ECE 445

Senior Design Laboratory

Project Proposal

Navigation Vest Suite For People With Eye Disability

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1. Introduction

1.1 Problem:

People with Eye Disability often face significant challenges navigating around in their daily lives. Currently, most available solutions range from white canes and guide dogs to AI-powered smart glasses, many of which are difficult to use and can cost as much as $3,000. A participant emphasized the financial barrier, stating, “These solutions are too expensive, I don’t know anyone who can afford these without support from PFRON.”[1]

Multiple resources show the urgent needs for a navigation system suite for people with blindness. According to a study published in the National Library of Medicine, at least 2.2 billion individuals worldwide suffer from vision impairment, and there is an urgent need for efficient assistance due to the rapid rise in their population [2]. Additionally, research highlights that visual impairment (VI) significantly reduces quality of life … due to poor product design and limited adaptation [3].

Thus, based on the above sources, we realized that there is an urgent need for us as an electrical and computer engineer to build an innovative and intuitive vest navigation suite for people with blind disability.

1.2 Solution:

Our solution is to create a Navigation Vest Suite that provides assistance for people with visual impairments. It provides step-by-step routing through GPS and magnetometer, and delivers guidance through haptic and audio cues. Users can interact with the system through voice commands, and find out where the vest is by querying the destination through speech. While in motion, onboard sensors and object detection models will identify obstacles and people, announcing their presence and the distance through a speaker. Users will also receive direction of obstacles along with the turning angle required to avoid/acquire them through vibration motors and the speaker.

Haptic Action	Motion
Zero Haptic Feedback	No Obstacles Around
Front Haptic	Obstacle Present Infront
Right Haptic	Obstacle Present Right Side
Left Haptic	Obstacle Present Left Side

Based on the above table, motors are able to work together in conjunction to represent multi direction feedback as well. For instance, if both the front haptic and right haptic are activated, that means that the obstacles are present in both the front and the right side of the user. Additionally based on the proximity of the haptic vibration, the user will know how close the objects are. Higher the frequency, the obstacle is closer in proximity, lower the frequency, the obstacle is further in proximity. For now, we are planning on to create equation in the form of $Motor\ Haptic\ Frequency\ =\ 1/Distance\ to\ the\ Object$ equation will be tweaked later to compensate for each variable domain where: $Distance\ to\ the\ object\ \epsilon\ [2cm,\ 400cm]$, $Motor\ Haptic\ Frequency\ \epsilon\ [141Hz, 200Hz]$. The final effect is that whenever the user is closer to the object, the motor vibration will exponentially increase, whereas when the object is faraway from the user, the vibration frequency will slowly decrease.

Cost Analysis

Module	Model	Cost	Quantity	Website
Raspberry Pi 4GB	4	$60	1	*[10]*
Vibrating Motor	Generic	$1.95	3-5	*[11]*

Disc	Vibrating Mini Motor Disc			
Motor Driver	DRV8210	$0.221	3-5	*[12]*
ToF (Time of Flight Camera) ToF Module	VL53L5CXV0GC/1 VL53L5CX-SATEL	$8.36 $19.34	2 1	*[14]* *[15]*
STM32 Microcontroller	STM32H750VBT6	$10.09	1	*[17]*
GPS Chip WisBlock GNSS GPS Module	L76L-M33 RAK12501 (GPS: Quectel L76K)	$10.57 (2) $8.90	1	*[19]* *[20]*
Magneometer	IIS2MDC	$1.71	1	*[21]*
External I2S DAC	PCM5100APWR	$1.55	1	*[22]*
Audio Amplifier	PAM8302AASCR	$0.50	1	*[23]*
Mylar Speaker 8 Ohm 1W	TAYDA HY57MS0810-H8.4	$0.95	1	*[24]*
Microphone	ICS-43434	$2.98	1	*[25]*
Button	Momentary Button - Panel Mount (Red)	$1.25	1	*[26]*
RC (Debounce)	TBH	~$1-2/$0	1-2	ECE 445 Lab!

Battery	21700 5000mAh Battery for TX16S and TX12 MKII	$31.24 (total after shipping and taxes)	1 ~ 2	*[28]*
Buck Converter (7.4V to 5V)	MAX20410EAFOC/VY+	$9.92	1	*[29]*
Buck Converter (7.4V to 3.3V)	TPS563207	$1.33	1	*[30]*
Charging IC	BQ25887RGER	$2.048	1	*[38]*
PCB Shipping and Fabrication	TBH	$10 ~ $15	5-10	N/A
Head Connector (40 Position Right Angle)	PPPC202LJBN-RC	$2.43	1	*[31]*
Surface Mount Components (Capacitor, Resistor, Diodes, Etc)	TBH	$5 <	TBH	N/A
Estimated Total: $160 ~ $200				

REASON For Vest over Glasses

The main reason we chose to house our components within a vest over glasses comes down to comfort. When utilizing vibration motors, wearers might feel some discomfort due to long usage, given that they are using the device for over longer periods of time. By utilizing a vest, not only are we able to house more components onto our device, but we are also able to enable users to wear the device more comfortably.

