T. team explored structured light grid projection using a diffraction optical element (DOE) and ThorLabs CS165CU camera. This setup allows us to visualize grid distortions caused by nearby objects—data that can eventually drive more advanced detection algorithms.

Projection Source: A class II laser diode shines through a DOE to project a grid of horizontal lines.

Flat Reference Surface: A white cardboard surface provides the baseline (undistorted) projection.

Obstacle Testing: Various items (blocks, poles, textured surfaces) are placed in front of the grid to analyze light warping.

Camera Analysis: The CS165CU captures 1440×1080 images, analyzed using OpenCV in MATLAB to detect line deviation.

This structured light work remains experimental but opens the door for SD2 expansion.

3.9 Maintenance and Replaceability Design

A wearable system like S.I.G.H.T. must be easy to repair and upgrade over time. We adopted a modular wiring scheme using JST connectors and socketed headers, allowing rapid replacement of defective components. Battery access is tool-free, and sensor modules are mounted in swappable compartments.

Replaceable Modules: Vibration motor, speaker, ultrasonic sensor

Reprogrammable Firmware: Updates via USB serial or OTA (future scope)

Accessible Power Source: Battery pouch on the boot's inner heel with easy Velcro closure. Future iterations may feature QR-coded instructions or a companion app to guide non-engineering users through simple maintenance.

3.10 Human Factors Engineering and Safety

Safety and usability for visually impaired users are paramount. All design choices were evaluated for potential user risk. For instance:

Vibration Strength: Carefully tested to ensure clear detection without causing discomfort or skin irritation.

Volume Control: Tuned to be audible in outdoor environments without being startling.

False Positives/Negatives: Reduction algorithms reduce erratic obstacle alerts that may confuse or trip the user.

Potential compliance with ADA design guidelines and future CE safety marking will further validate the product’s reliability and market readiness.

3.11 Sensor Selection Comparison:

To evaluate the most suitable sensors for obstacle detection and depth mapping in the S.I.G.H.T. smart shoe, our team conducted a comparative analysis of various options based on range, accuracy, power consumption, ease of integration, and environmental reliability. The goal was to identify components that would meet the practical demands of a wearable assistive device, especially in terms of size, cost, and performance under real-world conditions. The table below presents a comparison of several sensor types considered during the research phase, highlighting the reasons behind the final selection of both the HC-SR04 ultrasonic sensor and the Thorlabs CS165CU camera.

Table 26: Sensor Comparison for Obstacle Detection and Visual Mapping

Sensor Type	Pros	Cons	Used In Our Project
HC-SR04 Ultrasonic	Cheap, easy to integrate, accurate	Narrow beam, false positives	Yes
VL53L0X ToF	Compact, good short-range accuracy	Sensitive to reflectivity	No
IR Sensors	Low power, easy to use	Inaccurate in sunlight	No
Thorlabs CS165CU	High resolution, compatible with DOE	Expensive, requires processing power	Yes

3.12 Summary Table: Design Constraints and Their Impact

The table below presents a concise overview of the various design constraints the S.I.G.H.T. team encountered and how these factors influenced decisions regarding hardware, layout, and feature implementation. This summary helps illustrate the engineering trade-offs necessary to create a functional and wearable device under practical limitations.

Table 27: Constraint Overview and Impact

Constraint	Design Decision Impact	Example Component	Trade-Offs Made
Power Limitation	Required low voltage, efficient devices	3.7V Li-ion Battery	Limited continuous runtime
Ergonomic Fit	Lightweight, balanced enclosures	ABS Housing	Reduced sensor range for comfort

Cost Constraint	Prioritized low-cost components with multi-use	ESP32-CAM	Avoided premium processors
Environmental Protection	Dust/water sealing necessary	IP44 Conformal Coating	Not submersible
Safety/Comfort	Adjusted vibration/audio levels	DRV2605L, Buzzer	Lower maximum intensity for safety
Maintenance	Tool-free access and modular swaps	JST Wiring, Velcro	Slight increase in boot footprint

3.13 Design Constraints Comparison with Similar Products

Earlier in the design process in senior design 1, there were three similar products used in assisting the visually impaired. These three products were a \$175 Tavkomo smart cane, a \$1,150 WeWalk smart cane V2, and a \$147 Phoenix smart cane. The design constraints that were compared between our S.I.G.H.T. project and the three comparable products mentioned above are economic, time, environmental, social, political, ethical, health and safety, manufacturability, and risk. The table below explaining the reasoning on the design constraints can be found below.

Table 28: Design constraints

#	Constraint Category	S.I.G.H.T. Project	Tavkomco Smart Cane (\$175)	WeWalk Smart Cane V2 (\$1,150)	Phoenix Smart Cane (\$147)	Comments
1	Economic	Low-cost components (ESP32-Cam, laser) <\$100	Affordable but may have low sensor precision.	Very expensive and inaccessible to many users.	Moderately priced, with limited value features.	Much lower cost with similar or better features and functionality.
2	Time	1 summer semester and 1 fall semester timeline.	Off the shelf product.	Mass produced limited product updates.	Pre-built, limited adaptability/custom use.	Custom built with rapid iteration flexibility.
3	Environmental	Designed for outdoor use.	Likely uses generic plastic.	Unknown recyclability, more power use from AI.	Uses basic detection, unclear weather proofing.	Purpose built for rugged outdoor use.
4	Social	Non-stigmatizing shoe design.	Traditional cane form	High tech but bulky.	Follows traditional cane aesthetics.	Worn on foot so a lower profile design.

5	Political	Complies with low power laser regulations.	Unclear compliance with laser safety.	Uses AI may need to follow privacy policy.	Basic electrical compliance.	Explicitly follows laser safety from the start.
6	Ethical	Privacy respecting, user centered.	No clear info on privacy.	Cloud-based AI could bring up data concerns.	Minimal user feedback or control settings.	User retains full privacy.
7	Health and safety	Class 3R laser projection that points down only.	May lack thermal protection.	Includes feedback, but no laser safety classification.	May lack built-in protections for high current use.	Full safety assessment included in the design.
8	Manufacturability	3D printable parts. Off the shelf components.	Aluminum tube, standard electronics.	Plastic moldings, complex internals.	Standard factory design.	Modular and field repairs available.
9	Sustainability	Rechargeable, reusability of modules.	Uses reflective tape.	Higher carbon footprint.	Unknown battery sustainability.	Energy efficient and upgradeable.
10	Risk	cannot have false positive results.	Alarm only.	AI failure or network issues will cause detection breakdown	Limited resolution or surface mapping.	Real word depth mapping will give more reliable results.

In the comparison table above, the comment section explains how the design constraints for the S.I.G.H.T. project would be superior to the other similar products.

3.14 Safety Requirements for the Final Design

During the research process done for the S.I.G.H.T. project, information on safety requirements is crucial for following the correct protocol when attempting to design a product to help improve the everyday life and independence of the visually impaired. A table that goes over the safety requirements will be found below.

Table 29: Safety Requirements for Final Design

#	Safety Requirement	Implementation in Final Design
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1	Laser Safety	Laser power limited to Class 3R and mounted to only project downward
2	Electrical Safety	All wiring enclosed and insulated; components fixed in housing
3	Mechanical Safety	Components securely fastened to avoid detachment while walking
4	Thermal Safety	System tested to ensure no overheating during extended use
5	Eye Protection	Beam path designed to avoid accidental eye exposure
6	User Instruction	User guide provided with simple steps and warnings for proper use
7	Battery Safety	Rechargeable battery modules chosen with short-circuit protection
8	Environmental Safety	System designed to be resistant to dust and light water exposure
9	Feedback Clarity	Clear vibration or audio cues to ensure user knows when an object is detected
10	Public Interaction Safety	Device form is compact and low-profile to avoid interfering with others

The table above gives a clear and concise breakdown of the safety requirements needed to be followed by S.I.G.H.T. as a final product. There are many considerations to keep in mind, especially that the user of the product will be a visually impaired person, that the product will need to be able to keep safe by avoiding objects and obstacles as well as following proper laser safety.

3.15 Optical Design Standards

Doing the investigation into the safety standards for our S.I.G.H.T. project, eight specific standards were found for the optical design portion of the project. These standards will be presented in the table below.

Table 30: Optical Design Standards

#	Standard Regulation	Implementation in Design
1	IEC 60825-1 (Laser Safety)	Used Class 3R laser and aimed beam strictly at ground to ensure eye safety.
2	ISO 13482 (Robotics - Personal Care Safety)	Designed for non-contact obstacle detection and user comfort in wearable form.
3	ADA (Americans with Disabilities Act) Accessibility Guidelines	Project supports mobility for visually impaired users and encourages inclusivity.
4	FCC Part 15 (EMI Compliance for Electronics)	Selected low-frequency components and shielded wiring to minimize EMI.

5	RoHS Compliance (EU Restriction of Hazardous Substances)	Used RoHS-compliant components (e.g., ESP32-CAM modules, PCBs).
6	IEEE 802.11 (Wi-Fi standard used by ESP32-CAM)	ESP32-CAM follows IEEE 802.11b/g/n standards for wireless transmission (if used).
7	UL/CE Mark (Battery and power supply compliance)	Selected USB-rechargeable battery modules that meet UL/CE safety standards
8	ISO 9241-210 (Human-centered design)	User-centered iterative design and testing with emphasis on discretion and comfort

The above-stated standards are to be followed by our S.I.G.H.T. project, especially because our final design will be used by a visually impaired person, making safety a top priority.

3.17 Conclusion

In this chapter, we thoroughly examined both the hardware and software components that were needed to implement our wearable Smart Integrated Guidance and Haptic Technology (S.I.G.H.T.) shoe. We investigated several options for every subsystem, which included sensors, microcontrollers, communication protocols, power solutions, and applicable software developments. This was done by carefully comparing various parts and technologies.

Another thing we covered briefly in this chapter was ensuring that we meet basic electrical safety standards. Making sure that no component overheats during operation, haptic motor should operate within human comfort limits, and sound levels must remain below thresholds that might risk too loud alerts.

Every comparison was supported by concise tables and justifications for every option that was discussed, guaranteeing that our decisions were based on user requirements, cost, availability, compatibility, and performance.

Critical choices about processing, power supply, haptic feedback, connectivity interfaces and sensing were all part of our hardware technology comparisons. To ensure smooth integration and adaptable code development, software comparisons were also conducted across several IDEs, libraries, and communication protocols.

Each table included at least three options for each hardware component. It also included our choices that were supported by the project's objectives, which included low power consumption, lightweight design, ease of programming, and accessibility for individuals with visual impairments.

To summarize, by making sure that each component was selected not just for its technical value but also for its effect on the user experience, this chapter established the framework for our system design. Our decisions demonstrate a balance between innovation and practicality. With this research being complete, we have a clear plan for testing, prototyping, and more importantly improvement which will enable us to move confidently into the project's development and integration stages.

Chapter 4 Standards and Design Constraints

4.1 Relevant Standards

This chapter will outline the relevant standards and design constraints that influenced the development of the S.I.G.H.T. shoe. These include rules pertaining to safety, wireless communication protocols, size and power restrictions, and user comfort. The goal is to guarantee that the final design is both functional and consistent with applicable rules.

4.1.1 Power and Battery Safety Standards

Any wearable system must include power management, especially our S.I.G.H.T shoe project since it combines several components like our microcontroller, ultrasonic sensor, vibration motor, and camera as well as other components, that depend on either continuous or periodic power delivery. Ensuring safe, dependable, and effective energy utilization is crucial for long term durability and user safety as well as device performance. We will take a look at some of the following standards for power and battery safety.

IEC 62133

The most popular international standard for rechargeable lithium-ion battery safety is the IEC 62133. Some of its requirements include testing and ensuring lithium-ion batteries are dependable to use, especially with our wearable product since it will interact with a person [33]. Our S.I.G.H.T. shoe will rely on a compact lithium-ion battery that will be used to power the ESP32-CAM microcontroller, ultrasonic sensors, and vibration and audio feedback. The design is guided by this standard which specifies the safety for rechargeable batteries used in portable applications to protect user safety and reduce hazards like overheating and short circuits or even in dangerous situations, like for example a fire. This standard is a great example of how to use these batteries, especially with our shoes because these shoes will be used by a visually impaired individual. Making sure we follow these regulations will ensure that the S.I.G.H.T shoe provides safe and reliable power while minimizing hazards.

4.1.2 Audio and Vibration Feedback Standards

For this section we will cover the audio and vibration safety standards that will be considered for our product. The S.I.G.H.T. shoe is to be worn by an everyday user. This means that all standards set are needed to protect the user from any harm or damage.

IEC 62368-1: Audio Standards

The IEC is the International Electrotechnical Commission which helps create safety standards for electronics. The IEC 62368-1 is the safety standard for audio equipment and will be one of the standards we use to prevent pain, injury, or property damage due to hazards (e.g. electrical shock, fire, thermal burn). In the IEC 62368-1, the main topic of audio comes from the sound pressure levels or SPL section. SPL is a logarithmic measure of the effective pressure of a sound wave in relation to a reference value. The most commonly used unit of measure is decibels (dB). The standard requirements and testing methods that are necessary for protecting users from excessive acoustic energy emitted are in reference to components such as headphones and speakers. To begin, the acoustic energy source classification is the standard that classifies sound pressure levels as a type of energy

source. These classes depend on the level and duration of exposure and if not properly controlled, the user could experience pain or injury. There are five classification levels ranging from A - E, with A being the highest rated class. An A-rated product has the highest rated sound absorption performance. This means it is extremely safe for the user. The requirements listed in the standard for personal listening devices are as follows: maximum A-rated sound pressure level is limited to 100dBA (Loud Street noise, noisy factory, police whistle) when measured with a 500mV input, devices must have volume control - they must not exceed 85dBA. To test these conditions, we can use the Head to Torso Simulator (although for our project we would need to measure more along the lines of a Head-to-Toe simulator) which should specify input signals and methods to determine compliance. The standard also includes warnings and information about audio equipment. That is if the audio equipment outputs above a safe threshold, it must have warning labels or instructions indicating the risks of hearing damage to the user.

ISO 5349-1:2001: Vibration Standards

The International Organization for Standardization is a nongovernmental worldwide federation of national standards. It comprises over 160 countries to help in the standardization process and ensures that all countries are informed of changes or additions to standards to improve the safety of life. That being said, one of the main safety standards for this project is the vibration motor that will be mounted in the boot. It should vibrate at a comfortable rate and should not cause any harm or damage to the user. The ISO 5349-1:2001, which is the mechanical vibration - measurement and evaluation of human exposure to hand-transmitted vibration, is the ideal safety standard we will be using for this product. Although our product will be worn on the users' feet, we will negate the "hand-transmitted" and rather use that as a general "all parts of the body vibration standard". The purpose of the standard is to provide guidance on measuring and evaluating hand-transmitted vibration to assess the risk of vibration-induced injuries (e.g. HAVS - Hand-Arm Vibration Syndrome). This is a very important tool for any small vibrating device. The standard applies to the vibration transmitted from a surface (tool or workpiece, in this case boot) into the hand of the user (in this case the calf of the user). It focuses on long-term daily exposure instead of short-term impulses. It uses frequency-weighted acceleration which is based on how harmful different frequencies are to human tissue and is typically measured in meters per second squared. The outcome of the standard showed that exposure in prolonged periods of time can cause circulatory, neurological, and musculoskeletal disorders. The higher the vibration levels or longer durations can increase the risk of damage. For this project we will need to ensure the duration of a vibration is not long enough so as to cause health risks to the user. There are ways and tools to reduce the risk of these factors, which are vibration-reducing gloves, posture, and temperature of the environment. After reviewing this standard our product design should meet the industry standards for human exposure to mechanical vibration.

4.1.3 Electrical Safety Standards

There are many standards for electrical safety. We will be focusing on a few of them and how they relate to this project. Beginning with the general standards on electrical safety and wearable electronics, the IEC/UL 62368-1 is a standard that covers safety of audio/video, in-circuit testing (ICT) and similar electronic equipment. This is a good

standard we will follow since it is widely used for consumers and for wearable devices. The IEC 60601-1 applies to the product since some could say this is a medical device of some sort. Meaning since the product is for the visually impaired and is aimed at being an aid to help with sight. This provides the basic safety and performance we are looking for. In the same standard but different section, IEC 60601-1-2, this part refers to the electromagnetic compatibility (EMC) requirement for medical electrical equipment. In the IEC 60068 standard, this is in relation to environmental testing. Meaning when our product is in testing phases, we will need to follow these standards for vibration, shock, temperature, and humidity, which is incredibly important for the durability of the product. Another standard that fits under the general electrical safety standards is the IEC 61000-4-2, which is the electrostatic discharge (ESD) immunity which is the ability of a device to withstand the effects of ESD events without malfunctioning or being damaged. This standard is especially helpful for outdoor use.

Moving on to more specific electrical standards. The IEC 60364 standard covers general wiring and protection principles. Most of these standards are helpful for wiring harness/insulation, and although it is not very specific to small electrical components like our product. It does offer helpful information in terms of what general electrical standards look like in general wiring. Another standard for electrical safety is the IEC 61140, which focuses on the protection against electric shock. For battery safety standards, the IEC 62133-2 specifies safety for portable rechargeable cells (Li-ion/Li-polymer). This is an extremely beneficial standard since the battery we have chosen is a rechargeable Lithium-Ion Cylindrical Cell. The UL1642 and UL2054 are United States standards for battery safety in portable and consumer applications.

After researching an ample number of standards, there are plenty of electrical safety standards to consider when producing this project. Although this seems like a constraint to our project, this is extremely beneficial and will help our product in the long run and the safety of the user.

4.1.4 Camera and Image Quality

For a reliable structured light system to be able to detect objects, the camera system needs to be effective. This camera module needs to be able to measure image distortion in the projected stripes to be able to detect objects in real time through depth mapping of the area imaged. To ensure a quality imaging system, several constraints were followed when designing the S.I.G.H.T. project. The design constraints for the imaging system were resolution, as the resolution needs to be good enough to be able to capture the image of the projected stripes. Frame rates also need to be in the range where real time or semi real time detection is possible. The field of view is a very important constraint in that the field of view area needs to be able to detect obstacles but also drop offs and ditches. The module needs to function under low power and be able to operate under a current draw of 250mA to be able to be compatible with the ESP32 microcontroller. Size and weight constraints make the engineering design need small components and design. A swappable M12 mount enables easy switching between lenses during prototyping to optimize the design. The imaging acquisition system follows established standards for optical and digital performance. ISO 12233 is the standard that defines resolution test methods and includes

the use of charts to be able to calculate the modulation transfer function. EMVA 1288 is the European machine vision association's standard for parameters such as signal to noise ratio, dynamic range and quantum efficiency as cited in the references in the appendix. The ESP32-CAM sensor was selected due to its low power design and capability of detecting visible light and using an M12 lens mount allows for swapping to lenses with better field of view. To confirm image quality tests were run to test sharpness, field of view, and contrast. The stripe contrast can be evaluated under ambient light to ensure pattern visibility.

4.1.5 Safety for Lasers

The use of laser diodes in structured light systems such as projectors requires careful consideration of the optical design and safety standards and regulations. For this structured light system to be designed and implemented, a red laser diode is chosen that operates at 655 nm and 4mW optical output. This laser diode module complies with international safety standards and meets the optical design specifications for the project. The main governing bodies that give the primary classification grades are the International Electromechanical Commission (IEC) and the American National Standards Institute (ANSI). IEC 60825-1 classifies lasers by power and wavelength, where our laser falls under class 2, which is considered safe for the eye due to the blinking response in the human eye [34]. ANSI Z136.1 provides detailed guidance on the safe use of laser diodes in different environments. Our design will have the necessary safety and regulation markings, which include beam direction control to minimize the risk of any accidental exposure. From an engineering perspective, several measures were taken to ensure safe integration of the laser system for the projector. The laser diode used is at 4mW and puts it well below the limits of stretching out of class 2. This eliminates the need for extra safety training or eye protection. The directional setup of the laser projector and camera is pointed down and away from the eyes of any oncoming pedestrian. The use of the DOE will also diffuse energy throughout the stripe pattern. The mechanical mounting of the laser diode module will be able to house the system and ensure that beams don't stray or reflect. The laser is powered by a 5V source and is optionally modulated, but software level controls enable use of the laser to be active only during operation. To validate the safety of the laser, the optical output power was measured, and thermal monitoring can be used to ensure no excess heat is causing integrity issues in the housing. This system has strict adherence to guidelines IEC 608251 and ANSI Z136.1 while also introducing electrical engineering concepts to mitigate laser hazards and citations can be found in the appendix.

4.1.6 Communication Protocols Standards

The S.I.G.H.T. shoe integrates wireless communication to support modularity, real-time feedback, and potential future expansion such as mobile app pairing or sensor measurement. To ensure reliable and energy-efficient connectivity, the design follows standard communication protocols popularly adopted in embedded and wearable devices. These standards are used to help guarantee the device's compatibility, comparable signaling, and lower the amount of power drawn. These reasons are all strong necessities for battery-operated smart shoes.

4.1.6.1 Bluetooth Standards

The S.I.G.H.T. shoe employs Bluetooth Low Energy to support wireless communication between the embedded controller and external devices. The design adheres to the Bluetooth Core Specification 4, developed by the Bluetooth Special Interest Group (SIG). This protocol was selected due to its strong balance between performance and efficiency in wearable technology. BLE 4.2 is ideal for the real time and low data rate needs of this system. This will ensure seamless integration with mobile platforms and potential accessories. BLE 4.2 balances efficiency with real-time performance for wearable assistive technology.

Key Bluetooth Features:

- **Low Energy Operation:** Ideally used for battery-powered devices like smart shoes.
- **Increased Data Throughput:** Allows faster communication compared to older BLE versions.
- **Extended Packet Lengths:** Reduces overhead by enabling larger data payloads per packet.
- **Enhanced Privacy and Security:** Incorporates LE Secure Connections and addresses randomization, preventing tracking and data leaks.
- **Interoperability:** Compatible with most modern smartphones and embedded platforms.
- **Data packet extension:** Increased packet size improves efficiency during short-range transfers, useful for test logging or firmware update pairing.
- **Secure Connections:** Enhanced pairing privacy reduces risk if integration with a mobile app or caregiver module is added in the future.
- **Widespread Adoption:** Ensures maximum interoperability with mobile and embedded ecosystems.

Integration in S.I.G.H.T.

Hardware Layer: The ESP32-CAM's onboard BLE module can handle pairing as well as other possible features.

Current Role: Primarily reserved for debug transmission and optional integration testing.

Future Potential: Possible expansion to include audio cues, GPS assistive data, or mobile app alert systems.

