Group 17: Firefighter Health Monitoring Network

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Contents

1. Problem Statement and Solution

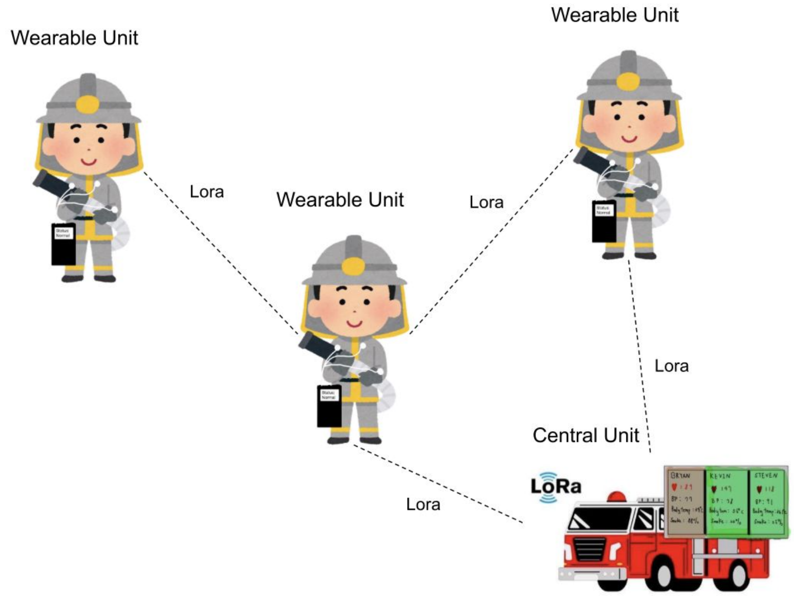
Problems

- Work in hazardous environments
- Health and Safety are at risk
- Current monitoring methods are relying on periodic check-ins or self reporting
- Lead to delayed responses
- Challenging to make decisions
- Some symptoms are difficult to notice, such as Cardiovascular events, heat stress, and physical exertion

Solution

- Wearable unit that contains multiple sensors for tracking health status of individual firefighter
- Central Unit for receiving health status from all firefighters
- Mesh Network implemented with LoRa module to create a self-healing network in case if any wearable unit fails

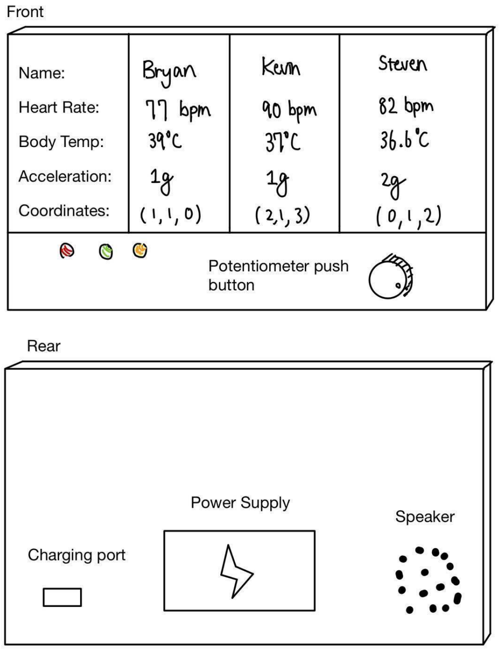
2. Visual Aid



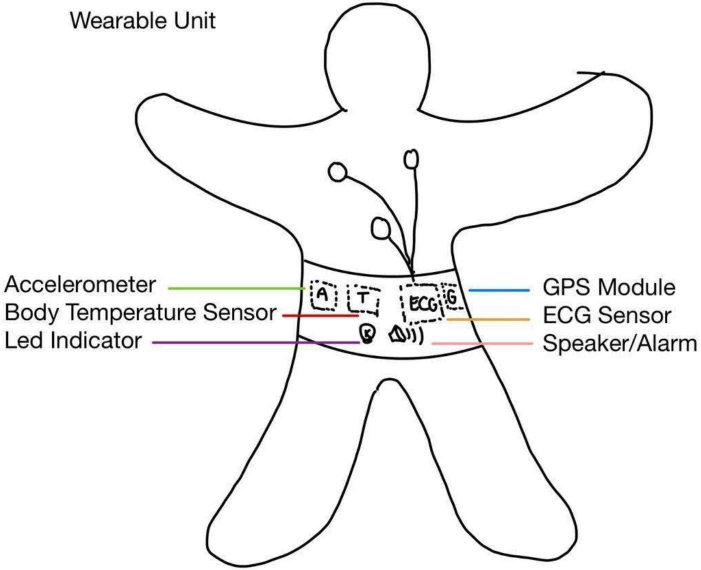
Wearable Unit
Wearable Unit
Lora
Wearable Unit
Lora
Lora
Central Unit
LoRa
Lora

2. Visual Aid

Central Unit



Wearable Unit



3. High-Level Requirements

1. The system shall continuously monitor and transmit the following data with 90% accuracy and operate on a single charge for at least 2 hours in typical fire fighting conditions above 30°C.

   a. ECG/EKG Data
   b. GPS Location
   c. Motion Data
   d. Surrounding Temperature Data