1.3 Visual Aid:

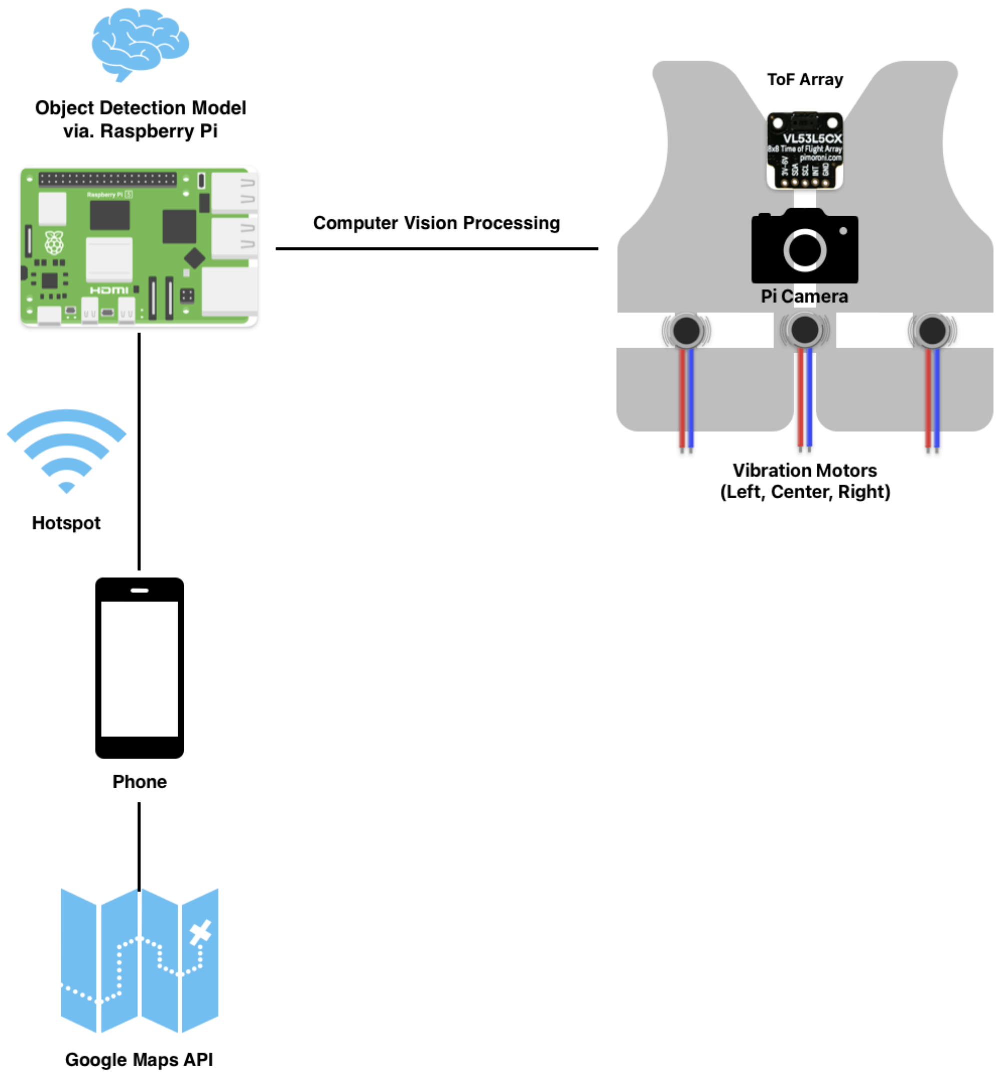

FIGURE 1.3.1 Visual Aid

We will be using Raspberry Pi that runs vision models (YOLO[1], MMDetection[2], MMTracking toolkit[3]) to detect objects, object bounding boxes, and the relative direction to the obstacle. This information will be sent to the STM32 microcontroller, and it will fuse this input with sensor data from the GPS, magnetometer, and ultrasonic/ToF to generate auditory and haptic feedback to guide the user. Meanwhile, the Raspberry PI will also be processing the voice based activation for destination queries and system control (power on/off, settings).

1.4 High Level Requirements

One of the main issues with these types of projects are related to the computational performance of these devices , specifically its false detections. We will be using these metrics to compute the effectiveness of our software.

- Prevalence
- F1 Score
- FP/FN
- Recall/Precision

Testing the Sensor's Capability:

-> **True Positive Case means:** Object is truly present and motor vibrates accordingly

-> **True Negative Case means:** The object is truly not present and the motor vibrates accordingly.