4.1.7 Ergonomics of Human System Interaction

ISO 9241-210:2019

This standard focuses on the ergonomics of the human system interaction. The ISO 9241 offers recommendations to better enhance interactive systems, ease of use, comfort, and accessibility [35]. These requirements allow for the S.I.G.H.T. shoe, which is intended for those with visual impairments, to not only be useful but also comfortable for long term usage and easy to operate. Understanding user needs, designing with users in mind, and reducing physical and mental stress are important guidelines that the ISO 9241-210 follows [36]. These guidelines guide our decisions regarding component arrangements, making sure that the microcontroller and the sensors don't interfere with walking, lightweight design to prevent user fatigue, and clear, consistent audio and haptic feedback that is not overpowering but also easy to understand. By adhering to ISO 9241, we hope to prioritize the everyday use requirements of the visually impaired users while making the S.I.G.H.T. shoe accessible, safe, and comfortable.

4.2 Design Constraints

A constraint is defined as a limitation or restriction. For the S.I.G.H.T. shoe we have run into many constraints that have altered potential ideas for this project. We will cover various constraints and how we have found alternative solutions in order to make this product work as efficiently as possible.

4.2.1 Power Consumption & Battery Life

4.2.1.1 Power Consumption

Our first constraint is power. In any electrical device or product, power is the most important feature. To operate an electrical device, power must be properly distributed safely and efficiently. For the S.I.G.H.T. shoe, our team went through many ideas and options for determining what would be the ideal choice for a power supply. Since these are shoes meant for everyday walking, the battery could not remain plugged into an electrical source and would instead require a battery of some sort. The next issue was determining how long the battery life would last. Shoes are worn everyday anywhere from 3 - 16 hours. This means we needed to find a battery that could power our device in a realistic way. We determined that the battery should last somewhere around 6 -10 hours as an initial goal and if possible 12 hours or more as a preferred goal. And since these shoes are to be worn every day, the battery would also need to be rechargeable, to not create excess waste (throwing away drained batteries). Since power would be supplied to many components in the product, the battery itself would also need to last for an extended period of time without needing to recharge until the user was ready. This then put a constraint on the duration of time the power would need to last, and how much power the devices would require operating. Could a rechargeable battery do both? The answer is yes. After researching many different types of batteries, we determined that a rechargeable Lithium-Ion Cylindrical Cell type battery would provide the best and safest power to our product without having to remove any of our desired devices.

4.2.1.2 Battery Life

This product is aimed at those who are visually impaired to live a more comfortable life. This means that when an electrical component is introduced into the product it must not affect the user's everyday life. This means that a key feature must be the battery life and battery lifespan. According to the constraints we have set on the product, the battery needs to be as weightless as possible. This means that the battery cannot be incredibly heavy to hinder someone walking uncomfortably. Two constraints that go together are concealment from outside interference (weather damage, physical damage, etc.) and easily accessible rechargeability. This means that we needed a battery that is lightweight, stable, and rechargeable. There is also the main important constraint we need in a battery. It needs to be able to support all devices we are installing on the shoe. These devices are the following: ESP32, boost converter, vibration motor, LRA driver IC, ultrasonic sensor, speaker, audio amplifier, laser, and camera. All of these devices will require the battery to run at peak performance. After researching we were able to find a battery that could supply enough power to all the constraints listed without removing required devices. Although constraints are typically meant to hinder a project's progress, in this case we were able to find a battery that can supply all the power we need to achieve our designs.

4.2.2 Size and Space Limitations

When creating and designing the S.I.G.H.T. shoe, one of the biggest design limitations was the small amount of physical space that could be found in a typical shoe form. In contrast to a portable or handheld device worn, for example on your wrist, a shoe needs to maintain both comfort and structural support despite the several electrical components included on the shoe. Some of the components we need to integrate onto the shoe are an ESP32-CAM, two ultrasonic sensors, a battery, an audio speaker, a vibration motor, and an LCD screen. Each of these components needs to be positioned carefully to avoid disturbing the user's comfort when walking.

Given that the user should not feel discomfort from these components, the electrical layout design, component dimensions, and mounting are directly impacted by this limitation. The ESP32-CAM needs to be oriented such that the shoe material does not block its camera's ability to detect obstacles. The ultrasonic sensors are also going to be used to detect obstacles and give reading distance measurements, which will be placed at the sides of the shoes.

Moving on to the battery, it needs to be small and strong enough to run the S.I.G.H.T. shoe for extended periods of time. The battery cannot be overly large, as this would cause discomfort, and it could be too heavy for the user to carry. Another thing to watch out for is the vibration motor. We need to ensure that this motor is positioned somewhere where the user can feel the feedback but also need to make sure that the feedback isn't too strong, as this could cause shock or pain when walking. Design strategies to address space issues include choosing components with compact designs, choosing smaller wires to make wiring as clean as possible, and we will design and create a PCB board to reduce the electrical footprints.

All things considered, the user experience, structure layout, and component selection are greatly impacted by the size and space constraints. This limitation requires a careful balance between aesthetics and functionality, guaranteeing that all parts are safely incorporated without sacrificing the S.I.G.H.T. shoe's use and comfort.

4.2.3 Cost Constraints

Another important design limitation that affects almost all parts of the S.I.G.H.T. shoe is the overall cost. Since this project is a group effort and is a student-developed prototype, the shoe has to be finished on a tight budget. The team's goal is not to go over \$300 but to stay under this amount. With this in mind, we have limitations that impact on the choice of components and materials we choose, so we can make sure that we stay within the parameters of the design.

The team gave priority to parts that provide multiple functions at a low cost in order to efficiently control expenses. For instance, the ESP32-CAM was chosen for our microcontroller since it was reasonably priced and also had features like Bluetooth and Wi-Fi, and a camera. We also chose a pack of two ultrasonic sensors as they were also at a low cost for two and had the features we were looking for. This was the case for all the components we used for this project. Overall, reliable object detection was made possible

without going over budget, which gives us room to buy any other components we might need in the future.

Components were purchased from reasonably priced suppliers, which included Amazon, with time frames and delivery prices that were taken into account. We also used spare parts we had from previous projects that were not used to conserve money. Over time, cost limitations can affect our goal, since tariffs are in effect now, so we can save money where we can, so we can spend it on our PCB to order and deliver, plus the fee.

All in all, making strategic decisions and compromising some features and quality were necessary when working within a limited budget. The team overcame these limitations by creating a functional prototype that satisfies important performance goals while remaining financially feasible.

In the next phase of the project, cost constraints will continue to shape our design decisions. Particularly as we transition to printed circuit boards (PCBs) and more advanced enclosure materials. Unlike the prototyping stage, which allows for flexible use of jumper wires and breadboards, Senior Design 2 will require us to invest in permanent assembly methods. This will involve evaluating low-cost PCB fabrication services and possibly sourcing components from international suppliers to minimize unit cost. We also plan to revisit our component selection with a cost-per-feature mindset, identifying opportunities to consolidate functions or substitute parts with more cost-effective equivalents. Moreover, in anticipation of future scale-up or potential commercialization, we intend to document a full bill of materials (BOM) with current unit prices and projected bulk costs, giving us a clear view of manufacturing feasibility under cost-sensitive conditions. By continuing to treat affordability as a core design requirement, we aim to produce a final product that balances performance, reliability, and real-world accessibility for users who may not have access to expensive assistive devices.

4.2.4 Environmental Durability

Environmental durability is a crucial part in the design of the S.I.G.H.T. shoe. Since the device is intended for use every day outdoors and indoors. The smart shoe must operate reliably across varying weather conditions, terrains, and user behaviors. As such, mechanical housing, sensor placement, and electrical components are selected and configured to withstand environmental stress while ensuring consistent performance.

The table below summarizes the key environmental durability features integrated into the S.I.G.H.T. shoe to ensure its reliable performance in a variety of real-world conditions. These considerations include protections against moisture, shock, temperature fluctuations, dust, and continuous vibration during use. Each row outlines a specific environmental factor, the protective measure implemented, and its relevance to maintaining system functionality and user safety in diverse operating environments.

Table 31: Necessities considered for environmental durability

Moisture and Water Resistance	The enclosure for all electrical components will be IP44 rated, providing protection
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	against low amounts of dust and water coming from these various weather conditions and terrains (sprinklers and rain). Components will be sealed in conformal coatings and housed in 3D-printed enclosures to mitigate dust and water. Vents are necessary to allow pressure to be released.
Shock and Impact Resistance	The internal components will be cushioned with foam to absorb mechanical shock from walking or accidental falls from the user.
Temperature Tolerance	The S.I.G.H.T. shoe is designed to operate in 32° F to 120° F, suitable for both urban and rural environments. The microcontroller and components revolving around the battery are selected because they extend operating range and thermal stability.
Dust and Debris Protection	Ultrasonic and optical sensors will be recess-mounted and shielded to prevent dirt buildup. Filter meshes may be implemented over sensor ports to reduce dust intrusion without interfering with the sensor's functionality.
Vibration and Motion Durability	Because the system is mounted in footwear, there is constant motion and vibration during usage. All internal wiring is routed through flexible conduit tubing. The components will also be fastened using low-profile brackets. Vibration motors will be selected based on the life cycle and shock tolerance.

The S.I.G.H.T. shoe is engineered with practical and realistic environmental durability in mind. This was done so that we would be able to balance protection and performance without having to sacrifice the user's comfort and portability. By addressing challenges that could come from the environment, we were able to eliminate issues such as moisture, shock, tolerance to different temperatures, and debris. This design strives to deliver a reliable and long-term solution for visually impaired users hoping to navigate in real-world conditions.

4.2.5 User Comfort and Safety

Designing a wearable structured light object detection system requires both adherence to user comfort but also must fall in line with safety standards. Since the user of the product will be using the S.I.G.H.T. directly for object detection for a visually impaired person, risk needs to be minimized; ease of use needs to be maximized, while still following all safety standards. Since this system will use laser projection and a camera module will be taking in images, standards for laser safety and unauthorized recording need to be followed [37]. Several constraints were followed during the process of designing the electrical and optical components. The form factor must be considered as components need to be compact and light weight to not impede the gait of the user. Weight distribution must be considered as well, to minimize fatigue or imbalance in the user. The material needed for the boot needs to be safe for the skin and non-abrasive to prevent any discomfort. Electronic components must not be in direct contact with the skin of the user to avoid irritating the skin. The safety standards for the optical system include the laser diode module used in the structured light system. The laser class of the laser used was within class 2 per IEC 60825-1. The laser system is well controlled as it is pointing down and away from the eyes of other pedestrians. The design of the class 2 laser includes warning labels in accordance with ANSI Z136.1 [37]. The system is running on low power between 3.3V and 5v which is relatively safe, and PCB's and exposed wires are enclosed to avoid electrical shock.

4.2.6 Ergonomic Constraints

Since the S.I.G.H.T. system is designed to be worn directly on the user's foot, ergonomics presented a major design constraint throughout the development of the prototype. The challenge was to integrate sensors, power systems, and feedback mechanisms without compromising comfort, balance, or natural gait. Early brainstorming sessions emphasized that any device worn over extended periods must be lightweight, non-intrusive, and well-distributed to avoid fatigue or physical strain.

Weight distribution was a key consideration when selecting both components and their placement. Heavy components such as the 6600mAh lithium-ion battery were strategically mounted near the ankle area rather than the toe or heel to avoid affecting walking dynamics. This placement also minimized the risk of the user accidentally damaging sensitive electronics while walking or navigating uneven surfaces. Additionally, foam padding and a protective inner liner were added to prevent hard edges from pressing against the user's foot.

Noise and haptic vibration levels were also tuned with ergonomics in mind. During testing, initial vibration settings were found to be too sharp and uncomfortable for prolonged use. As a result, the team adjusted both the intensity and duration of haptic pulses through the DRV2605L motor driver to deliver more subtle cues without sacrificing perceptibility. Similarly, speaker placement and volume levels were optimized to ensure that feedback remained audible in moderate outdoor environments without becoming disruptive or startling.

Lastly, because users with visual impairments may have unique footwear needs, we designed the system to be detachable and adaptable to multiple shoe sizes and styles using Velcro and adjustable brackets, supporting a more inclusive and user-friendly experience.

4.2.7 Maintainability and Upgradeability Constraints

In addition to performance and affordability, the S.I.G.H.T. system was developed with long-term maintainability and upgradeability as guiding constraints. The device is intended to be used by individuals who may not have access to technical support or advanced repair services, making modularity essential. This influenced both hardware selection and firmware structure from the earliest design stages.

Each subsystem was designed to be independently replaceable. For example, the ultrasonic sensors are mounted using detachable JST connectors and socketed headers rather than soldered directly to the board, allowing for quick replacement in the event of damage. Similarly, the microcontroller can be swapped with another ESP32-CAM module using a pin-and-socket configuration without rewiring the entire circuit. This strategy reduces downtime and enables users or technicians to repair the system with minimal training or tools.

On the software side, modular functions were written to support plug-and-play behavior. Sensor readings, haptic feedback, and speaker tones are handled through individual interface functions, allowing additional sensors or actuators to be introduced with minimal changes to core logic.

By designing maintainability, we not only improved the system’s reliability and longevity but also supported its real-world viability. In future phases of development, this modular framework will allow our team to add new capabilities such as structured light analysis without requiring a complete redesign of the shoe electronics or codebase.

4.2.8 Summary of constraints and impact

Throughout the development of the S.I.G.H.T. smart shoe, several engineering and real-world constraints influenced our design decisions. Each constraint required careful consideration to ensure that the final prototype remained functional, affordable, safe, and user-friendly. The table below summarizes these key constraints, how they shaped specific component choices, and the trade-offs we accepted to maintain system performance within realistic limits. This structured overview highlights the balance between ideal functionality and practical limitations inherent in embedded wearable systems.

Table 32: Summary of Design Constraints and Trade-Off Decisions

Constraint	Design Decision Impact	Example Component	Trade-Offs Made
Power Limitation	Required low voltage, efficient devices	3.7V Li-ion Batter	Limited continuous runtime, especially under high load
Physical/Ergonomic Fit	Enclosures must be lightweight,	ABS Housing, Velcro Mounts	Reduced sensor coverage area in some orientations

	balanced, and unobtrusive		
Cost Constraint	Favored low-cost components with multiple features		Avoided high-end sensors and limited onboard processing power
Environmental Protection	Design has to resist light water and dust exposure	Conformal Coating, IP44 Enclosure	Limited ability to submerge or operate in heavy rain
User Safety and Comfort	Requires safe vibration levels and non-disruptive sound cues	DRV2605L, PUI Audio Buzzer	Needed to tune intensity for perceptibility without discomfort
Maintainability	Modularity for component swaps and future upgrades	socketed headers, JST wiring	Increased physical footprint of electronics

Chapter 5 Application of ChatGPT and other Similar Platforms

5.1 ChatGPT

5.1.1 Overview

During the development of our Smart Integrated Guidance Haptic and Technology or S.I.G.H.T, which is a wearable smart shoe for the visually impaired using Structured Light, ChatGPT was used to help brainstorm ideas for design decisions, component selection and evaluation as well as providing helpful information on concepts. Used correctly ChatGPT can be a very powerful tool, however limitations become more glaring during the prototyping and testing phases of the project. For example, for our design, physical optics testing and imaging with real time feedback are the basis of detecting objects and giving the signal to be able to avoid the obstacle. This would not be possible from a ChatGPT only prompt, or any other available AI. Modern LLM can be very helpful and provide useful information, and goes as far to possibly simulating a system, but cannot replace benchmark testing done with physical components in a lab where empirical data is collected. Many times, when using an LLM, responses are limited by the user prompt, regarding explicitly mentioning any and every system constraint. Our S.I.G.H.T. also requires significant optical design, which needs computer programs such as ZEMAX to be able to model lenses and their aberration. ChatGPT cannot model this lens performance, or beam profiles needed for the structured light deformations on surface needed to calculate light deformation in quantifiable way. Ultimately, relying only on ChatGPT for a project like this can be very risky, because of the high chance that the solution being given by the LLM will not hold up with hands on testing in a lab.

5.1.2 Pros and Cons in Our Project

Aside from being limited in a physical benchmark testing phase, the use of ChatGPT and other similar LLM are helpful and provided significant helpful features for our S.I.G.H.T. project. The use of LLM's allows for rapid research and clarification of ideas and concepts. In our project quick summaries were given for different forms of sensing such as LiDAR, Time of Flight, Structured Light, and Stereo Vision. Other key concepts which LLM's were convenient in recapping were optical such as collimation, divergence, and Seidel aberration. The use of LLM's are also helpful in search and procurement of components. They group components and give a good starting point of reputable sellers and match components from different subsections of the design to be able to match and be compatible. Ultimately, this is a time-saving feature of LLM's. Another benefit of the use of LLM's for our Senior Design project is its helpful recommendation of code and test logic needed, especially for the use of the ESP32 system. Support for prototyping is also given in the form of the support system needed to hold the projector and camera for the structured light sensing system.

Ultimately the biggest con of using ChatGPT and other LLM's for our project is that it can never "see" what is going on with testing and prototyping in real time. What is meant by this is that any LLM is dependent entirely on the manual description given by the user. For optical systems, ChatGPT cannot help with aligning a laser system or calibrating the

camera component. Another con is lack of contextual awareness of our lab setup, unless remembered or brought up every time component recommendation can become generalized or even mismatched. Since LLM's have no direct optical simulation capability no numerical results can be given and cannot give simulation to improve aberration or beam path. From a standards and safety perspective ChatGPT might recommend a laser without accounting for the laser safety class, or regulatory compliance. This needs to be accounted for by all parties involved because of the inherent risk of eye damage by a laser. No LLM can create an original solution to solve a unique problem. This means that although existing databases can be searched, but an LLM cannot take the place of an engineer who can create an original solution.

5.1.3 Learning Impact with Examples

The use of LLM's such as ChatGPT can have both a positive and negative effect on the learning experience during senior design. A positive example of how ChatGPT has improved the learning experience has been through a combination of structured technical guidance. For the optical design portion of the project the LLM has helped provide a design workflow for lens design feedback, integration of the Diffractive optical element (DOE), and the principles of structured light according to instructor feedback. It has been helpful to have a tool that provides sourcing as well as justification for components and key theories needed for the success of the structured light system.

Recommendations that were given for the lens design were an aspheric lens for collimating the laser diode. The reason an aspheric lens is a good recommendation compared to the regular spherical lens is that they improve image quality through correction of spherical aberration which reduces blur. Distortion on the edges of the lens is reduced as well, which improves system performance for the structured light system which needs a wide field of view. This is crucial for getting a wide enough field of view to look for obstacles and drop-offs such as any possible ditches. Key details on the strategies needed to make a successful structured light system were provided and simple sketches and design blueprints were able to be generated.

One of the strongest aspects in the usefulness of the learning process in Senior Design and LLM's are the rapid prototyping support given. The microcontroller unit and camera system used for our project were able to be evaluated and enabled a quicker decision-making process. The ESP32 system used is an embedded system microcontroller, which both electrical engineers on the project were already familiar with. Through consultation of ChatGPT, these components can be ordered with a greater peace of mind of the design being successful and prototyping to begin to test feasibility for all models. The benefits given to justify the use of the ESP32 -CAM was the cost effectiveness and fact that it comes with a camera module already built in. Cost is one of the key factors for our project because we are entirely self-funded and do not count on any external sponsors or grants. Recommendations for this microcontroller were also given because of the compact size and low power consumption, which are also crucial components for the obstacle detecting shoe to be successful. The structured light system which will be used for obstacle detection is made up of laser which will project stripes of light. The camera system used will take pictures of the stripes and any distortion in the stripes can be calculated and a depth map

can be formed. The ESP32 has a dual core which can handle image data and processing. Finally, this microcontroller is compatible with an Arduino IDE, which the LLM used mentioned that it is relatively easy to program. With this information given by LLM, which matched the recommendations given by the electrical engineers on the team, the ESP32 was selected for prototyping.

In terms of the laser used for prototyping, ChatGPT did give a recommendation on why the laser diodes selected were good options. The low cost and easy integration to the ESP32 microcontroller were key features, along with tuneability of the laser dot. The laser diode module came with the driver circuit built in, which saves time for our electrical engineers and allows for plug and play usage within the 5V rails of the microcontroller. The 5mW output is considered class I, which is safe for the eye. The 650nm wavelength is compatible with the DOE, which were all recommendations given by the LLM and it is said that should be visible indoors and outdoors in short ranges.

ChatGPT was helpful in the evaluation of the light stripes generated by the DOE on selection. The structured light system that will be implemented for this project will be a series of horizontal stripes. For a mechanical system, one stripe could be scanned up and down and side to side. For our project the DOE will create a series of lines that can be scanned with one frame and eliminate the need for a mechanically active scanner. Going back to the basis for the idea of our project, object detection and avoidance is key. Therefore, the structured light system used needs to be able to pick up details in the frame for ditches, curbs, and any drop offs or obstacles. The choice for the DOE directly affects what can be mapped by the distortion in the stripes caught by the camera. For example, one option was a 7-stripe option, and if this DOE were to be chose, there is a good chance, that one of the obstacles that needs to be detected falls through the lines. With 25-line DOE's there could be overlap in the lines that can be hard to register on the camera, but there was a 15-line option, that according to ChatGPT would be a good option for our structured light sensing system. ChatGPT also gave a recommendation for sellers to be able to source the DOE, but ultimately the DOE was ordered from a website found by word of mouth from another group doing a similar project.

Many other options for sourcing were done for the DOE. It is always helpful to have more options in case the first component ordered was not functioning correctly or optimally. The main benefit is to have a multitude of options that one can research on a deeper level to be able to come to a selection. It is the hope of the user that after research is done and if there are options to choose from, these options for components can be ranked from good to best. This is the idea for using an LLM for a project like this. You would want a prompt where you ask for a specific task or need, and with the generated response, the user can further research these options and make a decision on the best component.

In terms of prototyping ChatGPT and other language models are beneficial with cad designs needed for 3D printing. One of the challenges of this project is going to be mounting the structured light system on the front of the shoe. On top of that, the PCB board needs to be onboard and attached to the microcontroller. A battery needs to be attached as

well. For this having at least a starting off point available from an LLM is going to save a significant amount of time on the design process.

When initially prototyping the design for the shoe, we came up with multiple hand drawn ideas that were adequate for our early ideas. However, using ChatGPT sped up the process exponentially. We were able to get a clear image and actually be able to picture what this product could be like in real life. This also helped clear up any confusion group members had when trying to describe where components needed to be placed on the shoes. For example, Camera and laser need to be placed at the shin of the boot to see the farthest forward and a rechargeable battery would need to be mounted somewhere on the shoe as well. However, this did not mean that ChatGPT was able to apply all aspects of our design. After many tests ChatGPT could not understand where the ultrasonic sensors should be placed or adding an LCD screen. Ultimately, we settled on a mixed combination of the ChatGPT design and hand-drawing our components onto the shoe.

