VISVESVARAYA TECHNOLOGICAL UNIVERSITY

JNANA SANGAMA, BELAGAVI-590014

A Project Report

on

"Smart Soldier Suit safety wearables with IOT/IIOT Integration for Health monitoring & Environmental Sensing"

Submitted in the partial fulfillment of the requirement for the award of

Bachelor of Engineering

in

Information Science and Engineering

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2025-2026

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This is to certify that the project report entitled "**Smart Soldier Suit safety wearables with IOT/IIOT Integration for Health monitoring & Environmental Sensing**" is a bonafide work carried out by **Anjali Ramesh Gurav(1DT22IS016), Anusha M(1DT22IS017), Anushree G M(1DT22IS018)** in the partial fulfillment of the requirement for the award of degree in Bachelor of Engineering in Information Science and Engineering in college name for Visvesvaraya Technological University, Belagavi for the year 2025-2026. It is certified that all corrections/suggestions indicated for the internal assessment have been incorporated in the report. This report has been approved as it satisfies the academic requirements in respect of project work prescribed for Bachelor of Engineering Degree.

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ABSTRACT

The modernization of military warfare requires advanced systems to ensure the safety, health, and situational awareness of soldiers operating in hazardous environments. The primary objective of this project is to design and implement a "Smart Soldier Suit," a wearable IoT-based system capable of real-time health monitoring, environmental sensing, and geolocation tracking without relying on internet connectivity.

The system is built using two ESP32 microcontrollers communicating via the low-latency ESP-NOW protocol. The Soldier Unit integrates a NEO-6M GPS for location tracking, a DHT11 sensor for environmental temperature, an Ultrasonic sensor for enemy motion detection, and inputs to simulate vital signs (Heart Rate and Oxygen levels). The Base Station acts as a command hub, displaying telemetry data on an LCD and forwarding it to a mobile application via Bluetooth.

Results from the prototype demonstrate successful wireless transmission of data with high reliability. The system effectively triggers immediate visual and digital alerts upon detecting critical anomalies, such as low oxygen levels, panic button activation, or approaching threats within a 2-meter radius. In conclusion, this project validates the effectiveness of using low-cost, decentralized IoT technologies to create a robust offline monitoring network, significantly enhancing soldier survivability and enabling rapid response coordination in critical field operations.

ACKNOWLEDGEMENT

We would like to take this opportunity to express our sincere thanks and gratitude to all those who have been kind enough to guide when needed which has led to the successful completion of the project.

We would like to express our special thanks and gratitude to **Management** of Dayananda Sagar Academy of Technology and Management for providing all the required facility.

We would like to convey our immense gratitude to **Dr**. **Ravishankar M**, Principal, Dayananda Sagar Academy of Technology and Management and **Dr.Nandini Prasad K S**, Dean-Foreign Affairs & HOD, Department of Information Science and Engineering, Dayananda Sagar Academy of Technology and Management, Bangalore, for their continuous support and encouragement which enabled us to come up with this project and also thank them for providing the right ambience for carrying out the same.

We would like to express our profound gratitude to our Project Guide**-Dr. Rashmi Soni, Associate Professor,** Department of Information Science and Engineering, Dayananda Sagar Academy of Technology and Management, Bangalore for her continuous support and encouragement.

We extend our sincere gratitude to the project coordinators, **Dr. Rashmi Amardeep,** Associate Professor and **Mrs. Kavyashree G M**, Assistant Professor, Department of Information Science and Engineering, Dayananda Sagar Academy of Technology and Management, Bangalore, for their guidance and suggestions for successful completion of our project.

We would like to thank our parents and friends who helped us in finalizing this project within the stipulated time frame.

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Overview

The landscape of modern military operations has undergone a radical transformation in the 21st century. We have transitioned from the era of large-scale, symmetrical industrial warfare to an age defined by asymmetric threats, rapid mobility, and information dominance. In this contemporary theater of conflict, the individual soldier remains the most critical asset of any defense force. However, the threats facing the modern infantryman have evolved significantly. Soldiers are no longer just targets of kinetic weaponry; they are exposed to extreme environmental hazards, unseen biological stresses, and the constant psychological strain of operating in hostile territory where the enemy is often indistinguishable from the civilian population.

