Navigation Assisted Shopping Cart (NASC)

Group 10 – Spring 2025 / Summer 2025

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Chapter 2 – Project Description

2.1 Project Background and Motivation

The World Health Organization estimates that at least 2.2 billion people globally are affected by some type of visual impairment [1]. While a large percent of these impairments is due to refractive errors, which can be corrected by visual aids such as glasses and contact lenses, a portion is also uncorrectable by glasses, medicine, or surgery [2,3]. The National Institute of Health categorizes these impairments as ‘low vision’ [4]. Low vision is commonly caused by visual disorders such as age-related macular degeneration, cataracts, diabetic retinopathy, and glaucoma, with many of these disorders being linked to aging [4]. In the United States, the Centers for Disease Control and Prevention predicts that the number of low vision individuals over the age of 40 will more than double by 2050 from 2012’s estimate of 4.2 million, largely due to America’s aging population [3,5]. 3% of children under the age of 18 in America also experience low vision even with wearable visual aids [3].

There are several ways to categorize the range of visual acuity for individuals with low vision; for the purposes of this project, we are focusing on individuals with visual acuity ranging from 6/18 to 3/60, as defined by the International Classification of Diseases [6]. Comfortable vision within this range is between one to six meters with potential challenges in central vision, peripheral vision, and light perception [6]. On the more severe end of this range, objects or signs beyond an arm’s length away may be difficult to perceive or recognize. This introduces challenges in activities of daily living, necessitating assistance from a caregiver in order to complete many tasks. While caregivers offer valuable support, the need for constant assistance may diminish autonomy and impact quality of life by reducing an individual’s independence.

The aim of this project is to improve on current assistive technology to promote autonomy of individuals with low vision by creating a portable device tailored to help independently navigate grocery stores. More specifically, this device will guide them to within one meter of requested items and offer directions and object avoidance along their path. By reducing the need for caregiver assistance for this instrumental activity of daily living, we hope to foster greater self-sufficiency and empowerment, enhancing quality of life and supporting the autonomy of individuals with low vision.

2.2 Current Commercial Technologies and Existing Projects

2.2.1 VIRAS: Visually Impaired Robot-Assisted Shopping

The VIRAS project was developed by the Institute for Lab Automation and Mechatronics (ILT) at the Eastern Switzerland University of Applied Sciences with the goal of aiding blind and visually impaired individuals with grocery shopping [7]. The device is comprised of the entire shopping cart, which has a navigation system composed of a stereo camera for 3D mapping the store environment and mapping the user’s hand for more precise object location [7]. The system takes in speech input from the user to generate the item list and provides audio instructions to direct the user’s hand when they attempt to make contact with the object [7]. AI-based object detection is used along with the stereo camera to determine the identity of objects rather than requiring users to scan barcodes [7]. The cart is motorized and self-driving, which allows it to guide the user to the object location and checkout.

This technology has the same goal of improving user autonomy and minimizing caretaker dependency in the use case of grocery shopping. This technology is not only meant for users with low vision but can also be used by those with more severe visual impairments and even certain mobility issues. However, the system comprises of the entire shopping cart, which requires the stores to already have these devices in place. Our project aims to create a similar system but make the device portable, so that the user may be able to use it in stores that do not already have this device in place.

2.2.2 The Augmented Cane

The Augmented Cane is a similar assistive device which builds on the traditional white cane to enhance independence and mobility for individuals with visual impairments [8]. It integrates information from multiple added sensors, including LiDAR, a camera, GPS, and IMU to aid users with environment navigation both indoor and outdoor [8]. A microcontroller processes the sensor information to plan navigational routes and provide real-time feedback to the user through audio instructions, steering assistance, and kinesthetic haptic feedback from the ground to the user's hand [8]. An omni-wheel at the base of the cane supplements the user's movement by providing additional steering in the case of avoiding certain objects or making navigational changes [8].

This device facilitates several tasks that may be more difficult with just a traditional white cane. It improves walking speed for individuals with visual impairments through its motorized guidance system, and it serves to effectively map the user's surroundings through camera-based object detection and LiDAR and GPS-based localization to promote more confident navigation [8]. Our project's scope aims to translate some of the successes of this project to the more specific application of grocery shopping. Although compared to the VIRAS project this device is much more portable by the user and can be applied in several locations, it may be difficult to maneuver a traditional shopping cart in tandem with the Augmented Cane; therefore, our device addresses both portability and usability within a grocery store environment compared to the Augmented Cane.

2.2.3 Summary

Existing assistive devices for individuals with visual impairments have made significant progress in augmenting existing technology to enhance the user's confidence in navigating their environment, which by extension supports their autonomy in performing several tasks. Two examples of these devices, the VIRAS project and the Augmented Cane, both employ several sensors to improve on a shopping cart and white cane, respectively, to map the users environment and provide valuable information to the user to allow them to navigate their surroundings [7,8].

