Senior Design 1
Depth Perception Haptic System (DPHS)

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1.0 Project Narrative

The purpose of our project is to develop a wearable guide system to assist the blind or visually impaired in navigating the world around them. The idea is to potentially remove the use of a cane or other similar tool while still maintaining awareness of the surroundings. While other visual impairment products exist on the market; our project differs by concept due to its distinct input features including lidar in conjunction with computer vision. Output features such as an external speaker aid and haptic feedback make it a more comprehensive solution to its competitors. Competition in the same market includes experimental vests that the average user would likely find difficult; or even dangerous to use. This design is meant to be more accessible, simple, and effective than what is on the current market.

1.1 Competitor Details

The goal for developing such a device stems from seeking the possibility of a blind individual sustaining an independent daily life in an uncontrolled setting. Current tools such as canes and innovations like the 'Live Braille' (Digit, 2016) device are helpful, however they are not always convenient nor effective at allowing a person to be in control of their environment; thereby increasing the chances of the endangerment and alienation of the individual.

Common practice of using a cane is the most widely utilized method for the blind or visually impaired, however it has been noted that objects of the thinner variety are often missed due to the wide sweeping motion used with the cane ('See It My Way', 2020). One of the goals of this project is to allow a person to be aware of painted symbols/objects on the floor including signs and crosswalks. More advanced ideas pertain to potentially being able to navigate uneven areas such as flights of stairs. The removal of a cane will also reduce injury caused by the jabbing effect into the gut from the cane itself; notably when quickly walking into an obstacle with force. A hands free design is a major proposition of the project. Further examining competitors:

- Standard Cane: A long stick to be held in front of a person and swept across until it hits an object, indicating an obstacle to be avoided
    - Has a limited range of motion, and requires the use of hands, while the DPHS is hands free and can potentially provide indication of more obstacles
- EyeCane: A handheld device that emits an infrared rays and audibly and tactibly directs the user
    - Operates in a similar fashion to a cane, and while more compact and with a greater range of up to five meters, still requires hand held use

- HeadsUp- Optical Mobility Aid: A head-mounted distance response device to be used in conjunction with a cane, providing extra information about the higher spaces in front of an individual
    - Head mounted device might be too conspicuous
    - Still needs the use of a cane for detection of obstacles closer to the ground

- LiveBraille: A device fitted over an individual's finger that can be pointed and used in a similar fashion to a cane, haptic feedback provided
    - Similar to what DPHS seeks to accomplish but still requires the use of the hand
- BackUp Buddy: While not necessarily used for blind aid, is a camera device that is mounted on the back of a vehicle and operates as a rearview camera to indicate obstacles while reversing the vehicle.
    - DPHS seeks to operate similarly but on a person and with tactile, haptic, and auditory feedback

As described, it can be observed that most devices for the visually impaired or blind replicate a variation of the cane, we seek to provide a device that can operate as a cane without some of the limitations that comes with using them.

1.2 Proposed Method

We have three possible methods of assembling the project with a similar fundamental design. The input system consists of simple communication between a camera and distance sensor that are programmed to identify obstacles and alert the user through haptic feedback (output system) in the form of a grid or arrangement of vibration motors and an external speaker. The three possible arrangements depicted in *Section 2.4 Concept Sketches* include the system fitted into a jacket design, lightweight vest, and a sash/belt.

1.3 Computer Vision Methods

Computer vision will be an integral portion of the main function of the system. We will consider the following image processing techniques.

1.3.1 Image Differencing Change Detection

Image differencing allows for the detection of change between two image frames, creating a remote sensing index, which are compared against one another, to identify the area of change, through the identified different pixels (ESRI, 2021). This method could be applied to the Depth Perception Haptic System by having our camera monitor by rapidly taking pictures and through our own image differencing raster function, identify approaching obstacles through comparative image recognition with our obstacle database. We observed a potential constraint with this method, where it works best for straight-forward recording or stationary camera. This is due to the fact that in the event the camera were to turn between the consecutive image frames, which is highly likely with a camera fitted to a person's body, all the pixels would be different, which negates identifying a particular obstacle.

