WalkGuard

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***Abstract*—WalkGuard is a wearable vest that aims at helping visually impaired individuals navigate streets alone by reducing risks of accidents or injuries through obstacle detection and emergency situation alerts. This is achieved through a system that integrates main components, including a microwave radar that detects obstacles in front and an accelerometer that detects fall incidents to report to the caregiver via WebApp instantaneously. Unlike the usual white cane for navigation, WalkGuard detects obstacles over longer distances to help users avoid obstacles in advance and further ensures their safety. Moreover, it relieves the burden on caregivers due to less constant attention needed.**

***Index Terms*—Accelerometer, Embedded Systems, Healthcare, Obstacle Detection, Radar, Raspberry Pi, Safety, WebApp**

1 INTRODUCTION

Urban environments can present significant challenges for visually impaired individuals, particularly in areas with cluttered sidewalks, uneven pavement, and unexpected obstacles such as construction materials or parked bicycles. These barriers, often overlooked by the general public, pose serious safety risks for those navigating with limited vision. In many cases, visually impaired individuals must rely on minimal or no assistance, increasing the risk of falls and other accidents. Recognizing the importance of creating a safer and more navigable environment, our goal is to develop WalkGuard, a wearable vest designed to mitigate these risks.

WalkGuard integrates radar sensors to detect obstacles in real time, alerting the user through audio cues to help navigate around hazards. In addition, it features an accelerometer that can trigger an emergency alert to caregivers if a fall is detected. With approximately 3.5% of the global population affected by visual impairment and 30-40% of them having to navigate independently, there is a pressing need for such a solution to reduce accidents and provide peace of mind for caregivers.

Our primary target audience includes visually impaired individuals in urban environments, as well as their caregivers, who are responsible for ensuring their safety. WalkGuard also addresses public health and safety needs, helping to reduce the incidence of accidents in pedestrian areas. Supplementary to white cane, WalkGuard detects obstacles farther away to help avoid obstacles in advance, further improving safety. Although there are existing tools aimed at enhancing mobility for visually impaired people, many are either cost-prohibitive or offer limited functionality (no fall detection for caregivers) [13]. WalkGuard aims to address these gaps by providing an affordable, reliable, and easy-to-use solution.

2 USE-CASE REQUIREMENTS

Our product serves two distinct groups of users: direct users, who are visually impaired individuals relying on the device for assistance in their day-to-day navigation, and indirect users, who are caregivers or guardians responsible for the safety and well-being of these individuals. The device is designed to meet the unique needs of both groups, ensuring that it improves the quality of life for direct users while providing peace of mind and accurate information to indirect users.

2.1 Use-Case Requirements for Direct Users

2.1.1 Audio Alerts

Visually impaired individuals need to navigate safely and independently. WalkGuard provides real-time audio alerts when obstacles are detected, allowing users to react in time. These alerts must be clear, customizable, and easily recognizable to suit different hearing abilities and preferences. The system should detect obstacles within 5 meters with directions for MVP and issue audio alerts within 1 second. The device must maintain a high level of accuracy, with a false negative rate of no more than 15% and a false positive rate not exceeding 20%.

2.1.2 Battery Life

The device's battery life is critical for direct users, as it must support at least a single trip, typically 3 hours for MVP, without the need for frequent recharging. This minimizes inconvenience for users who may not have regular access to charging throughout the day. Power efficiency also supports environmental sustainability, making the device an eco-friendly option. In case the battery life falls short, mitigation strategies include optimizing power consumption or increasing battery capacity.

2.1.3 Wearability

Comfort and wearability are key concerns for direct users. WalkGuard should be lightweight (no more than 3 kilograms for MVP), unobtrusive, and seamlessly integrated into daily life. It must be comfortable for extended periods without causing fatigue or inconvenience. The design should also take social factors into account, ensuring that the device is discreet and socially acceptable. If wearability is compromised, mitigation measures include using lighter materials or redesigning the vest for greater comfort.

2.2 Use-Case Requirements for Indirect Users

2.2.1 Emergency Alerts

For caregivers or guardians, the device's fall detection system ensures prompt notification in the event of a fall. It must accurately detect falls and send emergency alerts via email within 5 seconds for MVP, including the user's GPS location. Quick and reliable alerts allow caregivers to respond swiftly in emergencies. If the system fails to meet these expectations, mitigations include recalibrating the fall detection sensitivity or improving GPS accuracy.

2.2.2 Location Navigation

The system must provide accurate physical location data along with emergency alerts. This data must have minimal error, allowing caregivers to easily locate the user, whether they are at home or in a public space. GPS accuracy should be within 10 meters for MVP to ensure caregivers can respond effectively. If GPS accuracy falls short, mitigation may involve improving the GPS module or exploring alternative navigation technologies.

2.3 Summary

In conclusion, the design of WalkGuard carefully addresses the needs of both direct and indirect users. For visually impaired individuals, it enhances safety and independence through fast, accurate audio alerts, sufficient battery life, and comfortable wearability. For caregivers and guardians, the fall detection and emergency alert system acts as a vital lifeline, enabling them to monitor and respond to emergencies promptly with real-time email alerts that include the user's physical location.

3 ARCHITECTURE AND/OR PRINCIPLE OF OPERATION

The system integrates two primary functional subsystems: (1) the obstacle detection system and (2) the emergency alert system. These subsystems work in coordination to ensure proper operation and real-time response to dynamic situations.

3.1 Obstacle Detection System

The obstacle detection system is critical to ensuring that visually impaired users can navigate their surroundings safely. This system is built around a K-LD7 radar sensor and leverages advanced Doppler radar technology to detect obstacles within the user's path. The radar continuously scans the environment, covering a 1 to 5-meter range (see Fig. 1), and identifies both stationary and moving obstacles, such as street signs, parked vehicles, and approaching cyclists or pedestrians as long as there is relative velocity between the user and the obstacle. This is because the K-LD7 radar operates by emitting high-frequency radar waves and measuring the time and phase shift in the returned signals to detect the speed, distance, and direction of objects relative to the user.