Our developed device addresses the gap of a user-portable navigation-assistive device specific for streamlining shopping for individuals with low vision. It draws on several hardware and software features of both the aforementioned projects, including Depth camera sensing and IMU for mapping, a camera for object detection, and audio and haptic cues for feedback. Our device also aims to minimize cost in comparison to the two devices to make the technology more accessible; the VIRAS project requires stores to already have several of these shopping carts available for users, and the Augmented Cane has a total component cost of $400.

2.3 Goals and Objectives

This project's aim is to build a portable and mountable supplement for a shopping cart to aid individuals with visual impairments navigate stores and reach within 1 meter of the requested item.

Basic Goals

- Create a portable navigation device that users can mount onto a shopping cart
- Guide visually impaired users to within 1 meter of the requested items in the store
- Detect obstacles in front of the shopping cart to warn users of potential collisions

Advanced Goals

- Create an optimized route through the grocery store provided the user's item list
- Assist users with locating the position of the object on the shelf
- Incorporate additional feedback systems to avoid collisions with other shoppers, walls, and obstacles

Stretch Goals

- Extend application to more severe visual impairments (total blindness)
- Expand to other locations (different store types such as libraries, hardware stores, etc.)
- Modulate IR depth camera system in order to be unaffected by different sources of IR

The basic, advanced, and stretch goals are further elaborated into their respective objectives.

Basic Objectives

- Design a lightweight mounting system that is simple to setup and teardown
- Integrate a rechargeable power source with sufficient battery life for the average shopping trip
- Recognize text inputs from the user through a user interface to create the item list
- Determine item locations using a store database with detailed inventory information
- Assess cart speed and direction with Inertial Measurement Unit (IMU) data
- Detect obstacles within a few meters with IR depth camera system
- Provide directions through audio commands

Advanced Objectives

- Path plan based on localization estimates and user inputted item list to calculate an efficient path through the store
- Include haptic cues in addition to audio commands for guidance and collision avoidance in noisy environments or for individuals with hearing impairments
- Build and incorporate an IR depth camera system capable of at least 100 degrees of field of view (FOV) and 2 meters of object detection

Stretch Objectives

- Integrate a camera to identify and indicate shelf level upon reaching the requested object
- Incorporate real-time updates if users change the item list or obstacles require route changes
- Train a speech-to-text algorithm to recognizes verbal user input to generate the shopping list
- Track the user's hand position with a camera when attempting to grab an object and provide additional precise audio commands to direct the user
- Expand the store map database to support multiple locations and integrate with external mapping APIs
- Test the system in diverse lighting conditions to ensure the optical system can filter out other interferences

2.3.1 Hardware

2.3.1.1 Hardware for Basic and Advanced Goals

The primary hardware components for navigation and object avoidance include an IMU, an IR and RGB depth camera system, and a microcontroller for data processing. The IMU tracks the cart's speed and direction, allowing the system to understand its movement and adjust guidance accordingly. The IR depth camera system uses emission of IR constructed light and IR cameras to measure depth with a FOV of 100 degrees and a longitudinal range of 2 meters in front of the cart, which is essential for detecting objects in real time. These objects may be walls, aisles, other shoppers, obstacles, or warnings such as displays or wet floor signs. With the aid of diffractive optical elements (DOE), the system emits a series of evenly spaced vertical and horizontal lines, and the time for the emitted light to bounce back is detected by an IR camera with a similar FOV to the emission system. Measuring the spacing between the lines of light allows for the calculation of depth information. An RGB camera is also used to scan the same area as the IR depth camera to gather color information, which supplements the depth information gathered by the IR camera. The data from both cameras is processed to construct an environment map, which aids in detecting the user's position relative to their surroundings. This data is translated into cues for the users, signaled by audio through onboard speakers and haptic motors placed along the shopping cart's handlebars. The cues provide directional information to the user along with warnings and alerts to stop the cart in the event of an obstacle to ensure safe navigation through the store.

The item requests are handled by the app subsystem, which integrates user text input for the items list with a touchscreen device, such as a smartphone or tablet. The device processes inputs with an onboard computer containing the store's inventory database to determine the order of navigation for the listed items and the necessary directional cues to reach each item.

To ensure that the device is portable and easy to setup and takedown, power will be supplied through rechargeable LiPo batteries capable of powering for the duration of an average shopping session. Overall, the combined hardware setup, featuring the camera, depth camera, IMU, microcontroller, single-board computer, and app interface, ensures that the user is able to request items to shop and receive cues to safely navigate within range to those items.

2.3.1.2 Hardware for Stretch Goals

The primary stretch goal condition is to expand the system to individuals with more severe forms of visual impairments, including total blindness. This requires more robust navigation and object identification abilities. Some applications of this more advanced system include voice-recognition hardware for the user item input for individuals who may not be able to type to input this information. The optical subsystem would also undergo improvements to guide users to a more precise range within the object. This includes a depth camera lens system with a higher FOV and a detector with higher resolution to increase detection ranges and a camera with greater real-time identification capabilities.