1.3.2 Image Gradient

Image gradients, as one of the most basic forms of computer vision and image processing, primarily handles edge detection through the changes in pixel intensity within an image, allowing an edge map to be extracted (Rosebrock, 2021). This is most useful for still images and might not be an extensive enough method on its own to be used with the depth perception haptic system.

1.3.3 Optical Flow

Optical flow, like image differencing, examines the differences between two consecutive image frames, however, instead focusing on comparing against the change in the pixels, primarily follows highlighting the motion of objects and estimating their movements from the resulting flow vectors. This could be very helpful to the depth perception haptic system's detection of moving objects. Though, like image gradients, this method may not be comprehensive enough to cover the complex real time dynamic image processing required on its own, and additionally runs the constraint of being computationally expensive and slow (Nanonets, 2019).

1.3.4 Convolutional Neural Network

A convolutional Neural Network, potentially the most comprehensive computer vision algorithm we've come across, applies deep learning artificial intelligence in several layers with communication between nodes to accurately aid in image classification. With this algorithm applying machine learning and being a fore-runner in computer vision, already extensively used in retail, healthcare, motor vehicles, and marketing (IBM, 2020), Convolutional Neural Networks appears to be the best choice to dynamically identify obstacles in images captured by the camera fitted for the Depth perception Haptic system.

1.4 Constraints

There were potential constraints introduced that would impede the functional completion of our project, including a possible limit of processing power in the control system, weather conditions potentially affecting the camera, arm movements caught in the computer vision causing redundant feedback, the potential risk of haptic feedback not having the intended effects, and a number of other possible issues:

1.4.1 Economic Constraints

We observe that certain possible constraints that could arise economically pertaining to the affordability and social acceptance the device would possess

- The event that it is way more expensive than originally thought from our budget
- Ensuring it conforms to acceptable inconspicuous wear, would a person want to wear it?

1.4.2 Environmental Constraints

With the unpredictability of weather conditions, from rain, to extreme cold temperatures and vice versa, we observed the potential for the device to be affected by such contingencies.

- The event it wouldn't work if it got wet from rainfall
- The event it could break from the impact of a fall or bumping into an obstacle
- The event that snow and cold temperatures could frost over the motors
- In the hotter seasons, a particularly sweaty person introducing too much water to

1.4.3 Ethical Constraints

Examining how ethically sound the finished product will be.

- Gain trust in the product; how much testing is enough.

1.4.4 Health and Safety Constraints

Observing how the Depth perception haptic system holds up ethically raises some concerns pertaining to how we ensure it's as safe to use as possible.

- Ensuring that all exposed circuitry and wires are able to be safely housed within the fabric
- That the haptic feedback is not jarring
- May encourage the visibly blind to navigate streets without the aid of others

1.4.5 Time Constraints

- Machine learning for image analysis of shapes and surfaces
- Chip shortage resulting in issues with finished PCB delivery

1.4.6 Testing Constraints

- Limitation on battery
- Lack of available participants who have the desired disability (blindness)
- Small population size for testing
- The max detection distance not being far enough to allow proper reaction

The group will reevaluate these constraints throughout the duration of Senior Design.

2.0 Project Description

2.1 Goals and Objectives

As detailed above, our primary objective is to create a tactile-visual sensory substitution system which allows individuals that are blind, low vision, or vision obstructed to navigate through obstacles they may encounter in their daily lives. The list below contains our goals divided into categories: Core, advanced, and stretch. Our core goals are the foundation of the project which will be completed by the end of the second term. Advanced goals are additional features beyond the basic system requirements, which are likely to be completed on time. Stretch goals are the extra quality of life features to be implemented if time permits.

The device goals include:

- Core
    - Transmit information about the distances of large objects in the environment to the user via haptic feedback (e.g., walls, lampposts, people, vehicles)
    - Have enough battery to last the length of a typical workday
    - Be hands free and not restrict the range of motion of the wearer
    - Have a blind-accessible user interface
    - Be responsive, having a quick response time to changes in the environment
    - Have intuitively meaningful haptic feedback impulse patterns
    - Be a useful, non-trivial product for our target audience
- Advanced
    - Transmit information about the presence and orientation of sharp changes of elevation in front of the user (e.g., curbs, steps)
    - Be capable of transmitting information about the system via a speaker (e.g., the battery level, mode of operation [see Stretch goals])
    - Have a low power mode to extend battery life
    - Have an easily extensible software framework for development
- Stretch
    - Be capable of detecting crosswalks and relaying this information to the user via the speaker
    - Implement multiple modes of functioning (i.e., a City mode with pedestrian symbol detection, and a General mode)