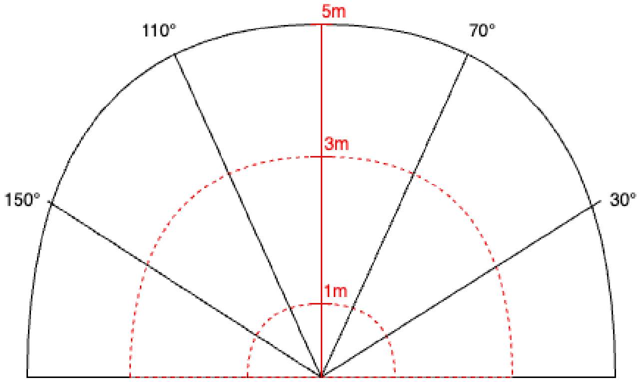

Figure 1: Range and distance of detection

The radar sensor's Doppler capability allows it to not only detect the presence of obstacles but also their movement patterns. The K-LD7 radar sensor calculates the coordinates of detected obstacles using the time delay and phase shift of reflected radar waves. This provides the distance r and angle θ of an object in relation to the user. These measurements are initially in polar coordinates (r, θ), but the system translates them into Cartesian coordinates (x, y) for easier processing. This is achieved through the transformation equations:

$$x = r \cdot \cos(\theta)$$
$$y = r \cdot \sin(\theta)$$

The Raspberry Pi 4 then uses these Cartesian coordinates to determine the exact position of each obstacle relative to the user. This coordinate data, combined with the obstacle's velocity, helps the system calculate time-to-collision (TTC) and assess the urgency of alerting the user. This process ensures precise and actionable feedback, allowing the user to navigate safely. In crowded urban settings where multiple objects may be present simultaneously, the radar system can track and prioritize threats, ensuring that users are alerted to the most immediate dangers. The radar's advanced filtering algorithms reduce false positives, focusing only on relevant obstacles.

Data from the radar sensor is processed by an embedded Raspberry Pi 4 (RPi4), which serves as the main computational unit (see Fig. 2). The RPi4 was selected for its powerful quad-core ARM Cortex-A72 processor, capable of handling complex radar data processing tasks while maintaining low power consumption. The RPi4 processes incoming radar signals using real-time signal processing algorithms to filter noise and calculate precise obstacle positioning and movement dynamics. Given its versatility, the RPi4 allows for custom software implementations, enabling WalkGuard to optimize radar data analysis and provide accurate, responsive alerts to the user.

To maintain optimal power efficiency, the radar operates with an intelligent scanning frequency, adjusting its scan rate based on environmental factors and the user's walking speed. This adaptive approach conserves battery power while ensuring that the user remains protected at all times.

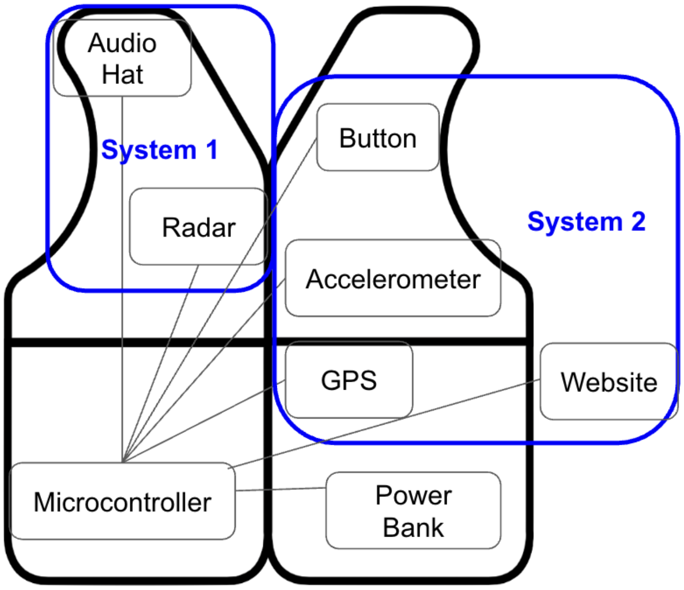

Figure 2: Layout of vest (front)

Figure 2 shows the exact layout of the WalkGuard vest. System 1, enclosed in the left section of the vest, consists of the radar and audio hat, responsible for detecting obstacles and providing real-time feedback to the user. System 2, located in the right section, integrates the accelerometer and button, which monitor for falls and allow manual cancellation of emergency alerts. The microcontroller, power bank, and GPS are located at the lower section. The physical positioning of each component will follow this layout sketch to ensure optimal performance and user comfort.

3.1.1 Real-Time Feedback System

The feedback system is designed to ensure that visually impaired users receive intuitive and actionable alerts based on obstacle proximity and severity. Once the RPi4 processes the radar data, it generates real-time alerts that are delivered via audio cues through a connected sound device. The prerecorded audio alerts are designed to vary based on the distance and direction, indicating whether the threat is from the left (110 degrees to 150 degrees), right (30 degrees to 70 degrees), or front (70 degrees to 110 degrees) (see Fig. 1). These real-time alerts empower the user to make quick decisions about their path.

3.1.2 Power and Performance Optimization

The RPi4 is configured to operate in a low-power mode during periods of inactivity, conserving energy for extended use. Despite the high computational requirements of radar data processing, the RPi4's efficient design ensures that the system can run for at least 3 hours on a power bank charge. This balance between performance and energy consumption is essential for maintaining the vest's portability and usability in various settings.

3.2 Emergency Alert System

The emergency alert system is designed to detect falls or sudden changes in the user's movement and immediately notify caregivers.

3.2.1 Accelerometer Integration

The emergency detection subsystem integrates an accelerometer to continuously monitor the user's movement. The accelerometer measures changes in acceleration and can identify sudden shifts indicative of a fall. These shifts are detected when acceleration exceeds a set threshold, allowing the system to distinguish between normal movements, such as walking or bending over, and critical incidents like falls. When an emergency is detected, the RPi4 sends an alert to a designated caregiver via the connected WebApp through Bluetooth. The alert includes the user's GPS location, provided by an integrated GPS module. The system is designed to transmit alerts with minimal latency, ensuring rapid notification in case of emergencies. According to the project's design specifications, the system is calibrated to achieve $a \leq 5\%$ false negative rate and $a \leq 20\%$ false positive rate, ensuring reliability in real-world use.

3.2.2 Emergency Detection Algorithm

Data from the accelerometer is processed by the RPi4, which runs an algorithm to classify detected movements as either safe or potentially dangerous. The algorithm continuously checks the acceleration data for sharp, sudden movements that exceed a predefined threshold (which will be adjusted through testing and calibration). For example, when a fall is detected, the vertical acceleration value may exceed a certain g-force threshold, triggering the system to classify the event as a fall.

The accelerometer measures acceleration in three axes: x, y, and z. The total acceleration a_{total} is calculated as:

$$a_{\text{total}} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Where a_x, a_y, and a_z are the accelerations along the three axes.

For fall detection, the system monitors the vertical acceleration a_z specifically. A fall event is identified when a_z exceeds a threshold:

$$a_z > 2g \quad \text{or} \quad a_z < -2g$$

Where g is the gravity acceleration ($9.8\,\mathrm{m/s^2}$). The threshold of 2g is supported by research on falling injuries, which states that falls typically involve acceleration forces exceeding 2g [10].

To ensure timely response, the alert will be sent within the following time:

$$t_{\text{alert}} = t_{\text{fall}} + t_{\text{processing}} + t_{\text{transmission}}$$

Where t_{fall} is the time to detect the fall, $t_{\text{processing}}$ is the time for the RPi4 to process the data, and $t_{\text{transmission}}$ is the time to send the emergency alert, all totaling less than 5 seconds.