Historically, military command structures have struggled with the "Fog of War"—the uncertainty in situational awareness experienced by participants in military operations. Commanders at base stations often lack real-time visibility into the physical and physiological status of their troops deployed in the field. Traditional communication methods, such as radio frequency (RF) voice transmission, have been the backbone of military coordination for decades. While effective for conveying orders, voice communication is inherently limited. It is non-continuous, prone to human error, and requires active participation from the soldier. A soldier suffering from silent hypoxia (low oxygen), heatstroke, or hypothermia cannot always articulate their condition over a radio. Furthermore, in stealth operations where radio silence is mandatory to avoid detection, a soldier has no way to silently communicate distress or receive alerts about immediate proximity threats.

This project, the IoT-Based Advanced Soldier Security and Health Monitoring System, addresses these critical gaps by proposing a paradigm shift from reactive communication to proactive, data-driven monitoring. By leveraging the Internet of Military Things (IoMT), this system transforms the soldier from a disconnected entity into an integrated node within a secure digital network. The core philosophy of this project is that "Information is Ammunition." By providing real-time data on the soldier's location (GPS), health status (Oxygen/Temperature), and immediate environment (Proximity), we can drastically reduce casualty rates caused by non-combat factors and improve tactical decision-making during combat.

1.1.2 The Physiological and Environmental Imperative

Military statistics globally indicate that a significant percentage of soldier casualties occur not due to direct enemy fire, but due to physiological failure and environmental exposure. Operations in high-altitude regions (such as the Himalayas or the Andes) expose soldiers to low atmospheric pressure, leading to Hypoxia—a condition where the body is deprived of adequate oxygen supply. Hypoxia is insidious; it impairs cognitive function and physical performance before the soldier is even aware of the danger. Without real-time monitoring of blood oxygen saturation (SpO2), a soldier may collapse without warning, jeopardizing the entire mission.

Similarly, operations in desert or tropical environments carry the risk of heatstroke and hyperthermia. The human body has thermal limits; when a soldier is encased in heavy body armor, carrying a standard load of 30-40kg, and moving through high temperatures, their core body temperature can spike rapidly. Conversely, in arctic conditions, hypothermia is a constant threat. This project integrates a Temperature Monitoring System (using the DHT11 sensor) to constantly track ambient and proximity temperature conditions, allowing the Base Station to issue recall orders or medical interventions before a soldier reaches a critical physiological state.

Furthermore, the modern battlefield is rarely a clearly defined front line. Enemies may approach from any direction. The inclusion of an Ultrasonic Proximity Sensor in this system addresses the need for "local situational awareness." In scenarios where visibility is low—such as night operations, dense fog, or jungle warfare—electronic eyes are faster and more reliable than human vision. By detecting obstacles or intruders within a specific radius (e.g., <50cm), the system provides an extra layer of automated security for the soldier.

1.1.3 Technological Architecture: The Dual-ESP32 Paradigm

To implement this vision, this project utilizes a Dual-Microcontroller Architecture centered around the ESP32 system-on-chip (SoC). The choice of the ESP32 is a deliberate technological leap over older 8-bit microcontrollers like the Arduino Uno or Nano for the primary processing tasks. The ESP32 offers a dual-core processor running at 240 MHz, built-in Wi-Fi and

Bluetooth capabilities, and significantly higher processing power required to handle multiple sensors simultaneously.

The system is divided into two distinct, synchronized units:

1.The Soldier Unit (The "Scout" / Sender):

This is a wearable, portable, and energy-efficient unit designed to be mounted on the soldier's uniform or gear. It acts as the "Data Acquisition Node." Its primary function is to aggregate data from the sensor array—specifically the GPS module for geolocation, the DHT11 for temperature, the Potentiometer (simulating SpO2 sensors), and the Ultrasonic sensor for radar-like proximity detection. Critically, the Soldier Unit is designed with a "Stealth-First" philosophy. In tactical scenarios, noise discipline is absolute. A loud buzzer going off on a soldier's arm could reveal their position to the enemy, leading to immediate danger. Therefore, this system implements a Silent Alert Mechanism using an OLED Display. When a threat is detected (e.g., an enemy approaching from behind or oxygen levels dropping), the screen flashes a high-contrast visual warning ("DANGER"). This allows the soldier to be warned without breaking noise discipline.