3. High-Level Requirements

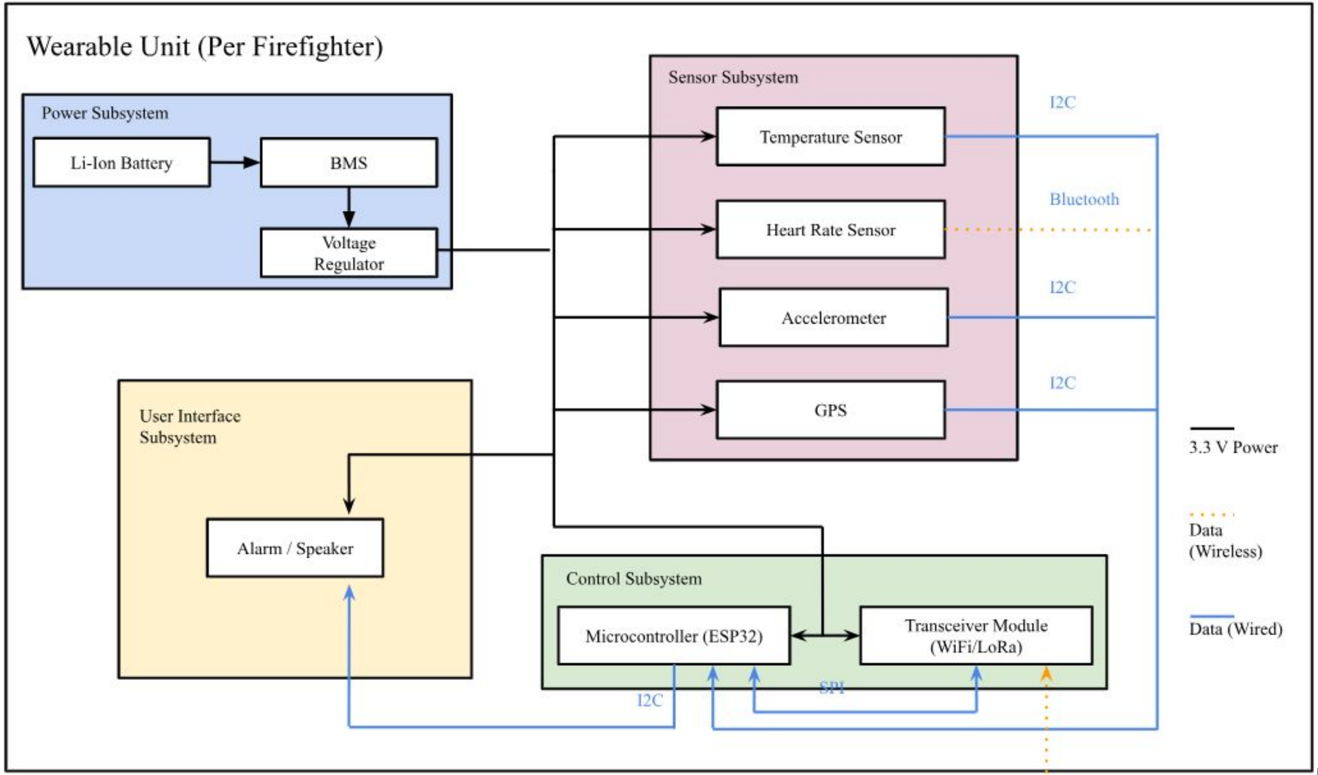
2. The system shall generate buzzer alerts on the wearable unit and central monitor within 10 seconds of abnormal detections based on thresholds on data from sensors:

   a. ECG/EKG Data
      i. Heart rates <40 bpm or >150 bpm sustained for >30 seconds, or upon detection of specified arrhythmias.
   b. Motion Data
      i. No significant motion detected for >60 seconds
   c. Surrounding Temperature Data
      i. Temperature exceeds 40°C for more than 3 minutes