3.2.3 Manual Emergency Override

WalkGuard includes a manual emergency button located on the vest that allows the user to cancel an automatically triggered alert if the user determines that no fall or emergency has occurred. When the button is pressed, the system halts the emergency alert process, and the connected WebApp's state is immediately updated to reflect the cancellation. This ensures that caregivers are aware that the situation is under control and no further action is needed. The button gives the user control over the system's alert functionality, preventing false alarms.

3.2.4 Connectivity and Data Security

The system connects to the user's smartphone via Bluetooth for communication with the WebApp. This allows the user's data, including emergency alerts and GPS coordinates, to be transmitted securely and efficiently. WalkGuard ensures that all transmitted data is encrypted both in transit and at rest, protecting the user's privacy and maintaining data security at all times. All user data, including emergency alerts and GPS coordinates, is securely stored in the AWS cloud services, which provides robust data protection and scalability.

3.2.5 User Comfort and Design

The vest is lightweight and ergonomically designed for maximum comfort. The materials are breathable and the manual emergency button is placed for easy access without interfering with the vest's usability, and the audio feedback system is designed to be non-intrusive while still providing clear alerts to the user. Additionally, the WebApp UI is specifically adapted for visually impaired users, offering high-contrast modes, and large, easy-to-navigate interface elements.

4 DESIGN REQUIREMENTS

The design of WalkGuard is driven by specific technical requirements that align with the use-case requirements, which are bridged by technical architecture design.

4.1 Obstacle Detection and Audio Alerts

In terms of providing audio alerts, the device must detect obstacles within a range of 1 to 5 meters, allowing users enough time to react safely. To maintain the accuracy necessary for reliable obstacle detection, the system must have a false negative rate of no more than 15% and a false positive rate not exceeding 20%. A false negative occurs when the system fails to detect an obstacle that is actually present, potentially putting the user at risk. On the other hand, a false positive happens when the system signals an obstacle when none exists, which can lead to unnecessary alerts and user frustration. By minimizing these rates, the device ensures that users are alerted only when necessary and that they can trust the system's reliability. Upon detecting an obstacle, the device must deliver an audio response within 1 second, ensuring that the user is alerted in time. The audio alert should be loud enough, with a minimum volume of 40 decibels, to ensure the user can clearly hear it. Furthermore, the system is designed to maintain a 99% uptime, ensuring consistent operation and reliability.

4.2 Power Consumption

To make sure the battery is long enough for a single trip, the device must be able to operate for at least 3 hours on a single charge. This can meet the requirement to let the user rely on the device during typical daily activities or trips without needing frequent recharging, thus minimizing any potential inconvenience.

4.3 Wearability and Comfort

Wearability is also a major design focus as mentioned before. The device must be lightweight to ensure that it can be worn comfortably for extended periods. To achieve this, the total weight of the device should not exceed 3 kilograms. Keeping the device lightweight enhances user comfort and encourages regular use, ensuring that the device integrates seamlessly into the user's daily routine.

4.4 Emergency Alerts and GPS Location

For caregivers, the fall detection system is designed to send emergency alerts promptly, accompanied by the user's real-time GPS location. The system must send the alert within 5 seconds of detecting a fall, ensuring quick notification for the caregiver. The GPS location data included in the alert must be accurate within a 10-meter radius to enable caregivers to locate the user efficiently, whether they are at home or in a public space. To maintain reliability, the system should have an uptime of 98

4.5 Fall Detection Accuracy

In terms of fall detection accuracy, the device will rely on an accelerometer to identify falls, and it must minimize both false positives and false negatives. A false negative in this context refers to the system failing to detect a fall when one has actually occurred, which could leave the user without timely assistance. To avoid this, the system should maintain a false negative rate of 5% or lower. Conversely, a false positive occurs when the system detects a fall when none has happened, which could trigger unnecessary alerts and cause undue concern for caregivers. The false positive rate should not exceed 20% to minimize these unnecessary disruptions. Striking this balance ensures that caregivers are notified only in genuine emergency situations, providing peace of mind while reducing false alarms.

5 DESIGN TRADE STUDIES

During the design of our product, we took different hardware and software alternatives into consideration before making the final design choice. The details of trade studies are as follows:

5.1 Radar

To detect obstacles with distance and directional information, we looked into a variety of sensors. Based on the use case requirements, we outlined the following considerations in choosing a sensor suitable in our case:

- All weather condition operation
- Daytime and night-time operation
- Range in distance
- Range in Field of View (FoV)
- Accuracy
- Affordability
- Energy consumption

The following types of sensors were compared and considered:

- Radar
- LiDAR
- Ultrasonic sensor
- Camera

5.1.1 All-weather operation

For the system to be effective in all weather conditions, the sensor must be resilient against atmospheric interference, especially during severe weather like rain or fog. Ultrasonic sensors are easily influenced by atmospheric conditions, making them unsuitable as they may provide inaccurate readings or fail altogether in adverse weather. In contrast, radar is less susceptible to these interference and performs reliably across varying weather conditions, ensuring consistent and accurate detection [14].

5.1.2 Enclosure and line of sight

To protect the sensor from potential damage in rainy conditions, it will be placed inside an enclosed pocket of the vest, providing basic waterproofing. This means the sensor should not require a direct line of sight to function effectively. LiDAR and camera-based solutions does not satisfy because they rely heavily on having a clear, unobstructed view of the target area. Radar, however, is capable of detecting objects without the need for a direct line of sight, making it a suitable option for enclosed placements where visibility might be obstructed [2].

5.1.3 Detection Range, Field of View (FoV), and Multi-Target Detection

The system requires a sensor capable of measuring distance over a certain range, providing a wide field of view, and detecting multiple targets simultaneously. Though detection distance would not be a large concern in our case, ultrasonic sensors typically have a narrow field of view, which makes them insufficient for these requirements [15]. Radar, on the other hand, excels in these aspects by offering a broad field of view and the ability to track multiple objects at once. This makes it an ideal choice for a system that needs comprehensive situational awareness.

5.1.4 Affordability

Affordability is a key consideration for the system, LiDAR, using lasers to achieve high precision, are generally more expensive compared to radar modules, making them less suitable when budget constraints are present. The Doppler radars offers a cost-effective solution while still meeting the technical specifications necessary for the application. This advantage allows for a balance between performance and budget, ensuring the system remains accessible without compromising on functionality.

5.1.5 Power Consumption

For a wearable system, power efficiency is critical. LiDAR systems, which use lasers, consume significant power and require high energy input [4]. Similarly, cameras typically need continuous streaming, drawing around 350mA to 900mA [1]. In contrast, Doppler radars have a much lower power requirement, typically in the range of 25-60mA, making them far more efficient for long-term and continuous operation without draining power resources quickly [11]. This efficiency makes radar a more sustainable choice for the system.