2**. The Base Station (The "Commander" / Receiver):**

This unit sits at the command post or with the squad leader. It acts as the "Data Aggregation and Visualization Hub." Unlike the Soldier Unit, the Base Station is designed for high-visibility alerting. It features a large 16x2 LCD Screen to display the incoming telemetry and a Loud Active Buzzer. The logic here is asymmetrical: while the soldier must remain silent, the commander must be immediately alerted to any danger. If the Soldier Unit detects a threat, it sends a wireless signal to the Base Station, which then sounds the alarm. This ensures that even if the soldier is incapacitated or unable to call for help, the Base Station is already aware of the emergency.

1.1.4 The Communication Protocol: ESP-NOW

A critical innovation in this project is the rejection of standard Wi-Fi or Bluetooth for the primary communication link in favor of ESP-NOW. Standard Wi-Fi requires a central router, which is non-existent in a forest or battlefield. Bluetooth has a very short range (approx. 10 meters) and high latency for pairing.

ESP-NOW is a connectionless communication protocol developed by Espressif that features:

- Low Latency: Data transmission happens in milliseconds, which is vital for real-time alerts.
- Long Range: Without a router, ESP-NOW can achieve ranges of up to 200 meters line-of-sight, which is significantly better than Bluetooth.
- Independence: It creates a peer-to-peer network. The Soldier Unit and Base Station talk directly to each other without needing the internet, a SIM card, or satellite connectivity. This makes the system resilient against infrastructure failure and jamming of standard cellular networks.

1.1.5 Strategic Integration of Global Positioning System (GPS)

Knowledge of "Where" is just as important as "How." A soldier suffering from a heart attack is difficult to rescue if their location is unknown. This project integrates the NEO-6M GPS Module, a high-precision satellite receiver. This module constantly communicates with orbiting satellites to triangulate the soldier's exact position on the Earth's surface (Latitude and Longitude).

This data is not just displayed locally; it is encapsulated into the data packet and transmitted to the Base Station. In a real-world scenario, this allows the Commander to input the coordinates into mapping software (like Google Maps or Military Grid Reference Systems) to direct Medevac (Medical Evacuation) helicopters or extraction teams to the precise meter where the soldier is located. This feature addresses the "Golden Hour" principle in trauma care, where the survival rate of a casualty drops precipitously if they do not receive care within the first hour of injury.

1.1.6 ID Authentication and Friendly Fire Prevention

In chaotic combat zones, distinguishing between friend and foe is a major challenge. This system incorporates an ID Authentication Mechanism (simulated via a Push Button). This feature serves a dual purpose. First, it acts as a "Dead Man's Switch" or a "Check-In" system. The soldier can press the button to signal "I am safe" or "I am authorized." Second, it integrates with the proximity logic. If the ultrasonic sensor detects movement nearby, but the ID button is NOT pressed (or a paired RFID tag is not detected in a future iteration), the system classifies the movement as a potential "Enemy." This rudimentary Identification Friend or Foe (IFF) logic is the foundation of preventing friendly fire incidents and unauthorized access to secure perimeters.

1.1.7 Energy Efficiency and Portability

For any wearable military technology, "Size, Weight, and Power" (SWaP) are the critical constraints. A system that is too heavy or runs out of battery in 2 hours is useless in the field. This project optimizes for SWaP by using the ESP32's power-management capabilities. The sensors chosen (DHT11, Ultrasonic) are low-power components. By using an OLED screen on the Soldier Unit instead of a backlit LCD, power consumption is drastically reduced, allowing the unit to run for extended periods on standard portable Power Banks (Lithium-Ion cells). This portability ensures that the system does not become a logistical burden on the soldier.

1.2 Existing System And Drawbacks

Existing System:

1.2.1 Existing System

The current standard for infantry coordination and health management in most defense forces relies heavily on legacy technology and manual protocols. The "Existing System" can be categorized into three primary domains: Communication, Navigation, and Health Monitoring.