2.2 Requirement Specifications

Table 2.2.1: Requirement Specifications				
No.	**Description**	**Test(s)**	**Value**	**Unit**
1.X	Power System			
1.1	Long-lasting battery	Lasts at an estimated 80% haptic feedback output with all input devices active.	> 4	hrs
1.2	Easy to charge	Rechargeable via a standard US 120 V electrical socket.	True	
*1.3	Audio to indicate power system state	Tones are played from a speaker to indicate: (1) powering on, (2) powering off, (3) battery level below 20%, and (4) battery level below 10%.	True	
*1.4	Low-power mode	Low power mode is activated after a period of no detected motion (or after user interface input).	≈ 20	s
2.X	User Experience and Interface			
2.1	Buttons to operate the system	Buttons must be available to (1) turn the system on and off, and (2) switch operating modes.	True	
2.2	Large buttons	Each button's surface area can contain braille.	> 0.7	in^2
2.3	Lightweight	Total weight, including the clothing which houses the electronic devices.	< 10	lbs
2.4	Unrestricted range of motion (ROM)	Arm ROM for any joint with the device present, is no different from deviceless ROM.	< 10	% diff.
2.5	Quick to arm and activate	Sighted user time to set up and turn on the device.	< 60	s
2.6	Quick to learn	Rate of collision against arbitrary objects (see requirement 3.1) after 10 mins of training.	< 20	% hit.
2.7	Durable	Remains intact and continues to function after being dropped onto tile flooring from specified height.	≳ 1	m
* Indicates Advanced goals, ** Indicates Stretch goals				
Note: All tests above will be conducted during daylight hours, in the absence of precipitation and fog.				

Table 2.2.1: Requirement Specifications (continued)

No.	Description	Test(s)	Value	Unit
3.X	General Navigation Mode			
3.1	Haptic feedback that encodes distance	Provides a relative indication of distance (e.g., within 5 ft, within 10 ft, beyond 15 ft) of arbitrarily shaped objects (> 3 ft.^{3} volume) visible to the camera.	> 80	% hit.
3.2	Haptic feedback that encodes velocity	Provides a relative indication of velocity (e.g., quickly approaching, slowly leaving, etc.) of arbitrarily shaped objects (> 3 ft.^{3} volume) visible to the camera.	> 80	% hit.
3.3	Quick response time	Time the device takes to react to an object (from requirement 3.1) 10 ft away from the camera.	< 900	ms
3.4	Restricted range	No response to objects that are far from the camera.	> 20	ft
3.5	Alerts to proximal objects	Objects near the device trigger an alert.	< 3	ft
*3.6	Curb detection	Curbs ($\lesssim$ 10 inch rapid inclines/declines) that appear in front of the device triggers an alert.	5	ft
*3.7	Curb description	Curb alerts indicate the (1) steepness and (2) direction (incline/decline) of the curb.	True	
**4.X	Outdoor Navigation Mode	A primarily computational system that will detect high-level entities such as crosswalks, walking paths, and roads.		
*5.X	Immediate Emergency Alerts	A primarily electrical system that will immediately alert (i.e., bypass computer processing) the user to dangers such as rapidly approaching objects.		

* Indicates Advanced goals, ** Indicates Stretch goals

Note: All tests above will be conducted during daylight hours, in the absence of precipitation and fog.

This product is an assistive device and as such should be easily maintainable, accessible, and useful to the intended demographic. The requirements presented in *Table 2.2* below are divided into five sections. *Section 1.X* contains the power system, *section 2.X* the user experience and interface, *section 3.X* our general navigation mode, *section 4.X* our outdoor mode, and *section 5.X* our immediate alert system requirements. The latter two are stretch goals, but we intend that our future design decision will make these simple to insert. Therefore our primary goals are ensuring that the product has a reliable and long-lasting power supply, that it is accessible to our users, and that it aids our users in avoiding obstacles which appear in front of them.