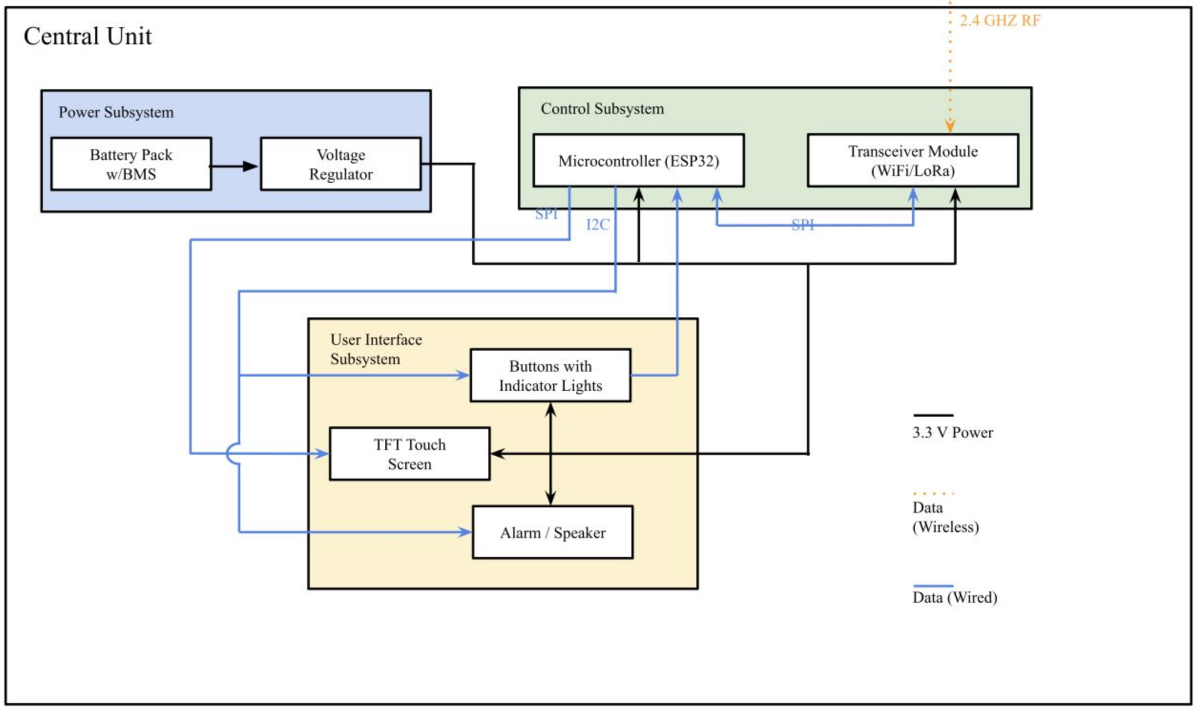
3. High-Level Requirements

3. The mesh network shall maintain connectivity in challenging environments with a minimum range of 300 meters in urban settings and 1 km in open areas, using LoRa technology. The system shall automatically route data through multiple hops (firefighter-to-firefighter) to reach the central unit when direct communication is not possible. End-to-end data transmission time from any firefighter to the central unit shall not exceed 15 seconds, even when relaying through multiple nodes.