Overall ChatGPT can be said to have a positive experience on learning for senior design by streamlining the design and sourcing timeline for components for our project. With the many time and size constraints for the summer semester, having a tool that can help save any time on the more tedious and administrative parts of the project, this allows more time for prototyping and more research and development.

5.1.4 Limitations and Risks

As much as ChatGPT and other LLM's have helped and enhanced the learning experience in this senior design class, there are also examples of them hurting the learning experience during this senior design process. Of the specific experiences these include, directly giving an answer that one might be better served looking oneself, oversimplification of engineering concepts and decisions, the encouragement of over-reliance on tools instead of thinking about design, and not challenging unjustified choices.

The most negative way that ChatGPT has affected the learning process in senior design is the direct answering of questions that may have been better for the team to think critically for a solution or component. For example, there may be a time when a calculation will be more appropriate to find a lens where ChatGPT could recommend something without the user doing any work. This is a problem because the key idea for senior design is to get something out of the class that we don't get in other classes. If ChatGPT can just give you answers instead of working through a problem and finding the best solution, this leaves something to be desired in the learning process.

A second way in which the learning process suffered under the use of ChatGPT during senior design is the oversimplification of complex engineering decisions. There were times when the LLM presented the use of a lens or DOE with limited comments on nuance or constraints that can only be considered through testing and prototyping. There are times that tradeoffs in components need to be considered. It would be better not to rely on ChatGPT and consider the opinion of a faculty member on the committee. A specific example of this can be that the LLM gives a recommendation on a laser diode module, but it could be that the LLM does not have a full grasp of lab availability and components, the

testing environment, or safety concerns. Doing this research will increase the scope of the analysis and feasibility of the project.

A third example of the use of ChatGPT hurting the learning experience during senior design is the encouragement of use of tools over design thinking. Many times, an LLM can provide flowcharts, Gantt charts, and other diagrams. Thinking about these processes as an engineer is crucial in the design process and can hurt the student learning experience. Flowcharts and diagrams should be original, and tools should be used, but not overly relied upon.

The final way in which the use of ChatGPT has hurt the learning experience in senior design is not pushing back on unjustified choices. For example, for our project, we are using a structured light sensing system. Even though heavy research was done on many different ranging systems, such as time of flight, machine learning, stereo vision, and triangulation, when the idea was presented to ChatGPT, the LLM did not ask if we had considered other options. Perhaps if we had not done the research and other options were better suited for our project, this would not have been recommended by ChatGPT. Even though ChatGPT can be a powerful tool in the modern world, the overreliance on this LLM can be harmful in the learning experience needed for ChatGPT.

The use of ChatGPT has had both positive and negative effects on the learning process for senior design. There are many benefits to the learning process by using the LLM, such as a streamline design process, easy to access component sourcing and background information, and help in the decision-making process for the design. There are also negative effects of ChatGPT on the learning experience during senior design. These include oversimplifications of complex design concepts. A component can be recommended that also is not in stock or could take a significant amount of time to arrive. An overreliance on ChatGPT instead of doing proper research is a danger of using the LLM.

5.2 Other AI Platforms

5.2.1 Claude AI

5.2.1.1 Overview

Claude is an AI assistant developed by Anthropic. Founded in 2021 by former OpenAI executives and researchers, they're known for focusing on building controllable and reliable AI systems. It belongs to the family of Claude 4 models, which is made to be intelligent and effective for daily use. It is powered by large language models (LLMs) that are trained on large datasets. The way these LLMs work is by using deep learning techniques based on systems that can learn from data and make decisions. Other examples of LLMs are ChatGPT, Google Gemini, and Microsoft Copilot. Claude (much like its other AI counterparts) is trained with data provided by users, the internet, and even licensed content from third parties. Claude can assist with research, coding, and other features. Its main difference from the other AI chatbots is that Claude can produce writing that is human-like compared to other platforms. Claude is especially useful when it comes to finding educational sources, engaging in human-like conversations, coding, and uploading files. Claude is constantly learning from the conversations it engages in due to its model style.

This is why Anthropic has made safety one of its top priorities. With the rise of AI, many people have questioned its ethical use and the possible dangers that it can create. Anthropic has taken it upon itself to be positioned as the “golden standard” of today’s AI companies

and models. Harmful prompts and responses are trained to be avoided in order to prevent the misuse of AI. Constitutional AI was created for the sole purpose of setting the example of AI ethics and safety created by Anthropic itself. Users are presented with options of Claude's responses that closely align with being reliable, clear intention, and least dangerous. Based on users' responses and guidelines, the model is able to train itself to meet safety standards. These are especially useful when it comes to providing information to the user that is as accurate as possible.

We used Claude as an alternative tool for tasks such as component research assistance, comparing power options, sensor modules, and more. It also served a vital purpose of explaining and reviewing technical concepts as a reference for other sources during our time developing the Smart Integrated Guidance Haptic and Technology (S.I.G.H.T) wearable shoe for the visually impaired. This reference/guidance is complementary to instructor feedback, team collaboration, and course materials provided. Claude was primarily used as an unofficial advisor who helped support decision-making for components and strategy, such as the tradeoffs and technical justifications. It streamlined and improved the understanding of identifying and comparing compatible electrical components like battery packs and power regulators.

5.2.2 Pros and Cons in Our Project

As we started this project, we knew that AI was going to be a major learning tool to assist us in the early planning and research phase. For the S.I.G.H.T system, we used Claude as a support and reference tool to help guide decisions related to multiple areas of engineering for development. This includes but is not limited to electrical components, power systems, research sources, optical design, and more. One of the biggest pros of using Claude was its ability to explain technical concepts in a simple, easy-to-understand way. This is due to Claude's AI being known as being able to have human-like conversations compared to other AI tools. When we were deciding between certain components, such as power sources, Claude excelled in showing the differences between each component and even provided additional feedback on items we may be missing or have to do more research on. This allowed us to work efficiently and manage our time effectively when narrowing down which parts to use for our wearable shoe system. Another strength of Claude was its usefulness for additional brainstorming as an advisory role once we had a human brainstorming session. These ideas ranged from communication methods, how to structure our development timeline, items to research on our own, and organizing our own thoughts, such as logical steps on how to begin and approach the design of the model. The main selling point of Claude is its security/privacy priorities, which means it doesn't store or use data without permission, which gave us more comfort when working on the project.

However, this doesn't mean that Claude is perfect and was the only tool we used. Several limitations and drawbacks, such as analyzing images or diagrams, were something we wouldn't be able to use Claude for. As with any AI tool, there are massive cons when it comes to real world design and testing. The main con is the inability of AI to provide feedback on simulations, testing in real time, which is something we will begin once we move onto the next phase of the project. Physical design, like board spacing or wiring, is up to us as engineers, and we cannot rely on AI for everything. Claude won't be able to catch future problems, such as malfunctioning circuits or sensors. Claude also tends to give more cautious or general responses, which can lead to slow decision-making and cause us

to do more follow-up research on our own, since we cannot rely on the information it provides, since AI tends to be inaccurate. Prompts must be specific and include important information, as it might recommend parts or sources that won't work in our planned setup. Claude (and any AI) is best used as a support tool during the research and planning stages, but not as a replacement for hands-on work, engineering experience, first-hand decision making, and real testing. Claude helps guide and educate, but the most important skill we can develop will come from our own experiences with building, testing, and problem-solving using everything we've learned in our previous and current classes.

5.2.3 Differences between Claude and ChatGPT

This section outlines the key differences between Claude and ChatGPT, both AI language models developed by Anthropic and OpenAI. The basic design ideas, training methods, capabilities, and inference styles of the two systems vary, despite the fact that both are made to produce text that is human like and help with a variety of activities. Knowing these distinctions helps one better understand how each model meets the demands of users in different applications.

Table 33: Differences between Claude and Chat GPT

	Claude	ChatGPT
Company	Anthropic	OpenAI
AI Models	• Claude Sonnet 4 • Claude 3.5 Haiku • Claude Opus 4	• GPT-4o • GPT-4o mini • o1 • o1-mini
Web Search	Yes (available in some versions)	Yes (available in Plus/Pro plans and some free versions)
User Interaction Style	More cautious, reflective, asks questions, good for brainstorming	More direct, decisive, and often faster to provide solutions
Image Generation	Not Supported	Supported (via Dall-E in GPT-4o)
Performance/Capabilities	File uploading (useful for analyzing datasheets or technical docs), lacks image creation,	Image creation, internet search are available in some versions
Data usage and storage	Doesn't use prompts or responses for training without permission, retains data for 90 days	May use conversations for training unless you opt-out
Ethical and safety focus	Uses constitutional AI principles for self-learning	Uses reinforcement learning from human feedback
Context Window	200,000 - 500,000 tokens	Typically 32,768 tokens - 128,000 tokens

5.2.4 Learning Impact with Examples

Utilizing Claude during the development of the S.I.G.H.T. shoe, it offered significant learning opportunities, particularly when addressing hardware design and component integration.

The first example, where we used Claude was to learn about how to figure what power to use to connect to several parts using a single battery, which included the ESP32-CAM, vibrational motor, LCD screen, audio speakers, and two ultrasonic sensors. We used Claude about safe and effective ways to handle various voltage requirements. We then were able to figure out what power distribution for our shoe design needed so it didn't cause any damage to components or the users that will be using our product. Overall, Claude gave us multiple resources to standards to research about and this helped a lot for chapter 4 when writing about standards.

Another example where the team used Claude was for assisting with components specifications and how to read their respective datasheets. Things like the LCD screen display and the ultrasonic sensors. Rather than providing brief responses, it clarified the why we would need a certain wire or component.

All things considered, Claude was a helpful resource that helped with improving our understanding of the backgrounds of some of our components.

5.2.5 Limitations and Risks

Claude is able to play a key role in assisting in research, advising, learning, and even design exploration. However, since it is only an AI model, it's unable to be used as a tool that interacts with the physical hardware itself or provide real-time analysis of SIGHT being built. It is massively unsuitable for tasks such as custom PCB configuration, physical fit, and real-world integration. Recommendations are able to be made as a reference point for the project. However, Claude isn't able to verify specific components' compatibility, performance, or reliability. Identifying these tasks is up to us by using our best judgment and experience. Physical integration, choosing the correct parts, and design are something AI cannot replace just yet. Claude is effective for clarifying technical ideas/strategies, offering initial component comparisons, or serving as a starting point for code and documentation. A major risk is using Claude without verifying safety guidelines or other information provided, as with any other AI model. This can lead to making wrong decisions, a waste of resources, or even incompatible and unsafe configurations. Component recommendations provided by Claude could pose a risk in wearable electronics. Another risk is the possibility of generic/incomplete answers based on the prompt given. It is our job to verify and validate the information AI gives us.

All in all, Claude was used for some parts of the S.I.G.H.T. shoe process for research and planning purposes. From helping the team break down complex engineering topics to helping us find datasheets for some components that we needed to use. Having Claude be able to do human like communication made it easier to use as well and easier for us to understand.

5.3 Copilot by Microsoft

GitHub Copilot is an AI-powered coding assistant developed by Microsoft and OpenAI. It integrates directly into code editors like Visual Studio Code and provides real-time code suggestions, autocompletions, and context-aware snippets. For engineering students, Copilot serves as a powerful tool for accelerating development, especially in low-level or syntax-heavy environments like C/C++ used in embedded systems.

5.3.1 Pros and Cons of Our GitHub

The following table presents a comparison of GitHub Copilot and ChatGPT, two popular AI tools that are both helpful in their own ways. Although they both use sophisticated language models to increase productivity, their ideal use cases, design, and interface style are different. The tables below outline key pros and cons of each tool to help users determine the best option.

Table 34: Benefits of Using GitHub Copilot in Our Project

Rapid Code Generation	Copilot helped scaffold initial functions for sensor reading (e.g., ultrasonic distance), timer setup, and interrupt-based button handling.
Syntax Assistance	Reduced time spent looking up obscure C syntax for ESP32 libraries.
Comment-to-Code Conversion	Enabled us to write natural-language comments like “read ultrasonic sensor and return distance in cm,” and receive full function definitions.
Helps Avoid Common Errors	Suggested proper pin Mode and analogRead/digitalRead sequences compatible with ESP32.
Code Style Consistency	Copilot maintained consistent indentation and variable naming, reducing stylistic mismatches when multiple team members worked on the same files.
Learning Accelerator	By watching Copilot’s suggestions, we learned new C++ idioms, array handling, and efficient loop control mechanisms.
Library Integration	It recognized libraries like Adafruit_NeoPixel or ESP32Servo and scaffolded setup code that saved hours of manual trial-and-error.

Table 35: Limitations of Using GitHub Copilot in Our Project

Context Limitations	Sometimes misunderstood the project’s real-world application (e.g., it would
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generate LCD display code when our system uses haptics).	
Over-Suggesting	At times, Copilot generated redundant or insufficient code requiring manual cleanup.
Debugging Dependence	Risk of treating Copilot as a crutch, delaying deeper understanding of microcontroller architecture or communication protocols.
Lack of Project Memory	It didn't remember context across multiple files, which led to inconsistent suggestions unless comments were added repeatedly.
Security Oversights	Occasionally, it suggested code with potential vulnerabilities, like reading uninitialized memory or skipping null checks in Bluetooth setup.
No Context of Sensor Hardware	For example, Copilot sometimes treated our ultrasonic sensor as an analog device, suggesting analogRead() instead of using pulseIn() or digitalWrite().

5.3.2 Differences between Copilot and ChatGPT

In our senior design project, we extensively used both GitHub Copilot and ChatGPT to accelerate development, debug code, and gain a deeper understanding of embedded system design. While both tools use AI to assist developers, they serve different purposes and complement each other in functionally different ways.

Copilot GitHub Copilot is integrated directly into the code editor (Visual Studio Code). This will provide inline suggestions as developers type. It is particularly useful for syntax-heavy or repetitive tasks. It learns from context within the file and auto-completes functions or logic blocks. This would be helpful in writing C++ code for the ESP32.

Use Case in Our Project: While working on sensor interfacing, Copilot was useful in writing initialization logic for the ultrasonic module. For example, typing a comment like “// measure distance using HC-SR04” would result in Copilot generating a fully functional function with “pulseIn()” and “digital pin control”. Copilot also helped us avoid small but critical errors like mismatched brackets, incorrect syntax, or uninitialized variables.

ChatGPT

On the other hand, ChatGPT serves as a technical consultant throughout the design process. Unlike Copilot, which operates line-by-line, ChatGPT allowed us to explore high-level system design, generate diagrams, and troubleshoot issues that could span across various

files. It provides code explanations, helps with writing state machines, and generates initial pseudocode from logic descriptions.

In Our Use Case:

When designing the overall software state machine, ChatGPT could be used to effectively convert written state descriptions into functional state diagrams and supporting code. ChatGPT could also help understand how interrupts, delays, and memory could affect real-time responsiveness on the ESP32.

Table 36: Comparison for Copilot vs ChatGPT

Feature	Copilot	ChatGPT
Integration	Inside VS Code/IDE	Web-based or plugin via browser/API
Best For	Code completion and boilerplate generation	Explaining logic, system architecture, debugging
Speed	Real-time suggestions while coding	Slower, but more in-depth answers
Code Explanation	Minimal	Extensive and detailed
System Design Support	Limited to file context	Great for flowcharts, architecture, and logic development

5.3.3 Learning Impact with Examples

AI tools had a strong positive impact on our learning process. They were used to:

- Explain unfamiliar C++ constructs in the Arduino environment.
- Generate pseudocode and convert it to working code.
- Create system diagrams (flowcharts, state machines) using prompts like “generate a state diagram with idle, detecting, alert, and SOS states.”
- Accelerate troubleshooting such as resolving ESP pin conflicts or misconfigured PWM outputs.

5.3.4 Limitations and Risks

- **False Confidence:** AI can sometimes give incorrect answers which could cause issues throughout the project. This required us to manually validate results, especially for sensor interfacing or pin configurations.
- **Outdated Context:** Copilot and ChatGPT can occasionally suggest libraries or APIs that are outdated or lack compatibility with the ESP32.

- **Plagiarism Risk:** Over-reliance on generated content without understanding it could violate academic integrity or result in undebuggable code.
- **Lack of Physical Awareness:** AI does not account for electrical limitations (e.g., current draw, real-world timing issues), which must be tested manually.

The integration of AI tools such as GitHub Copilot, ChatGPT, and Claude significantly enhanced our development workflow and technical learning. These tools acted as accelerators and were not replacements for real understanding. When used responsibly, they enabled rapid prototyping, deeper comprehension of embedded systems, and clear documentation. However, we remained aware of their limitations and exercised judgement in applying their suggestions. Overall, AI is a valuable tool throughout our Senior Design journey. However, there are some strong limitations within using AI that are strongly observed.

Chapter 6 Hardware Design

This chapter outlines the hardware design of the S.I.G.H.T. shoe system which is developed to enhance the navigation for the visually impaired through tactile and auditory alerts. The system is embedded into the shoe and integrates many hardware subsystems. By combining distance measurement, real-time processing, and a multimodal alert system, the S.I.G.H.T. shoe system provides the user with appropriately timed obstacle warnings through vibration and audio feedback. The major components included in the product are, a microcontroller (ESP32-CAM), an ultrasonic distance sensor (HC-SR04), a vibration motor, a speaker, a rechargeable lithium-ion battery, a camera, and a laser range finding module. The hardware was selected with an emphasis on durability, long-lasting power supply, and a seamless integration within the shoe environment. The following sections detail the architecture, subsystems, schematic overview, and physical layout of the device.

6.1 System Architecture

We will begin this section by giving a brief introduction to each component we will be using in our product. The core of the system is built around the ESP32-CAM, which is a low-power microcontroller equipped with Wi-Fi and a camera interface. It will be responsible for processing sensor inputs and controlling output devices. The ultrasonic sensor, HC-SR04 will measure the distances of nearby obstacles while the LCD Display will print these values to show the product is working. The Vybronic VG0840001D vibration motor and PUI AS02708CO-WR-R waterproof speaker will provide haptic and audio feedback, respectively. And lastly the Dantona L37A26 Li-ion battery supplies power to the entire system. The architecture following the modular design will allow for easy future upgrades or replacements and power regulation will be managed through a compact onboard voltage regulation system. Below are photos of the components listed above for easier visualization.

Speaker: PUI Audio AS02708CO-WR-R:

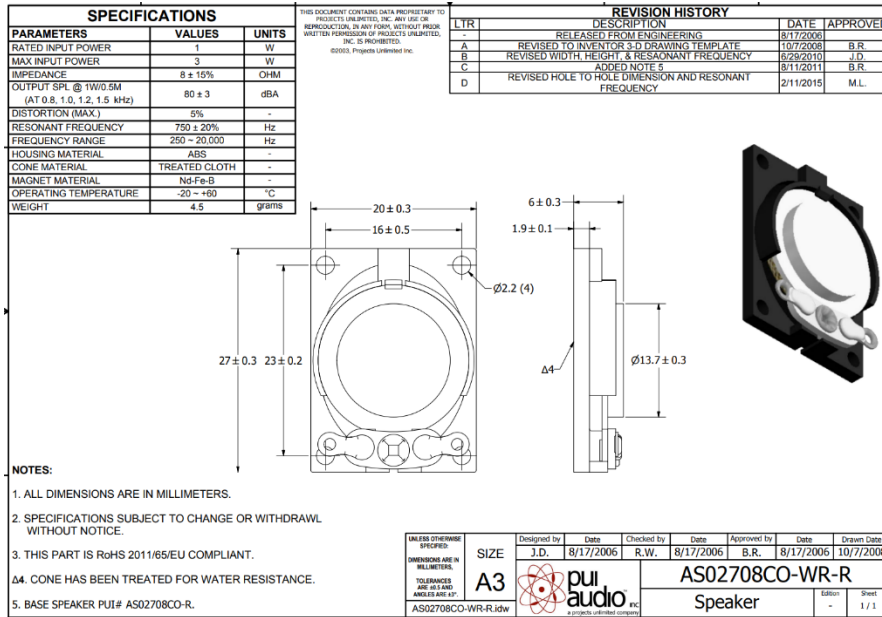


Figure 14: Speaker Illustration

This speaker is compact and waterproof. It can deliver sound output between the ranges of 800Hz-20kHz and has an impedance of 8 ohms. It is small and portable and due to its weather resistance, it is ideal for outdoor use.

Audio Amplifier:

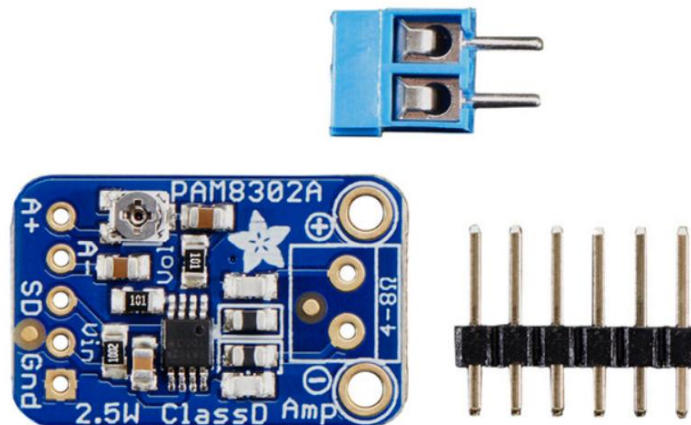


Figure 15: Adafruit Mono 2.5W Class D Audio Amplifier - PAM8302

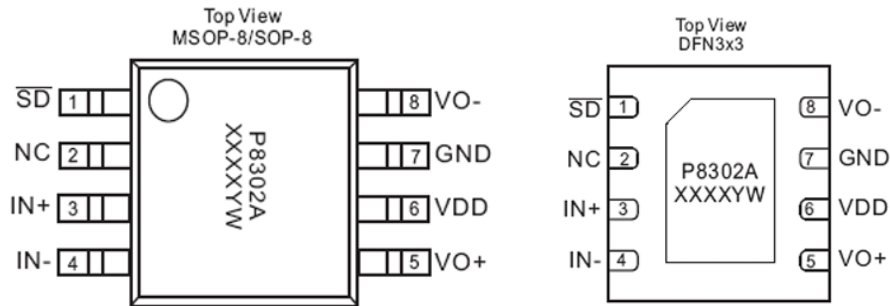


Figure 16: Adafruit Mono 2.5W Class D Audio Amplifier - PAM8302 Schematic

This amplifier is a compact, high-efficiency amplifier. It can deliver up to 3.5W output at 4 ohms with a 5V supply. The amplifier has a low total harmonic distortion, which is important for audio output and has a short-circuit protection component. Due to its size and efficiency, it is perfect for this product since it will drive a small speaker in a low-power audio system.