2.3.2 Software

2.3.2.1 Software for Basic and Advanced Goals

The software system is divided into various modules to support navigation, object detection, and user interaction.

The user interface operates to take the text inputs from the user to generate the grocery list. The list order is determined through communication with the store's database for item location, which allows the items to be categorized by sections of the store to optimize the path the user would take to reach all requested items. This information is communicated to the navigation module to provide real-time navigational cues to the user.

The navigation module is comprised of a simultaneous localization and mapping (SLAM) algorithm fusing the incoming data streams from the IMU, IR camera system, and RGB camera to determine the user's position in the grocery store and gather information about the surrounding environment. This data, along with the item list from the user interface module, is used to direct the user to items on the list in sequence. Continuous localization allows the system to adjust the planned route dynamically based on the user's movement and any objects and obstacles the IR camera system and RGB camera detect. This information is conveyed to the user through the audio cues, which provide details about which direction to move or turn and when to stop, along with haptic feedback which acts as secondary cues to indicate turns and alert the user of obstacles.

For object detection, the camera scans the shelves once the user is within range of the requested item; the captured information is processed to confirm the user has been brough to the requested object and determine its relative location, which is communicated to the user through audio cues to indicate the shelf direction the object can be found in.

To summarize, the workflow begins with the user inputting their grocery list into the app, which maps and categorizes the items using the store's inventory database. The navigation module generates an optimized route and tracks the cart's movement through the fused sensor information. As the cart navigates to waypoints within 1 meter of the requested item, directional information and item confirmation is communicated to the user, which obstacle alerts also provided if needed. Once all items in the list have been collected, the system guides the user to checkout and exit the store.

2.3.2.2 Software for Stretch Goals

Similar to the hardware improvements for the stretch goals, the software application requires more robust processing of sensor information to support use of this device with more severe forms of visual impairments. The optic subsystem camera would need to recognize the user's hand while the user is attempting to locate the object and provide additional audio cues to guide the user's hand to the object. For user list inputs, the app would also need to process audio input from the user to accurately identify the item being listed.

2.4 Required Specifications

Table 2.1: Overall Specifications for the Navigation Assistive Shopping Cart

Specification	Description	Parameters
Size	Overall – The dimensions of the portable device must be able to comfortably fit in the baby seat of a standard shopping cart.	Approx. 50x50x30 cm3
Weight	Overall – The device must be reasonable to carry around and not interfere with the ability to maneuver the shopping cart.	2.5 – 5 lbs
Battery Life	Overall – Use of the device must last for the duration of the shopping trip, around an hour.	At least 1 hour
Connectivity	Overall – The delay between the sensors and the cues to the users must be short enough to provide effective navigational instructions and warn users in time to avoid collisions.	Within 100 ms
Distance User Guided from Product	Users must be brought to an object so that the object is in their conformable visual range, where they can identify and pick it.	Within 1 meter
Setup/Teardown Time	The portable device must be fairly easy to mount and remove from the shopping cart.	Within 2 minutes

Success Rate	The device must accurately bring users to the requested object within the specified range.	At least 90%
Optimal Route Planning	The directions provided to the user should minimize time and distance from the user's current position to the object. The order of objects should also be ranked according to the store map regions.	Within 10 minutes per item

Specifications that will be demonstrated are highlighted, including the distance the user is guided to within the request a product, the success rate of the user reaching the requested product, and the efficiency of the route planning algorithm as to minimize time spent and distance traveled within the store.

Table 2.2: Component Specifications for the Navigation Assistive Shopping Cart

Specification	**Subsystem and Description**	**Parameters**
Object Avoidance Distance	Navigation and Object Avoidance – The onboard sensors must be able to detect objects that the user would have trouble seeing outside of their comfortable visual range.	Up to 2 meters
Output Quality	App – The app display must be at least standard resolution for the user to interact with it and input the item list.	480 p – 720 p
IR Camera System Range	Optical – The IR camera sensor must be able to provide object and navigational information in the range beyond the user's comfortable visual range.	1 – 6 meters
IR Camera System Field of View	Optical – The IR camera system sensor must be able to gather signal information from a	At least 100 degrees

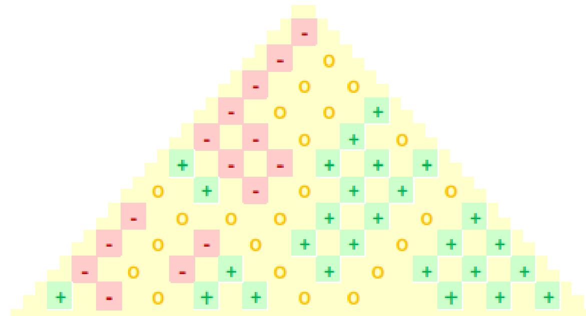
	large enough field of view to ensure sufficient object information to the user	
Laser Diode Power	Optical – A sufficient laser diode power is needed in order for the IR CMOS detector to be able to detect most of the reflected light.	100mW - 200mW
RGB Camera System Field of View	Optical – The RGB camera system sensor must be able to gather signal information from a large enough field of view to ensure overlapping information to the IR camera	At least 100 degrees

Additional component specifications are included above and distinguished by the subsystem they belong to: Navigation and Object Avoidance, the user interface App, and Optical.