5.1.6 Accuracy and Precision

Both radar and LiDAR are capable of providing accurate measurements; however, while LiDAR may have a slight edge in precision, the difference is negligible within the 1-5 meter detection range required by the system [9]. Radar's accuracy within this range is sufficient to meet the needs of the application, and given its other advantages, it is the most balanced and practical choice.

Combining all the above considerations, radar is clearly the ideal choice for obstacle detection of the system. We have chosen the K-LD7 radar as the module because it would provide direct serial output, facilitating our signal processing procedures [11]. However, one characteristic needing attention is that the K-LD7 will not register a target if the radar and the target are relatively stationary. For the specific case of obstacle detection, it is less of an issue because if the object is close to the user, the white cane can be used for the detection. Moreover, as soon as the user starts walking, the stationary object of certain distance away can be detected.

5.2 Microcontroller

Another decision we made was on the device to use as the compute module for the system. Raspberry Pi 4 and 5 were among our final considerations. The reasons why we were focusing on Raspberry Pis were that they were available on the ECE inventory (hence zero cost), and that our group members have prior experience with it. We then compared the 4th generation series with the 5th generation series to arrive at our final decision of using Raspberry Pi 4 (RPi4) over Raspberry Pi 5 (RPi5).

According to documentations, the Raspberry Pi 5 has significantly better performance compared to the Raspberry Pi 4 [5]. In exchange, the peak power for the Pi 5 is 12 W, while it is only 8 W for Pi 4. This poses a challenge for us, as the battery life endurance of more than 3 hours to support a single trip is one of our design requirements, and excessive power consumption could make it difficult to meet that goal.

Furthermore, we believe that the RPi4 would have enough performance to run our software algorithms, so additional performance was not necessary compared to power consumption considerations. Thus, we decided to stick with RPi4 as our compute module for the project.

5.3 Accelerometer

In the fall detection system, maintaining high accuracy is essential, with our target design requirements specified in the design requirements section. To recap, a false negative occurs when the system fails to detect an actual fall, which poses a significant risk to the user's safety. On the other hand, a false positive is when the system incorrectly identifies a fall when none has occurred. We prioritize minimizing false negatives to ensure that all real fall incidents are detected and addressed appropriately, as the safety of the user is our primary concern.

To accommodate this, the system is designed with a higher tolerance for false positives, as we would rather trigger an unnecessary alert than miss a genuine emergency. If a false alert is sent, the user can easily dismiss it by pressing a designated button to cancel the false alerts, informing the caregiver that everything is fine. This approach ensures that the system remains responsive to all potential fall incidents while providing a straightforward method for managing incorrect alerts, balancing safety and usability effectively.

5.4 WebApp

For our web app and alert system, we chose AWS over alternatives like Google Cloud Platform (GCP) due to its scalability, ease of use, and global reach (see Table. 1) for detailed comparison). AWS offers a broad range of integrated services—such as Lambda for serverless computing, S3 for storage, and SNS for notifications—that make it easier to build, deploy, and manage our real-time alert system. While GCP is also scalable and competitively priced, AWS provides a more comprehensive set of tools, especially for handling critical applications like fall detection. AWS's global network ensures fast and reliable alert delivery to caregivers, and its strong security and compliance features protect sensitive user data. Additionally, AWS's pay-as-you-go pricing offers flexibility, allowing us to optimize costs as the system grows.

6 SYSTEM IMPLEMENTATION

Our implementation is designed with two primary systems to assist visually impaired individuals as well as their caregivers or family member responsible for their safety: Obstacle Detection and Emergency Detection. Each system, composed of multiple components to achieve the subsystem performance, is detailed in the following to provide a comprehensive understanding of their operation and how it integrates to ensure user safety and independence. In addition, the Raspbian OS available from the Raspberry Pi also facilitates our system integration and helps us program the microcontroller.

Fig. 3 provides the schematics for the integration of the system with the specified pin-outs (note: GPS will be connected to the RPi4 using a USB-C port. The RPi component module package did not specify the USB ports, and thus the connection is not reflected on the schematics. All other connections are clearly identified).

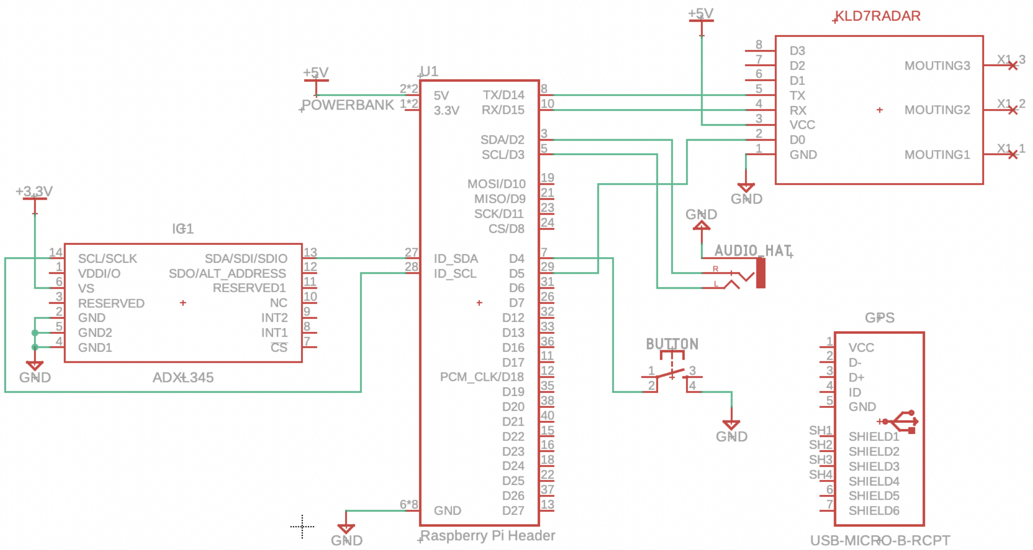

Figure 3: Specification of system integration with connections

6.1 Obstacle Detection

To help visually impaired users navigate their surroundings safely by providing real-time feedback on potential obstacles in their path, the obstacle detection system consists of two components: radar and audio hat. The radar is for detection, whereas the audio hat is for instantaneous obstacle report.

6.1.1 Radar

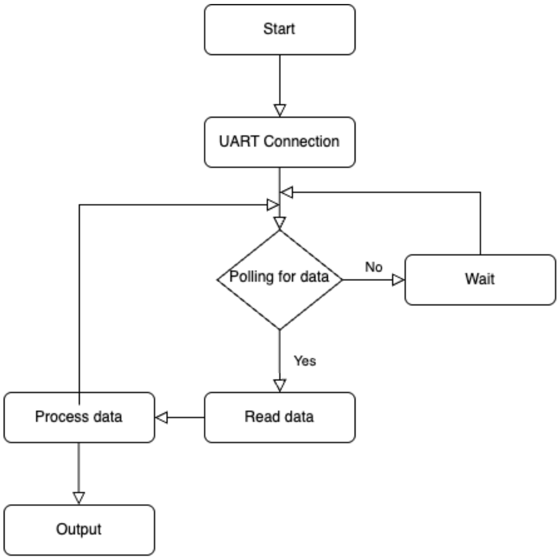

Figure 4: Flow chart for radar data processing.