2.3 Hardware and Software Block Diagram

The intended design has been divided into a series of blocks. A user interface will set the mode which our core system will operate in. For example a low power mode, or a general active mode. The core system will function as a translator which translates input responses into haptic or speaker output. The emergency subsystem will be for dangers that require the user's immediate attention.

<u>2.3.1 Hardware Topology</u>

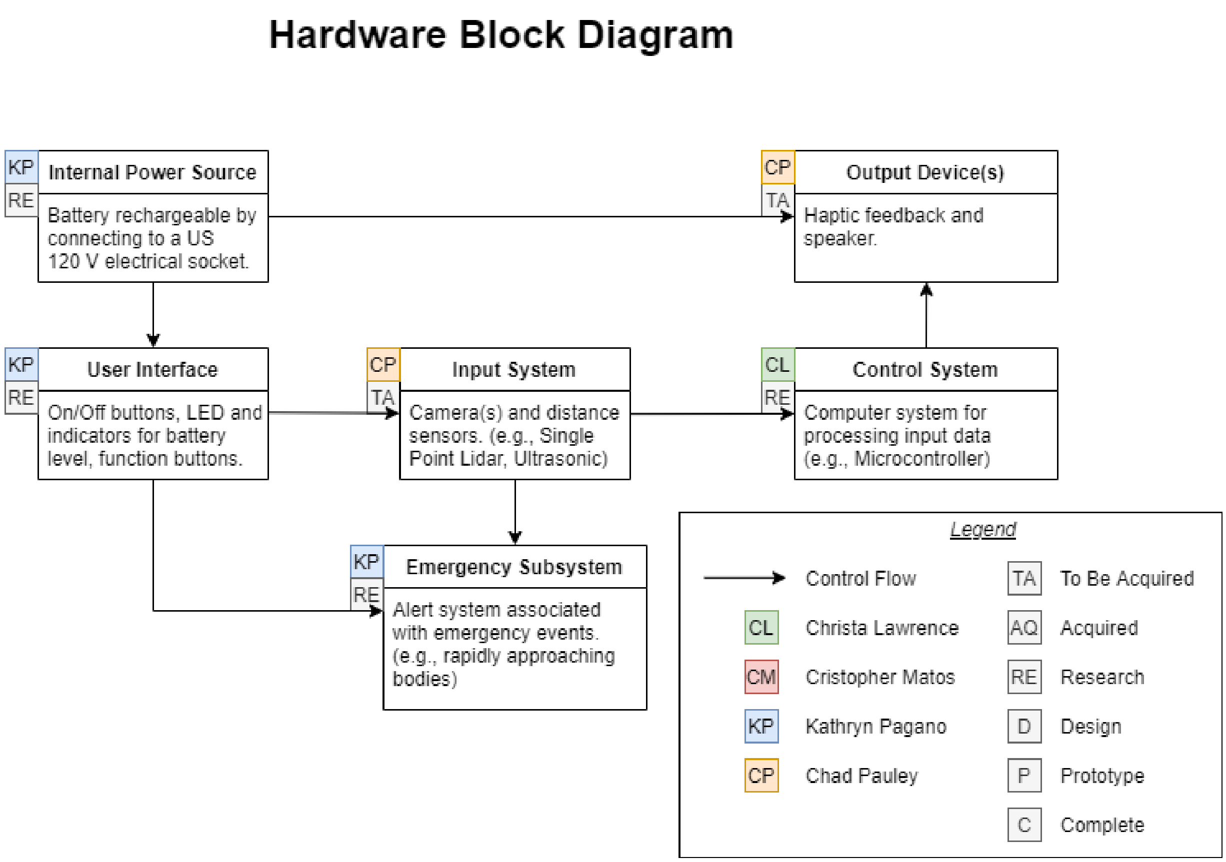

Figure 2.3.1: Hardware Block Diagram

Hardware implementation begins with finding the expected wattage of the system at idle and maximum power consumption, then finding a corresponding power source. The user interface will be the unit before the input system and emergency system as the power button that will be implemented in the design will also act as a kill switch should a bug or error occur that a reboot may fix. The input system will be responsible for various sensors that will be split between the control system and emergency subsystem. In terms of the emergency subsystem, the input system will use the lidar in the design to protect the user in case of an emergency in the fault that the camera does not detect an object accurately. Should a fault occur with the camera that the lidar detects, an emergency beacon will be sent to a simple output speaker. The input system also is the control data that will be sent to the control system through pins utilizing UART and I2C.