Vibration Motor: Vybronic VG0840001D:



Figure 17: Vibration Motor Illustration

This vibration motor is a coin-shaped linear resonant actuator. It operates at a frequency of 170-175Hz and provides a strong clear haptic response. It has a low operating voltage and fast rise time. These reasons make it ideal for applications which require localized tactile feedback specifically in wearable haptic interfaces.

Haptic Driver:

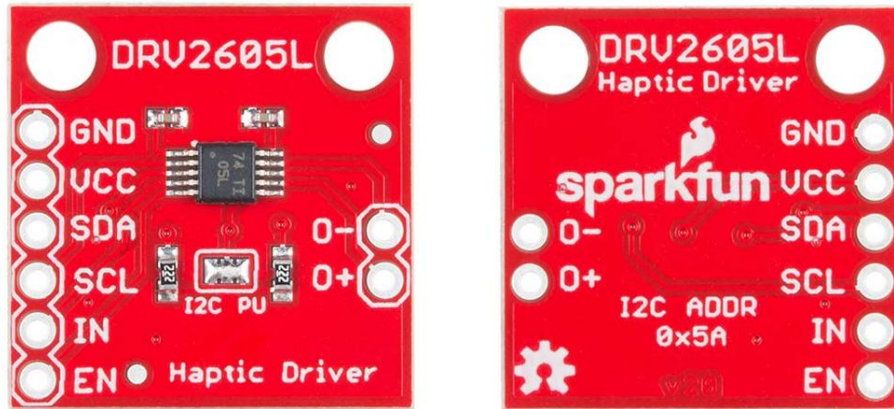


Figure 18: SparkFun Haptic Motor Driver - DRV2605L

The haptic driver enables precise control of the linear resonant actuator. It includes a waveform library (click, buzz, ramp effects) and has an automatic resonance tracking to optimize motor performance. Due to its size (compact) it is easy to integrate onto PCBs and allows for seamless haptic feedback implementation.

Ultrasonic Sensor: HC-SR04:

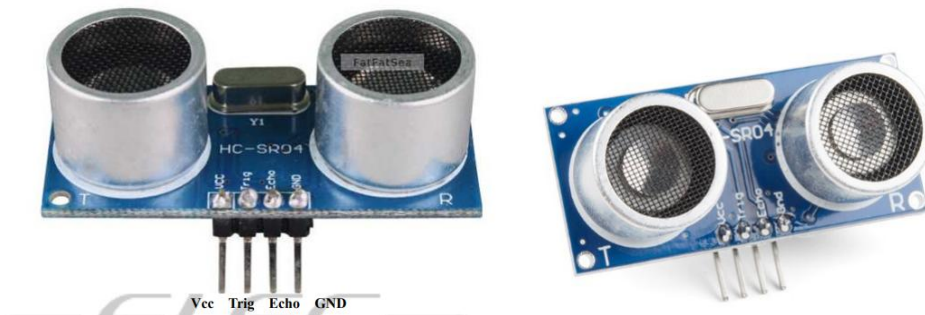


Figure 19: Ultrasonic Sensors

The ultrasonic sensor will be used for precise, no-contact distant measuring. It operates by emitting high frequency pulses which calculates the time delay of the reflected echo to determine the distance of objects. We use this to get an accurate measure of obstacles in front of our product. This ultrasonic sensor allows flexible integration, supporting both serial and pulse-width interfaces and will allow the MCU to have smooth integration.

Battery: Adafruit 3.7V 6600 mAh:



Figure 20: Battery

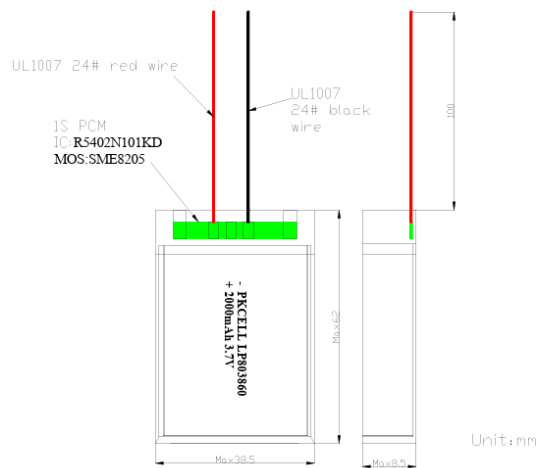


Figure 21: Battery Schematic

This rechargeable lithium-ion battery is ideal for our product. It delivers a nominal voltage of 3.7V and has a capacity of 2000mAh. This means it is ideal for providing power for low-medium current devices. It has a standard connector and includes built-in protection circuitry to prevent overcharging, over-discharging and short circuiting.

Battery Charger:

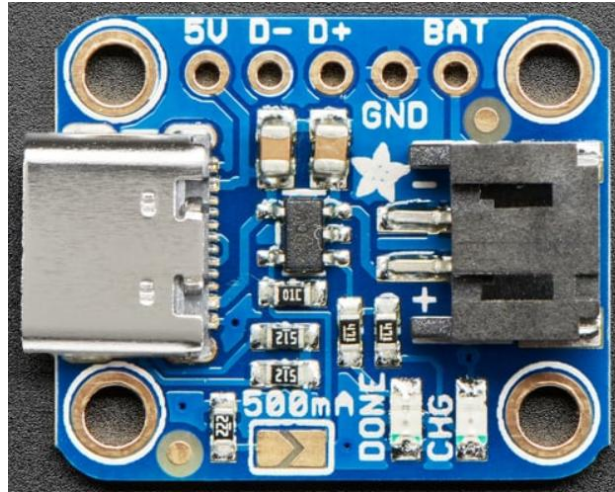


Figure 22: Adafruit Industries LLC 4410

Adafruit PowerBoost 500:

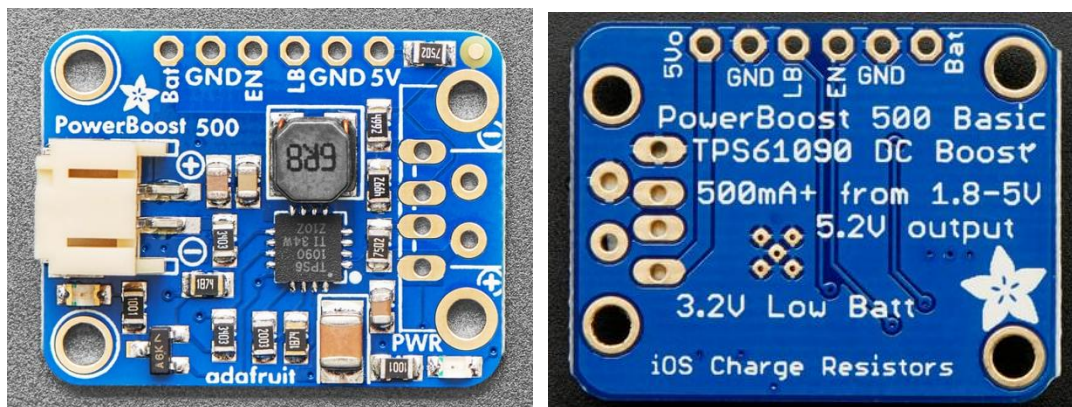
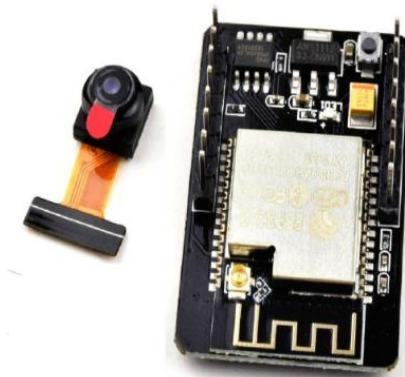


Figure 23: Adafruit PowerBoost 500

The Adafruit PowerBoost 500 is a compact, high-efficient boost converter module that helps step up a single cell LiPo battery of 3.7V to a stable 5V output. Built around the TPS61090 synchronous boost converter IC, it can deliver up to 500mA of continuous current making it suitable for low to moderate 5V power loads. The module includes key features such as an enable pin for power control and a low battery indicator output. It is a PCB friendly design and includes easily readable and labeled through-hole and surface-mount pads.



MCU: ESP32-CAM:



The ESP32-CAM is not only the MCU for our product but also provides the camera we will be using to track obstacles. This ESP-CAM is highly performing and with the

additional laser and camera lens we are able to implement a highly efficient obstacle tracking system.

Battery Buck Regulator:

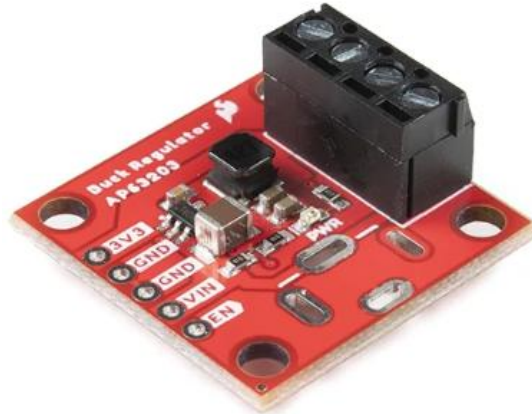


Figure 26: SparkFun Buck Regulator Breakout - 3.3V (AP63203)

The SparkFun buck regulator will help convert our 5V input voltage into 3.3V which is required for some of our components. This regulator is capable of efficiently converting input voltages up to 18V to a 3.3V at 2A load. It is ideal for a high-voltage battery source.

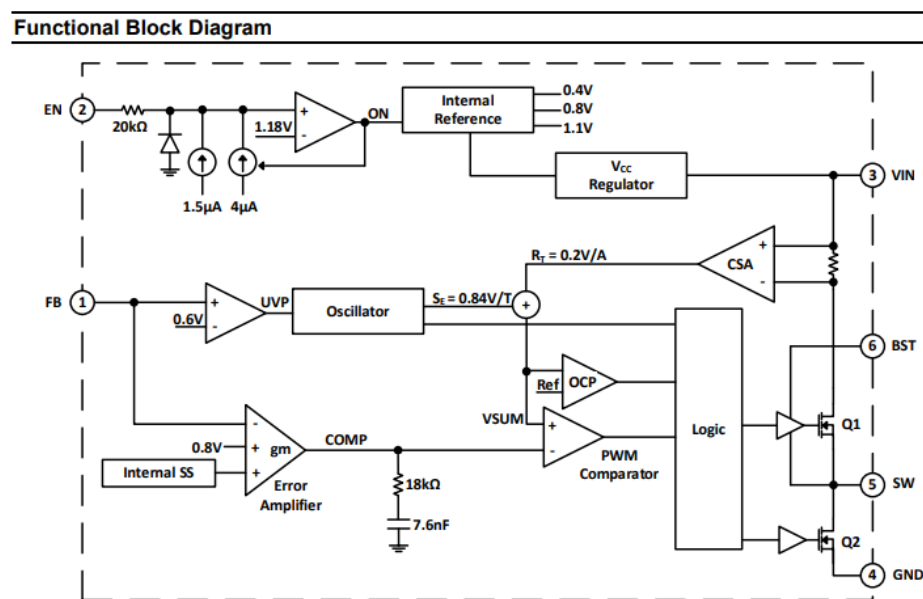


Figure 27: SparkFun Buck Regulator Functional Block Diagram

The USB-C battery charger is ideal for our battery selection about. Since we are working with a standard JST-PH converter, this charger will have a seamless integration for our battery to PCB design. It supports a 500mA charge rate and includes LEDs to monitor

charging. The charger also includes an integrated protection circuit which prevents overvoltage and overcurrent conditions.

LCD Screen:

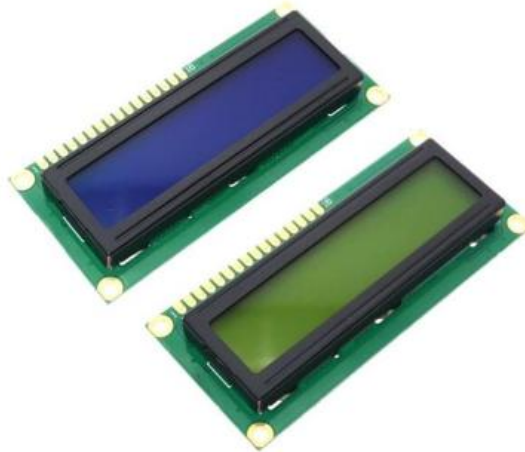


Figure 28: LCD 1602 Screen

The LCD display board is a 16-character 2-line alphanumeric screen. It runs on a 5-volt power supply and has an adjustable contrast potentiometer and backlight. This is the ideal display screen for real time data for our product. This LCD display will demonstrate to others that the ultrasonic sensor is working efficiently. This display is typically used with I2C interface since it reduces GPIO usage.

6.2 Subsystem Block Diagram

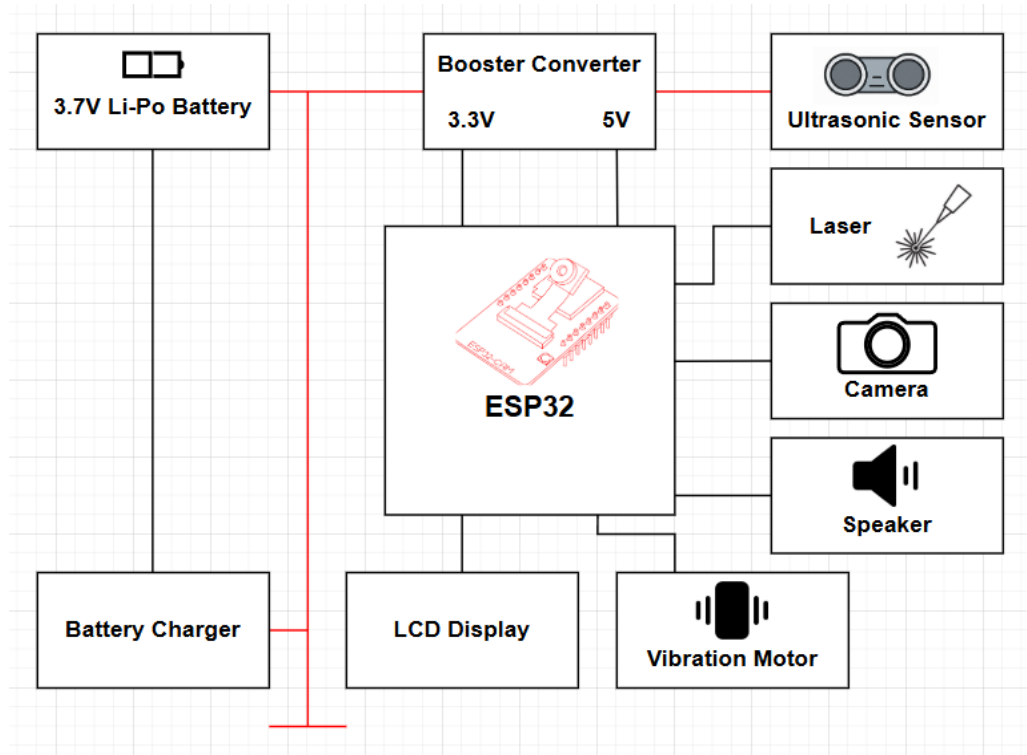


Figure 29: Schematic

Camera:

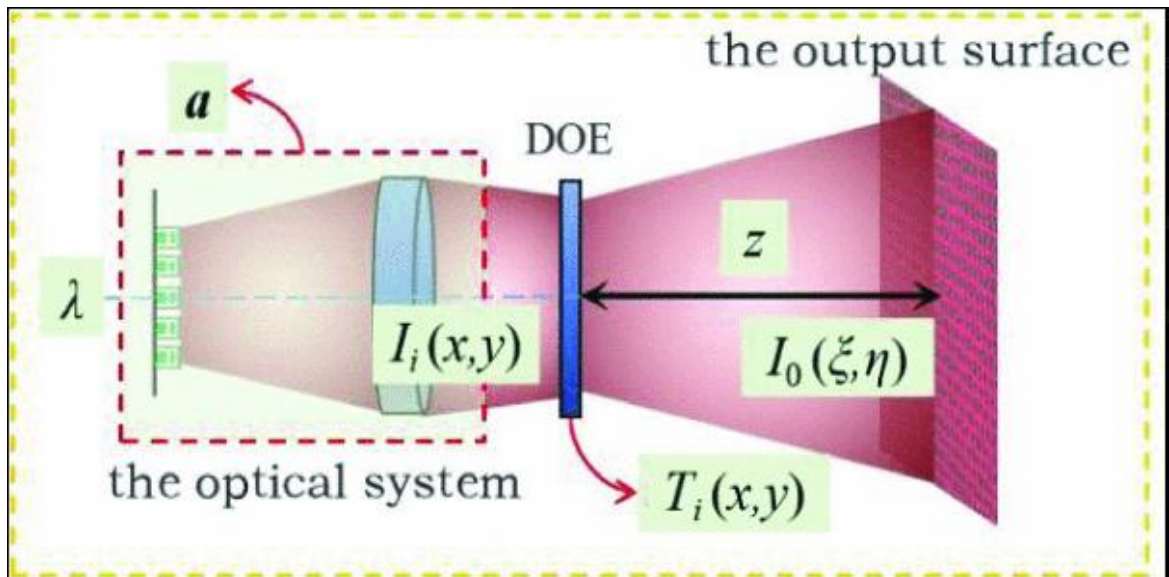


Figure 30: Optical System Diagram

The figure above is a typical diffraction optical element (DOE) based optical system which is used for beam shaping or wavefront transformation. In the figure above the wavelength enters the optical system, the system contains an input plane with an input field, the beam

is manipulated using lenses and a DOE. After passing through the DOE, the beam propagates a distance, z , to reach the output intensity distribution is I_0 . The system is designed to shape light from a known input intensity profile I_i into a desired output distribution I_0 at a distance z , using the DOE to modulate the phase and/or amplitude of the light.

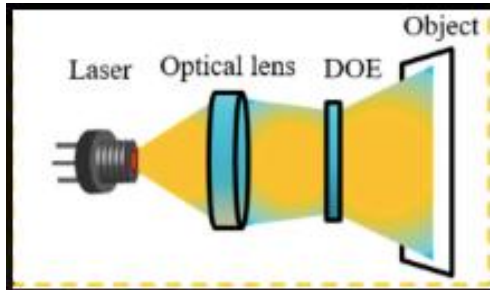


Figure 31: Laser with Optical Lens Diagram

The figure above illustrates a basic laser illumination and beam shaping system using a DOE. The laser, a coherent light source, emits a collimated beam which is usually monochromatic and narrow-divergent, which is ideal for precise optical control. The optical lens focuses or collimates the laser beam and shapes the beam into an intermediate profile which prepares it for modulation. The DOE alters the phase (sometimes amplitude) of the beam, transforms the beam shape or directs the light into a desired intensity pattern and often is used to generate structured light. And finally, the object is the target plane where the beam hits, for this project this is a image plane for analysis or processing to determine if it is an obstacle. This configuration is typical in systems where someone would want to generate a specific light pattern on an object using a DOE.

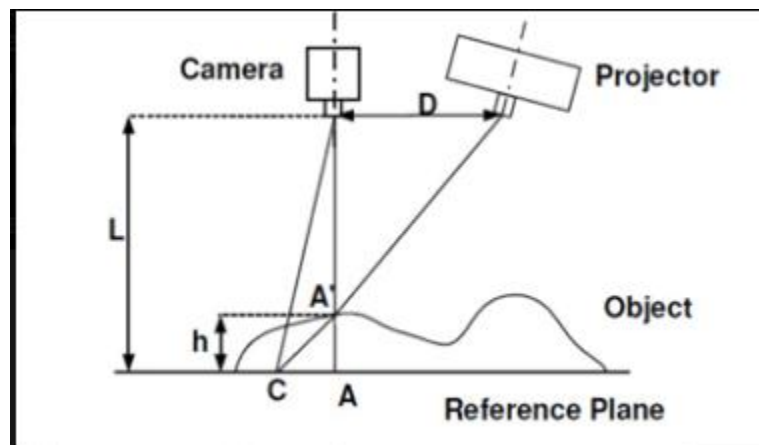


Figure 32: Camera Diagram

The figure above represents a structured light scanning system using triangulation. We are using a typical setup in machine vision, optical metrology, and 3D reconstruction. The projector will project a known light pattern onto an object and is positioned at a certain distance from the camera. The camera captures the deformation of the projected pattern caused by the shape of the object and is located directly above the reference plane. The

reference plane is a flat baseline surface used for calibration, point A lies on the plane directly below the camera's line of sight and point C is the corresponding projection from the projector onto the reference plane. The object is the 3D surface being scanned and at point A the object deviates upward from the reference plane at a particular height. This diagram is known as a triangulation principle, in which the projector and camera form a triangle with a point on the surface of an object. By knowing the geometry (distance, height, and angles) the system can calculate the depth information using triangulation.

Laser:

Outline Dimensions of LJP Series Laser Module (unit: mm)



Figure 33: Laser Diagram

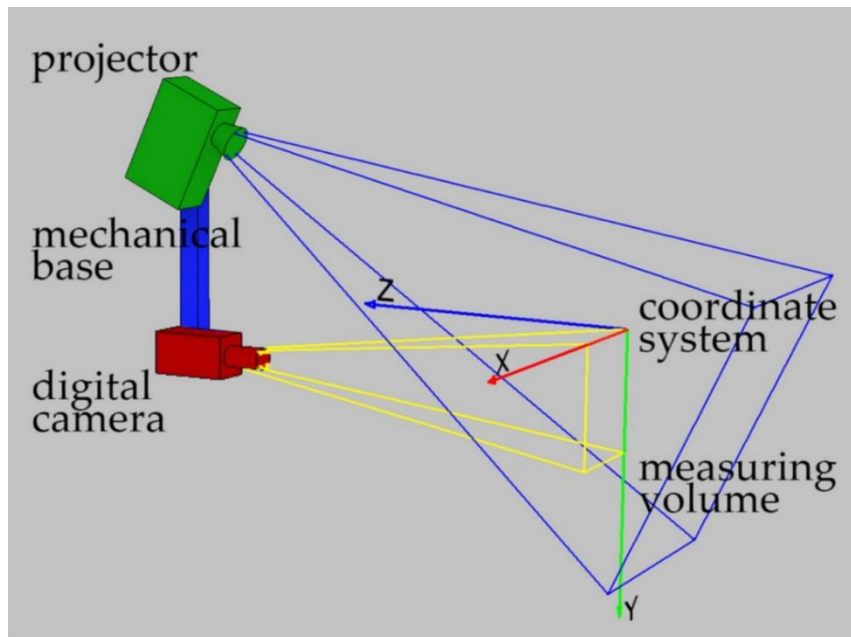


Figure 34: Camera and Laser Diagram

6.3 Schematics

Schematics are an important tool for electrical components and systems. They provide a clear standardized visual representation of how the components are connected and how the system should function. Schematics let everyone interpret the layout regardless of who builds or troubleshoots the circuit. They show the logical flow of electricity (which makes it easier to understand how the system works). They are an important form of documentation, especially if the product requires safety standards. And lastly, if something

should go wrong, schematics can help trace back the connections and components to find the issue.