The K-LD7 Radar sensor is placed on the front of the vest to continuously scan the environment ahead of the user. The radar will be powered by the 5V output from RPi4. The TX and RX pins of the radar will be connected to the UART RX and TX pins on the RPi4 respectively. Digital output 0 on radar will be connected to port D5 on RPi4. According to the K-LD7 datasheet, this pin goes high if the detection algorithm finds a target in front of the sensor [12]. .

The radar sensor will communicate with the RPi4 using the UART port 115200-8E1. A Python driver is available for interfacing with the K-LD7 radar module, allowing us to adjust various parameters. Fig. 4 illustrates the communication flow chart. The radar offers 22 configurable parameters that can be fine-tuned to enhance detection performance. Our primary focus is on the distance range and field-of-view parameters to optimize the detection range for our specific application. With software algorithms for radar data analysis, obstacles will be reported at distances of 5, 3, and 1 meter, with a margin of error of 0.1 meters. In addition, the direction of the obstacle will be communicated to the user for precise guidance, alerting users to take appropriate action based on the distance and direction of the obstacle.

6.1.2 Audio Hat

The audio hat will communicate with RPi4 using the I2C communication protocol. Referring to Fig. 3, the SCL (Serial Clock Line) and SDA (Serial Data Line) signals on the audio hat will be connected to the SDA and SCL respectively, and the audio hat is powered up and grounded (not reflected in the schematics due to the different pin-out from the module; the purpose is to show I2C connection). The RPi4 acts as the master device, initiating communication by controlling the SCL and sending commands to the audio hat, which is configured as the slave device. The audio hat receives these commands and processes the data accordingly, triggering audio responses that provide direction and distance information to the user. To establish communication, the RPi4 identifies the audio hat using its unique 7-bit I2C address, ensuring that it correctly targets the audio hat among any other devices connected on the same I2C bus.

6.2 Emergency Detection

To help caregivers identify potential falls that occur in visually impaired users, the emergency detection system consists of several components that work together to detect falls and transmit alerts. Below is a detailed description of the hardware and software setup for this system.

6.2.1 Accelerometer (ADXL345)

The fall detection relies on the ADXL345 accelerometer, which is connected to the Raspberry Pi 4 (RPi4) via the I2C protocol. The second set of SDA and SCL pins on the ADXL345 are connected to the corresponding pins on the RPi4, and the accelerometer is powered by the RPi4's 3.3V pin. The I2C communication allows the accelerometer to transmit real-time data about the user's motion, specifically focusing on acceleration in different axes.

To identify falls, the accelerometer is calibrated to monitor rapid changes in acceleration, particularly in the vertical direction (the z-axis in our setup). Since a fall typically results in a sudden spike in vertical acceleration, these data are used as the primary indicator. A threshold is set to differentiate between falls and normal movements, such as bending over or sitting down. The system assumes that regular motion will have a slower acceleration pattern, while falls will exhibit a rapid acceleration spike that crosses the threshold. The RPi4 continuously processes these data to determine if an alert should be triggered.

6.2.2 Button for Canceling False Alerts

To allow users to cancel false alerts, a QTEATAK Tact switch button is integrated into the system. The button is connected to the GPIO D4 pin on the RPi4, which allows it to send input to the RPi4 whenever it is pressed. For enhanced usability, the surface of the button will be enlarged, ensuring that users can easily press it, even in stressful situations.

6.2.3 GPS Module

The system includes a GPS module connected via the USB port on the RPi4. This GPS module continuously monitors the user's location and provides real-time positional data. If a fall is detected, the system retrieves the user's exact GPS coordinates. This data is critical for alerting caregivers, as it allows them to know the precise location of the user in case of an emergency.

6.2.4 Network Connectivity and Website Communication

The RPi4 is connected to the user's smartphone via bluetooth, which provides continuous access for the system. Once the RPi4 detects a fall, it needs to transmit the alert, along with the GPS coordinates, to the caregiver via a web-based interface. To achieve this, the system leverages AWS (Amazon Web Services), which provides cloud-based infrastructure for handling the alert data.

The RPi4 sends the alert data (fall detection status, user location, etc.) to AWS within webapp. Webapp handles the backend processing by receiving this data and triggering a notification to the caregiver's mobile device. This setup ensures that caregivers, no matter how where they are, receive timely alerts. The AWS infrastructure could also be used to integrate real-time notifications through SMS or email, allowing for a multi-channel alert system.

7 TEST & VALIDATION

The verification and validation of WalkGuard are conducted through a series of detailed testing procedures, including unit tests and integration tests, that ensure all design requirements meet their technical specifications. Each requirement is evaluated through measurable metrics, and potential mitigation plans are prepared for any issues that arise during testing.

7.1 Unit Test

This section describes the test procedures for validating the individual components of WalkGuard. Each unit component is evaluated to ensure that it meets the specified technical requirements, with corresponding mitigation strategies in place for potential issues.

7.1.1 Wearability Testing

The wearability of the vest is assessed by weighing it on a scale to ensure it remains below the 3 kg threshold. A standardized one-size vest is used to test consistency. If the vest exceeds the weight limit, alternative lighter materials or design modifications will be explored to reduce the overall weight and improve user comfort.

7.1.2 Power Consumption Testing

For power consumption, the energy use of the device is measured using an ammeter under normal operating conditions. The total energy consumption is calculated to estimate whether the device is operating for at least 3 hours on a single charge. If battery life is insufficient, mitigation measures include identifying areas of excessive power usage, increasing battery capacity, or switching to more power-efficient components.

7.1.3 Fall Detection Testing

The accuracy of fall detection is verified using the device's accelerometer. Wearing an accelerometer and simulated falls and typical movements, such as bending over, will be performed 100 times to evaluate the system's ability to distinguish between real falls and non-critical movements. The goal is to achieve a false negative rate of 5% or lower and a false positive rate not exceeding 20% for MVP. If the system performance is inadequate, further adjustments will be made to the accelerometer sensitivity or fall detection thresholds.

7.1.4 Emergency Alert and GPS Location Testing

For the emergency alert and GPS location system, testing involves measuring the time between fall detection and the delivery of the alert, which must be within 5 seconds. Additionally, the GPS accuracy will be verified by testing the system under various real-world conditions, ensuring that the location data is accurate to within 10 meters. If delays or inaccuracies are identified, improvements to the web server or Bluetooth communication will be explored. In case of significant GPS issues, mobile phone GPS could be used as an alternative solution.

7.1.5 Radar Accuracy Baseline

The purpose of this evaluation is to assess the radar's performance in detecting obstacles, measuring distances, and providing accurate speed and direction data. Multiple tests will be conducted to simulate real-world use, covering various angles, speeds, and distances.