The control system will be based around a pre-existing model to enable product testing, act as a testing backup, and be a last resort should the recent chip shortage make finding specific parts from manufacturers difficult to acquire (refer to *section 2.5.1* for more details). Connecting to the output devices will be both the control system and internal power system. To explain the reasoning for this connection, the design was planned to utilize amplifiers to allow the haptic feedback motors to display full power without draining the power that could be used by the microprocessor. Following the output of traditional embedded systems; there was an expectation of only having an output voltage of 5 volts per designated motor. As the design may have multiple haptic feedback motors running with varying levels of power, an amplifier will be used as a probable solution and will be created for each motor.

2.3.2 Software Topology

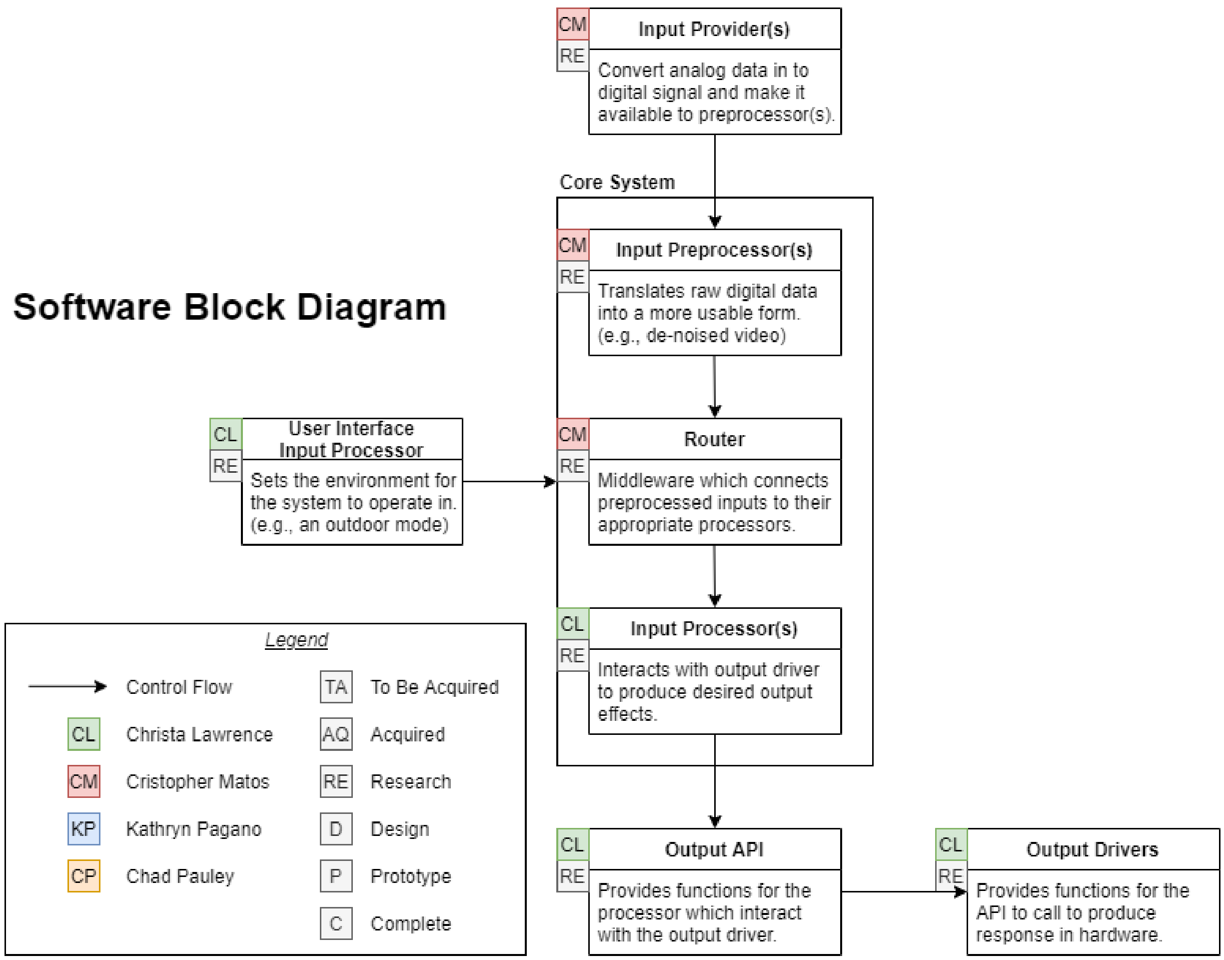

Figure 2.3.2: Software Block Diagram

The overarching design of the system software will resemble a translator. Output will be generated in response to (1) the state of the environment, and (2) the state of the device. This translation process is represented by the Core System (see *Figure 2.3.2*). Information about the environment will be provided to the system by a variety of sensors (e.g., camera, lidar, accelerometer). The input space must then be reduced by the Input Preprocessor(s). These units are responsible for extracting high-level information from the input. For example, using a convolutional neural network for depth estimation and combining it with Lidar to generate a point cloud, or curb detection as a result of instantaneous changes in the height of the floor).