Listed below are just some of the components schematics we were able to find. This includes the ESP32-CAM, speaker, vibration motor, and ultrasonic sensor. The HC-SR04 sensor is connected to two GPIO pins, the vibration motor is driven by a transistor controller, and the battery connects through a power management IC regulator.

MCU: ESP32-CAM

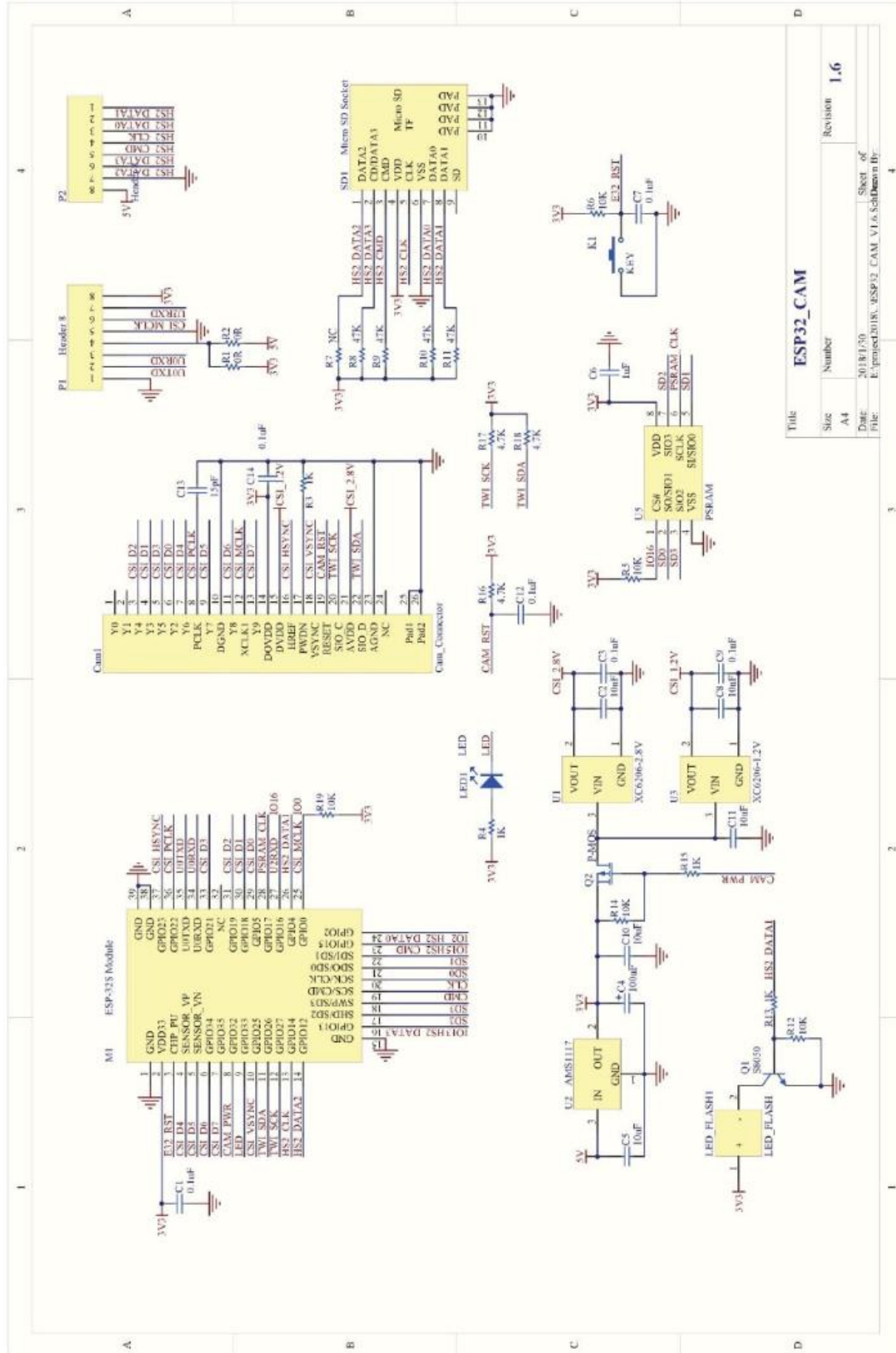


Figure 35: ESP32CAM Schematic

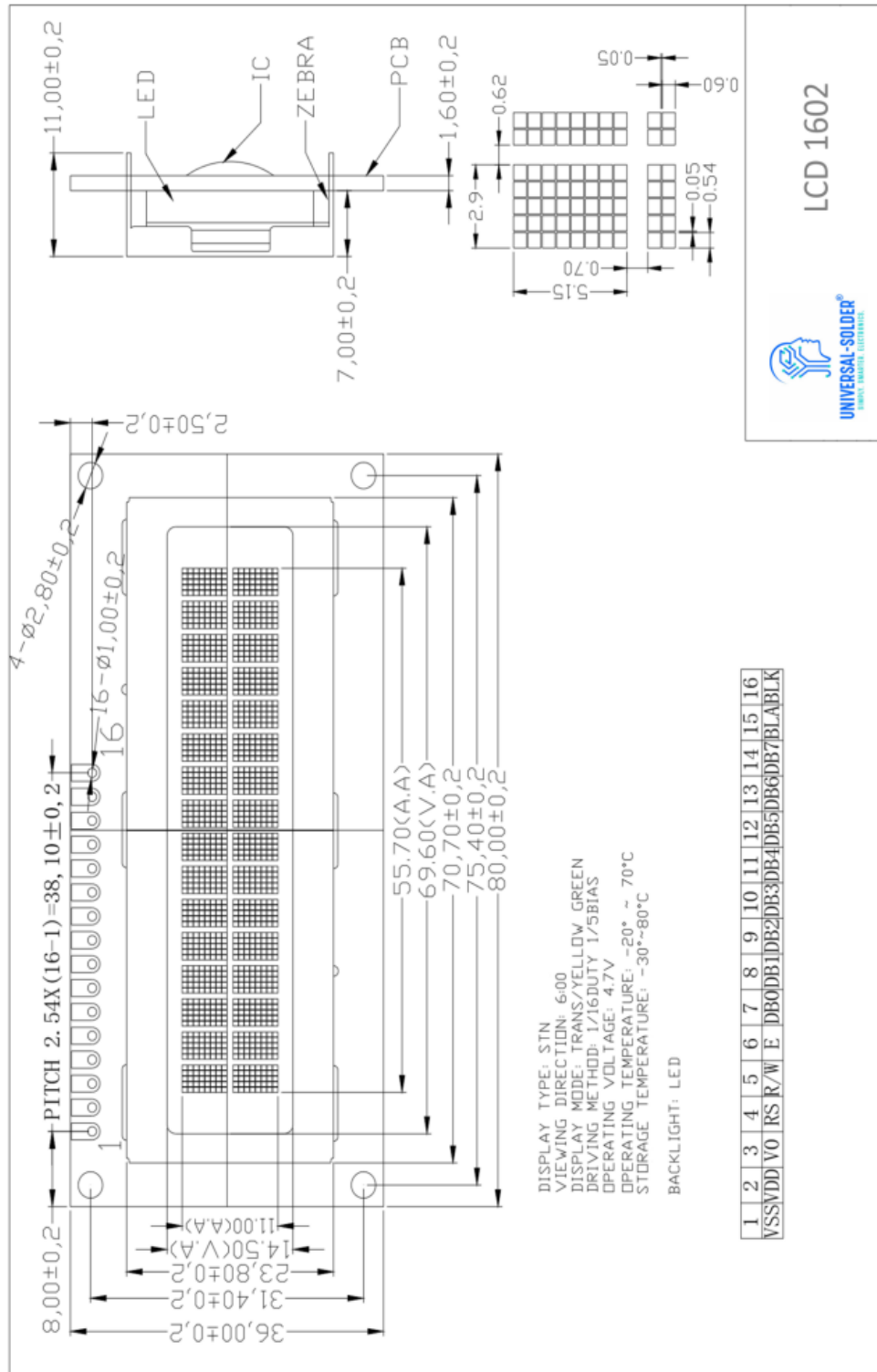


Figure 36: 5V standard LCD with HD44780 compatible controller and backlight

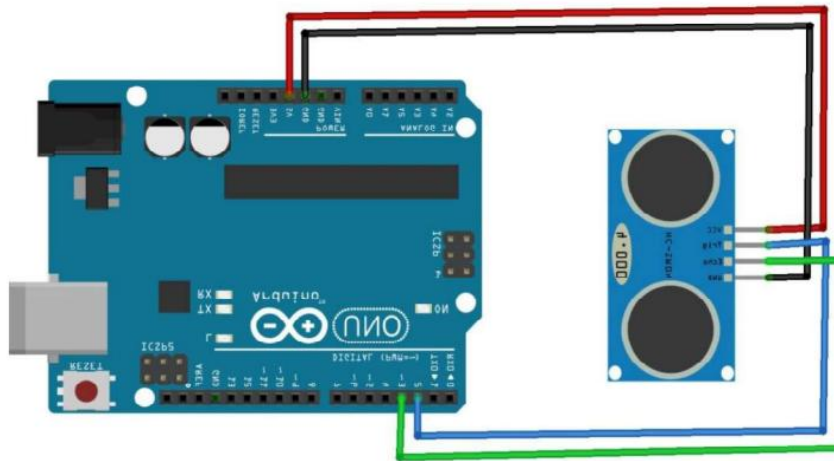


Figure 37:Ultrasonic sensor

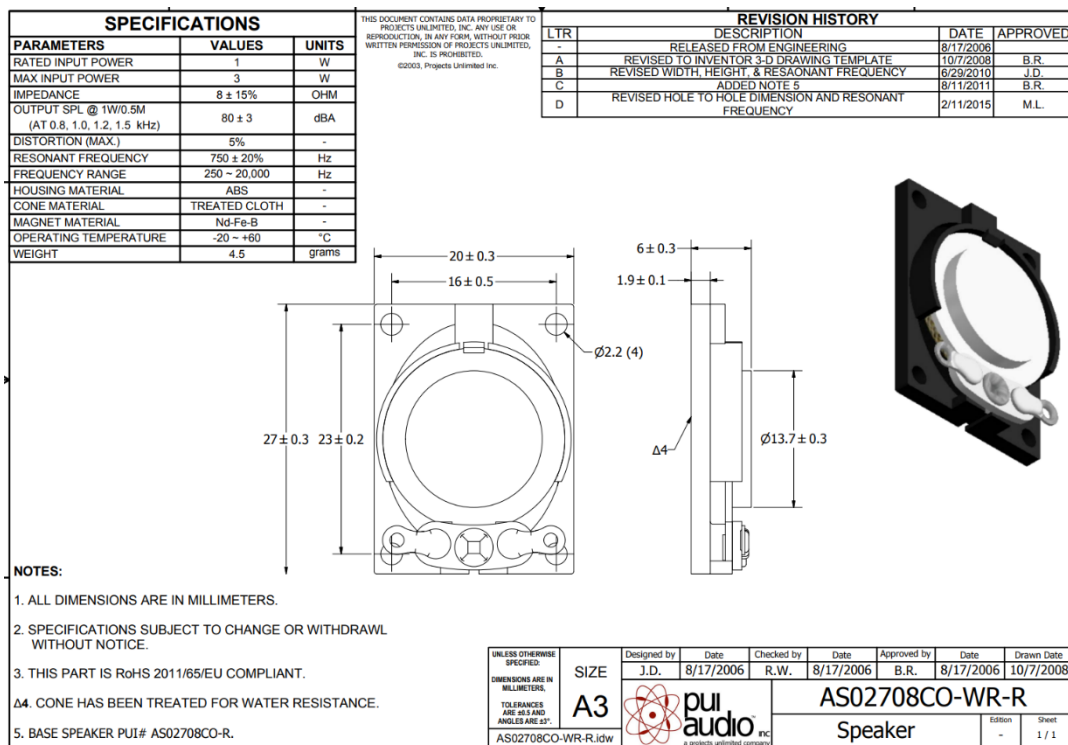


Figure 38: Speaker

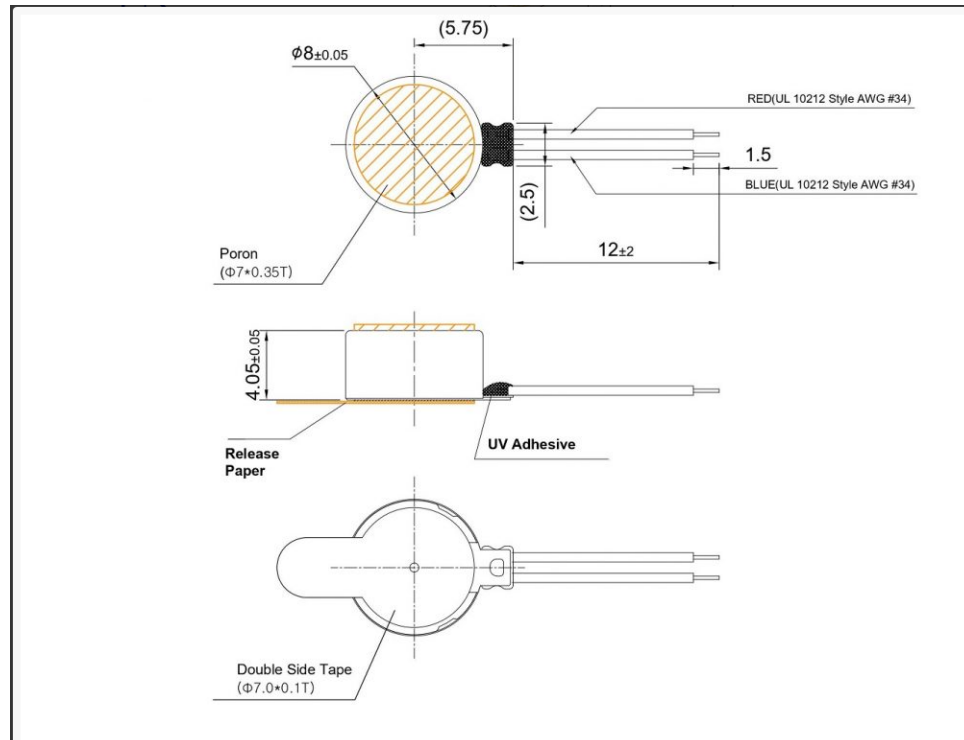


Figure 39:Vibration Motor

6.4 Structural Design

For the last section of this chapter, we will go over a rough structural design of our product. Throughout the designing process we have changed this concept many times, however, the components have never changed. The shoe itself will be a rain boot to have stability, durability, and safety. An added bonus when selecting rainboots is the weather resistant material. Starting with the ultrasonic sensor, it will be placed at the bottom front sides of the shoe in order for it to give an accurate reading of distance from an obstacle. The ESP32-CAM are enclosed on the inside of the shoe away from significant damage. The battery is also placed on the inside of the shoe. An LCD display will be placed in a cutout hole (only allowing for the screen to show) and project the distance the ultrasonic sensor is reading. The speakers will be placed as close to the top of the shoe as possible, to bridge the gap even slightly between the user's ear and speaker. The vibration motor will be placed on the back inside lining of the shoe. The benefit to this vibration motor is that it is weather resistant, which means we can place the motor near the top and should run fine. The Camera and laser will be mounted in front of the shoe and will be aimed down at the ground to help detect obstacles.

The hardware platform serves as the foundation of the S.I.G.H.T. shoe system, enabling real-time perception and feedback for visually impaired users. Each component—from the ESP32-CAM microcontroller to the vibration motor and speaker—was chosen to balance functionality, compactness, and efficiency. Together, these elements form a cohesive system that supports the core objective of improving user “visibility” and autonomy through technology.

Chapter 7 Software Design

This chapter presents the software design of the S.I.G.H.T. system shoe, detailing the logic and flow that enables the smart shoe to interpret environmental data and provide real-time feedback to the user. Building on the hardware framework described in the previous chapter, this section outlines how software modules interact with sensors, control haptic and audio outputs, and manage system states for obstacle detection and navigation support. We included a high-level overview of the program structure, followed by diagrams and explanations of the key operational states, logic sequences, use cases, and class/module architecture. Additionally, this chapter highlights the data transfer mechanisms, user interface logic, and memory-efficient data structures used to ensure the system is both responsive and lightweight enough for embedded implementation on the ESP32 microcontroller.

7.1 Overview

The software for the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T) shoe is designed to provide real-time environmental sensing, decision-making, and user feedback through embedded systems. We will be including object detection using ultrasonic sensors and a gridded light laser system, an ESP32-CAM for data processing, and vibration motors and audio feedback for users to safely navigate through various environments. The software will be coded in Arduino(C/C++ style) using an Arduino IDE. The code logic will be structured around four operating states: Idle, Detecting, Alert, and the possible stretch goal (SOS). These modes will fluidly be transitioned based on data received through the button interface and data received from the ESP32/laser system.

7.2 System States and logic

The S.I.G.H.T. system operates as a finite state machine, with each state representing a specific operational mode that governs system behavior. Table below outlines the primary states of the system, including the default idle mode, the active detection state, and the alert state triggered by nearby obstacles. These clearly defined states allow the microcontroller to efficiently manage resources and provide timely feedback to the user.

Table 37: State Descriptions

Idle	Default mode when the system is powered off
Detecting	System is scanning surroundings using sensors
Alert	Activated when an obstacle is detected within 2 meters.

Transitions:

To ensure reliable system behavior, our smart shoe operates through defined state transitions that manage its response to environmental factoring. These transitions govern how the device moves between idle, detection, and alert states based on sensor input. The system powers on from an idle state through a manual power button. It transitions into the detecting state, where both the ultrasonic sensor and gridded light laser continuously scan

the environment. When an obstacle is identified within 2 meters by both systems, the shoe enters the alert state, triggering haptic and auditory feedback. If the obstacle is no longer detected, the system seamlessly reverts to the detecting state, maintaining readiness for future hazards.

Table 38: Transitions between States

Idle to Detecting	Turned on using power button
Detecting to Alert	If an obstacle is detected within 2 meters by both ultrasonic and gridded light laser systems.
Alert to Detecting	If the obstacle is no longer detected.

7.3 Software Flowchart

The figure down below outlines the initial system boot sequence for the S.I.G.H.T. smart shoe. The sequence begins with the system powering on and checking for a user-triggered event through the power button. Upon detecting that the power button has been pressed, the microcontroller proceeds to initialize all critical modules, including sensors and I/O peripherals. This structured initialization ensures that the system enters a stable and prepared state before entering the continuous scanning loop. The logic ensures no feedback mechanisms are activated until all hardware components are properly initialized.

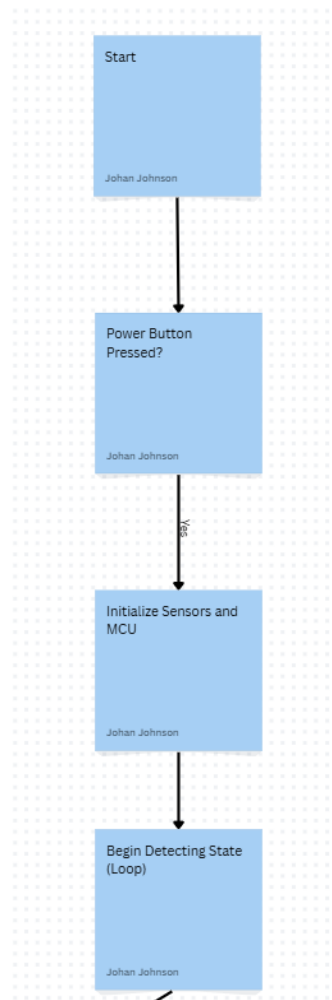


Figure 40: System Startup and Initialization Flowchart

Figure down below illustrates the real-time obstacle detection logic executed after system startup. Once the microcontroller enters the continuous detection loop, the sensors actively scan the environment for obstacles. If an obstacle is detected within a 2-meter threshold, the system immediately triggers the corresponding haptic and audio feedback modules to alert the user. If no obstacle is detected, the system continues scanning without initiating feedback. This flowchart emphasizes the non-blocking loop design and reactive feedback mechanism used to assist visually impaired users in real-time navigation.

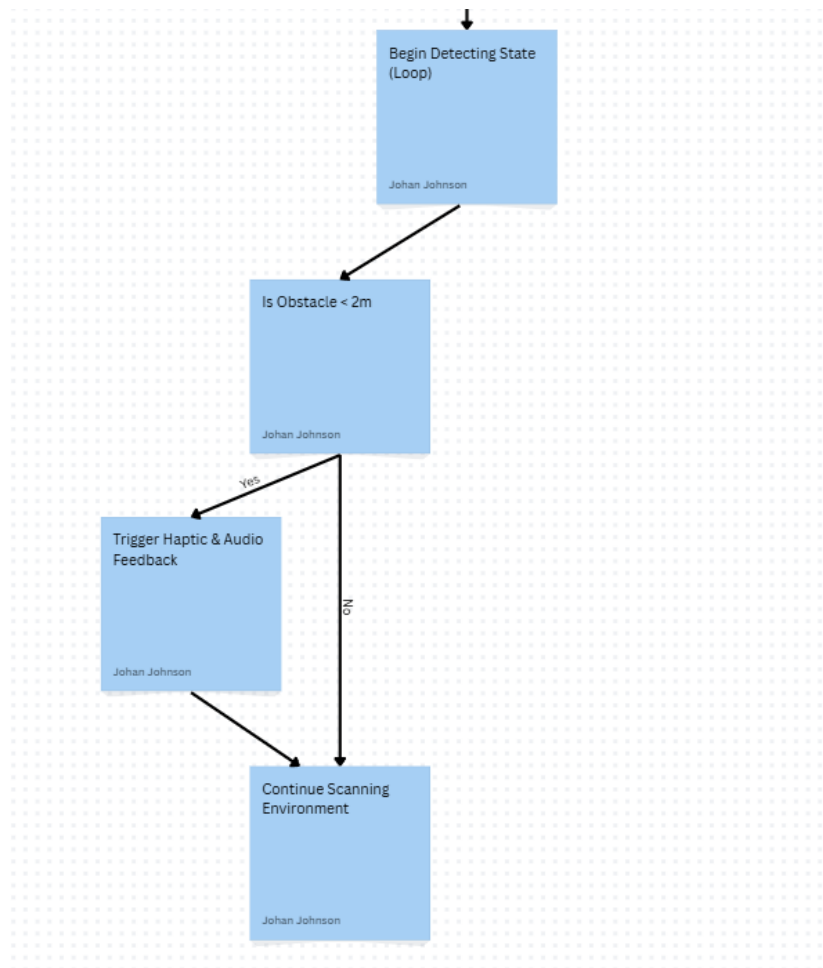


Figure 41: Obstacle Detection and Feedback Flowchart

7.4 Use Case Diagram

The figure below provides a high-level overview of how input signals from both the user and the sensors interact with the core system logic of the S.I.G.H.T. smart shoe. Upon powering on, the user activates the system, initiating its operational readiness. Simultaneously, real-time sensor data is fed into the system to monitor the environment for potential obstacles. Based on the system's interpretation of this input, it issues appropriate outputs such as audio signals or vibration feedback to assist the user in navigating their surroundings safely.