False Positive Cases	False Negative Cases
1) The wall is detected as present, but isn't there. 2) The object detection model detects a street sign, but in reality a street sign does not exist. 3) After an object passes by, the camera ghosting or the device latency may detect the object to be still present, but in reality, the object is already passed.	1) The wall is detected as not present, but it is there. 2) The object detection model fails to detect the street sign but in reality, the street sign exists. 3) The detection fails whenever a transparent object is present. 4) Environmental factors like weather, humidity, and terrain can obscure the

[1] YOLO:

[2] MMDetection:

[3] MMTracking Toolkit:

4) The camera detected an object, but in reality it is a shadow of an object/person. 5) Pattern surfaces or walls may confuse the model to detect an object, but in reality it is just free space.	camera and sensors, which can have false negative readings even though the object does exist. 5) Vest blind spots can be a potential false positive as sensors cannot detect any obstacles/objects in such areas.

1. The device must be able to detect obstacles at a minimum distance of 1 meter and generate haptic and auditory feedback with at least 70% precision, 65% recall. Similar research employing YOLO models for outdoor obstacle detection reported ~80% precision and ~68% recall, providing a realistic benchmark for this requirement [5].
2. Vest must generate the accurate haptic and auditory feedback within 200 ms of obstacle detection, and the total detection to feedback delay must not exceed 320 ms threshold, which is the industry standard requirement for the acceptable limit for wearable obstacle-avoidance devices [4]
3. The device must provide at least 3–4 hours of continuous battery life without significant degradation in accuracy, precision, recall, or latency.

2. Design

2.1 Block Diagram

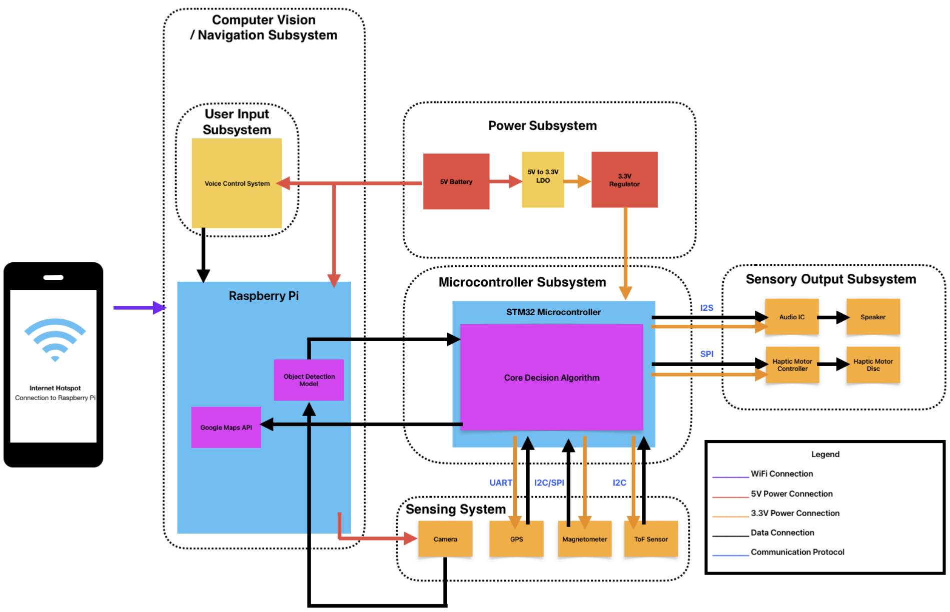

FIGURE 2.1 Block Diagram

2.2 Subsystem Overview & Requirements

2.2.1 Power Subsystem

Description and Purpose: The power subsystem is responsible for powering all of the other subsystems in our project. It consists of 2x3.7V Li-Ion batteries, supplying 7.4V at an estimated continuous discharge current of ~7-10A at 5000mAh. The design utilizes multiple Buck Converters to convert the battery voltage level to 5V, and also to 3.3V. It should be able to supply at least 25W for the 5V system and 7W for the 3.3V system.

Requirements:

Power Analysis:

- 5V: ~25W
    - Raspberry PI 5: 25W
- 3.3V: ~6W
    - GPS: 0.0825W
    - 3 x Motor Disc: 0.60W
    - 3 x Motor Drivers: 0.012W
    - 2 x ToF: 0.626W
    - ST Microcontroller: 2.64W
    - Magnetometer: 0.003W
    - Speaker: 1W
    - Audio Amplifier: 0.8W
    - External DAC: 0.150W
    - Microphone: 0.002W
    - Others: ~1W

Parts & Verification:

- Battery: 7.4 V Battery
    - Over 2 Hour Battery Life
    - 37 Wh total / (~15W average load) ~= 2.5 hour of usage
    - 37 Wh total / (~30W peak load) ~= 1.25 hour of usage
    - Discharge termination Cutoff: ~3V per Cell x2 ~= 6V
    - Fully Charged Voltage: ~4.2V per Cell x 2 ~= 8.4V
    - 7.4V to 5V Buck Converter Input Voltage Range: ~3-36V

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage Range	V_{SUP}		3.0		36	V

Figure 2.1.1.1: Max20408 Voltage Range [27]