Radio Frequency (RF) Voice Communication:

The backbone of the existing system is the tactical radio. Soldiers communicate with their squad leaders and Base Stations using half-duplex RF transceivers. This requires active participation; a soldier must physically press a Push-to-Talk (PTT) button to convey information. Status reports are typically given at set intervals (e.g., "Check-in every hour") rather than continuously.

Manual Navigation and Handheld GPS:

While Global Positioning System (GPS) technology is widely used, it is often deployed as a standalone handheld unit (like a Garmin or military-grade DAGR) rather than an integrated wearable. The soldier must look at the device, read the coordinates, and then verbally relay them over the radio to the commander. There is no automated telemetry stream that puts the soldier's dot on the commander's map automatically in real-time.

"Buddy System" Health Monitoring:

Currently, there is no widely deployed automated system for monitoring soldier physiology. Health monitoring relies entirely on the "Buddy System," where soldiers are trained to visually observe their team members for signs of distress (sweating, confusion, pallor). If a soldier suffers from Hypoxia (low oxygen) or heatstroke, the symptoms are often internal and cognitive before they become physical. By the time a "Buddy" notices the soldier is stumbling or incoherent, the medical emergency is already critical.

Drawbacks

Despite their widespread use, these traditional systems suffer from critical limitations in the context of modern, high-stakes warfare:

1. **Discontinuous Data Stream (The "Blind Spot" Problem):**

   The most significant drawback is that communication is non-continuous. Between radio check-ins, the Base Station has zero visibility into the soldier's status. A soldier could be ambushed, suffer a cardiac event, or fall unconscious in the time between check-ins, and the command center would remain unaware until the next scheduled contact. This time lag can be fatal.

2. **Reliability on Human Input (Cognitive Load Failure):**

   The existing system assumes the soldier is conscious and capable of speaking. However, in scenarios of Hypoxia (altitude sickness) or Hypothermia, cognitive function degrades rapidly. A confused soldier often believes they are fine and will not radio for help. Furthermore, during an intense firefight, a soldier cannot spare a hand to key a radio microphone to report their health or position. The system fails exactly when it is needed most.

3. **Lack of Stealth (The Noise Discipline Issue):**

   Traditional radios generate noise. Incoming transmissions can give away a position, and the act of speaking into a microphone compromises silence. There is currently no effective mechanism for a "Silent Alarm" where a soldier can silently signal distress or receive a warning without making a sound or looking at a bright handheld screen.

4. **Inability to Detect Environmental Threats:**

   Human senses are limited in the dark or in dense terrain (jungle/fog). The existing system relies entirely on the soldier's eyes and ears to detect enemies. There is no automated "Sixth Sense" or proximity radar to warn a soldier of an enemy approaching from a blind spot or waiting in ambush in low-visibility conditions.

5. **Post-Trauma Location Latency:**

   If a soldier is injured and becomes unconscious, they cannot read their GPS coordinates to the Medevac team. Search and rescue teams must rely on the "last known position," which may be kilometers away from the soldier's actual current location. This delay in locating the casualty violates the "Golden Hour" principle of trauma care.

Problem Statement:The core problem addressing this project is the lack of real-time, automated, and continuous visibility into the physiological and physical status of infantry soldiers operating in remote or hostile environments.

Modern military command structures suffer from an information gap—the "Fog of War"—where the precise location and health condition of deployed troops are unknown during the intervals between manual radio communications. This disconnect leads to three critical issues:

1. Preventable Non-Combat Casualties: Soldiers succumb to environmental hazards such as high-altitude hypoxia, heatstroke, and hypothermia because these conditions are not detected until they reach a critical, often irreversible, stage.
2. Delayed Rescue Response: In the event of incapacitation, the lack of automated GPS telemetry forces rescue teams to search wide areas based on outdated information, significantly increasing the time to treatment.
3. Tactical Vulnerability: Soldiers lack automated proximity awareness in low-visibility scenarios and lack a method to receive silent, stealthy warnings, making them vulnerable to ambushes and compromising mission secrecy.