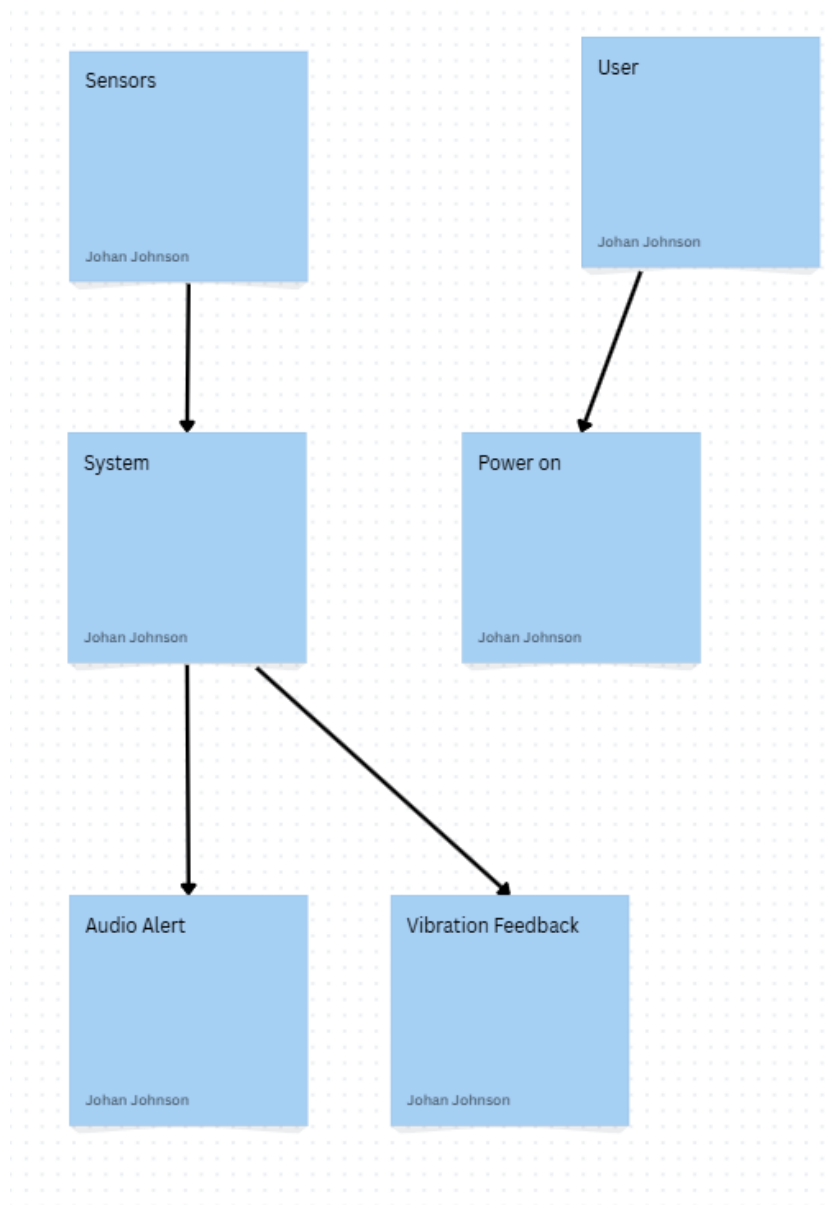


Figure 42: System Input and Output Signal Flow

7.5 State Diagram

The figure below illustrates the finite state machine governing the behavior of the S.I.G.H.T. system. The system transitions from an Idle state to a Detecting state upon power-on and enters an Alert state if an obstacle is detected. The transitions ensure that the device reacts appropriately to both normal navigation and emergency events, enabling adaptive user assistance.

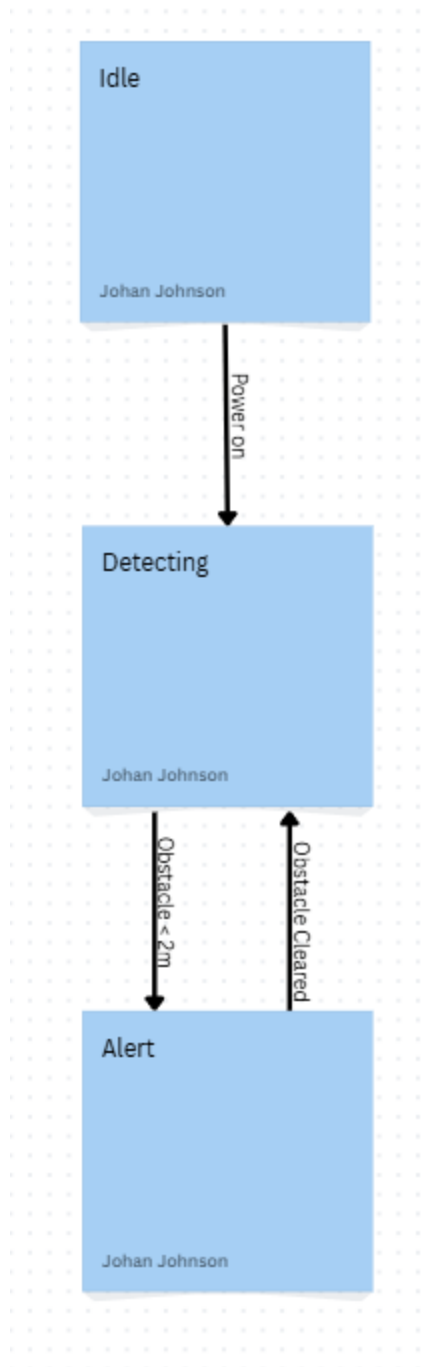


Figure 43: System State Machine Diagram

7.6 Class and Module Design

The S.I.G.H.T. software uses a modular design that separates the functions of the code into separate classes that work independently to handle user interaction, sensing, feedback, communication, and logic to accomplish the tasks intended. This allows for debugging, testing, and upgrading features to be done easily. The structure using the C classes allows the ESP32-CAM to execute smoothly.

Key Modules:

The functionality of the S.I.G.H.T. system is distributed across several modular components, each responsible for a specific aspect of operation. These key modules work in coordination to ensure seamless performance, responsiveness, and adaptability in real-world environments. The SensorManager handles data from the ultrasonic and gridded light sensors, processing distance measurements and determining obstacle presence. The FeedbackManager translates system states into tactile or auditory feedback through vibration motors and speakers. The CommunicationModule oversees wireless emergency messaging, while the PowerManager ensures energy efficiency by monitoring battery health and managing low-power transitions. The MainController serves as the central hub, coordinating interactions between all modules. Supporting modules like the ButtonHandler enable user input via the power button. Together, these components form the backbone of the smart shoes' intelligent guidance system.

Table 39: Descriptions of Key Modules

SensorManager	Interacts with ultrasonic and gridded light sensors, manages distance calculations and obstacle detection logic.
FeedbackManager	Controls vibration motors and triggers specific haptic/audio signals based on the system state.
CommunicationModule	Manages Bluetooth or Wi-Fi based emergency messaging.
PowerManager	Monitors battery voltage and transitions system to power-saving mode if needed.
MainController	Orchestrates all components and manages system states.
ButtonHandler	Reads button presses from the Power button.

Figure below details the core operational loop of the obstacle detection logic running on the ESP32-CAM microcontroller. The process begins with initialization of all sensors and GPIO pins, followed by continuous data acquisition from the ultrasonic sensor and structured light camera system. If an obstacle is detected within 2 meters, the system triggers audio and haptic feedback to warn the user. The loop structure ensures consistent scanning and rapid response to changes in the surrounding environment, supporting real-time guidance.

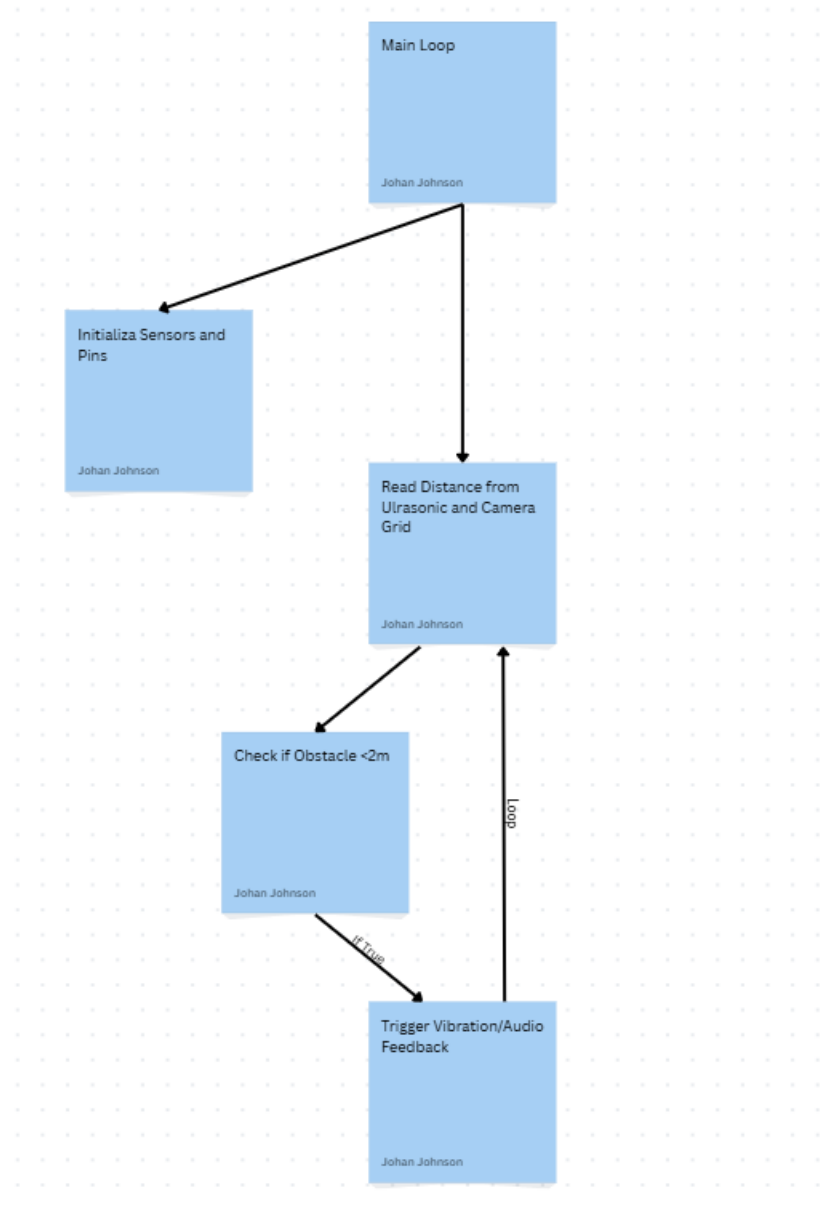


Figure 44: Real-Time Obstacle Detection Loop

7.7 Data Transfer & Integration

The S.I.G.H.T. system facilitates constant communication between sensors, the ESP32 core, and feedback actuators. The architecture emphasizes real-time unidirectional data flow, which is used to process every loop cycle.

Table 23 outlines the data flow between the primary components of the S.I.G.H.T. system, detailing how information is received, processed, and acted upon within the smart shoe. Each component plays a distinct role in sensing the environment, interpreting inputs, and delivering responsive outputs. The ultrasonic sensor and gridded light module serve as the system's main input devices, capturing environmental data in the form of echo pulses and laser pattern reflections, respectively. This information is processed by the ESP32

microcontroller, which coordinates sensor inputs, user interactions, and system logic to generate corresponding feedback through vibration motors and audio tones. This flow of data ensures smooth interaction between all components, enabling the system to function efficiently and intuitively.

Table 40: System Components Data Flow

Component	Input	Output
Ultrasonic Sensor	Echo Pulse	Distance (float)
Gridded Light	Laser Pattern Reflection	Depth Map (array)
ESP32 Microcontroller	Sensor data, button signals	Vibration Control and Audio Tones
Vibration Motors	Alert state from ESP32	Physical vibration pulses

The ultrasonic sensors and lasers work together. If both indicate that there is an object within 2m, the system enters the Alert state and outputs a feedback pattern.

7.8 User Interface Design

The S.I.G.H.T. shoe uses a minimal tactile interface to reduce cognitive burden for visually impaired users. The interface elements are physical buttons and haptic/audio outputs.

Interface Features:

- Power Button: Single press turns the system on (Idle to Detecting).
- Vibration Feedback
 - 1 Pulse: Object in 1.5-2m range
 - 2 Pulses: Object in 1-1.5m range
 - Continuous pulses: Object 0-1m
- Directional Alert (left/middle/right) to signal which direction object is in.

7.9 Data Structure Overview

Efficient memory use is critical to the viability of the system. The data structures are used to optimize the ESP32's limited RAM and real-time requirements.

Table 24 presents the core variables and data structures that form the foundation of the S.I.G.H.T. system's software architecture. These variables are essential for real-time decision-making, system monitoring, and feedback generation. Each variable captures a specific aspect of the device's operation. From environmental input like `distance_cm` and `depthmap`, to system status indicators such as `alert_triggered` and `state`. Variables like `battery_level` support power management by providing continuous voltage readings, while `vibration_pattern` encodes the appropriate haptic feedback in response to system states. The `state` variable, defined as an enumeration, ensures orderly transitions between operational modes such as Idle, Detecting, and Alert. Collectively, these definitions enable efficient data handling and system responsiveness in an embedded environment that limits resources.

Table 41: Core System Variables and Data Structure Definitions

Variable Name	Type	Description
distance_cm	float	Value derived from ultrasonic sensor
depthmap[20][20]	Int[][]	Matrix from gridded light system
alert_triggered	bool	True if system is in alert state
battery_level	float	Voltage read from battery monitoring circuit
vibration_pattern	String	Encoded to determine which haptic feedback to use
state	enum	Tracks current system state (Idle, Detecting, and Alert)
battery_level	float	Live reading from voltage monitor

The software architecture of the S.I.G.H.T. smart shoe combines modular embedded design, real-time sensor feedback, and a simple user interface to create a responsive and intuitive assistive device for the visually impaired. Through a clean state-based control model, users receive consistent obstacle alerts with minimal latency. The ESP32's connectivity allows for future integrations into apps, cloud services, or advanced navigation features if necessary. This solid software foundation sets the stage for a seamless transition into the hardware integration and testing phase during Senior Design 2.

Chapter 8 System Fabrication/Prototype Construction

This section is about the printable circuit board (PCB) layout and how we were able to integrate all our components for our project on our PCB. Printable Circuit Board (PCB) design is a fundamental aspect of modern electronics and serves as the physical foundation in which electronic systems are built. PCBs provide a compact, long-lasting, and electrically reliable way to interconnect components. Unlike with breadboards PCBs are permanent precise connections that ensure signals are carried smoothly across a device. They minimize interference especially in high-frequency or sensitive applications. By using specific elements in PCBs (like copper) and embedding traces of them into the boards, the PCBs allow for efficient flow of power and signal between components while maintaining structural integrity.

The layout of a PCB is incredibly important, since this can influence the performance, reliability, and manufacturability of the actual product. Good practices for PCB design layout are optimizing component placement, routing traces with appropriate width and spacing, implementing a ground plane, and managing heat. By following these tips users can prevent issues like noise, voltage drops, or thermal buildup. Another aspect to consider is the physical arrangement of the components and not just their functionality. Each product's size, weight, and cooling capabilities also have a major effect on how the PCB can carry each load. For our product we needed to focus on the size and weight of the board since we were looking for a compact system. We needed to reduce space while maintaining accessibility and repairability - which was crucial since our layout design was originally created for someone visually impaired.

From our product design perspective, the PCB needed to bridge the gap between an idea and a functional manufacturable prototype. A PCB can transform our conceptual schematics and ideas into tangible and testable forms that can be optimized for performance and scale. Just like typical PCB design engineers we planned our PCB for possible future upgrades, complied with standards, and ensured user friendliness, which is a key component to this project since it is aimed at someone who is visually impaired. A well-designed PCB is not just a technical achievement but also a strategic design tool that elevated our project in quality, reduction of cost, and efficiency.

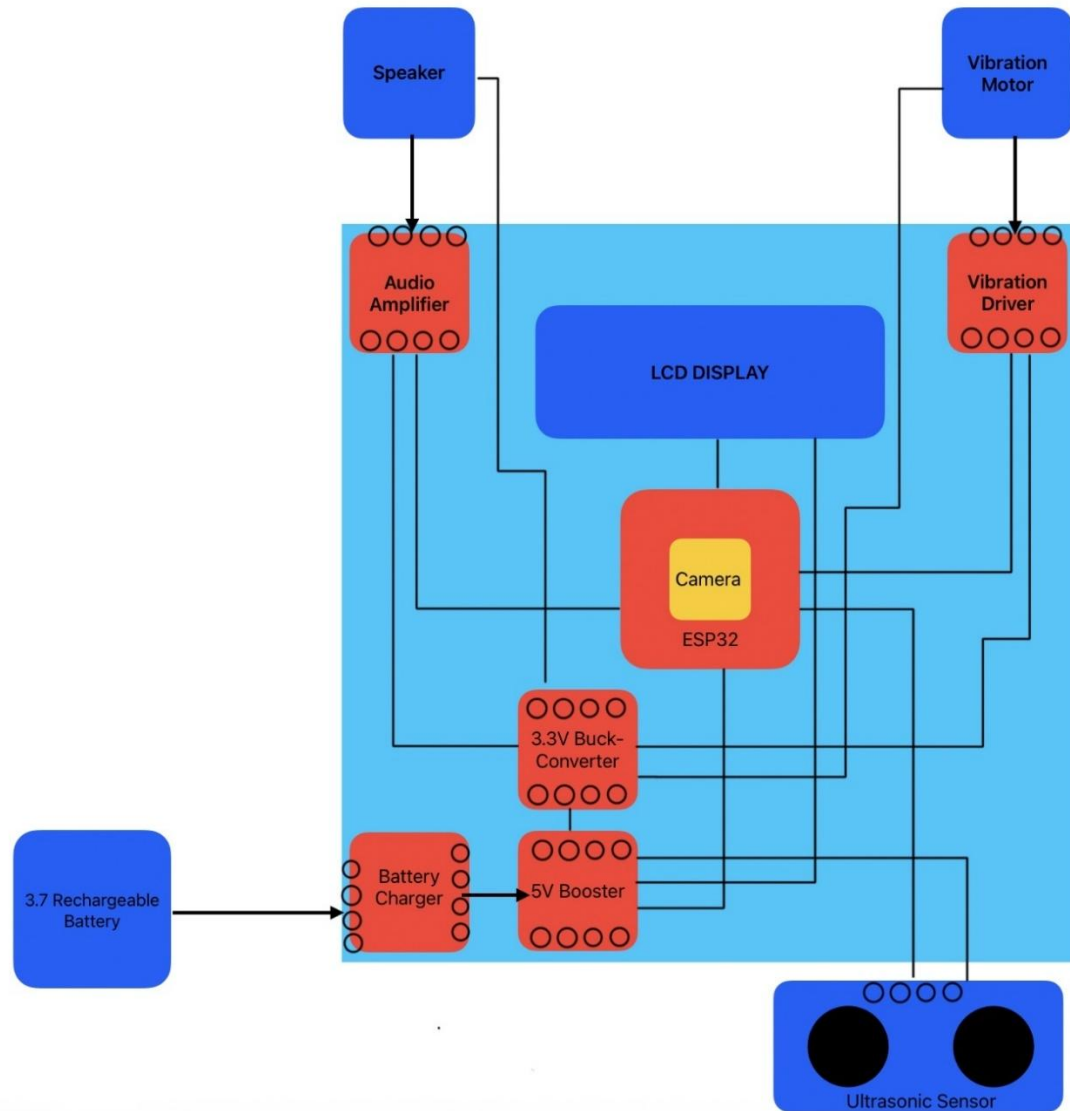


Figure 45: PCB Diagram

In the early developmental stages of the block diagram above we can see at its core is the ESP32-CAM which is our selected MCU and includes the camera for our optical design. This is the core of the system and coordinates communication with all connected components. The components surrounding the ESP32-CAM are the vibration motor which will not be connected to the MCU but rather feed through the vibration driver which did connect to the MCU, the speaker which did not connect but will use the audio amplifier as a feed which then connects to the MCU. And lastly the LCD display and ultrasonic sensor that both connect directly to the board and MCU. All these components individually will be connected to the battery and the battery buck converter or boost converter depending on which item is needed. The buck converter will bring down the voltage from 3.7V to 3.3V while the boost converter will bring up the voltage from 3.7V to 5V.

Keeping all these components in mind we also needed to make sure that components that although need to connect to the PCB can also connect to the user. For example, the vibration motor needs to be connected to the PCB but also attached to the user and needs to be kept away from the camera so that it did not cause disturbance to the machine. The speaker is another good example. The speaker needs to be high enough on the boot for the user to hear it and therefore can be positioned at a further distance on the board. The ultrasonic sensors need to be placed at the bottom sides or in front of the shoes to ensure optimum obstacle detection. This means that it will need to be spaced out as well from the board (although attached by wires). And finally, the ESP32-CAM is the most difficult component we needed to mount on our device. Since the MCU we have chosen has a camera accompanying it, and we are using it for obstacle detection, we needed the camera to be mounted in such a way that would not hinder any obstacle detection implementation. The camera will need to be mounted standing up at a 45-degree angle to get a clear visual at the obstacles surrounding the user. The PCB had to stand with it. This means that all components attached need to fit on a board that could stand up with the camera and not be affected. For our design we decided on a vertical PCB board which would allow user friendly connectivity and easy to space and reduce the risk of interference from the haptic components to the more sensitive ones.