The Router component is responsible for scheduling the input translations. For example, the General Subsystem (see *Table 2.2, Requirement 3.X*) may be scheduled to be serviced after the Emergency Subsystem. It is also the point at which the input space is no longer reduced, but is made available for the input processor(s) to produce output (feedback) patterns. These processors will use the input information and relay it to the output devices by consuming some output API.

The output API will serve as an abstraction over the output device drivers. Output devices (e.g., array of haptic feedback motors, speaker) can be accessed by the Core System via this API. Operating beneath this layer are the high-level and low-level device drivers. These drivers must be created for the array of haptic feedback motors, and a sound alarm that will be programmed as a first priority real-time system in case of an emergency.

Core software will likely be developed within a Windows 10 environment with C/C++. Software may ultimately run on a microcontroller which is supported by TensorFlow lite. When programming the device drivers an OS such as Linux will be used to allow for ease of installation and testing. Lidar, camera, microSD (storage device), accelerometer, and an estimate of one USB 2.0 input will be used to give functionality between the programmer and the device itself. For methods of communication between devices refer to *section 2.3.1.*

2.4 Concept Sketches

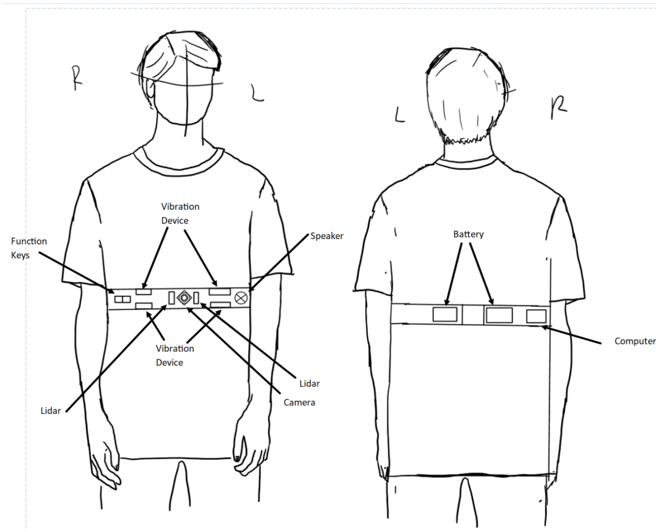

Figure 2.4.1 Belt Design: A sash worn across the center of the torso, similar to a heart rate monitor.

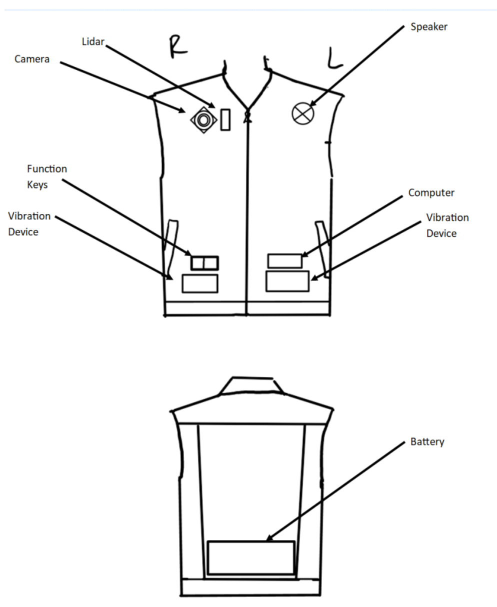

Figure 2.4.2 Vest Design: A vest, which is a common design choice for sensory-substitution devices.