Correlations	
Positive	+
Negative	-
No Correlation	O

Relationships	
Strongly Positive	↑↑
Weakly Positive	↑
No Relation	○
Weakly Negative	↓
Strongly Negative	↓↓

Direction of Improvement	
High	▲
Low	▼



Column #		1	2	3	4	5	6	7	8	9	10	11	12
Functional Requirements / Customer Requirements (Explicit and Implicit)	Direction of Desirability	Size	Weight	Battery Life	Connectivity	Object Avoidance Distance	Distance User Guided from Product	Setup/Teardown Time	Depth Sensing Range	Depth Camera Field of View	Output Quality	Success Rate	Optimal Route Planning
Direction of Desirability		▼	▼	▲	▲	▲	▼	▼	▲	▲	▲	▲	▲
Affordability	▲	↓	↓	↓↓	↓↓	↓↓	↑↑	↑↑	↓↓	↓↓	↓↓	↓↓	↓↓
Technical Portability	▲	↓↓	↓↓	↓↓	↓	↓↓	↑	↓	↓↓	↓↓	↓↓	↓↓	↓↓
Ease of Use	▲	↓	↓↓	↓	↑↑	↑↑	↓↓	↓	↑↑	↑↑	↑↑	↑↑	↑↑
Reliability	▲	○	○	↓	↑↑	↑↑	↓↓	↓↓	↑↑	↑↑	↑↑	↑↑	↑↑
Store Compatability	▲	○	○	○	↑↑	↑	↑	○	↑	↑	↑	↑	↑↑
Ease of Maintenance	▲	↑	↓	↓	↑	○	○	↑	↓	↓	○	○	○
Multi-Person Use	▲	○	○	↑	↑	↑	↓	↑	○	○	↑	↑	○
Remote Use	▲	○	○	↑	↑↑	↓	○	○	○	○	↑	↑	○
Efficient Routings	▲	↑	○	○	↑	○	○	○	○	○	↑↑	↑↑	↑↑
Avoid Obstacles	▲	○	○	○	↑	↑↑	↓↓	↓	↑↑	↑↑	↑↑	↑↑	↑↑
Target		Approx. 50x50x30 cm3	2.5 lbs - 5 lbs	At least 1 hour	Within 100 ms	Up to 2 meters	Within 1 meter	Within 2 minutes	1 - 6 meters	At least 60 degrees	480 p - 720 p	At least 90%	Within 10 minutes per item

Figure 2.1 House of Quality

Since the system is mounted directly to the grocery cart, this limits the importance of certain specifications of the overall cart, including those of weight and size, as they do not severely limit the usability of the system. On the other hand, it’s incredibly important to achieve the greatest possible success rate, along with a goo route planning algorithm and a reasonable object avoidance distance (the ladder mostly determined by the IR camera depth system). This is because the reliability of the system is of the upmost importance and comes first before the vast majority of the other goals and objectives for the project as a whole. While we should strive to improve all of the measured specifications to the greatest extent possible but the reliability and performance of the system should come first before the others.