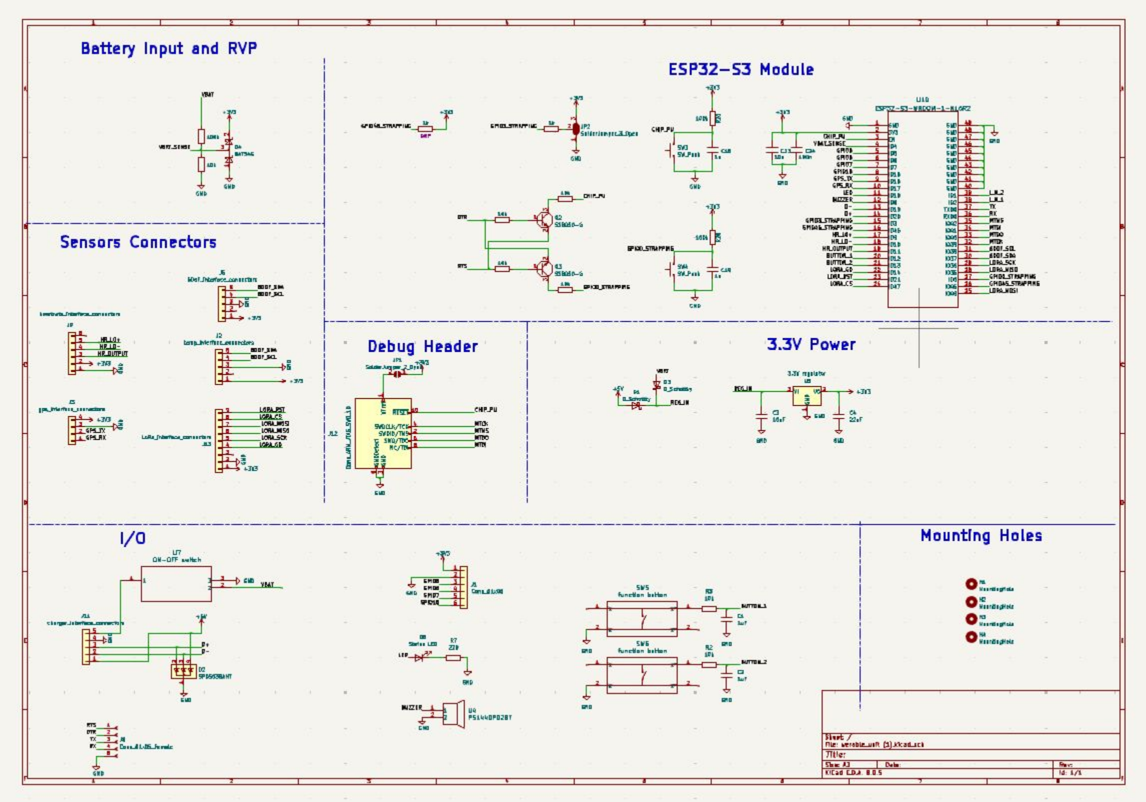
4. Block Diagram



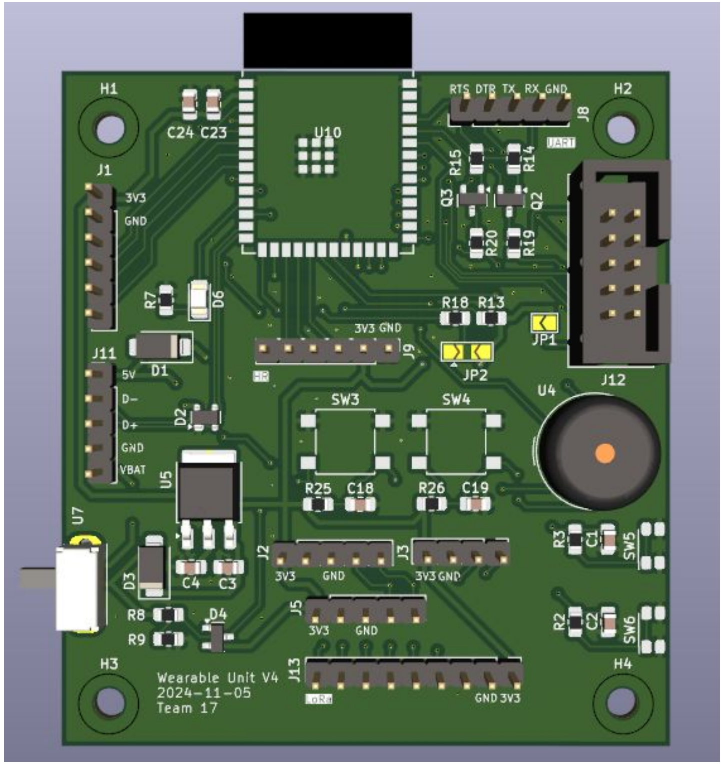
4. Block Diagram

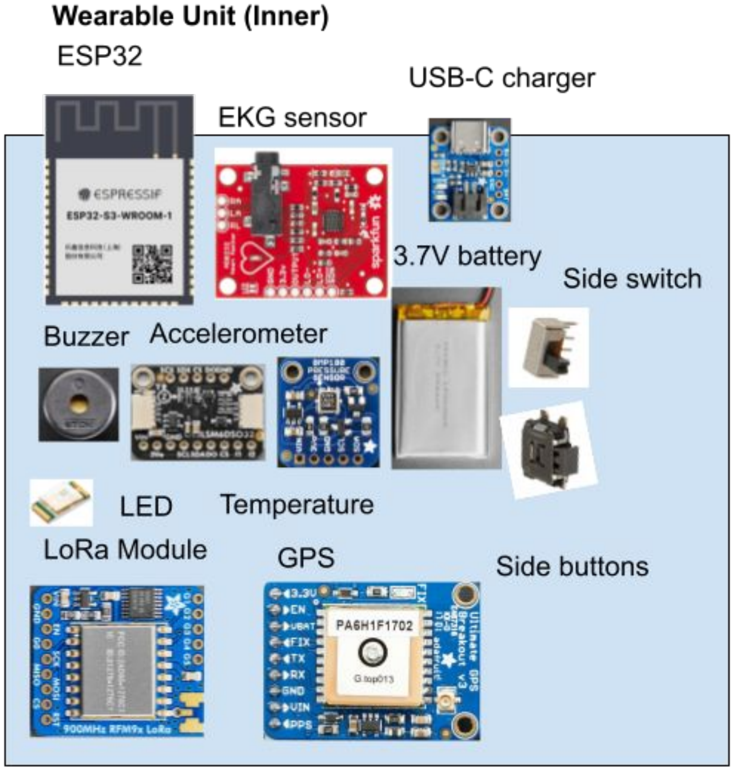


4. Wearable Unit Schematic



4. Wearable Unit





5. Requirements and Verification

Wearable Sensor Subsystem

This subsystem is responsible for continuously collecting real-time health and environmental data from individual firefighters. The sensors track vital signs like heart rate, surrounding temperature, and motion. The data is sent to the mesh network of the ESP32 and the central hub via reliable communication methods ESP-MESH and LoRa. The enclosure will be designed using 3D Computer-aided design software and printed out using a 3D printer with Polylactic acid material (PLA). Although PLA might have lower heat-resistance, other material like Polyetheretherketone (PEEK) could be replaced with the same design but with higher cost. For the purpose of this project, we will prioritize the design.

5. Requirements and Verification: Wearable Sensor Subsystem

Requirements	Verification
Wearable unit measures the surrounding temperature, heart rate, acceleration, and location of the user and sends it to the Central Monitoring Hub subsystem with a 90% accuracy.	1. Place a thermometer in a closed box and see if the values are the same for the device and the thermometer 2. Place the device on a person equipped with Apple Watch and validate the heartbeat count 3. Place the device on a steady surface and see if the acceleration read is equal to gravity (9.8m/s^2) 4. Measure the current coordinate with phone and validate the values from the gps sensor in the wearable unit 5. Output the readings to a terminal and confirm that the central unit is reading the values in real time
Alert is generated if a firefighter's heart rate exceeds 150 bpm or falls below 40 bpm for more than 30 seconds. These thresholds account for both sustained tachycardia and bradycardia, indicating potential danger to the firefighter's health.	1. Simulate the heart rate readings using ADALM2000 2. Set the wearable unit to monitor heart rates while gradually increasing to 160 bpm and decreasing to 35 bpm. 3. Validate that the wearable unit triggers an alert when heart rate exceeds 150 bpm for more than 30 seconds and when it falls below 40 bpm for the same duration. 4. Record response times and ensure alerts are activated correctly.

5. Requirements and Verification: Wearable Sensor Subsystem

Requirements	Verification
Alert is generated when the temperature exceeds 40°C for more than 3 minutes.	1. Place the device nearby a stove (or controlled heat source) to gradually increase the temperature around the wearable unit. 2. Monitor the wearable unit's temperature sensor and record readings. 3. Validate that the wearable unit triggers an alert when the temperature exceeds 40°C for more than 3 continuous minutes.
Alert is generated if no significant movement is detected on the firefighter for over 60 seconds.	1. Secure the wearable unit to a stationary object or user. 2. Ensure that no movement is detected (within a calibrated margin) for a continuous period of 60 seconds, and verify that an alert is triggered at that moment. 3. Test with varying degrees of movement to ensure the threshold for "significant movement" is correctly calibrated.