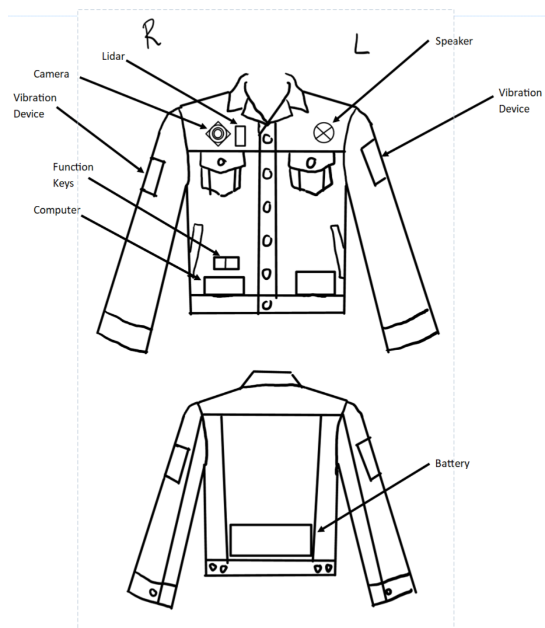

Figure 2.4.3 Jacket Design: A jacket, which could be used to help conceal sensors placed around the arms.

A wearable design will be implemented in the project through one of three designs focusing on comfort and reliability. Three designs were sketched as shown in *Figure 2.4.1-2.4.3* to allow for various options to be implemented in the placement of haptic feedback to the user, as well as the placement of input sensors such as the lidar and camera. The form factor of the device will revolve around the safety of the device and the comfort of the user.

2.5 Bill of Materials

Item Type	Quantity	Estimated Price (U.S. Dollars)	Description
Fabric	≤ 3 Yds	≤ $15/Yd	Clothing material
Lidar	≤ 2	$40	Object distance measurement
Power Source	Set acquirement (2)	$40	Device Power (Battery)
Accelerometer	1	≤ $10	Measurement tool for vibration, position, and acceleration
Camera	1	≤ $15	Input sensor for data manipulation and motion sensing
Speaker	1	≤ $10	Output device
Control System	1	≤ $50	An embedded system with I/O
Haptic feedback	Set acquirement (15)	≤ $20	Motors that provide vibration
Wiring	N/A	donate	Minimal gauge power connection
Custom PCB	≤ 2	≤ $30	Prototype and final product motherboard
3D Printed Objects	N/A	donate	3D printed buttons and applicable to clothing
Miscellaneous	N/A	≤ $100	Spare parts, prototyping
Total (Estimated Range)		≈ $370	

Table 2.5: Bill of Materials

Estimated project budget and financing.

The overall standing budget provided by the group is a self-funded $400 for the intended project. Prices are listed above as estimates from well known E-commerce companies including Amazon Inc and Digikey. Estimates displayed in the table do not include the cost of spare parts should some component fail. Note that the table above includes ‘set acquirements’ where bundles of parts will be acquired at wholesale.

2.5.1 Verification of Embedded Control System

The final version of the product will involve the industrial soldering of embedded components for the microprocessor and its many components. To ensure product success and proof of theoretical ability; an early PCB will be developed solely for the verification of a working control system. This control system (namely an embedded system) will then be compared to a prebuilt version to ensure that the core of the project works as intended. These tests may result in a larger overall cost but will serve as backups should the shipment or some error of manufacturing result in a hiatus to the PCB order.

Due to the recent chip shortage the project is expected to face difficulty in procuring all the expected parts, thus may be required to expand the budget to buy pre-existing components that will be soldered after PCB delivery from the industrial soldering companies.