2.5 System Diagrams

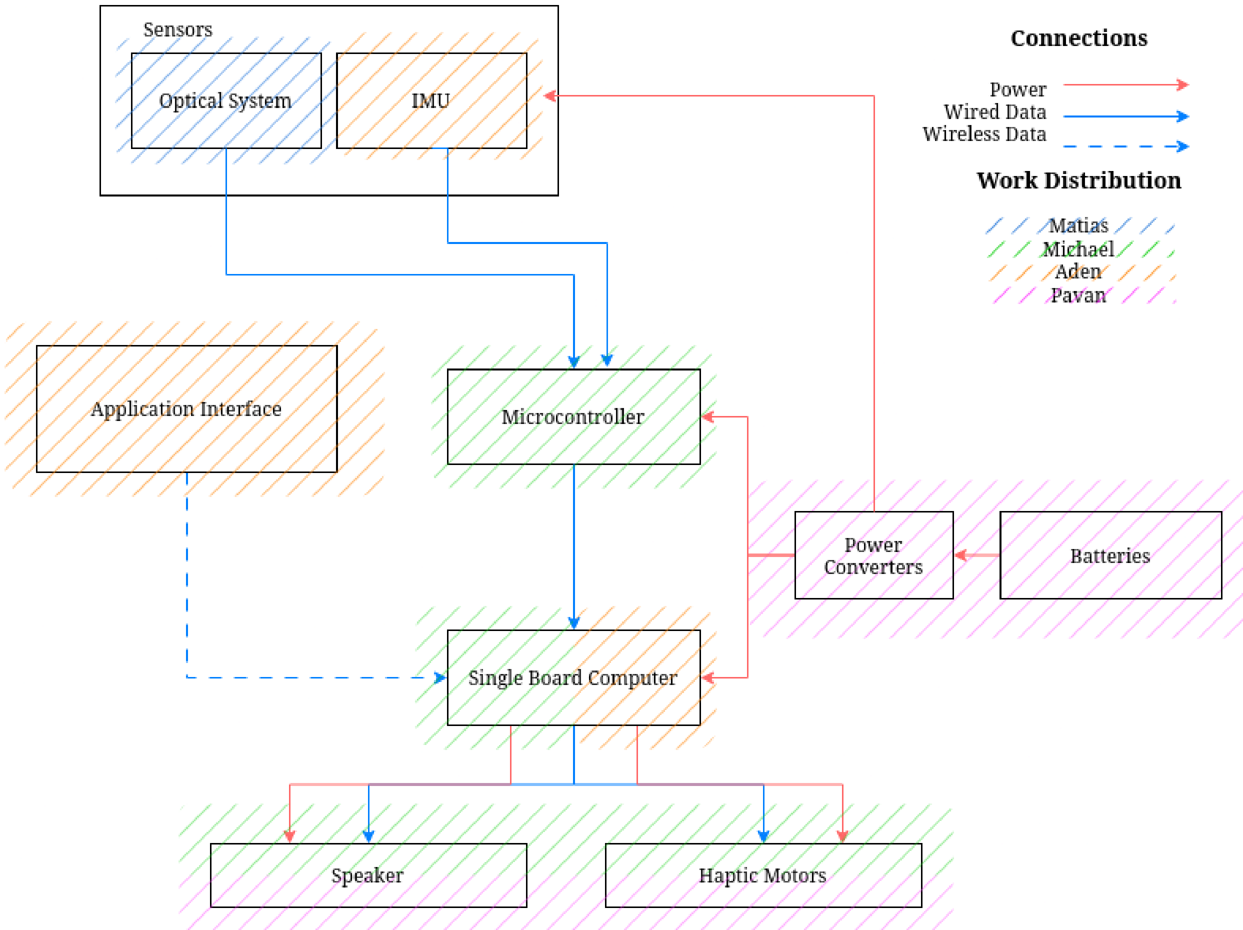


Figure 2.2 Hardware Flowchart

The hardware generally consists of a set of computers connected to various sensors and outside devices for input along with user feedback devices as output. Power will also be an input into the system with the voltages changed as necessary for each system component with the use of boost and buck converts. The sensors used as inputs will consist of an IMU for general location information as well as an IR depth camera system for more localized guidance. A mobile application or similar will be used for the user to input their desired grocery list. On the other hand, haptics and speaker/voice outputs will be used to guide the user throughout the store.