The components we provided above all support multimodal feedback to the user which ensures the obstacles detected will communicate through sounds, vibration and visualizations. However, to get all these components working correctly the battery had to be prioritized. The battery, charger, booster, and buck-converter had to be mounted in such a way that it did not interfere with the other components. This means the PCB was safe and could easily be reached to recharge the battery and will not cause the user any harm on recharge.

The charger must be mounted and safely installed in such a way that it will not affect the user. In order to have no interference from the battery components (buck-converter, charger, or booster) with our haptic and audio components as well as the camera - we placed the battery at the bottom of the PCB so it can be easily accessible for charging. Since we used a rechargeable battery for the user's convenience, we had to design our PCB in a way that could comply with the functionality of having that capability. Thus, the battery gets placed at the bottom of the PCB for user-friendly access and the charger on top, the buck and booster converter above that but side-by-side. This completes our PCB design.

As we can see from this early development diagram, this is what our PCB looks like. When going through ultra-librarian we discovered that most components would not be listed and would require a simple 3-pin or 4-pin block in order to implement them. Below are the

components that are available or not available on Ultra-Librarian and how we found way to overcome this setback.

Table 42: PCB Component Availability on Ultra-Librarian

Component	Manufacturer	Ultra-Librarian	Other Specs
ESP32-CAM	Hoysond Store	Not available	Will use a generic ESP32 with similar pin layout
LCD Display	UNIVERSAL-SOLDER Electronics Ltd	SSD1306 or ST7735 could work as spacing substitutes	Not the specific part. Will keep looking
Ultrasonic Sensor	DIYables	Not available directly	Basic pin header will work
Battery	Adafruit Industries LLC	Not available directly	JST pin battery connector
Battery Charger	Adafruit Industries LLC	Available	Possibility: MCP73831
Buck Converter	SprakFun Store	Not Found	3 pin block or possibility: MP1584 IC
PowerBoost	Adafruit Industries LLC	Not Found	Possibility: TPS61090 or 3 pin head
Speaker	PUI Audio, Inc.	Available	Possibility: AS02708CO-WR-R
Audio Amplifier	Adafruit Industries LLC	Available	Possibility: MAX98306ETD+
Vibration Motor	Vybrionics Inc.	Available	Possibility: VG0840001D or JST pad layout
Driver	SparkFun Store	Available (use transistors available)	Need to choose based on current needs (transistor)

Ultra-Librarian is an electronic component CAD library that offers free access to symbols, diagrams, footprints, and 3D models for PCB design use. The company is designed to help streamline the PCB design process by offering compatible CAD data with various ECAD applications, like Eagle and Fusion 360. For our project requirements we needed to design our own printable circuit board (PCB). As we explained above, the PCB for our project will require multiple components that will be attached to the board in some way. In order for our group to design this board we needed to use Ultra-Librarian to find our components and use the CAD configuration in their database and in our chosen electronic schematic CAD design application, Fusion360, to make a circuit board that we could use.

Using the table above to track down each component, we immediately ran into issues. Not every specific component we selected is available. For example, the MCU we selected –

the ESP32-CAM – is not specifically available for selection. They do have the component in the form of schematic, but the actual 3D Model, Downloadable CAD model, and an exact match are nowhere to be found. Requesting these schematics from Ultra-Librarian could take weeks and that’s assuming they can make the designs for our particular products. After going through each component and finding them on Ultra-Librarian we were able to find only a handful of components. This is not necessarily an issue since we can use similar types of components just for sizing and for channel blocking. The components we could not find are the ESP32-CAM, LCD Display screen, ultrasonic sensor, the buck-converter, and booster. Below are some examples of what is listed on ultra-librarian and how we needed to find alternatives for some of our components. For the components we could find, like the battery charger (see figure below), of how ultra-librarian offers a downloadable CAD design if the diagrams are all available. But there are times, like with our speaker, where it is listed in ultra-librarian, but the downloadable CAD application is not available because it is a product that does not need to have one or a way to be mounted on the PCB.

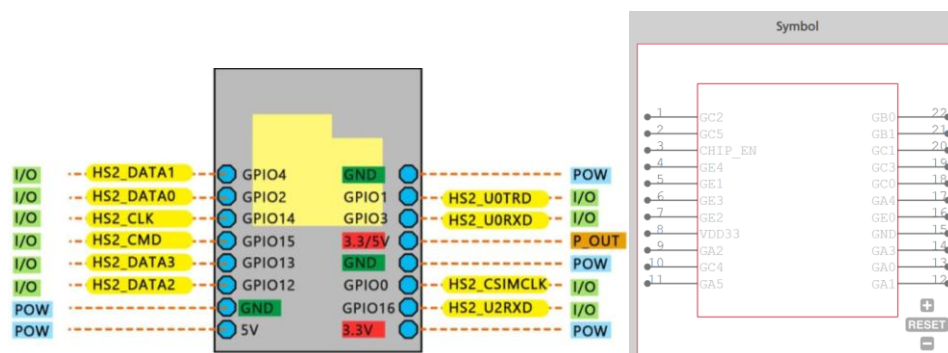


Figure 46: ESP32-CAM schematic comparison to Ultra-Librarian schematic

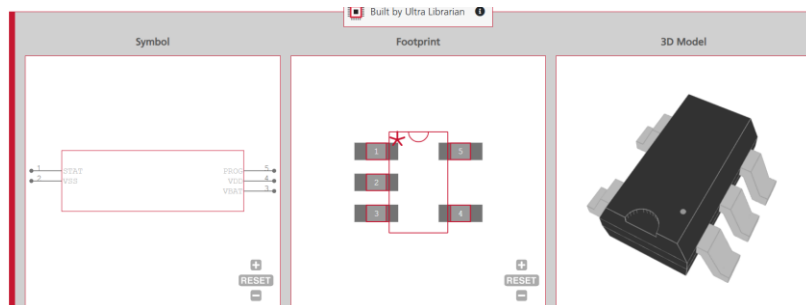


Table 43: Battery Charger Option

 Electro Sonic	PUI Audio AS02708CO-WR-R	Speakers Neodymium Iron Boron 650±20%Hz 3W 80±3dBA 80hm Oval Solder Lug	Availability 	Price \$3.02	Compliance  	Request Model   
Visit Site: TLC Electronics (\$2.82) Onlinecomponents.com (\$2.79) DigiKey (\$3.34) Verical (\$3.906) More Pricing Details						

Figure 47: Speaker component - is listed on ultra-librarian but does not have CAD design

Using these three examples, we can see that although we ran into multiple issues when building our PCB, we used pinholes and similar products to make our PCB as accurate as possible. This ensured we have a safe and fully functioning PCB design and follows safety and electrical standards.

Chapter 9 System Testing and Evaluation

As the Smart Integrated Guidance and Haptic Technology (S.I.G.H.T) shoe progresses from initial prototyping toward full implementation, we will need to ensure reliability, safety, and efficiency of our final product by having an evaluation plan. This chapter will define the procedures for testing and evaluating each subsystem from hardware to software components. Our ultimate objective is to ensure that the S.I.G.H.T. shoe functions reliably in a range of settings so that users can move more confidently and independently. As we move to the next stage of the design and as we prepare for Senior Design 2, the outcomes of these testing procedures will directly influence enhancements in functionality, comfort, and usability as well as ensuring a smooth transition into the next phase.

9.1 Hardware and Software Testing

During the hardware and software testing phase of the project, most of the experimentation will take place under regular and low light ambient settings in the CREOL optics laboratory. As the project progresses and we enter senior design 2, testing will be conducted outside, in ambient light conditions. The outdoor testing is crucial, because the final design for the S.I.G.H.T. shoe will need to be reliable and accurate in an outdoor setting. To verify calibration of the projected visual stripe pattern by the laser, a gridded pattern with known distances can be used. For a more basic goal of stripe distortion, this is not needed.

Component level hardware testing will take place as well, for the laser diode module, diffractive optical element, and camera module. For the laser diode module, stable output needs to be verified, and how long the laser diode module can continuously operate. The diffractive optical element needs to operate at the same wavelength as the laser diode module. The camera needs to be tested for image quality, field of view, and proper alignment with the laser projection.

For the structured light system to work effectively, the laser diode module needs to be properly collimated before passing through the diffractive optical element. This can be done with the aspheric plano convex lens mentioned earlier in the chapter. Through proper collimation, the diffractive optical element will be filled fully, and the full projected stripe pattern will be visible.

Functional system integration tests will be conducted to test the power supply under continuous use. Microcontroller testing will be done to determine connectivity between the subsystems. Obstacle detection tests will be conducted to determine the various distance and angles for which objects will be detected, and latency time will be measured as well.

9.2 Performance Evaluation

The main goal of the performance evaluation is to determine how effectively the S.I.G.H.T. shoe achieves its design goals. More importantly, make sure that the requirements for the final product are met. Which includes 100% obstacle detection accuracy, response time, zero fault tolerance, and power efficiency. For our requirements specifications table please go to chapter 2 section 2.5 table 2. All these metrics need to be thoroughly validated as this

product is intended for individuals with visual impairments. This section describes how we measure and evaluate system performance. During Senior Design 2, the main setting for performance evaluation will be outdoor and indoor testing. The table below summarizes a key performance plan that we will need to make sure that the final product meets.

Table 44: Performance Testing Plan for the S.I.G.H.T. shoe

Metric	Test Method	Tool/Equipment	Pass Criteria
Obstacle Detection Range	Place object at increasing distances and record detection distance	Laser rangefinder, ruler, ultrasonic sensor distance	Must detect obstacles at 2.0+0.2 meters
Accuracy	When testing outdoor/indoors place multiple objects at random distances/angles	Multiple object types (tree, door, person, wall)	100% detection of objects within range
Battery Life	Fully charge system and run in idle/active conditions for extended duration	Stopwatch	Last at least 6 hours under active usage
Response Time	Measure time from obstacle appearance to actuator output	ESP32-CAM	Signal sent to actuator $\leq 150\text{ms}$ after detection
Weight	Weigh entire shoe product	Digital scale	System weighs between 4.5-5.5lbs.
Sensor Field of View	Rotate obstacle around sensor	Rotating test platform	Detects object within 60° horizontal field
Light Compatibility	Test detection in full daylight and dim room conditions	Outdoor test during the day, and indoor settings.	Detection is consistent in both lighting cases.

This performance evaluation plan will guide us through the critical metrics to verify safety, responsiveness, and usability of the S.I.G.H.T shoe.

9.3 Optoelectronics Feasibility Study and Testing (for all CREOL projects)

The purpose of a feasibility study and testing for the optoelectronics subsystem is to verify that the performance and functionality of the system meets the required specifications and intended use of the product. For our S.I.G.H.T. project, structured light will be used for obstacle detection. Testing will be crucial to check for the reliability and performance of the structured light system for obstacle detection in real time. This includes evaluating metrics for optical output and wavelength to confirm that they meet standards. We will also

check the subsystem for failures and points where the design might be able to be improved. Individual components will be tested and verified, such as the laser diode and camera system. Through this testing, the quality of the final product will be verified as throughout the study improvements will be made to the system to ensure functionality. For object detection to be viable, and for other obstacles and drop-offs, such as ditches and curbs, to be detected, these obstacles need to be visible to the camera module. The structured light system needs to be able to capture a field of view directly in front and under the foot and needs to be able to project fully through the DOE to project full stripes. The camera module will be taking measurements of distortion in the stripes. For the stripes to be fully visible to the camera, the optoelectronics system needs to be optimized through this feasibility study and testing.

The components used in the optoelectronics subsystem that will be evaluated include the laser diode module, diffractive optical element (DOE), ESP-32-CAM, and collimating lens. For the laser diode, the optical power of the emitted light will be measured using a power meter. The wavelength of the laser diode will be measured using a spectrometer. There are electrical components to consider for laser diodes, for example threshold current, slope efficiency, and optical degradation. Finally, the beam profile of the laser will be evaluated as well, by looking at the shape, size, and beam divergence. The DOE will be evaluated for its diffraction efficiency, which shows how well light is redirected into the correct diffraction order. Since our structured light system needs a pattern striped light design, this testing is crucial. The wavefront quality of the DOE will also be tested as well to get the best striped light projection. The overall beam shape will attempt to have uniformity in its diffraction pattern and that it operates at the same wavelength as the laser diode. Control of feature size is crucial to create the desired output diffraction pattern. Defects in the DOE are inspected to avoid any issues with performance. The ESP-32-CAM will also be tested at various image resolutions to check for image quality and for the detection of distortion in the stripes produced by the projector. The RAW image capture data will be evaluated to verify the integrity of the image data. The testing of the frame rate of the camera will be helpful in verifying real-time object detection. A collimating lens will be used in the laser module projection subsystem. Focal length testing will be done to verify that the light is focused on the intended distance. Choosing a quality collimating lens can ensure that light that is exiting the plane is parallel. Aberration and distortion need to be as minimal as possible to get clean straight stripes. The alignment of the lens system will be tested to ensure the highest quality beam output and ensure overall alignment of the system.

There are certain constraints to be considered for this senior design project, which are time, power consumption, and environmental factors. The time constraints, including senior design1, taking place in the summer, which compared to a regular semester, will be missing 4 weeks. There are also power limits on the design because of the size and space on the shoe. Also, the imaging system cannot draw too much power or current. The battery cannot be too big as the space is limited.

Description of Optoelectronics System

The laser diode that will be used for S.I.G.H.T. is at 650nm wavelength, has an optical output power of 5mw, and has a dot or circular beam shape. The reason for the 650nm wavelength is that the DOE is 650nm. In our case it is easier to source a laser diode module than the DOE, therefore if the available DOE is for 650nm, then we will use a 650nm laser module. The power class used for the laser diode module is 3R. This is for lasers up to 5mW. This is considered a safe rating, but the eye could still be potentially harmed. It will be important to see what angle the laser can be positioned to avoid potentially harming a fellow pedestrian. This power output rating will also be tested to see if there is a correlation with ambient light visibility. The Diffractive Optical Element (DOE) is transmissive where the stripe fans out to create a pattern. This stripe pattern is key in structured light because the base line can be measured between stripes. If there is any distortion in these stripes, the depth can be obtained for the measured area. This DOE creates the stripes that enable the structured light patterns to be measured. The camera system used is an ESP-32-CAM which is a small low power OV2640 camera built on an ESP-32 microcontroller. The camera uses a 2-megapixel sensor to record images and videos. The microcontroller used includes an onboard SD card slot, as well as Bluetooth and Wi-Fi capabilities. The system uses low power consumption as well, and this should improve the battery life of the project. The last component to be tested for in the optoelectronic subsystem is the collimating lens. Focal length will be calculated for the lens to achieve the correct distance in object detection. The effects of the collimating lens on beam shape and projection of the stripes need to be updated.

Testing Methodology

To validate the performance and reliability of the laser diode, diffractive optical element, collimating lens, and camera module, a controlled test bench environment will be set up in our optics lab. The purpose of the test bench experiments will be to simulate the real-world environment a user will encounter to allow fine tuning of the optical components to enable obstacle detection in real time. The laser diode module is aligned with the collimating lens and DOE on an optical breadboard with metric holes to verify stable placement and alignment. The laser diode module is attached to an optical post, which should be connected to a translation stage that can be finely tuned in the x, y, and z direction for alignment. The DOE will be fixed to a separate mounting post directly in front of the laser diode module using either an adjustable cage plate or lens holder. Proper spacing is to be found between the laser diode module and DOE to find the optimal 15 stripe fan out, where all the stripes are visible, and the projection is clear. The next steps include testing the target projection surface, where a flat checkerboard with even distribution between the squares can be used to calibrate the structured light system. The stripe design is then projected onto the checkboard with a starting distance of approximately 1 meter. The surface is then held vertically and perpendicular to the laser axis to evaluate uniform stripe distribution and calculate the distortion of the stripes. To validate the best placement for the camera sensor, the camera is mounted on an optical post, with a baseline that can be measured to the laser projector and can be tilted in a downward position. This simulates different viewing angles and fields of view can be captured and assessed. Ambient conditions also need to be tested to observe system reliability in low light, normal light, and ambient light conditions. A multimeter will be used to measure the laser diode voltage

draw, and operating current. A ruler and calipers can be used to measure beam divergence and spot size for the laser diode module. The safety considerations needed in the lab during testbench experiments include the use of beam stops and warning signs when a laser is in use, as well as proper eye protection when necessary.

Feasibility Considerations

Optical alignment will be tested to ensure that the diffractive optical element (DOE) is positioned correctly with respect to the laser diode module to produce clear and distinct light stripes. The baseline to the camera module needs to be calibrated to measure the distortion in the light stripes to give proper depth reading in real time. Beam visibility needs to be clear to capture by the camera sensor. Field of view testing will be done to confirm that the projected grid will cover the most important area in front of the user to be able to detect ditches, steps, and curbs. Compatibility between the ESP-32-CAM, laser diode module will be tested as well to be able to ensure real time object detection without lagging in signal to make sure the S.I.G.H.T. hits its specification detection zone regarding object detection out to 2 feet. The laser diode module and camera will be tested for operating current and voltage drawing to calculate the operating time for the S.I.G.H.T and make sure that components fall within the constraints of the battery powering the system. Overheating issues and thermal behavior will be tested as well to test the S.I.G.H.T. under continuous use. Laser safety will be accounted for during lab testing and the laser module itself for its safety in public.

Preliminary Results and Observations

The laser diode module that will be used during the prototyping process was able to get baseline tested for optical output power and its wavelength using a spectrometer. The calculated optical output power measured was 4mW and measured wavelength was 655 nm. The image below represents the wavelength.

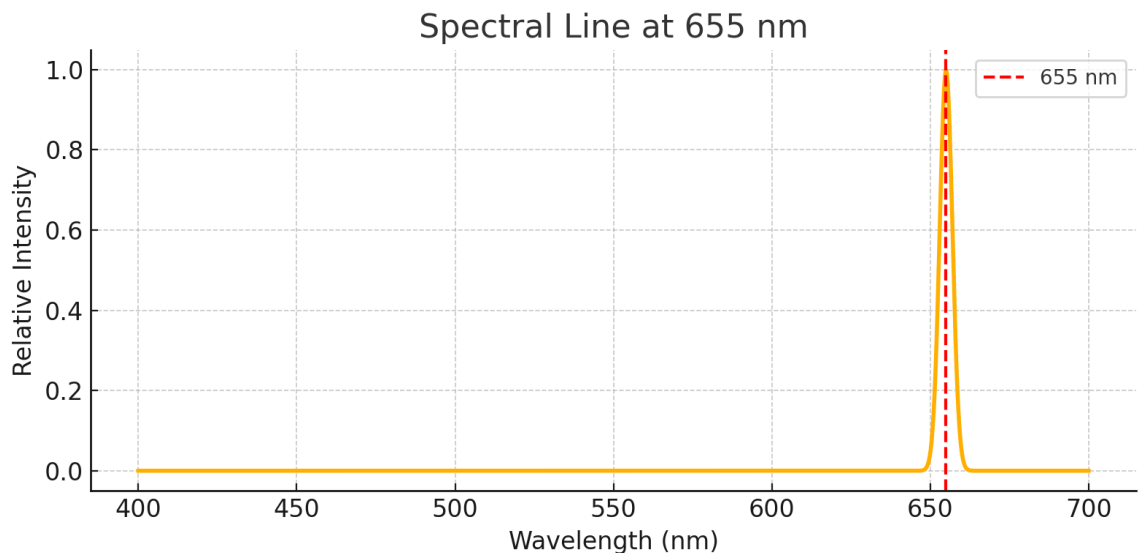


Figure 48: above shows measured wavelength of laser diode module

Potentially down the road for final demonstrations, there could be issues with the DOE wavelength being set at 650nm and this laser diode module at 655nm being slightly off. At this point for prototyping, these will be due, but down the line a more precise laser diode module may be needed. Through the first demonstration it seems as if a camera module will be able to capture the image of the laser projection of the 15-line fan out. Using the baseline between the camera sensor and laser diode module, the distortion in the light pattern will be able to give a depth mapping. Through a matrix-based algorithm, any object distorting the stripe pattern will be observed, and the user will be alerted.

Analysis and Discussion

The proposed setup for the design should meet and exceed project goals. The components needed to make the structured light system viable are available. Correct alignment and housing for the optical setup are crucial and will be worked on through the prototyping process. The key ideas on the sensing technology are able to be achieved by the ESP-32-CAM microcontroller and laser diode module with 15-line fan out DOE. This technology, which is used in 3D scanning, can be easily used as an application for object detection of ditches, curbs, and steps. Some early issues that may need to be addressed in the design will be housing that most likely will need to be 3D printed to align the laser diode module with DOE. Because of the relatively small size of the shoe, placing and spacing will need to be optimized. A field of view will be very important to be able to detect the area needed to be able to walk safely and assist the visually impaired user. Sensitivity to different light situations, most importantly ambient, will need to be tested and ensure that the projected stripes will be visible by the camera sensor. Lens tuning for the camera sensor might be necessary to get the clearest image, but this can be simulated in the optics lab and can be calibrated to the 2-meter distance needed specifications set for the project. Through testing for the S.I.G.H.T. housing to hold the optoelectronic system will need to be built. This housing will need to account for any extra filters that may need to be added, either to better capture the light stripes in ambient light, or perhaps a 650nm filter may be used to correct the output of the prototyping laser diode module. Depending on the performance of the DOE with the laser diode module, a more powerful laser might need to be tested, or a beam expander might be to uniformly fit the DOE to project evenly space lines.

Future Testing and Improvements

The group anticipates having to create mechanical housing higher up the boot design to get the best field of view to be able to detect ditches, curbs, and steps. Depending on if the housing can be attached to the front of the top of the boot can hold the optoelectronic subsystem, this might need to be built separately and then be attached to the boot in another way. The use of optical filters might need to be used to better perform in ambient light settings. With more time, better lenses can be considered to account for aberration or widen the field of view. Software goals will go hand in hand with the optics of the project in the form of measuring the distortion and stripe detection, as well as evaluating frame rate and the processing lag in the ESP-32 microcontroller. These software systems will be integrated into optics to be able to demonstrate a working prototype for object detection and ultimately avoidance. Testing will begin in the optics lab and graduate to hallways, and finally outdoor testing will need to be completed. The progression of this testing will ensure

that at all stages of the prototyping process the system is successfully and reliably detecting objects.