There is an urgent need for a low-cost, low-power, wearable solution that bridges this gap by converting the soldier from a disconnected individual into a monitored node within a secure data network, ensuring that "No Soldier is Left Behind."

1.3 Proposed System

The proposed solution is an IoT-Based Advanced Soldier Security and Health Monitoring System utilizing a Dual-ESP32 Architecture to create a robust, long-range, wireless telemetry link between the field soldier and the command center.

This system replaces manual reporting with Automated Telemetry. It consists of two distinct, synchronized subsystems:

The Soldier Unit (Wearable Transmission Node)

This unit is designed to be worn by the soldier. It operates on a portable power source (Power Bank) and prioritizes Stealth and Sensing.

- Central Processor: ESP32 Microcontroller (chosen for its dual-core processing and Wi-Fi capabilities).
- Physiological Sensing:

    - Oxygen Monitoring: A sensor simulation (Potentiometer) represents a Pulse Oximeter, constantly tracking blood oxygen saturation levels to prevent hypoxia.
    - Environmental Monitoring: A DHT11 Sensor tracks ambient temperature to warn against heatstroke or freezing conditions.
- Tactical Sensing:
    - Proximity Radar: An Ultrasonic Sensor (HC-SR04) acts as a short-range radar, detecting obstacles or intruders within a 50cm radius, useful for guarding blind spots or navigating in the dark.
    - Geolocation: A NEO-6M GPS Module constantly communicates with satellites to acquire precise Latitude and Longitude coordinates.
- Stealth Output Interface: Unlike traditional radios, this unit utilizes an OLED Display for alerts. If a threat is detected (Low Oxygen or Enemy Proximity), the screen flashes a high-contrast visual warning ("DANGER"). This ensures the soldier is alerted without a sound, maintaining noise discipline.

The Base Station (Command & Monitoring Node)

This unit is stationed with the Squad Leader or at HQ. It acts as the "Dashboard" for the operation.

- Wireless Receiver: A second ESP32 unit utilizes the ESP-NOW protocol to receive encrypted data packets from the Soldier Unit without needing a Wi-Fi router or internet connection.
- Visual Dashboard: A 16x2 I2C LCD Screen displays a constant feed of the soldier's vital signs (Oxygen %, Temp) and tactical status (Safe/Danger).
- Audible Alert System: An Active Buzzer is integrated here. While the soldier remains silent, the Commander is loudly alerted to any anomalies. If the Soldier Unit sends a "Distress" flag, the Base Station buzzes immediately, prompting the commander to check the GPS coordinates and deploy help.

C. The Communication Link (ESP-NOW)

The system connects the two units using ESP-NOW, a connectionless communication protocol. This enables:

- Range: Up to 200 meters line-of-sight communication.
- Independence: The system works in deep forests, deserts, or mountains where no cellular network (GSM/4G) exists.

- Speed: Data is transmitted in milliseconds, ensuring real-time responsiveness.

1.4 Advantages

The proposed system offers significant operational improvements over existing legacy methods:

1. **Real-Time Health Analytics (Proactive vs. Reactive):**

Unlike the "Buddy System" which relies on human observation, this system provides objective, quantifiable data. It detects a drop in Oxygen levels (e.g., $<85\%$) *before* the soldier faints, allowing for preventative recall or oxygen administration. It shifts medical response from "Reaction" to "Prevention."

2. **Stealth Capability (Silent Operation):**

The inclusion of the OLED-based "Silent Alert" system is a major tactical advantage. Soldiers can receive critical warnings about their health or environment without breaking radio silence. This preserves their camouflage and position secrecy during covert operations.

3. **Infrastructure Independence (Works Anywhere):**

By using ESP-NOW, the system does not rely on GSM towers, Satellite phones, or Internet Routers. It creates its own private network. This means the system is fully functional in dead zones, deep valleys, or dense jungles where standard mobile phones fail.

4. **Automated Distress Signaling:**

In the event a soldier is incapacitated (unconscious), the system continues to broadcast their location and status automatically. The "Dead Man's Switch" functionality (via the ID button logic) ensures that if a soldier cannot respond, the Base Station is still notified of the potential threat.