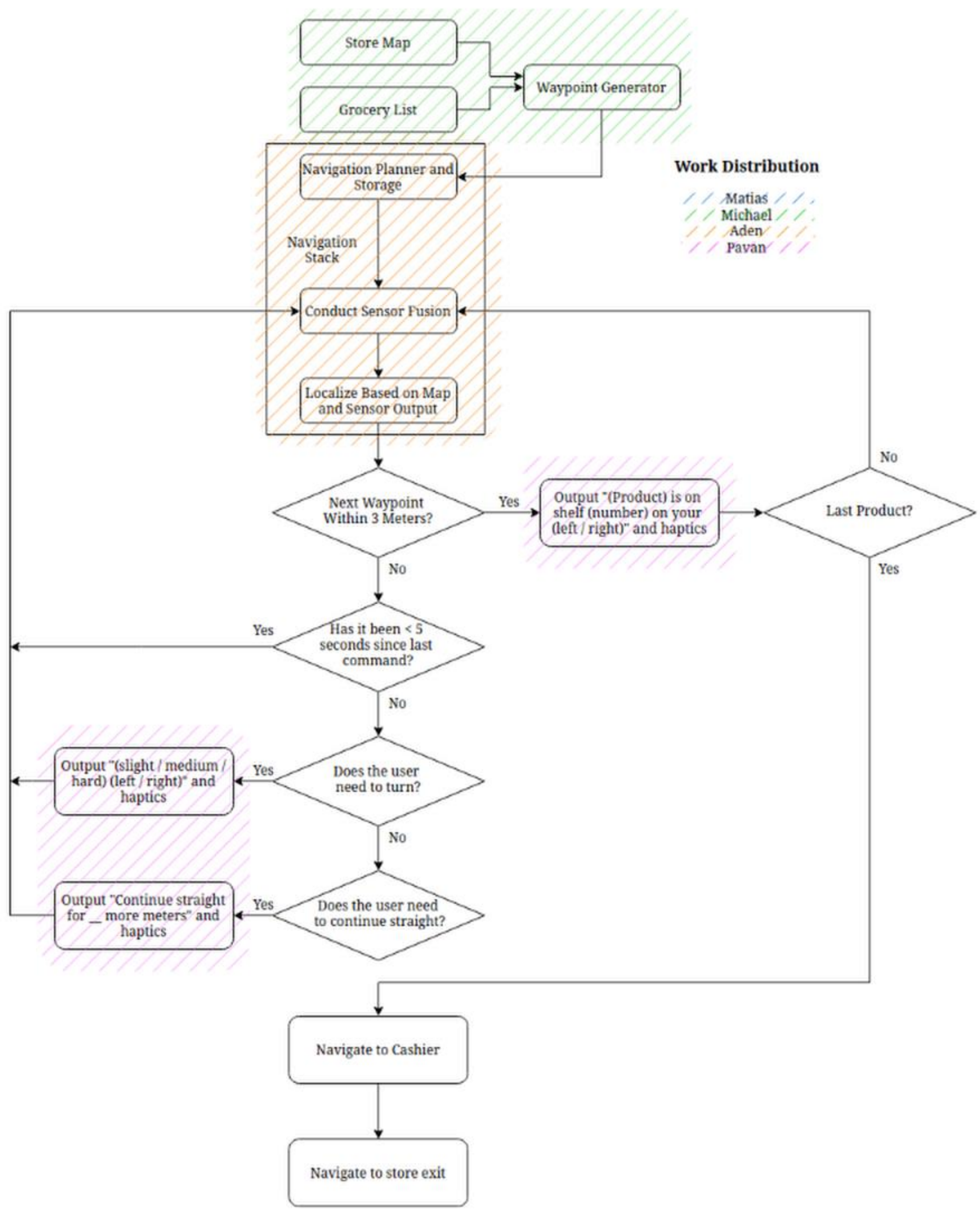


Figure 2.3 Navigation Software Flowchart

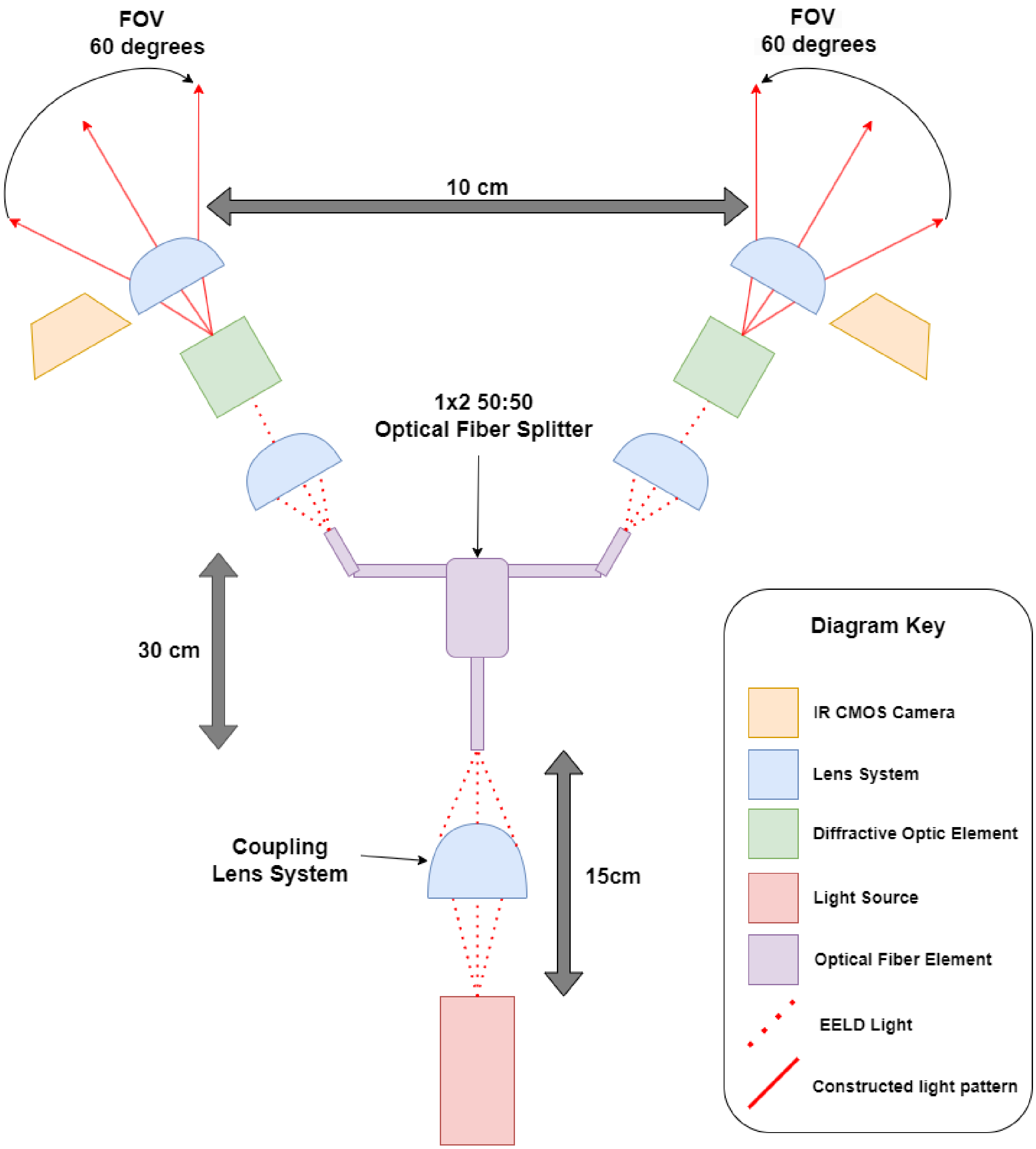


Figure 2.4 Optoelectronic Hardware Flowchart

This Hardware flowchart consists of the emission and detection of constructed IR light (850nm). The light emitted from a EELD is coupled into a fiber optic from which its output its splitted into two, afterwards two identical optical system refocus the light into a diffraction grating, which shapes the light to create an array of vertical and horizontal lines of light, and the following lens is to further diverge the constructed light to increase the FOV. This signal is reflected from the objects in the surrounding and reflected into two IR CMOS cameras, (1 for each system) from where the depth from the emission to the reflecting objects can be calculated.