5. Requirements and Verification: Wearable Sensor Subsystem

Requirements	Verification
In emergency situations where one or more alerts have been triggered, the GPS update frequency increases from every 30 seconds to every 5 seconds.	1. Trigger one of the alerts (heart rate, temperature, or motion) while monitoring the GPS update frequency. 2. Have the person wearing the monitoring unit be continuously moving. 3. Record the GPS update intervals to verify that the unit updates every 5 seconds during an alert condition.
Reset the device if the button is pressed	1. Press the button and verify the device restarts

5. Requirements and Verification

Central Monitoring Hub Subsystem

The central hub acts as the control center for the network, gathering and visualizing health data from all firefighters in real time. It allows incident commanders to monitor the team's health status, detect potential health risks, and respond quickly to emergencies. Its rugged design ensures that it remains operational during operations in harsh environments. The enclosure will be designed using 3D Computer-aided design software and printed out using a 3D printer with Polylactic acid material (PLA). Although PLA might have lower heat-resistance, other materials like Polyetheretherketone (PEEK) could be replaced with the same design but with higher cost. For the purpose of this project, we will prioritize the design.

5. Requirements and Verification: Central Monitoring Hub Subsystem

Requirements	Verification
The central unit display should be able to visualize the firefighter data holistically	Have three wearable device sending out simulated information to the central unit to verify it is able to display the firefighters data holistically
Send out a critical alert and change of LED color when abnormal activities occur	Manually input data with different conditions (normal, abnormal, dangerous) to the subsystem and observe whether the alert is turned on or off and whether the LED color changes according to the condition

5. Requirements and Verification

Power Subsystem

The power subsystem ensures that both the wearable units and the central hub have the energy to operate continuously.

Power Consumption for Wearable Unit:
ESP32 Microcontroller (DOIT ESP32 DEVKIT V1): 2.2V to 3.6V at ~100mA to 200mA (Active)
Electrocardiogram Sensor (ECG/EKG Sensor) (SEN-12650): 3.3V to 5V at ~10 mA
Temperature Sensor (BMP 180): 3.3V at ~5 µA (1 sample/second in standard mode)
Accelerometer for Motion Detection (LSM6DS032): 1.71V to 3.6V at ~1.5 mA (Active Operation) and ~0.5 µA (Low-Power Mode)
GPS Module (MAX-M10S): 3.3V VCC at ~6mA to ~25mA
Buzzer (PS1240): 1.71V to 3.6V at ~20mA
LoRa Module for Extended Communication (RFM95W): 1.8V to 3.7V at 13.5 mA (Transmission) and 10 mA (Reception)

Power Consumption for Central Monitoring Unit:
ESP32 Microcontroller (DOIT ESP32 DEVKIT V1): 2.2V to 3.6V at ~100mA to 200mA (Active)
LoRa Module for Extended Communication (RFM95W): 1.8V to 3.7V at 13.5 mA (Transmission) and 10 mA (Reception)
3.5" TFT Touch Screen (HX8357D): 3.3V at ~20 mA to ~40 mA
Buzzer (PS1240): 1.71V to 3.6V at ~20mA

5. Requirements and Verification: Power Subsystem

Requirements	Verification
Wearable units should send alerts when the battery is low (below 10%) to the central unit.	Charge the device to 15% and operate the device until the battery drops down to 10% measuring with a multimeter to verify if the alert is sent.
Both the wearable unit and the central unit should last at least 2 hours on a single charge under typical operation conditions (temperatures above 30°C).	Simulate the sensor readings using ADALM2000, record the battery voltage every 5 mins to verify both the wearable unit and central unit has battery life longer than 2 hours.

5. Requirements and Verification

User Interface Subsystem

The user interface is designed to provide incident commanders with a comprehensive and intuitive platform for monitoring firefighter health data in real time. It features a custom-designed graphical user interface on a 3.5" TFT touch screen, ensuring clear visibility and easy navigation.

5. Requirements and Verification: User Interface Subsystem

Requirements	Verification
Custom-designed graphical user interface (GUI) for the 3.5" TFT touch screen	1. Visually inspect GUI layout on the actual 3.5" screen 2. Perform touch interaction tests covering all UI elements 3. Verify responsiveness and accuracy of touch inputs
Real-time data visualization components (graphs, charts, status indicators)	1. Simulate data input for graphs, charts, and status indicators 2. Verify real-time updates of visualizations 3. Test different data scenarios (normal, critical, edge cases) 4. Measure and verify update frequency matches requirements

5. Requirements and Verification: User Interface Subsystem

Requirements	Verification
Alert management system with visual and auditory cues	1. Trigger various alert conditions 2. Verify visual cues appear correctly on screen 3. Test auditory alerts for proper sound and volume 4. Confirm alert prioritization works as designed 5. Test alert acknowledgment and dismissal functionality
User input handling for system configuration and data queries	1. Test all system configuration options 2. Verify data query functionality with various input parameters 3. Confirm changes are applied and persist after system restart 4. Test edge cases and invalid inputs for proper error handling

5. Requirements and Verification

Mesh Network Integration

The LoRa Mesh Network provides long-range communication between nodes, ensuring connectivity even when traditional communication infrastructure is unavailable. This system enables reliable data transmission from firefighters' wearable units to the central hub in challenging environments.