        - Aiming for at least 6V Battery Input
    - **Verification:**
        - Connect via the battery connector on PCB, and use the battery power test points on the board to verify the correct power output between 6V and 8.4V
- 7.4V-5V Buck Converter:
    - Minimum 25 Watts
    - Fixed 5V Output * 10A max ~= 50Watts
    - 85% Conversion Efficiency
    - Raspberry PI Voltage Cutoff: 4.63V(±5%)
    - Raspberry PI Voltage Upperbound: ~5.1V
        - Assumption: PI 5 official Power Supply is 5.1V
            - PI 5 can operate safety at that voltage

- Buck Converter Output Range: (Mode Undecided)

$V_{OUT\_SKIP\_5V}$	V_{OUT} = 5.0V, skip mode, no load	MAX20408/ MAX20410	4.92	5	5.05
		MAX20408E/ MAX20410E	4.93	5	5.05
$V_{OUT\_PWM\_5V}$	V_{OUT} = 5.0V, PWM mode, no load	MAX20408/ MAX20410	4.93	5	5.06
		MAX20408E/ MAX20410E	4.95	5	5.05

Figure 2.1.1.2: Max20410E Chip Voltage Output Range [36]

  - Skip Mode: $4.93 \leq 5 \leq 5.05$
  - PWM Mode: $4.95 \leq 5 \leq 5.05$
  - Both Mode fits within the Raspberry PI's Cutoff and Upperbound
- **Verification:**
  - Verify the Battery Output, solder the 7.4V to 5V Buck Converter
  - Use the 5V test points on the board to verify the correct power output to between 4.9 and 5.1V

- 7.4V-3.3V Buck Converter:
  - Minimum 7W
  - Converts 7.4V to 3.3V at 90% efficiency (~7W)
  - Max 3A * 3.3V ~= 10W fits our requirement
  - Microcontroller STM32H750VBT6 Operating Range: 3.0 to 3.6 (3.3V Typical)
    - Aiming to get within 3% of 3.3V (3.2-3.4V)

$V_{DD33USB}$	Standard operating voltage, USB domain	USB used	3.0	3.6
		USB not used	0	3.6

Figure 2.1.1.3: H750 Microcontroller Operating Range [37]

  - **Verification:**
    - Use the 3.3V test points on the board to verify the correct power output within 3% of 3.3V (3.20-3.40V)

Post-Assembly Verification:

- Idle/Active Current Draw Test:
  - Shunt-Resistor will be in series with the battery and ground
    - Measure the Voltage
    - Use Ohm's Law (V/R = I) to get the current draw

$$I = \frac{V_{shunt}}{R_{shunt}}$$

- I * V = Power should be within 5% of the expected range

$$P = V_{battery} \times I$$

- Power Usage/Stability Over Time:
  - Triple-Channel Current/Voltage Sense (Undecided)
    - Check Voltage and Current Level via I2C to the MCU
    - Monitor the values for at 15-30 minutes during typical operation
    - Save logs and feed to Python script for automated analysis/graph generation
    - Verify that all voltage bus remain stable within tolerance and that no excessive/transients current draw occur

BMS:

- Over-voltage Protection:
  - 5V Bus - Champ 7.4 to 5V Buck Converter output to ~5.25V
    - Buck Converter Absolute Max Voltage: 42V: N/A

Absolute Maximum Ratings

SUP, EN to PGND .... -0.3V to +42V
BST to LX .... -0.3V to +2.2V
BST to PGND .... -0.3V to +44V

Figure 2.1.1.4: Max20410E Absolute Max Voltage [27]

    - USB Standard for 5V Supplies allows for ±5% tolerance (~5.25)
  - 3.3V Bus - Clamp the min(all components' Upper Limits): ~3.6V
    - GPS: 4.3V

Power Management

Power Supply:

2.8–4.3 V

Figure 2.1.1.5: GPS Absolute Max Voltage [19]

- Motor Disc: 3.8V

	电机安装位置	任何位置都可以
2-5	Voltage Range for Use 工作电压范围	DC 2.5~3.8V

Figure 2.1.1.6 : Motor Disc Absolute Max Voltage [11]

- Motor Drivers: 5.75V

Over operating temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Power supply pin voltage	VM	-0.5	12	V
Logic power supply pin voltage, DSG	VCC	-0.5	5.75	V

Figure 2.1.1.7: Motor Driver Absolute Max Voltages [12]

- ToF: 3.6V

Table 11. Absolute maximum ratings

Parameter	Min.	Typ.	Max.	Unit
AVDD, IOVDD	-0.5	—	3.6	V
SCL, SDA, LPn, INT, and I2C_RST	-0.5	—	3.6	

Figure 2.1.1.8: ToF Absolute Max Voltage [9]

- ST Microcontroller: 3.6V

$V_{DD33USB}$	Standard operating voltage, USB domain	USB used	3.0	3.6
		USB not used	0	3.6

Figure 2.1.1.9: H750 Microcontroller Operating Range [37]