Distance and Angle Testing: We will place an object, such as a stationary stone, at predetermined distances and angles relative to the radar's field of view. Using precise measurement tools, we'll compare the actual distance and angle of the object with the radar's readings. The test will be performed at different points along the radar's detection radius to evaluate its accuracy across multiple positions. This process will be repeated 10 times to account for environmental variables and ensure consistency in the radar's detection capabilities.

Speed Detection Test: To verify the radar's ability to detect moving objects, a volunteer will walk past the radar at a controlled speed (e.g., 1 m/s). The radar's recorded speed will be compared with the actual walking speed. The test will be conducted for both approaching and receding movements to ensure the radar accurately tracks object velocity from different directions. Any deviations from the set speed will be noted and analyzed for consistency.

Movement Direction Assessment: We will test the radar's capacity to correctly interpret the direction of motion. Volunteers will walk toward and away from the radar, and we will verify if the radar correctly identifies whether the object is moving closer or farther away. Multiple trials will be performed, and any errors in identifying movement direction will be logged for further analysis.

Detectable Range Test: To establish the radar's effective detection range, we will position an object at increasing distances and monitor when it is first detected by the radar. This will be repeated at various angles to ensure the radar is capable of detecting objects at its maximum advertised range across the entire detection field which covers our product's range requirements 1-5m.

7.1.6 Obstacle Detection Testing

Testing for obstacle detection involves moving the radar at a speed of 1 m/s to simulate human walking and evaluating its performance both with and without obstacles in controlled and real-world environments. At least 50 trials will be conducted across 10 common scenarios to assess the system's accuracy by measuring the rates of false negatives and false positives. The system should achieve a false negative rate of no more than 15% and a false positive rate of no more than 20% for MVP. If these targets are not met, adjustments to radar parameters such as detection range, speed, and frequency will be considered. Additionally, optimization of the radar data analysis software may be required, or alternative technologies like LiDAR could be explored as potential solutions.

7.1.7 Audio Response Testing

For the audio response, testing involves interpreting the radar signal and converting it into a clear, human-understandable audio message. The time it takes for the system to produce an audio alert after detecting an obstacle must be recorded to ensure it meets the requirement of responding within 1 second. Additionally, the volume of the audio response should be at least 40 decibels, and the system is expected to maintain 99% uptime during operations. These tests will be repeated 100 times to ensure consistency and reliability. If the system does not meet the required performance metrics, improvements in radar signal processing speed through parallel computing will be explored, and audio wiring connections will be checked for potential issues.

7.2 Integration Test

This section focuses on evaluating the complete WalkGuard system in a real-world scenario where all components work together.

7.2.1 Testing plan

In this test, five volunteers will wear the vest, along with an eye-blinder to simulate visual impairment, while walking through the CMU campus. The test will simulate daily activities during both busy and quiet periods—approximately 10 minutes during class times with high foot traffic and another 10 minutes during quieter periods when classes are over. The scenario will assess the system's ability to detect obstacles within a 1 to 5 meter range and provide timely audio alerts within 1 second. The system is expected to achieve at least 82.5% accuracy in obstacle detection, with no more than 15% false positives or 20% false negatives. [8]. Battery performance will be monitored to ensure it lasts for a single trip, as required. Additionally, each volunteer will simulate 4 falls at a designated point. The system should detect 95% of the falls during the test (5% false negatives), sending an emergency alert to a designated caregiver within 5 seconds. The GPS coordinates provided in the alert are expected to have an accuracy of within 10 meters. The test will also measure the response time of the caregiver, who is expected to follow the GPS location and reach the user within 5 minutes. After the test, feedback will be collected from all volunteers on various aspects, including comfort, ease of use, and system effectiveness. Each volunteer will rate the system on a scale of 1 to 5, expecting an average rate around 4 or higher for the test to be considered successful. Their feedback will provide insights into potential improvements in wearability, audio clarity, and overall system responsiveness.

7.2.2 Limitations and Acknowledgements

Admittedly, due to limited resources and time, we were unable to conduct a fully comprehensive test that was both feasible and thorough. For instance, while a typical outdoor trip for a visually impaired user would last at least 30 minutes, our integration test was limited to about 10 minutes of walking time. This shortened duration may affect how accurately the test reflects real-world usage. However, we will make the most of these 10 minutes by incorporating a variety of reasonable scenarios to ensure the test remains as representative as possible given the circumstances. Additionally, we were unable to invite actual visually impaired or blind individuals in the test, so while our visually healthy volunteers wore eye-blinders to simulate impaired vision, their feedback may not fully capture the authentic experience of visually impaired users.

8 PROJECT MANAGEMENT

8.1 Schedule

The schedule is shown in Fig.6.

The development of WalkGuard has been divided among team members based on expertise in embedded systems, web applications, and signal processing. An overview of the schedule is as follows: Phase 1 (Weeks 1-3): Initial design and component selection. Phase 2 (Weeks 4-6): System integration and testing of subsystems (obstacle detection and fall detection). Phase 3 (Weeks 7-9): Full system testing, refinement, and validation. Phase 4 (Week 10-11): Final presentation and project submission.

8.2 Team Member Responsibilities

Zhixi Huang: Responsible for the development and integration of the obstacle detection system. This includes radar signal processing, microcontroller programming, and system testing.

Eleanor Li: Focused on the integration of the emergency detection system, including the accelerometer, fall detection algorithms, and GPS alert functionality. Responsible for testing of the overall system.

Connie Zhou: In charge of the design and implementation of emergency detection system and web application that interfaces with the vest, enabling caregivers to receive emergency alerts and monitor the user's status remotely.

8.3 Bill of Materials and Budget

Please refer to Table. 2 for the comprehensive list of the materials.

8.4 Risk Mitigation Plans

In our development of WalkGuard, several risks have been identified, along with corresponding mitigation strategies to ensure the project stays on track and meets performance expectations.

There is a risk of inaccurate fall detection due to the accelerometer's sensitivity settings, which could result in false positives (classifying normal movements as falls) or false negatives (failing to detect actual falls). To mitigate this, we have implemented a thorough calibration and testing process, adjusting the threshold based on user feedback and controlled testing. The system is designed with a sensitivity of ¡= 5% false negatives and ¡= 20% false positives, but ongoing tests will allow us to fine-tune this further. In case the chosen threshold still leads to issues, we will explore advanced filtering techniques to distinguish between various motion types, such as sudden stops or slips.

Since the system relies on Bluetooth for communication with the user's smartphone WebApp, there is a risk of intermittent connection issues or delays in transmitting critical emergency alerts. To mitigate this, we will perform extensive real-world testing in various environments to identify potential areas of weak connectivity. As a fallback, the system will include a retry mechanism in case of failed transmission attempts, and the GPS location data will be sent as soon as the connection is re-established.

With several components, including the RPi4 and sensors, relying on battery power, there is a risk of the system running out of power during use, particularly if it operates longer than expected. To address this, we aim to design the system with a minimum operational time of 3 hours, based on typical use cases.