Preliminary lab testing shows promising results that the structured light system will be a viable technology for object detection in the S.I.G.H.T. The laser diode module will be within the proper voltage and current to operate properly, and with proper alignment with the D.O.E. a 15-stripe projection will be clear and visible to have an image taken by the ESP-32-CAM. The microcontroller will be able to detect any distortion in the stripe pattern and alert the user of a detected object. Any real-world limitations will be addressed in the prototyping process to ensure success of the project, while solutions are already being brainstormed for any potential issues that might arise. All in all, the subsystem seems viable with minor improvements. Full prototyping and integration are ready to begin.

9.4 Overall Integration

All of the S.I.G.H.T. shoe's hardware and software components will be combined into a single cohesive platform. During SD2, we plan to systematically combine the following major subsystems.

Table 45: Overall Integration

Subsystem	Description	Purpose in System
Obstacle detection and feedback module	This system will include ultrasonic sensors, a microcontroller with camera, vibration and speaker.	This will help detect obstacles in real-time and alerts the user through haptic and audio feedback.
Power supply and battery management	Provides regulated voltage and power to all system components for extended periods.	Ensures consistent and reliable operation of the system over 6-10 hours of usage.
User interface and display	LCD and LED indicators used for real time debugging and feedback during testing phases.	Assists in development and debugging during SD2.
Housing and enclosure	Encloses and mounts all hardware components on and around the shoe without messing with user movement.	Protects the hardware, ensures safety, and maintains comfort for visually impaired users.

Each subsystem will be tested independently before being integrated into the full shoe system. As the central processing unit, the microcontroller will regulate the actuator output, processing logic, and sensor input. For a portable and durable prototype, we will first integrate using a breadboard before designing and ordering a PCB board. Following integration, a thorough, final validation will be performed using the performance testing plan found in section 9.2. This validation will mimic actual walking conditions for both indoor and outdoor settings to confirm:

- Detecting and avoiding obstacles reliably at various speeds
- Long term battery life throughout regular cycles of use
- Stability and robustness of the components that are installed
- Reliable operation under a range varying lighting circumstances

To guarantee consistency and make debugging easier, we will document all integration processes.

9.5 Plan for Senior Design 2

The goal for Senior Design 2 is to focus on executing the test and evaluation strategies outlined in this chapter. The following are some milestones that we plan to follow for SD2, for more milestones see chapter 10 section 10.2.

Table 46: Senior Design 2 Testing and Development Milestones

Milestone	Timeline	Objectives	Tasks
Complete PCB Assembly	Weeks 1-2	Finalize and order PCB board	Finish PCB board design and order
Subsystem Testing	Weeks 3-4	Verify individual modules	Test ultrasonic sensor, microcontroller, and power supply independently. Verify code protocol communications.
System Integration	Weeks 5-6	Assemble working prototype and ensure logic functions	Integrate all hardware components, validate requirements specifications are met.
Full System Testing and Debugging	Weeks 7-8	Perform realistic testing and identify design issues	Conduct multiple tests in various conditions, measure battery life and detection accuracy.
Final Validation	Weeks 9-10	Confirm product meets engineering goals	Test against metrics in section 9.2. Obtain user and faculty feedback, implement final design refinements.

Final Documentation and Showcase	Weeks 11-12	Prepare deliverables and present project	Finish all required videos and documentation, demo completed system in showcase.
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Throughout SD2, the team will hold weekly meetings to make sure we are on track. The goal is to deliver a fully integrated, functional, and safe wearable assistive shoe for the visual impaired individuals and be ready for demonstration.

Chapter 10: Administrative Content

10.1 Budget and Financing

An itemized list of materials needed for this project, their costs, and their quantity, are shown on the table below. These costs will be covered by the group and split into equal amounts. Our goal for this project is to not exceed more than \$400 dollars but just in case we have allocated \$200 each.

Table 47: Bill of Materials Needed for the S.I.G.H.T. Shoe

Item #	Component Name	Quantity	Unit Cost (\$)	Total Cost (\$) plus taxes	Supplier	Description
1	ESP32-CAM	1	\$ 7.54	\$ 15.08	Amazon	Bundle of 2; only 1 used; Main MCU with camera and Wi-Fi/Bluetooth
2	Ultrasonic Sensor	2	\$ 3.84	\$ 7.68	Amazon	For obstacle detection via distance sensing on the sides
3	1602 LCD Display	1	\$ -	\$ -	Previously owned	Displays distance readings
4	Vibrational Motor	1	\$ 5.39	\$ 6.68	Digi-Key	Provides haptic feedback to user
5	Haptic Driver for Vibrational motor	1	\$ 11.95	\$ 13.24	Digi-Key	Controls vibration patterns to user
6	Speaker	1	\$ 3.34	\$ 4.63	Digi-Key	Audio output for alerts
7	Audio Amplifier Evaluation Board	1	\$ 3.95	\$ 5.24	Digi-Key	Amplifies signal to drive the speaker
8	Battery	1	\$ 12.50	\$ 13.79	Digi-Key	BATTERY LITH-ION 3.7V 2AH - power supply
9	Charging Module	1	\$ 5.95	\$ 7.24	Digi-Key	LIPOLY BATTERY CHARGER W/USB C
10	USB 2.0 Cable A Male to C Male	1	\$ 1.76	\$ 3.05	Digi-Key	Cable used for charging
11	Voltage Regulator	1	\$ 7.95	\$ 8.57	Amazon	Regulates input voltage to a stable output level (e.g., 5V or 3.3V)

12	Laser Module	2	\$ 11.89	\$ 23.78	Amazon	650nm red laser module that projects a visible dot for alignment
13	Lens	1	\$ -	\$ -	Amazon	Used to focus camera and laser module
14	Diffraction Optical Elements	2	\$ 32.00	\$ 64.00	From the lab	Optical component used to shape laser beams into a specific grid pattern
15	FTDI Board	1	\$ 6.49	\$ 6.91	Amazon	USB-to-Serial interface for programming ESP32-CAM
16	Shoes (Boots)	1	\$ -	\$ -	Already own	Physical platform for mounting all wearable hardware
17	Shin guard	1	\$ 9.74	\$ 10.36	Amazon	Protective attachment to mount components on the leg and hold wiring securely
18	Sock	1	\$ 10.79	\$ 11.41	Amazon	Soft base layer worn under the device to improve comfort and prevent skin irritation from the electronics
19	PCB	-	\$ -	\$ -	JLPCB	Custom printed circuit board for integrating and routing all components
20	Jumper Wires	-	\$ -	\$ -	Previously owned	Wiring connections between components on breadboard or PCB
21	3D Filament	-	\$ -	\$ -	Previously owned	Used for printing custom enclosure or mounts for hardware
Total			\$ 135.08	\$ 201.65		

The table shown below provides a comparison between the estimated and actual cost for our components used for the S.I.G.H.T. shoe project. This breakdown highlights how well the project stayed within its original spending plan. While there are some components in the table that are slightly over budget, most of our other parts are within reasonable bounds. In order to evaluate overall cost efficiency and guide future purchase decisions, the table additionally features a computed difference column that indicates where savings or surpluses occurred.

Table 48: Budget vs. Actual Cost Comparison

Component Name	Estimated Total (\$)	Actual Total (\$)	Difference (\$)	Status
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ESP32-CAM (1 of 2 used)	\$ 10.00	\$ 15.08	-5.08	Over Budget
Ultrasonic Sensor (2x)	\$ 7.00	\$ 7.68	-0.68	Over Budget
1602 LCD Display	\$ 5.00	\$ -	+5.00	Under Budget
Vibrational Motor	\$ 5.00	\$ 6.68	-1.68	Over Budget
Haptic Driver for Vibrational motor	\$ 15.00	\$ 13.24	+1.76	Under Budget
Speaker	\$ 10.00	\$ 4.63	+5.37	Under Budget
Audio Amplifier Evaluation Board	\$ 10.00	\$ 5.24	+4.76	Under Budget
Battery	\$ 12.00	\$ 13.79	-1.79	Over Budget
Charging Module	\$ 9.00	\$ 7.24	+1.76	Under Budget
USB 2.0 Cable A Male to C Male	\$ 8.00	\$ 3.05	+4.95	Under Budget
Voltage Regulator	\$ 10.00	\$ 8.57	+1.43	Under Budget
Laser Module (2x)	\$ 16.00	\$ 23.78	-7.78	Over Budget
Lens	\$ -	\$ -	0.00	Under Budget
Diffraction Optical Elements (2x)	\$ 70.00	\$ 64.00	+6.00	Under Budget
FTDI Board	\$ 7.00	\$ 6.91	+0.09	Under Budget
Shoes (Boots)	\$ 25.00	\$ -	+25.00	Under Budget
Shin guard	\$ 10.00	\$ 10.36	-0.36	Over Budget
Sock	\$ 15.00	\$ 11.41	+3.59	Under Budget
PCB	\$ -	\$ -		Not yet ordered
Jumper Wires	\$ -	\$ -		Under Budget
3D Filament	\$ -	\$ -		Not yet ordered
Total	\$ 244.00	\$ 201.65		Under Budget for Project

10.2 Project Milestones and Timeline

To ensure steady progress, the group has made a thorough project milestone table that lists important tasks, their respective time periods, due dates, and assigned responsibilities in order to guarantee consistent progress and efficient time management. Over the course of the two-semester project, this schedule helps track the timely completion of goals while minimizing the risk of delays. The table below shows the complete list of project milestones.

Table 49: Project Milestones

Senior Design I – Summer 2025				
Task	Time Period	Dates	Responsibility	Status
Project Selection	1 Week	5/13 - 5/17	All	Complete
D&C Documentation	1 Week	5/23 – 5/30	All	Complete
D&C Meeting with Advisors	30 Minutes	6/2	All	Complete
Update and Upload D&C report onto website	1 Week	6/6	Ana	Complete
Research Obstacle Sensor	1 Week	6/6	Giovanny	Complete
Research Laser Types	1 Week	6/6	Giovanny	Complete
Research Battery	1 Week	6/6	Jasmine	Complete
Research Vibration & Audio Haptic Feedback	1 Week	6/6	Ana	Complete
Research Water-Resistant Material	1 Week	6/6	Jasmine	Complete
Start Coding	3 Weeks	6/30 – 7/20	Johan	In Progress
Start PCB Design	3 Weeks	7/1 – 7/21	All	In Progress
Final Decision on PCB Design	1 Week	7/21-7/27	All	Not yet started
Order PCB and Other Materials	1 Week	7/28-7/30	All	Not yet started
Midterm Report	2 Weeks	6/23 -7/7	All	Complete
Midterm Report Meeting	1 Week	7/9 – 7/11	All	Complete
Update and Upload Midterm onto Website	1 Week	7/18	Ana	Complete
120 Page Draft	2 Weeks	7/14 – 7/23	All	Complete
Final Documentation & Mini Demo Video	2 Weeks	7/14 -7/23	All	Complete

Senior Design II – Fall 2025				
Task	Time Period	Dates	Responsibility	Status
Start Project Prototype	4 Weeks	~8/11 – 9/1	All	Not yet started
Start Model Building	4 Weeks	~8/11 – 9/1	All	Not yet started
Connect the Obstacle Sensor to ESP32	4 Weeks	~8/11 – 9/1	Johan and Ana	Not yet started
Connect the Laser to Microcontroller	4 Weeks	~8/11 – 9/1	Giovanny	Not yet started
Connect Battery to charging module and then to Microcontroller	4 Weeks	~8/11 – 9/1	Ana and Jasmine	Not yet started
Use either Serial/I2C to Connect to Microcontroller's UART/I2C Port	2 Weeks	~9/1 – 9/15	Johan	Not yet started
Implement all code and make sure it is fully working	4 Weeks	~9/15 – 10/8	All	Not yet started
Final Testing and Adjustments	4 Weeks	~10/8 – 11/5	All	Not yet started
Final Testing	2 Weeks	11/10 - 11/24	All	Not yet started
Final Presentation	1 Hour	~12/5	All	Not yet started

The table below outlines our current plan for the distribution of work. The project has been divided into multiple tasks, and each task is assigned to a primary team member for its completion along with a secondary member who will assist and help ensure accountability throughout the development process.

Table 50: Work Distribution

Task	Primary	Secondary
Obstacle Sensor	Giovanny	Ana
Laser	Giovanny	Johan
Rechargeable battery	Jasmine	Ana
Ultrasonic sensor	Ana	Jasmine
Camera Module	Giovanny	Johan

Vibrational Motor System	Ana	Jasmine
Coding	Johan	Ana and Jasmine
PCB Design	Ana	Jasmine
Water-Resistant Enclosure Design	Johan	Jasmine
Speaker System	Jasmine	Ana

The table shown below outlines the chapter distributions among the team members for the S.I.G.H.T. shoe final report. Each member was assigned specific chapters based on their contribution to the project while certain sections were completed collaboratively to ensure accuracy and completeness.

Table 51: Chapter distribution of final report responsibilities

Team Member	Assigned Chapters	Group Chapters
Ana	Ch 1, 10	Ch 2, 3, 4, 5,
Jasmine	Ch 6, 8	Ch 2, 3, 4, 5,
Giovanny	Ch 5, 9	Ch 2, 3, 4, 5,
Johan	Ch 7,11	Ch 2, 3, 4, 5,

Chapter 11 Conclusion

The Senior Design 1 phase of the Smart Integrated Guidance & Haptic Technology (S.I.G.H.T.) smart shoe project marked a foundational period of ideation, system planning, component integration, and early-stage validation. Over the course of the semester, our team transitioned from a broad concept of wearable assistive technology into a functional, modular prototype capable of detecting nearby obstacles and delivering multi-modal feedback to the user. While the project remains in active development, our accomplishments in embedded systems architecture, hardware-software integration, and design for accessibility form a strong basis for the next phase of development in Senior Design 2.

Our focus during Senior Design 1 was to establish a proof of concept that prioritized the core functionalities of obstacle detection, haptic and audio feedback, battery operation, and fortified enclosure. These were chosen based on direct input from visually impaired users and gaps identified in prior smart footwear solutions. We began by thoroughly researching past projects and commercially available products to understand both the potential and the limitations of current technologies. This led to a well-defined set of engineering requirements that balanced cost, performance, modularity, and user comfort.

One of the primary subsystems we tested was the ultrasonic-based obstacle detection. Using the HC-SR04 sensor, we successfully achieved consistent detection of objects within the target range of 2 to 400 centimeters. The sensor will be mounted on the toe region of our prototype boot and calibrated using a basic averaging algorithm to minimize erratic readings caused by sensor jitter or off-axis reflections. Our firmware was structured to support rapid sensor polling with minimal latency. This module became a cornerstone of our navigation aid, providing real-time spatial awareness for users without relying on vision.

The feedback system proves equally critical to our design and receives substantial development attention. We implement a vibration motor (Vybronic VG0840001D) and speaker (PUI Audio AS02708CO-WR-R) to create redundant channels of feedback. This ensures that the user can receive alerts even if one modality is momentarily ineffective due to environmental conditions or personal sensory limitations. The DRV2605L motor driver allows us to vary vibration patterns based on obstacle distance, which adds intuitive feedback cues. Similarly, the speaker system, initially limited by PWM distortion, is refined through signal filtering and physical mounting improvements, leading to clear, discernible tones in testing environments. These outputs are essential to creating a system that users can both hear and feel, depending on context and preference.

Power management was another area of priority during this phase. After evaluating multiple battery options, we selected a 3.7V 6600mAh lithium-ion battery with built-in protection circuitry.

Housing and structural durability were evaluated through the use of the Dunlop Chesapeake plain toe boot. The boot's large internal volume and rugged exterior provided a stable platform for securely mounting the electronic components, including the battery, sensors, speaker, and motor.

Despite these successes, several areas of the system remain under development and will be refined in Senior Design 2. Our structured light module, which uses a laser projection and camera system for advanced obstacle detection, encountered limitations due to ambient light interference and insufficient real-time processing capability on the ESP32-CAM. As such, this feature was not included in the initial integration and remains a stretch goal for next semester. Early experiments revealed challenges with pattern distortion analysis under variable lighting and uneven surfaces, suggesting the need for more sophisticated image processing algorithms, potentially powered by machine learning and better environmental calibration.

Another challenge involves refining the tactile and audio feedback for different users. In testing with team members and preliminary users, we note differences in sensitivity to vibration and sound cues. Some users prefer more intense and longer vibration pulses, while others require greater audio volume or more distinct pitch differentiation. These observations highlight the importance of configurable settings in the final design, such as adjustable vibration strength or multi-profile audio feedback.

Software reliability was a final area of technical exploration. We encountered a few issues with UART buffer overflows and interrupt conflicts, which temporarily disrupted system operation. These bugs were resolved by restructuring our code to better handle concurrent sensor readings and feedback triggering. The experience emphasized the importance of robust firmware design, especially in wearable embedded systems where real-time responsiveness and system stability are essential for user safety.

In summary, the first phase of the S.I.G.H.T. smart shoe project achieves its primary objectives: building a modular, wearable prototype with effective short-range obstacle detection and responsive haptic and auditory feedback. We select and validate hardware components, write and test modular firmware in the Arduino IDE, and iterate on the mechanical design to meet real-world usability needs. These efforts culminate in a successful preliminary demonstration of our system in realistic indoor and outdoor conditions. The lessons learned throughout this phase lay a strong foundation for Senior Design 2, where we continue to develop our design into a working and viable option for visually impaired users. Most importantly, our work this semester reaffirms our commitment to delivering reliable, affordable, and user-centered assistive technology that improves mobility and confidence for individuals with visual impairments.

Looking ahead, one of the most significant outcomes of this phase was our team's collective alignment around a clear design philosophy: modularity, accessibility, and adaptability. Every subsystem was designed with modularity in mind, ensuring that future iterations can evolve without requiring full redesigns. Whether it involves swapping sensors, upgrading the processing unit, or integrating new feedback mechanisms, our architecture was intentionally structured to support iterative growth. This decision will hopefully pay dividends in Senior Design 2, where the focus will shift from core functionality toward feature expansion and user personalization. We plan to build upon this modular framework by adding support for dynamic sensor calibration and advanced object classification

We also made a deliberate effort to ground our technical development in human-centered design principles. As engineering students, it's easy to become absorbed by hardware specs and algorithm performance, but throughout this semester we worked to reframe our design decisions through the lens of real-world usability. Being that our target, user individuals with limited or no vision, we require more than just functionality; they need trust, comfort, and consistency from the tools they rely on daily. We've recognized how critical intuitive feedback, reliable performance, and ease of use are essential criteria. Features such as customizable vibration intensity and multilingual audio alerts are more than stretch milestones. They represent our growing commitment to inclusivity.

Furthermore, our progress in SD1 has sparked discussions around ethical and societal implications. As assistive technology designers, we have a responsibility not only to meet functional requirements but to ensure dignity, independence, and safety for our users. For example, we deliberately avoided camera-based facial detection and location tracking features unless absolutely necessary, to protect user privacy. We will remain vigilant about data handling, user control, and cybersecurity, especially since our target demographic may include individuals unfamiliar with advanced digital interfaces.

From a broader perspective, the S.I.G.H.T. project has revealed how accessible technology can empower underserved populations when it's developed thoughtfully. We envision that a refined version of this system could eventually be distributed through nonprofits, rehabilitation centers, or low-cost licensing programs to ensure affordability. Even within our university community, the interest in our prototype has shown that there's a demand for practical, student-developed solutions that directly address day-to-day challenges.

In essence, Senior Design 1 has been far more than a technical exercise; it's been an opportunity to practice engineering with empathy, purpose, and real-world impact. The knowledge and momentum gained in this phase will serve not only as a launchpad for completing the full prototype in Senior Design 2, but as a reminder of the kind of innovation that is possible when technology is built with humanity in mind.

Appendices

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Appendix D – software code (if necessary)

The following code represents the core object-oriented structure used in the S.I.G.H.T. firmware. It defines the major software modules: SensorManager, FeedbackManager, CommunicationModule, and MainController.

```
// SensorManager handles obstacle detection logic
class SensorManager {
public:
    float getUltrasonicDistance(); // Returns distance in centimeters
    bool isObstacleNear();        // Returns true if obstacle within threshold
};

// FeedbackManager handles haptic and audio feedback
class FeedbackManager {
public:
    void vibrateShort();           // Vibrates once briefly
    void vibrateWarning();         // Vibrates rapidly to indicate danger
    void playAudioFeedback(String type); // Plays audio cue based on type
};

// CommunicationModule manages BLE or Wi-Fi messaging
class CommunicationModule {
public:
    void sendSOSMessage();         // Sends an SOS message (future feature)
};

// MainController orchestrates system operation
class MainController {
    SensorManager sensor;
    FeedbackManager feedback;
    CommunicationModule comm;

public:
    void run();                    // Main loop controlling system states
};
```

The following MATLAB script demonstrates a basic image comparison method used in the S.I.G.H.T. system to identify object-induced distortions in a projected grid pattern. By converting both undistorted and distorted images to grayscale and applying Canny edge detection, the code highlights structural differences between the two. It then compares edge patterns to detect anomalies that may indicate the presence of nearby obstacles:

```

% full path of images
imageNormal      =      imread('C:\\Users\\johan\\OneDrive\\Desktop\\SD1      video
demo\\undistorted_image.jpg'); % Full path to undistorted image
imageDistorted   =      imread('C:\\Users\\johan\\OneDrive\\Desktop\\SD1      video
demo\\distorted_image.jpg'); % Full path to distorted image

% both images to gray scale
grayImageNormal = rgb2gray(imageNormal);
grayImageDistorted = rgb2gray(imageDistorted);

% apply canny edge detection
edgesNormal = edge(grayImageNormal, 'Canny');
edgesDistorted = edge(grayImageDistorted, 'Canny');

% compare two images by subtracting edges
diffImageNormal = abs(edgesNormal - edgesNormal); % Compare normal with itself
diffImageDistorted = abs(edgesNormal - edgesDistorted); % Compare normal with
distorted

% threshold for detecting changes
threshold = 100000;

% dif greater/less than threshold of normal image
if sum(diffImageNormal(:)) > threshold
    disp('Object detected');
else
    disp('Detecting');
end

% dif greater/less than threshold of distorted image
if sum(diffImageDistorted(:)) > threshold
    disp('Object detected');
else
    disp('Detecting');
end

```

Appendix E – ChatGPT prompts and outcomes (if necessary)

Appendix F – Links to Items

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