- Magnetometer: 4.8V

Symbol	Ratings	Maximum value	Unit
Vdd	Supply voltage	-0.3 to 4.8	V
Vdd_IO	I/O pins supply voltage	-0.3 to 4.8	V

Figure 2.1.1.10: Magnetometer Absolute Max Voltage [21]

- Speaker: N/A
- Audio Amplifier: 6V

Parameter	Rating	Unit
Supply Voltage at No Input Signal	6.0	V
Input Voltage	-0.3 to V_{DD} +0.3	

Figure 2.1.1.11: Audio Amplifier Absolute Max Voltage [23]

- External DAC: 3.9V

		MIN	MAX	UNIT
Supply voltage	AVDD, CPVDD, DVDD	–0.3	3.9	V
	LDO with DVDD at 1.8 V	–0.3	2.25	
Digital input voltage	DVDD at 1.8 V	–0.3	2.25	
	DVDD at 3.3 V	–0.3	3.9	
Analog input voltage		–0.3	3.9	

Figure 2.1.1.12: External DAC Absolute Max Voltage [22]

- Microphone: 3.63V

PARAMETER	RATING
Supply Voltage (V_{DD})	−0.3 V to +3.63 V
Digital Pin Input Voltage	−0.3 V to V_{DD} + 0.3 V or 3.63 V, whichever is less

Figure 2.1.1.13: Microphone Absolute Max Voltage [25]

- 5-3.3V Buck Converter: 19V

		MIN	MAX	UNIT
	VIN, EN	–0.3	19	V

Figure 2.1.1.14: TPS563207 Absolute Max Voltage [30]

- Under-voltage Protection:
  - Battery:
    - Discharge termination Cutoff: ~3V per Cell x2 ~= **6V**
  - 5V Line:
    - Raspberry PI Cutoff: **4.6V**

- Charging IC: 2S Li-Ion Cells Charging
  - USB-C Charging
    - Input 3.9V to 6.2V operating

- Battery Voltage Range: 3-4.2V
    - IC: 3.4-4.6V

2.2.2 Sensing Subsystem

Description and Purpose: The sensing subsystem is an integral part of the navigation vest system. The subsystem will gather location and direction information from the GPS and magnetometer. The raw information from the GPS and magnetometer will be passed to the STM32 microcontroller to be data processed, and finally passed into the Raspberry Pi that is running the Google Maps API. Similar to the above, the ToF sensor will monitor distance and pass the draw distance output to the STM32 microcontroller. The ToF's input angles are as follows:

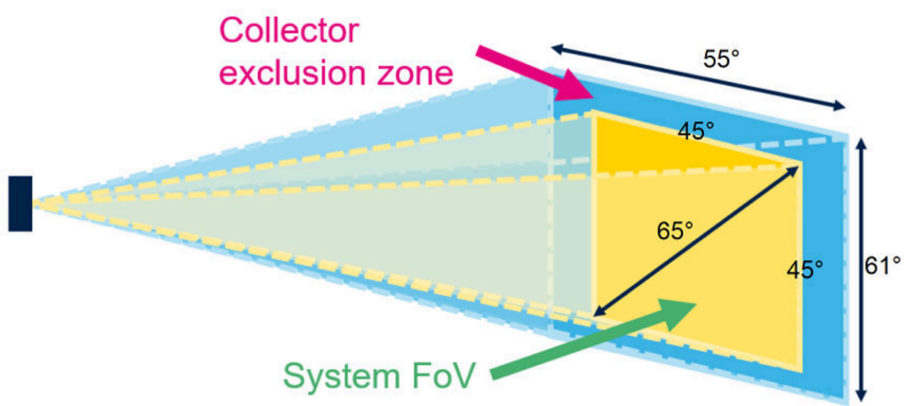

Figure 2.2.2.1: ToF Sensor Field of View [9]

Requirements;

- ToF: Monitors Obstacle distance within its field of view and passes measurements to the ST Microcontroller
  - Monitor obstacle distance within its field of view from 0.1m to at least 4m
    - Accuracy ±5cm for distances ≦ 2m
    - Accuracy ±10cm for distances >2m
  - Data passes to ST microcontroller at minimum update rate of 10Hz
  - **Verification:**
    - Place/walk near objects at distances (0.1m, 0.5m, 1m, 2m, 4m) and record ToF readings
      - Confirm all readings fall within tolerance and updates occur at > 10Hz