5. Requirements and Verification: Mesh Network Integration

Requirements	Verification
End-to-end (including hops) data transmission time from any firefighter to the central unit shall not exceed 15 seconds, even when relaying through multiple nodes. Communication range of at least 1 km in open areas and 300 meters in urban environments.	Calculate the differences between the wearable unit packet sent time using gps time vs the central unit received time to verify the communication time is within 15 seconds.
The devices should be able to create its mesh network so even if a wearable is not directly in range to the central unit it can hop between the other wearable that's in range to connect to the central unit	1. Set up a test environment with multiple wearable units and obstacles to force multi-hop routing. 2. Gradually move units out of direct range of the central hub. 3. Verify data from out-of-range units successfully reaches the central hub via other units. 4. Use network visualization tools to confirm the mesh topology. 5. Simulate node failures to test self-healing capabilities. 6. Measure and compare latency for direct vs multi-hop communications.

5. Requirements and Verification: Health Status Assessment Data Processing

Requirements	Verification
For ECG signals, use filtering techniques, such as a low-pass filter with a cut-off frequency of 100 Hz to remove high-frequency noise, combined with a stop-band filter around 60 Hz to eliminate electrical noise interference	1. Use Matlab to plot raw and filtered ECG signals in the time domain. 2. Compare frequency spectra of raw and filtered signals using FFT. 3. Verify attenuation above 100 Hz and at 60 Hz.
For ECG signals, apply the Butterworth or Chebyshev filter to ensure sufficient attenuation of at least -60 dB/decade in the stopband, preserving the integrity of the ECG signal's primary components (P, QRS, T waves).	1. Apply the chosen filter (Butterworth or Chebyshev) to a known ECG signal. 2. Plot the frequency response of the filter and measure the attenuation in the stopband to confirm it meets or exceeds -60 dB/decade. 3. Compare the filtered signal with the original in both time and frequency domains to ensure preservation of P, QRS, and T waves. 4. Perform a quantitative analysis (e.g., cross-correlation) between original and filtered signals to verify integrity of primary components.

6. Tolerance Analysis

LoRa Communication Range

Requirement:

The LoRa module must ensure a communication range of at least 1 km in open areas and 300 meters in urban or obstructed environments.

Analysis:

To assess the feasibility of meeting this requirement, we'll consider the following factors:

1. LoRa Link Budget
2. Environmental Factors
3. Transmission Power

6. Tolerance Analysis

1. LoRa Link Budget

Link Budget = Transmitter Power + Transmitter Antenna Gain - Path Loss + Receiver Antenna Gain - Receiver Sensitivity

Assuming typical values for a LoRa system:

- Transmitter Power: 14 dBm (25 mW)
- Transmitter Antenna Gain: 2 dBi
- Receiver Antenna Gain: 2 dBi
- Receiver Sensitivity: -137 dBm (for SF12, BW125)

6. Tolerance Analysis

1. LoRa Link Budget

The path loss for 1 km in an open area can be estimated using the free-space path loss formula:

FSPL (dB) = 20 * log10(d) + 20 * log10(f) - 147.55

Where:

- d = distance in meters (1000)
- f = frequency in Hz (assume 915 MHz for US LoRa)

FSPL = 20 * log10(1000) + 20 * log10(915*10^6) - 147.55 ≈ 92 dB

Link Budget = 14 + 2 - 92 + 2 + 137 = 63 dB

This positive link budget suggests that communication at 1 km in open areas is feasible.

6. Tolerance Analysis

2. Environmental Factors

In urban or obstructed environments, additional path loss occurs due to obstacles. We can estimate this additional loss to be around 20-30 dB.

For 300 meters in an urban environment:

- FSPL = 20 * log10(300) + 20 * log10(915*10^6) - 147.55 ≈ 81 dB
- Total Path Loss = 81 dB + 25 dB (urban environment) = 106 dB
- Link Budget = 14 + 2 - 106 + 2 + 137 = 49 dB

This positive link budget indicates that communication at 300 meters in urban environments is also feasible.

6. Tolerance Analysis

3. Transmission Power

The analysis uses 14 dBm (25 mW) as the transmission power. Many LoRa modules can transmit at up to 20 dBm (100 mW), which would add an extra 6 dB to the link budget if needed.

6. Tolerance Analysis

Resilience of Mesh Network Communication to Maximum Allowable Delay

Requirement:

- Node Connectivity: Each wearable device must communicate with neighboring devices to relay data back to the central hub.
- Maximum Latency: The total transmission delay from a firefighter's device to the central unit must not exceed 15 seconds.

Analysis:

We'll consider the following factors:

1. Transmission Time Using LoRa
2. Maximum Number of Hops

6. Tolerance Analysis

1. Transmission Time Using LoRa

LoRa communication allows for long-range transmission with low data rates. LoRa uses a feature called the spreading factor (SF) to control the trade-off between data rate and range. As the distance between the transmitter and receiver increases, you may need to increase the spreading factor to maintain reliable communication.

Assuming a payload size of 400 bytes (3200 bits) and using a data rate of 3.13 kbps (for 3km in Open Areas and 500m in Urban Environments):

Transmission Time = 3200 bits / 3130 bps = 1.02 seconds (1022 ms)

This calculation indicates that transmitting data between neighboring firefighters will take approximately 1022 ms per hop.