Another risk is that users may accidentally trigger false emergency alerts, leading to frustration or confusion. To mitigate this, we will include a manual emergency button that allows users to cancel alerts if they realize the system has falsely detected a fall. The WebApp will also update its state to reflect the cancellation, preventing unnecessary caregiver notifications. Extensive user testing will help us improve the usability and placement of this button to reduce accidental presses.

9 RELATED WORK

Several wearable technologies have been developed to assist visually impaired individuals, but each comes with its own set of limitations. For instance, a team from Harvard has been working on improving assistive technologies, particularly focusing on enhanced feedback mechanisms for visually impaired users. Their approach integrates sensors that help users navigate environments with fewer external aids, but their system tends to be costly due to the high-tech sensors and advanced algorithms employed [7].

Similarly, engineers have designed wearables that help the blind walk with greater confidence. A notable example comes from ASME's work on haptic feedback systems, which use ultrasonic sensors to detect obstacles. However, while effective, these systems can be affected by environmental conditions like rain or fog, which can reduce their accuracy. Additionally, the price of these devices tends to be high due to the use of advanced sensor technology [3].

Another relevant project comes from a team of engineering students who designed a haptic feedback vest, which directs blind and partially sighted people using vibrations. Although this technology provides intuitive feedback and helps users navigate complex environments, its primary limitation lies in its reliance on touch-based feedback alone, which may not be suitable for all users, particularly in noisy or crowded environments. Like many advanced assistive devices, it faces challenges in terms of affordability and widespread adoption [6].

In contrast, WalkGuard integrates radar technology, which provides superior obstacle detection capabilities while remaining immune to adverse weather conditions. Additionally, by using cost-effective components like the K-LD7 radar and RPi4, WalkGuard aims to address the pricing challenges faced by many existing solutions, making it a more affordable option for users.

10 SUMMARY

WalkGuard is a wearable vest designed to enhance public safety and support the mobility of visually impaired individuals by detecting obstacles and responding to emergency situations. Using radar technology, WalkGuard detects potential hazards within a 1-5 meter range, offering real-time audio alerts to guide users safely through urban environments. In the event of a fall, an accelerometer triggers an emergency alert that is sent to designated caregivers via the WebApp, including the user's GPS location, ensuring timely assistance.

By integrating multiple technologies into a single wearable device, WalkGuard empowers visually impaired individuals to navigate their surroundings with independence and reduces the need for constant caregiver supervision. This innovative system is optimized for daily use, with a focus on comfort, long-lasting battery life, and low power consumption.

Moving forward, our team aims to enhance WalkGuard's functionality through extensive field testing and iterative development. We are confident that WalkGuard will deliver reliable performance in real-world conditions. Although challenges such as sensor integration and performance optimization remain, our risk mitigation strategies will help us address these issues effectively. Ultimately, WalkGuard has the potential to improve the quality of life for visually impaired individuals while promoting public health and safety in urban environments.

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Table 1: Comparison of AWS and GCP for WebApp System

Feature	**AWS**	**GCP**
Scalability	Highly scalable with a wide range of services	Scalable, but more specialized towards ML/Big Data
Global Reach	Extensive global presence with more availability zones	Global, but fewer regions than AWS
Ease of Use	Seamless service integration, large community	Good, but steeper learning curve for some setups
Cost	Flexible, pay-as-you-go with cost management	Competitive, but fewer integrated features
Security	Extensive security features and compliance	Strong security, but AWS offers more tools

Table 2: Bill of materials

Description	**Model #**	**Manufacturer**	**Quantity**	**Cost @**	**Total**
Raspberry Pi 4 - 8GB	BCM2711	Inventory	1	$64.00	$64.00
PowerBank	Anker 26800 mAh	Amazon	1	$33.00	$33.00
Radar	K-LD7	RF Link	1	$91.00	$91.00
Audio HAT	WM8960	Amazon	1	$21.00	$21.00
Accelerometer	ADXL345	Amazon	1	$8.98	$8.98
GPS	GT-U7	Amazon	1	$9.00	$9.00
AWS	AWS	AWS Educate	1	$0.00	$0.00
Vest	Fishing Vest	Amazon	1	$26.88	$26.88
				Total	**$217.98**