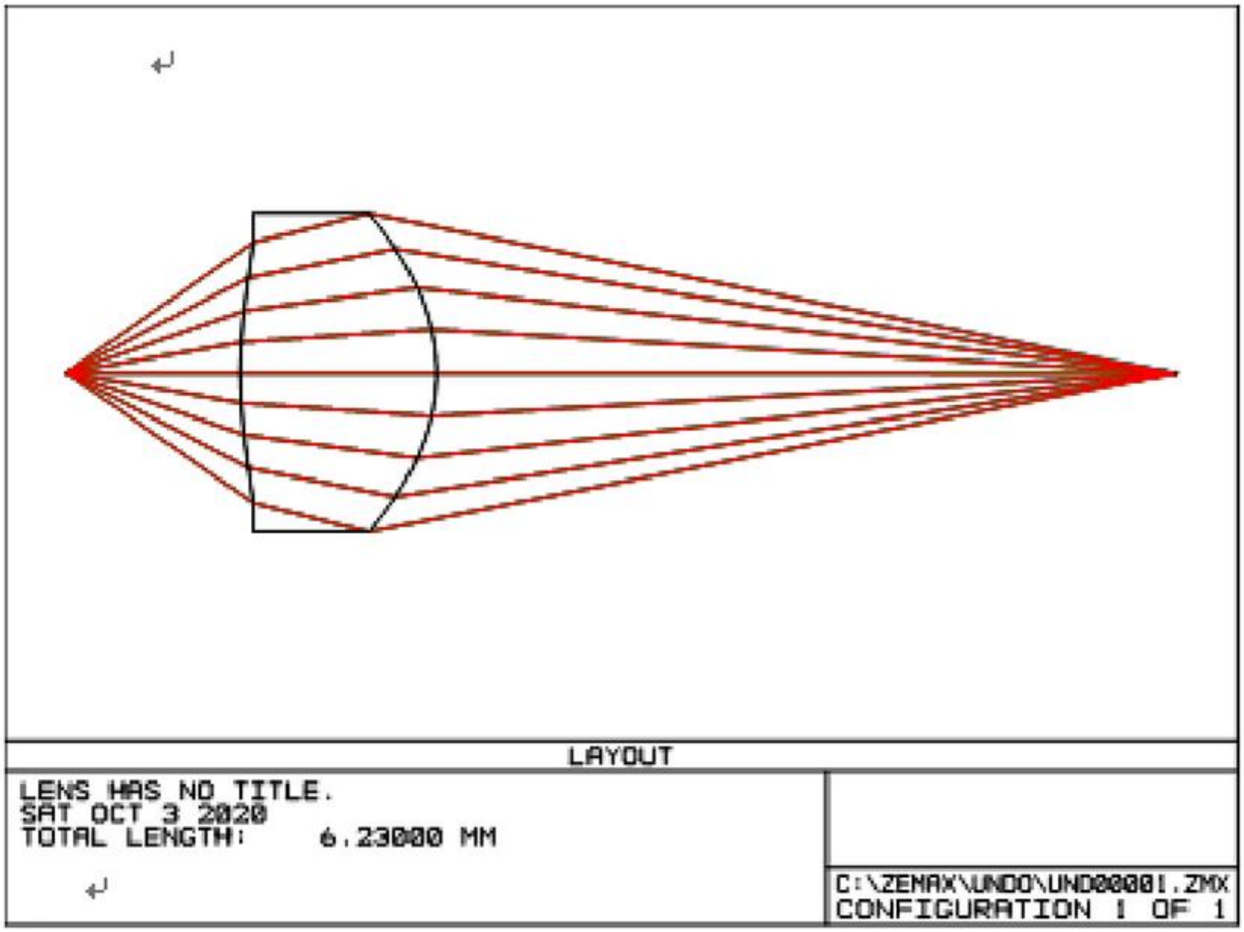


Figure 2.5 Example Lens System to couple light from EELD into Fiber

This Optical Hardware diagram depicts the source light from the EELD which is focused into a beam with a smaller NA to be efficiently coupled into the fiber.

Chapter 10 – Administrative Content

10.1 Budget

The budget for this project shall be around 1000 USD, which should be enough for the team to complete a successful project while keeping costs minimal for everyone involved. The goal of the members is to keep costs within this budget as to reduce the amount of personal expenses incurred by the individual members.

Higher complexity components, such as the optical system and single board computer, are allocated a larger proportion of the budget as shown below. On the other hand, smaller items aren't allocated nearly as much since although we may require more of them, they are relatively inexpensive in total.

Sub-System	Budget

Optics	$300
Power	$200
Control Electronics	$400
Mechanical Components	$100
Total	$1000

Table 10.1 Expected Budget Table

10.2 Bill of Materials

[NOT INCLUDED YET]

10.3 Distribution of Works

The tables below detail the distribution of work that has been decided collectively among the group members. Although each member might be assigned a specific task, it is expected that they will have assistance in completing some parts if needed from other members. In addition, the members must work together to ensure that each component works with the others of the completed system and meets the overall system requirements as outlined in Chapter 2. Members are expected to provide regular updates on the progress of the tasks that they are individually assigned during group meetings.

Major: Photonics Science and Engineering	Responsibilities
Matias Barzallo	RGB Depth Camera Optical Design and Development
	RGB Depth Camera Electrical Integration
Major: Computer Engineering, VLSI	Responsibilities
Michael Castiglia	Microcontroller Software Integration
	Sensor Driver Integration
	Mobile App Design and Development
	High Brain – Low Brain Board Communications
Major: Computer Engineering, Comp.	Responsibilities
Aden McKinney	Autonomous Navigation Stack Design and Development
	Mobile App Design and Development
	Control Output Software Development
Major: Electrical Engineering, Comp.	Responsibilities
Pavan Senthil	Power System Design and Implementation
	PCB Design

	Sensor Hardware Integration
	Control Output Hardware Integration

Table 10.3 Distribution of Works Table

10.4 Milestones

Project Initialization				
Planned Begin Date	Planned End Date	Required End Date	Task	Description
7/5/24	7/15/24	1/14/25	Team Formation	Form team with 4 known members for Spring and Summer
7/15/24	9/1/24	1/24/25	Idea Generation	Discuss and decide on final project idea
9/1/24	12/1/24	1/24/25	Divide and Conquer Document	Chapters 2, 10, and relevant appendices
12/1/24	1/24/25	--	Chapter 3	Implementation Research
1/24/25	2/7/25	3/24/25	60-Page Milestone	Chapters 2-5, and 10
2/7/25	2/28/25	4/22/25	Final Paper (120 pages)	Final Document as Submitted

Table 10.4 Project Initialization Timeline Table

The team has met and will continue to meet several times outside of those indicated above, both without others and with assistance from the review committee, advisors, and others, to complete the milestones within the given tie limit. This project's research started well before the beginning of the Senior Design 1 semester as an attempt to get ahead of deadlines, mainly in Senior Design 2 which would be more compressed due to the nature of completing it in the Summer C section.

Project Fabrication				
Planned Begin Date	Planned End Date	Required End Date	Task	Description
1/1/24	1/24/25	3/24/25	Component Selection	Selecting components for each part of the project.
1/15/25	2/21/25	3/24/25	Software Design	Design the software stack
1/15/25	2/21/25	3/24/25	Optical Design	Design for the optical subsystem
1/15/25	2/21/25	3/24/25	Other Hardware Design	Design for the PCB, power, and other hardware.
2/21/25	3/15/25	4/22/25	Manufacturing and Integration	Making the prototype and integrating the individual components together.

2/21/25	3/15/25	4/22/25	Testing	Test the assembled prototype and fix any issues that may arise.
2/14/25	3/15/25	4/22/25	First Prototype Completion	Final demo video for website of the breadboarded sample proposal for SD1

Table 10.5 Project Fabrication Timeline Table

Due to the nature of this project and the complexity contained within, as well as deadlines for demonstrations of a small prototype inside of Senior Design 1 to the review committee, several of the tasks overlap between the two stages.

Appendices

Appendix A - References List

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