6. Tolerance Analysis

2. Maximum Number of Hops

Given a maximum allowable total delay of 15 seconds, we can calculate the maximum number of hops n:

$$n = 15000 \text{ ms} / 1022 \text{ ms} \approx 14.68 \text{ hops}$$

While this theoretical maximum is high, practical application in a firefighting context is much lower. Considering a typical firefighting team size of 4 to 10 members, our analysis demonstrates that the mesh network can reliably support up to 14 hops between firefighters while still adhering to the 15-second maximum allowable delay for data transmission. This is based on a payload size of 400 bytes and a data rate of 3.13 kbps using LoRa communication.

6. Tolerance Analysis

Power Management

<u>Requirement:</u>

- The battery should last at least 2 hours on a single charge under typical operation conditions (temperatures above 30°C).

<u>Analysis:</u>

1. Battery Capacity (C): 2000 mAh lithium-ion battery.
2. Power Consumption (P): Total power consumption depends on the combined power draw of the sensors, ESP32 microcontroller, and communication modules (LoRa, ESP-MESH). The following current draw is based on the upper bound of current consumption data included in the power subsystem section.
3. Battery Discharge Efficiency (n): Efficiency factor, assume 60% due to heat and inefficiencies in power delivery (conversion losses).

6. Tolerance Analysis

1. Total Power Consumption

- Power Consumption of each Components
  - ESP32 microcontroller: 200 mA during active use.
  - EKG sensor: 10 mA.
  - Temperature sensor: 5 µA.
  - GPS sensor: 25 mA
  - Motion sensors (accelerometer/gyroscope): 1.5 mA.
  - LoRa module: 13.5 mA during transmission.
  - Buzzer: 20 mA
- P = 200 mA + 10 mA+ 5 µA +25 mA+ 1.5 mA + 13.5 mA + 20 mA<=271mA

6. Tolerance Analysis

2. Battery Runtime Calculation

To calculate the battery runtime, we can use the following formula: t = C*nP

Where:

- t is the battery runtime in hour
- C is the battery capacity in mAh
- n is the battery discharge efficiency
- P is the total power consumption

P = 200 mA + 10 mA+ 5 µA +25 mA+ 1.5 mA + 13.5 mA + 20 mA<=271mA

As a result, we get t = C*n / P=2000*0.6 / 271 = 4.43hr >= 4hr

Thus, the battery is expected to last approximately 4 hours under typical usage conditions, which satisfies the requirement of 2 hours of operation.

7. Cost Analysis

Three Subcategories

1. Purchased Components and Parts

2. Labor and Wages

3. Other Resources

1. Purchased Components and Parts

Description	Manufacturer	Part Number	Quantity	Unit Price	Extended Price	Part Link
GPS	SparkFun	MAX-M10S	1	$44.95	$44.95	Link
LoRa Transceiver	Adafruit	RFM95W	3	$19.95	$59.85	Link
3.5" TFT LCD Display	Adafruit	HX8357D	1	$39.95	$39.95	Link
Single Lead Heart Rate Sensor	Sparkfun	SEN-12650	1	$21.50	$21.50	Link
Temperature Sensor	Adafruit	BMP 180	1	$9.95	$9.95	Link
Accelerometer and Gyroscope	Adafruit	LSM6DS032	1	$12.50	$12.50	Link
Piezo Buzzer	PDK Corporation	PS1240	2	$1.50	$3.00	Link
Lithium Ion Battery	Adafruit	3.7V 2000mAh	3	$12.50	$37.50	Link
Micro-Lipo Charger	Adafruit	Micro-Lipo Charger	3	$4.90	$14.70	Link
ESP32-WROOM	Espressif Systems	DOIT ESP32 DEVKIT V1	3	$15.98	$47.94	Link
Total Purchased Components Price: $291.84						

2. Labor and Wages

- Annual salary for Computer Engineering students as a reference ($109,176/yr according to the Grainger College of Engineering)
- The number of work days in a year is approximately 365*(5/7) ≈ 261 days.
- Assume a person works 8 hours a day and 261 days per year
- Wage per hour is roughly $109,176 / (261*8hr) ≈ **$52/hr.**
- Over the course of 2 months, we plan to spend an average of 2 hours per day. Thus, the total labor cost will be $52/hr * 2 hr/day * 60 days * 3 students = **$18720**.

3. Other Resources

- Design doesn’t require any customized enclosure for the product, we do not plan to order any part from the ECE Machine shop.
- Plan to use the Senior Design Lab resources, such as PCB creation, multimeters for debugging, and soldering, which has no cost.

7. Cost Analysis

Total Cost

1. Purchased Components and Parts: $291.84
2. Labor and Wages: $18,720
3. Other Resources: $0

Total Cost: $19,011.84

8. Schedule and Division of Labor

Role	Name	Specialized Work
Network Communications Specialist	Kevin Huang	• Mainly focus on **Mesh Network and Data Transfer** • In charge of implementing and optimizing the mesh network • Will ensure reliable data transmission in challenging environments
Lead Hardware Engineer	Bryan Chang	• Mainly focus on **PCB Design and Battery** • Responsible for overseeing the design and integration of the wearable device hardware • Will focus on power management to ensure the 2-hour battery life goal is met
Software Integration Lead	Steven YM Chang	• Mainly focus on **User Interface and Monitoring Hub Software** • Responsible for developing the central monitoring hub software • Will work on data processing and alert generation algorithms