        - Sweep object across sensor's FOV and confirm detection coverage to its specs
- GPS: Provide latitude and longitude for global positions and passes them to the ST Microcontroller
    - Must Provide latitude and longitude coordinate
        - Horizontal accuracy of ±5m outdoors
        - Update Rates of 1Hz at minimum
    - Cold Start must be ≦ 60 seconds
    - **Verification:**
        - Compare GPS coordinate outdoors to Iphone location for at 5 minutes
            - Iphone: Use Compass Logging App
            - Log values and compare differences by passing it to Python script
                - Horizontal accuracy of ±5m outdoors
            - Update Rate of 1Hz can verified by doing: Total Time/Number of Samples
            - Repeat 2-3 times
        - Confirm that Cold Start is within 60 seconds using Iphone's timer/MCU Code
            - Repeat 2-3 times
- Magnetometer: Provides orientation in degrees and passes measurements to the ST Microcontroller
    - Provide orientation readings in degrees relative to magnetic north with resolution of ≦ 1 degrees and accuracy within 5 degrees after calibration
    - Data passed to STM32 microcontroller at 100 kHz minimum
    - **Verification:**
        - Compare magnetometer readings with iphone compass for multiple orientation
            - Iphone: Compass Logging App
            - Log Magnetometer reading via ST Code
            - Pass magnetometer and Iphone readings through Python script and check resolution and ensure accuracy within 5 degrees
            - Repeat 3-5 times

2.2.3 Microcontroller Subsystem

<u>Description and Purpose:</u> The microcontroller subsystem acts as the core of our navigation vest system. Most of our core decision algorithm is carried out inside of this subsystem. It essentially takes direct inputs from our sensing subsystem and sends commands to our sensory output system based on the sensing outputs.

Main Pseudocode for MCU

```
-----------------------------------MCU Code-----------------------------------------

* all the output from the raspberry pi to the MCU will be treated as interrupt and there will be specific interrupt service routine for such.

main_function:

  set left motor <- 0
  set right motor <- 0
  set forward motor <- 0



  while(1): # while the user keeps walking in random direction

     depth_array_left = TOF_1.read() # depth Array is in size 8 by 8
     depth_array_right = TOF_2.read() # depth Array is in size 8 by 8

     depth_array_total = stitch_depth_array(depth_array_left, depth_array_right) # stitch the array to make full 8 by 16 map.

     right_most_map, mid_map, left_most_map = partition_map(depth_array_total) # will return three separate unique maps for right, forward, and left.

     # Prepare for the worst case scenario
     max_left = max(left_map)
     max_right = max(right_map)
     max_mid = max(mid_map)

     motor_left_output = output_pwm_intensity(max_left)
     motor_right_output = output_pwm_intensity(max_right)
     motor_mid_output = output_pwm_intensity(max_mid)


  return 0;
```

FIGURE 2.2.3.1 MCU Pseudocode

Other than taking inputs from the sensing subsystem, we will also implement an interrupt-based communication with the Raspberry Pi, which will communicate instructions such as the path to the correct destination from the Google Maps API, as well as the output from the object detection model. Both of these responses will be translated into a speech output from the speakers connected to the microcontroller.

Requirements;

- Microcontroller should be able to support all communication protocols required by all of components from Sensing and Sensory Output simultaneous
    - **Verification:**
        - Unit Test Each Component from Sensing and Sensory Output
        - Test Sensing Subsystem Altogether
        - Test Sensory Output Subsystem Altogether
        - Verify that Sensing and Sensory Output Subsystem can operate at the same time

2.2.4 Computer Vision / Navigation Subsystem

Description and Purpose: The computer vision and the navigation subsystem allows the user to be aware of surrounding important objects. For the object detection system, the camera will take an input around 30fps rate and pass the video input to the model running on Raspberry Pi. After the video is processed, it will output a list of objects or signs that it detected. We will then choose the top 10 detected objects or signs, then filter one last time down to the list of objects or signs that are in the important list. The important list includes lists of objects and signs both indoors and outdoors that matters the most when making navigation decisions. This way, we will have a method in which the speaker doesn't speak out the entire list of all surrounding objects that are not relevant to making important decisions during navigation. For the Google Maps API, once the button is pressed to speak into the microphone, the algorithm will fetch the destination and utilize real time GPS status from the MCU, allowing it to guide the user to the set destination. For the speaker & microphone systems, detailed layout is written under requirements below.

Requirements;
Parts:

- Raspberry Pi
    - Must provide sufficient memory to store and retrieve navigation data and audio prompts (at least 32GB)
    - RAM: (at least 4GB)
        - Capable of running Google Maps API and Computer Vision inference at a minimum rate of 20 FPS
    - Must support a camera input with resolution of at least 8 MP for reliable object detection
    - Has the necessary to support all communication, interrupts, and data transmissions

[32]

- Pi Camera Requirement
    - Compatible with Raspberry PI 4 and 5
    - Resolution greater than 8 megapixels
    - Must maintain minimum frame rate of 25FPS during operation

[33]

- Speaker & Microphone
    - The core layout for the audio system is utilizing I2S protocol to communicate between the audio modules and Raspberry Pi. Within the Raspberry Pi lies algorithm to convert from I2S readable format to text as well as conversion to one way another. This will allow a full experience of speech to text conversion and text to speech conversion.