2.5.2 Verification of Sensors

Referring to *Table 2.5*; three sensors can be found: lidar, accelerometer, and camera. These units will all be tested on the prebuilt version of the embedded system to compare performance to the early model PCB that will be implemented as noted in *section 2.5.1*. Quality tests will be used to verify the quality of the camera through bit rate, accurate distance measurements with a tape measure for the lidar, and the observation of the accelerometer in real-time with the use of a leveler.

2.6 Project Milestones

Number	Task	Start	End	Status	Responsible
Senior Design 1					
1	**Ideas**	8/23	8/27	Compete	Group
2	**Project Selection & Role Assignments**	8/27	9/17	Complete	Group
	Project Report				
3	Divide & Conquer 1.0	9/10	9/17	Complete	Group
4	Divide & Conquer 2.0	9/17	10/01	Complete	Group
5	First Draft (60 pg)	10/01	11/7	Started	Group
6	Second Draft (100 pg)		11/19	Not Started	Group
7	Final Document		12/07	Not Started	Group
	Documentation, Research & Design				
8	Microcontroller	9/18	10/4	Research	Cris & Christa
9	Computer Vision	9/18	10/18	Research	Cris & Christa
10	Schematics	9/18	10/4	Research	Chad & Kathryn
11	Haptic Feedback System	9/18	10/18	Research	Chad & Kathryn
12	Accelerometer	9/25	10/25	Research	Chad & Kathryn
13	LIDAR	9/25	10/25	Research	Chad & Kathryn
14	PCB design	9/25	10/25	Design	Chad & Kathryn
15	Power Supply	9/25	10/25	Research	Chad & Kathryn
16	**Order & Test Parts**	11/01	11/07	Research	Group
Senior Design II					
17	Build Prototype	1/3	1/17		Group
18	Testing & Redesign	TBA	TBA		Group
19	Finalize Protype	TBA	TBA		Group
20	Peer Presentation Final Presentation	TBA	TBA		Group
21	Final Report	TBA	TBA		Group
22	Final Presentation	TBA	TBA		Group

Table 2.6: Project Milestones

Initial project milestone for both semesters.

As previously discussed in *section 2.5.1*; the software implementation of the project will be held back due to the PCB platform needing to be raised and tested. Sample code and testing of input instruments will be done after the shipment of the PCB (sometime before December). Building of prototype will occur once schematics and parts are gathered, however this date may be delayed in the case of difficulty in finding specific components during the current chip shortage.

2.7 House of Quality

Marketing Requirements	Engineering Requirements	Justification
1, 2, 3, 5, 7	Reliability	Functions working within a range of weather conditions (i.e. mist or sunshine). Ability to work indoors or outside.
2, 3, 4, 5, 7	Ease of Use	The overall size and shape of the device will affect the user in daily use.
1, 2, 4, 5, 6, 7	Accuracy	The ability to identify objects and distance with precise measurement to enable the user to feel distance through haptic feedback.
1, 2, 3, 4, 5, 7	Cost	As a major portion of the project relies on the embedded system, the cost of components will affect the selected base model and its performance.
1, 3, 6	Ease of Installation	The manufacturing perspective of duplicating the device.
Marketing Requirements 1. Power System 2. User Experience 3. Haptic Feedback Quality 4. Reliability 5. Sensor Resolution 6. Cost 7. Weight		

Table 2.7.1 House of Quality Relationships

House of Quality

Relationships	
Strong	●
Medium	○
Weak	▽

		Engineering Requirements				
		Reliability	Ease of Use	Accuracy	Cost	Ease of Installation
Customer Requirements	Power System	●		▽	●	●
	User Experience and Interface	○	●	▽	○	
	Haptic Feedback system Quality	●	●		●	▽
	Reliability		○	●	●	
	Sensor Resolution	●	○	●	●	
	Cost	○	○	●		▽
	Weight	▽	○	▽	●	

Table 2.7.2 House of Quality

In concern to the designing of the device, the house of quality focuses heavily on reliability, accuracy, and cost. The customer requirements on the left hand side cover the important qualities of the project that need to be considered when designing. The Engineering requirements cover the qualities that will help create a desirable product. This gives a good idea of the possible trade off that might have to be made based on the engineering requirements. Deciding factors for these selected values include the model of microprocessor the device is designed to use for programming overhead, and the quality of components such as the motors for haptic feedback and how much power the device will require.

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