8. Schedule and Division of Labor

Week	Task	Person
09/30 ~ 10/06	Finalize Proposal (due on 10/04 at 11:59 PM)	Everyone
	Complete Design Document (due on 10/03 at 11:59 PM)	Everyone
10/7 ~ 10/13	Design Review with Professor and TAs (10/08 at 1:00 PM)	Everyone
	Order Components	Everyone
	Learn to use LoRa Module and ESP-32	Kevin
	Learn to use GPS, EKG, and temperature sensors	Steven
	Finish PCB Design and Review (due on 10/13 at 3-5 PM)	Bryan
10/14 ~ 10/20	First Round PCBway Order (due on 10/15 at 4:45 PM)	Everyone
	Team Evaluation I (due on 10/16 at 11:59 PM)	Everyone
	Get LoRa Transceivers to communicate	Kevin
	Start Designing the User interface and LCD	Steven & Bryan
	Learn how to do power management of Lithium-ion battery	Bryan
10/21 ~ 10/27	Second Round PCBway Order (due on 10/22 at 4:45 PM)	Bryan
	Assemble the Central Unit	Bryan
	Collect data from each sensor and design the algorithm for automatic alert	Steven & Kevin
	Implement the mesh network	Kevin & Bryan
10/28 ~ 11/03	Third Round PCBway Order (due on 10/29 at 4:45 PM)	Bryan
	Assemble the Wearable Unit	Bryan & Steven
	Test the mesh network to guarantee reliable data transmission	Kevin
	Implement algorithm for abnormal EKG/ECG activities	Steven & Kevin
11/04 ~ 11/10	Fourth Round PCBway Order (due on 11/05 at 4:45 PM)	Bryan
	Individual Progress Report (due on 11/06 at 11:59 PM)	Everyone
	Finalized Design Document (due on 11/10 at 11:59 PM)	Everyone

8. Schedule and Division of Labor

11/11 ~ 11/17	Fifth Round PCBway Order (due on 11/12 at 4:45 PM)	Bryan
	Start Integrating the Software	Steven
	Mount LCD & User Interface	Bryan & Kevin
	Finish Verifications of Sensor Results	Steven & Kevin
	Finalize Data Transmission and Alert Triggers	Bryan
	Practice Demo	Everyone
11/18 ~ 11/24	Mock Demo (during weekly TA meeting)	Everyone
	Team Contract Fulfillment (due on 11/24 at 11:59 PM)	Everyone
	Fix any Errors (if necessary)	Everyone

11/25 ~ 12/01	Fall Break	Everyone
	Work on Final Presentation and Paper	Everyone
	Practice Final Demo	Everyone
12/02 ~ 12/08	Final Demo with Instructor and TAs	Everyone
	Continue working on Final Paper	Everyone
	Mock Presentation with Comm and ECE TAs	Everyone
12/09 ~ 12/15	Final Presentation with Instructor and TAs	Everyone
	Final Paper (due on 12/11 at 11:59 PM)	Everyone
	Lab Notebook (due on 12/12 at 11:59 PM)	Everyone

9. Ethics and Safety

Data Privacy and Security

According to the ACM Code of Ethics, members should "respect the privacy of others" and "honor confidentiality" [8]. Monitoring firefighters' health data involves collecting sensitive personal information such as heart rate, surrounding temperature, and potentially location data. Any breach of this data could lead to privacy violations.

Solution: Implement strict access controls so only authorized personnel (e.g., the incident commander) can view the data.

Informed Consent

Firefighters must be fully informed about what data is being collected, how it will be used, and their rights to privacy under the IEEE Code of Ethics (Clause 1). This includes consent not only for data collection during their active duty but also how their data may be used in post-incident reviews.

Solution: Ensure that firefighters provide informed consent before wearing the monitoring devices. Offer clear and accessible explanations of what data will be collected, why, and how it will be protected.

9. Ethics and Safety

Fire and Water Resistance

Given that firefighters operate in extreme environments, we made the design choice to house the wearable unit within the protective layers of the firefighter's suit. This placement ensures that the components are shielded from direct exposure to high temperatures and water. While this reduces risks, we acknowledge that no system can fully eliminate all dangers. We aim to improve safety standards by enhancing the protection of critical electronics without compromising the function or comfort of firefighting gear. By situating the electronics inside the suit, we significantly reduce the risk of component failure due to environmental factors, contributing to both firefighter safety and operational reliability, in line with the IEEE's Code of Ethics Section I.5 to "be honest and realistic in stating claims or estimates" [3].

9. Ethics and Safety

Lithium-Ion Battery Safety

Lithium-ion batteries, while efficient, can pose risks such as overheating or physical damage, leading to dangerous conditions like thermal runaway—a situation where excessive heat can trigger a self-sustaining reaction resulting in fire or explosion [5]. To mitigate these risks, we will implement general safety precautions when using lithium-ion batteries, including:

- Proper Storage: Store batteries in a cool, dry place away from flammable materials to prevent overheating and reduce fire risk.
- Avoiding Physical Damage: Ensure that batteries are not exposed to impacts, punctures, or other physical stresses that could compromise their integrity.
- Safe Charging Practices: Use compatible chargers and avoid overcharging batteries, as this can lead to thermal runaway. Disconnect chargers once the battery reaches full charge. Ensure that charging is performed using LiPo safety bags.
- Regular Inspections: Conduct regular inspections of the battery for signs of swelling, leakage, or corrosion, and replace any batteries displaying these signs

By integrating these precautions and following best practices for lithium-ion battery usage, our design aligns with the IEEE's ethical commitment to enhancing the safety, health, and welfare of the public [3]. These measures ensure the reliability and long-term safety of our monitoring system, supporting firefighter operations in hazardous environments.