  - The system will be tested with the following test suite:
    - I2S Signal Integrity and Clock Synchronization
    - Microphone Module Functionality
    - Speaker/Amplifier Module Functionality
    - STT Basic Accuracy with Clear Speech
    - STT Performance with Background Noise
    - STT Language with Vocabulary Coverage
    - TTS Basic Accuracy
    - TTS Performance with Microphone on
    - Full Loopback Latency (latency of TTS/STT)
    - Error Handling and Fall Back
- Google Map API (Alternative Map Apis will be also used to test) & GPS
  - The geocoding accuracy should be at least above 75% accuracy based on the equation: (Number of correctly geocoded address)/(Total Address) * 100. Our approach is to create a test suite of 20 diverse addresses around the town of Champaign-Urbana.
  - The reverse geocoding accuracy should be at least above 75% accuracy based on the equation: (Number of correct & precise address)/(Total Tests) * 100. For the test suite, we will be taking 20+ coordinate pairs and checking if the returned address is correct and precise.
  - For both geocoding latency and the reverse geocoding latency should be less than or equal to 100ms response threshold. We will be testing 4 main categories when it comes to the latency measurement. We are planning to write a timeout latency test for re-routing, initial-routing, next maneuver updates, and geocoding with GPS. Specifically we are targeting map apis that consistently hits less than or equal to 100ms response time.
- Object Detection Model
  - Less than 5 billion parameters. The majority of the successful models such as YOLO V11 for Raspberry Pi have as little as 1.5 million parameters.
  - Object Detection Model should be able to detect the following: All the street signs and crosswalk lights that relate to pedestrians, Car, Bicycle, Motorcycle, Door, Chair, Elevator, Desk, and Stairs.
  - Ensure that the detection model fetches at least 70% mAP for critical labels mentioned in above bullet point.
  - Provide strict ML model evaluation based on *[35]* metrics.

2.2.5 Sensory Output Subsystem

Description: The sensory output is responsible for providing audio and vibration feedback to the user. Audio feedback includes three categories:

1. Direction prompts (e.g., turn left, adjust orientation)
2. Object detection alerts (e.g., warning of obstacles)
3. Destination Confirmation (arrival notification)

The audio feedback starts from Raspberry PI, converted to I2S through Text to Speech, and into I2S. The I2S is fed into an External Digital to Analog Converter, amplified, and played on a speaker.

At the same time, haptic signals are generated by the MCU as PWM, which works with the object detection alerts from Raspberry PI. The microcontroller decides how strong, and when to start/continue/stop vibrating each of the 3 haptic motor discs. The PWM signal is fed to the Motor Driver and it outputs to the speaker/haptic motor discs.
fetching the output from the MCU via I2S (for audio) and SPI (for control) protocols. This data is converted into analog audio via a DAC and amplified, while haptic data is translated into PWM and other motor drive signals.

Requirements;
Audio Feedback

- Must generate more than **30 distinct audio alert** (direction, object detection, destination)
- Must output at a minimum **70dB at 1 meter** for audibility in outdoor environment
- Latency from MCU trigger to audible playback must be **within 200ms**
- Parts:
  - External DAC [22]
  - Amplifier [23]
  - Speaker [24]
- **Verification:**
  - Measure Audio dB with Phone
  - Calculate and Log the Latency via Software from the
  - Configure MCU to output a GPIO trigger pulse when an audio alert is sent over I^2S
    - Connect oscilloscope channel 1 to this GPIO
    - Connect Channel 2 to the speaker's output (via amplifier or speaker
    - Measure the time difference between the GPIO trigger and the start of the audio waveform
    - Repeat for 5 representative audio alerts.

Haptic Feedback

- Must actuate the **3 vibration discs** individually via PWM control
- Must produce vibration force relative to the distance from obstacle detected
  - **At least 6 different vibration force**
- Response latency from **detection event** to haptic actuation must be **within 200ms**

- Parts:
  - Haptic Motor Driver [12]
  - Haptic Motor Discs [11]
- **Verification:**
  - Trigger each motor individually and simultaneous
  - Output 6 different PWM duty cycles from the microcontroller to each of the disc
  - Configure MCU to output a GPIO trigger pulse when an obstacle is detected
    - Connect oscilloscope channel 1 to this GPIO
    - Channel 2 to the motor driver's PWM input
    - Measure time difference between detection event and start of the first PWM signal

3. Tolerance Analysis:

3.1 Data Transmission:

GPS navigation typically consumes around 5-10 MB/hour and around 1-3MB/hour for live traffic updates [16]. By combining these totals, we can expect to require around 6-13MB/hour, which equates to 0.01-0.03 Mbps. To assume the worst case scenario, we could apply this formula:

- $Total\ Bandwidth\ (Mbps)\ =\ B\ +\ O$
  - $B\ =\ Bandwidth\ (Mbps)\ for\ usage$
  - $O\ =\ Overhead\ (Mbps)\ due\ to\ packet\ errors,\ retries$
    - $O\ =\ 0.25B$

In the worst case scenario, we could expect around 20-30% (25%) of our bandwidth to contain errors, which means we would need around 0.0125-0.0375 Mbps of bandwidth at minimum. If we estimated anything above the 20-30% threshold, we would have an error rate of around 40%, which is almost half of the usage bandwidth, making our transmission unreliable and not efficient. Although typical packet loss rates are at around < 1% in normal conditions, accounting for a 20-30 % tolerance will give us a larger bound to account for retries, and latency spikes [13].