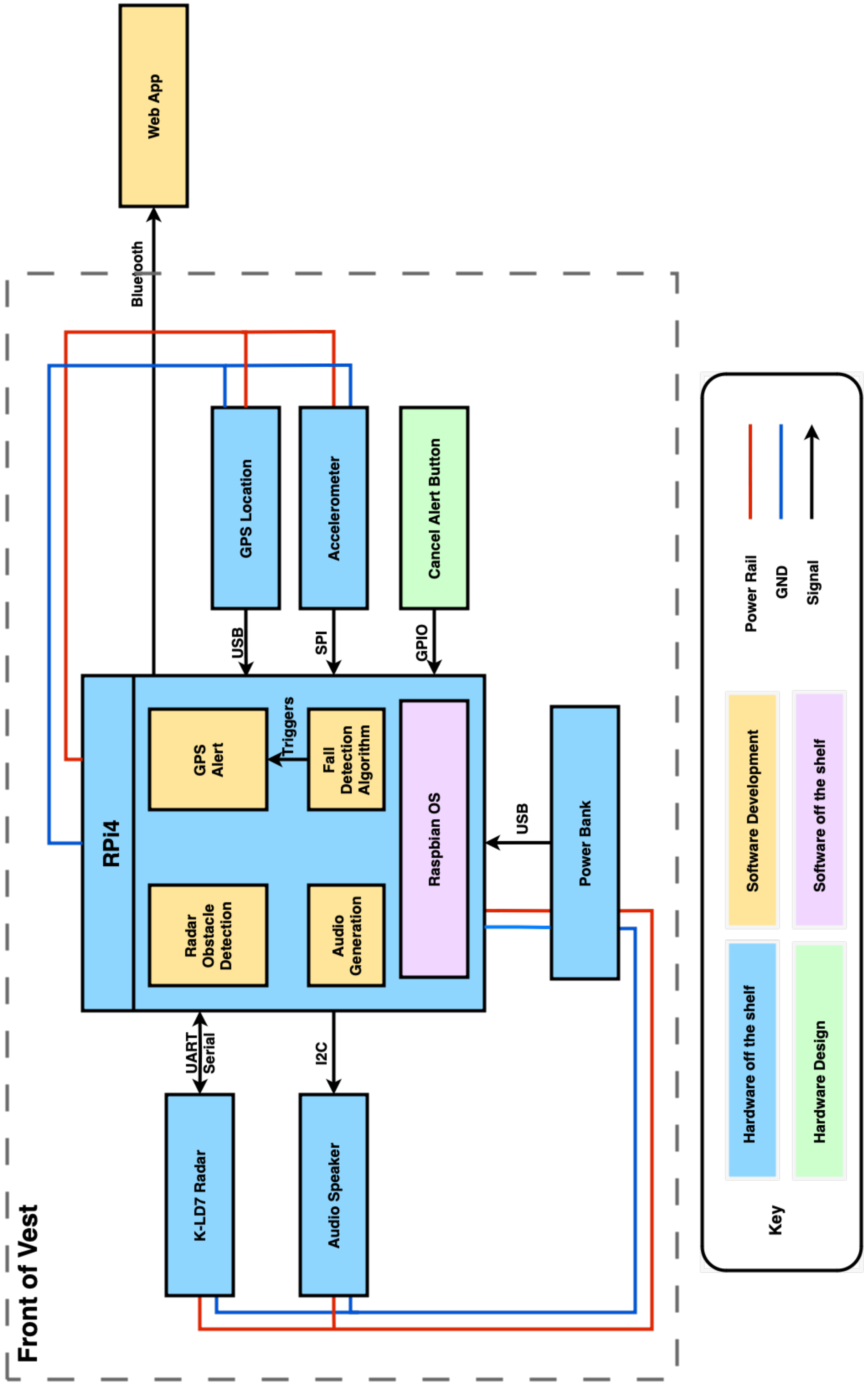
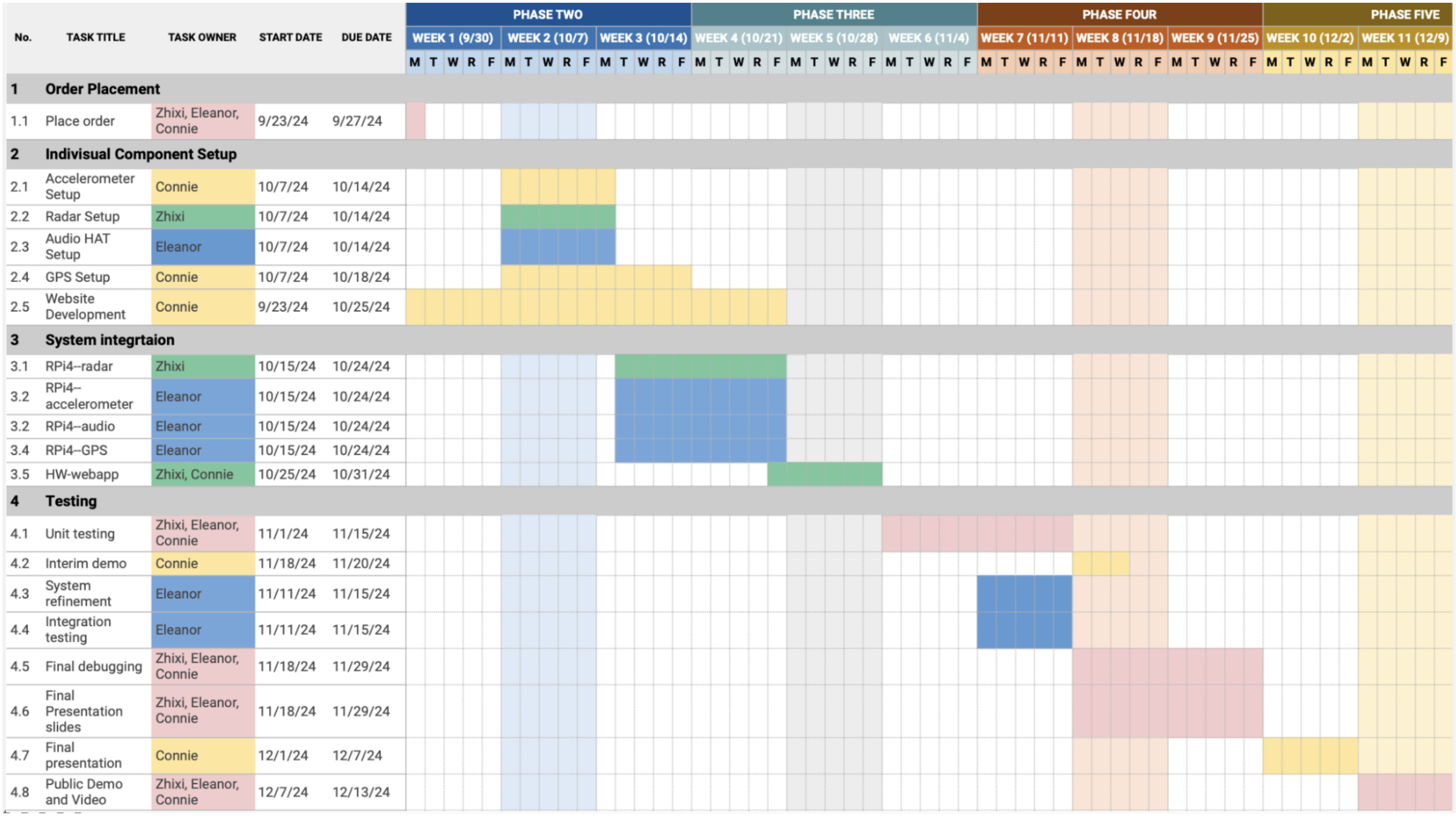


Figure 5: A full-page version of the same system block diagram as depicted earlier.



No.	TASK TITLE	TASK OWNER	START DATE	DUE DATE
1	**Order Placement**			
1.1	Place order	Zhixi, Eleanor, Connie	9/23/24	9/27/24
2	**Indivisual Component Setup**			
2.1	Accelerometer Setup	Connie	10/7/24	10/14/24
2.2	Radar Setup	Zhixi	10/7/24	10/14/24
2.3	Audio HAT Setup	Eleanor	10/7/24	10/14/24
2.4	GPS Setup	Connie	10/7/24	10/18/24
2.5	Website Development	Connie	9/23/24	10/25/24
3	**System integrtaion**			
3.1	RPi4–radar	Zhixi	10/15/24	10/24/24
3.2	RPi4–accelerometer	Eleanor	10/15/24	10/24/24
3.2	RPi4–audio	Eleanor	10/15/24	10/24/24
3.4	RPi4–GPS	Eleanor	10/15/24	10/24/24
3.5	HW-webapp	Zhixi, Connie	10/25/24	10/31/24
4	**Testing**			
4.1	Unit testing	Zhixi, Eleanor, Connie	11/1/24	11/15/24
4.2	Interim demo	Connie	11/18/24	11/20/24
4.3	System refinement	Eleanor	11/11/24	11/15/24
4.4	Integration testing	Eleanor	11/11/24	11/15/24
4.5	Final debugging	Zhixi, Eleanor, Connie	11/18/24	11/29/24
4.6	Final Presentation slides	Zhixi, Eleanor, Connie	11/18/24	11/29/24
4.7	Final presentation	Connie	12/1/24	12/7/24
4.8	Public Demo and Video	Zhixi, Eleanor, Connie	12/7/24	12/13/24

Figure 6: Gantt Chart