5. Enhanced Situational Awareness for Command:

The Commander no longer has to guess the status of the squad. The Base Station provides a "God's Eye View" of the troops, displaying exact GPS coordinates and health vitals. This reduces the cognitive load on the commander and allows for faster, data-driven decision-making during combat or rescue operations.

6. Cost-Effective and Scalable:

Compared to military-grade biometric suits which cost thousands of dollars, this system utilizes off-the-shelf components (ESP32, Ultrasonic, DHT11), making it extremely cost-effective to deploy for large numbers of troops. It is modular, meaning sensors can be added or removed based on the specific mission requirements.

CHAPTER 2

LITERATURE SURVEY

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction to the Domain

The modern battlefield is undergoing a paradigm shift from conventional warfare to technology-driven operations. In this context, the infantry soldier remains the most valuable yet vulnerable asset. The concept of the "Future Soldier" or "Smart Soldier" has emerged as a focal point for defense research organizations worldwide. This domain intersects several cutting-edge fields: the Internet of Things (IoT), Industrial IoT (IIoT), Artificial Intelligence (AI), Biomedical Engineering, and Embedded Systems.

The primary objective of this literature survey is to explore the evolution of soldier support systems, ranging from basic health tracking mechanisms to advanced, AI-integrated combat suits. By reviewing recent publications, conference papers, and technical reports, we aim to understand the current state of the art, identify the technological limitations regarding power consumption, communication range, and sensor integration, and justify the necessity of the proposed "Smart Soldier Suit" system.

The survey is categorized into four distinct themes:

1. **Health and Vital Signs Monitoring Systems:** Focusing on physiological tracking.
2. **Robotics and Autonomous Support:** Focusing on external assistance.
3. **Advanced Computing (AI & FPGA) in Defence:** Focusing on data processing.
4. **Wireless Communication Infrastructures:** Focusing on data transmission protocols.

2.2 Thematic Review of Existing Literature

2.2.1 Evolution of Health Monitoring Systems

Monitoring the physiological status of a soldier is crucial for preventing non-combat casualties caused by heatstroke, hypothermia, or fatigue.

Patel et al. (2024) [8] presented a foundational framework in their paper *"Soldiers Health Monitoring and Position Tracking System."* Their research highlighted that a significant percentage of military casualties occur due to the delay in medical response rather than the injury itself. They proposed a system integrating GPS tracking with basic pulse monitoring. While effective in logging data, their system relied heavily on cellular (GSM) connectivity, which poses a significant risk in remote operational areas where signal jamming is common or infrastructure is non-existent.

Building upon this, **Arsalan et al. (2018) [2]** developed the *"Military Uniform for Health Analytics for Field Intelligent Zone (MUHAFIZ)."* This project introduced the concept of a "Field Intelligent Zone," where soldiers act as nodes in a network. The MUHAFIZ system utilized bio-sensors to monitor vital signs and transmit them to a control room. A key strength of this study was the integration of environmental sensing alongside health data. However, the study noted limitations regarding the bulkiness of the sensors and the lack of real-time predictive alerts; the system was primarily data-logging rather than decision-making.

Jethwa et al. (2020) [7] focused on the embedded electronics aspect in *"Realtime Wireless Embedded Electronics for Soldier Security."* Their work emphasized the need for miniaturization. They argued that traditional medical equipment is too heavy for combat. Their proposed solution utilized low-power microcontrollers to read body temperature and heart rate. A significant critique of this work is the lack of encrypted communication, leaving the data vulnerable to interception by enemy electronic warfare units.

2.2.2 Smart Uniforms and "E-Outfits"

Moving beyond discrete sensors, recent research has focused on integrating technology directly into the fabric or structure of the soldier's attire.

Daou et al. (2021) [5] detailed the *"Design and Implementation of a Smart Soldier Uniform."* Their approach was holistic, suggesting that the uniform itself should be the platform for all sub-systems. Their prototype included modules for communication, health, and navigation. The study provided excellent insights into power management, suggesting that distributing batteries across the vest could improve balance and longevity. However, their reliance on standard Wi-Fi protocols limited the effective range of the system in dense urban environments.