When delivered over 4G LTE hotspot, those requirements are well below the limits of practicality. Since 4G LTE hotspots can provide around 30-40 Mbps of bandwidth on average, and about 20-30 ms of latency [18], we can safely predict that our GPS model should be able to work consistently, even with occasional drops in bandwidths.

3.2 Power:

The detailed power analysis for this subsystem has been completed in Section 2.1, please refer to Section 2.1 for more details!

4. Potential Product Phase Iteration

Starts the Week after Proposal is due:

Phase Iteration	Expectation	Tentative Schedule	Expected Amount of Time

0 (Pre-Setup)	Getting software and hardware components ready for future implementations	- Hardware:
		  - Components Picking
		  - Schematics
		  - Layout
		  - Routing
		
		- Software:
		  - Machine Learning Model Selection & Testing
		  - Core Algorithm Pseudocode Design & Draft Implementation for phase 1
		  - Select accurate map APIs & Testing
		  - Install all the IDEs, modules, and softwares
			1 week (9/22-9/27)

1 (Naive	Obstacle Avoidance	- Testing Basic Functionality:	1-2 weeks

Implementation)		- Being able to detect obstacles
		- Generate Depth map for 2 8x8 arrays
		- Basic Breadboard Circuit
		  - ToF Sensor(s)
		  - Vibration Motor(s)
		  - GPS (Basics)
		  - MCU Development Board
		- Hardware:
		  - PCB Schematics Adjustment
		  - PCB Layout Adjustment
		  - PCB Routing Adjustment
			(9/28-10/6)

2 (Object Recognition)	Obstacle Avoidance + Object Detection	- ML: (Testing Basic Functionality)
		  - Being able to classify basic pedestrian street signs and crosswalk lights.
		  - Being able to classify basic outdoor objects: Car, Bicycle, Motorcycle.
		  - Being able to classify basic indoor objects: Door, Chair, Elevator, Desk, Stairs.
		- Embedded:
		  - The core algorithm should take the output from the object recognition module and provide output feedback to the audio module.
		  - Magneometer
		  - GPS (Advanced)
		  - Audio Output
		  - Audio Input
		- Final Hardware Adjustment
		  - Possible PCB design
			2-3 weeks (~10/6 - 10/27)

		updates (based on how well the first set of PCBs perform)	

3 (GPS Implementation)	Street Navigation	- Testing Basic Functionality:
		  - The map API and GPS in tandem should lead the user to the set destination safely.
		  - Should work within the campus domain via walking. Extreme cases include consideration of riding transportation to reach far destination.
		  - Hardware Requirement:
		    - MCU should handle all the system requirements without faults.
		    - The battery should maintain at least 3 hours with all the systems working together.
			4+ weeks (~10/27-End of Semester)

5. Ethics and Safety

Ethics:

User Data Privacy:
ACM code of ethics part 1.6 highlights that the responsibility of respecting privacy applies to computing professions, and computing professionals should take special care for privacy when merging data collections [7]. To satisfy and comply with ACM code standards, for any sensory input data, we will be asking consent to the user. Additionally, we won't be saving user's private locations by default, but such functionality can be enabled under the user's will to activate smart destination mode selection. Lastly, we will never be asking for a user's personal data such as name, phone number, and home address by default as it is not required for the core navigation functionality of the vest and ensures privacy.

Campus and Lab Policies: As ECE students from University of Illinois Urbana Champaign, we will abide by the laboratory safety rules highlighted under Division of Research Safety. Based on Section 4.4, we will be following the minimum attire regulations for labs (PPE): *Closed-toe shoes, long pants (or equivalent), and safety glasses [8].* We will also ensure to follow the emergency procedures that deal with fire extinguishers, emergency power shut-offs, first aid kits, and eyewash stations.

User Safety:

The IEEE code of ethics states that we need to *"To uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities" and "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices" [6]*. In order to satisfy these standards, we must create our product to be as accurate as it can be, as inaccuracies may lead to injuries on those who are relied on.

Battery Safety: Our device should ensure the following configurations to abide by the IEEE 1725 $5.2.1 requirements [34]:

Feature	Requirement / Specification
Battery Chemistry	Lithium-Ion
Voltage	5v
Capacity Limit	[5000 mAh, 10000mAh]
Battery Label	Labels showing: Wh and Voltage
Operating Temperature	[0℃, 40 ℃], [32℉, 104℉]
Charging Temperature	[0℃, 35 ℃], [32℉, 95℉]
Physical Enclosure	Battery Ensure that can protect the main battery from physical impact

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