In a similar vein, **M. S. H. et al. (2022) [3]** coined the term *"Smart Military E-Outfit of the Future."* Their research explored the integration of flexible electronics and conductive fabrics.

They envisioned a system where the "wiring" is woven into the uniform. While revolutionary, the manufacturing complexity and cost of such systems currently make them prohibitive for mass deployment in developing nations. Our proposed project attempts to bridge this gap by using modular, off-the-shelf components that can be retrofitted onto existing gear rather than requiring custom fabrics.

F. A. et al. (2024) [9] discussed *"Revolutionizing Remote Mission Support: A Smart Suit for Tracking and Vital Sign Monitoring."* This paper is particularly relevant as it introduces the concept of "Remote Mission Support," where the base station plays an active role in the soldier's safety. Their work validates our choice of including a "Base Station" module with visual displays (LCD), ensuring that the data collected has an immediate observer.

2.2.3 Artificial Intelligence and Advanced Computing

The influx of sensor data creates a need for intelligent processing. Raw data (e.g., a heart rate of 100 bpm) is useless without context (e.g., is the soldier running or resting?).

Gaikwad et al. (2019) [4] took a high-performance approach in *"FPGA Implementation of Real-Time Soldier Activity Detection."* They utilized a Field-Programmable Gate Array (FPGA) to run Neural Network classifiers. Their system could accurately distinguish between crawling, running, and falling. While FPGAs offer immense speed, they consume significantly more power than microcontrollers like the ESP32. For a battery-operated wearable, the high power draw of an FPGA is a critical drawback that our project aims to solve by using lightweight algorithmic logic on a low-power MCU.

El-Sofany (2024) [11] focused on security in *"Using machine learning algorithms to enhance IoT system security."* This paper addressed a critical vulnerability: the hacking of soldier wearables. El-Sofany proposed AI algorithms to detect anomalies in network traffic that might indicate a cyberattack. This literature informs our project's future scope, highlighting the need for encrypted communication protocols like ESP-NOW, which offers better security through localized pairing than open public networks.

2.2.4 Robotics and IoT Infrastructure

The broader ecosystem of the battlefield includes robots and the overarching Internet of Military Things (IoMT).

Gnanaprakasam et al. (2023) [1] proposed a *"Novel Design of Smart and Intelligent Soldier Supportive Wireless Robot."* Their work suggests that soldiers should not carry heavy loads; instead, a wireless robot should follow them carrying supplies and sensors. While this reduces the physical burden on the soldier, robots cannot accompany infantry into tight spaces, tunnels, or rugged mountain terrains. This reinforces the need for a *wearable* suit that ensures the soldier is self-reliant even when separated from support units.

Perwej (2021) [13] conducted an *"Empirical Study on the Current State of Internet of Multimedia Things (IoMT)."* This paper explored the transmission of high-bandwidth data (video/audio). While our current project focuses on telemetry (text/numbers), Perwej's work highlights the bandwidth limitations of current military networks.

Rajora (2024) [12] analyzed *"The Impact of the IoT on Military Operations."* This broad survey paper categorized the challenges of military IoT into three buckets: Energy Efficiency, Interoperability, and Reliability. Our project directly addresses "Reliability" by using a dual-alert system (Local OLED + Remote Base Station) to ensure redundancy.

2.3 Comparative Analysis of Existing Methodologies

The following table summarizes the key technologies, features, and limitations of the most relevant papers reviewed.

Table 2.1: Comparative Analysis of Literature

Ref	**Author / Year**	**Core Technology**	**Key Features Proposed**	**Limitations / Gaps Identified**
[8]	Patel et al. (2024)	GSM Module, GPS, Pulse Sensor	Tracks soldier location and heart rate; sends SMS to control room.	Dependent on GSM cellular towers. If the tower is destroyed or jammed, the system fails.

				High latency in SMS.
[2]	Arsalan et al. (2018) (MUHAFIZ)	Zigbee, Bio-sensors	Monitors health within a "Field Intelligent Zone." Low power consumption.	Zigbee has a very short range (10-20m). Requires a complex mesh network to cover a battlefield.
[7]	Jethwa et al. (2020)	Embedded Electronics (AVR)	Focus on miniaturization of electronics for comfort.	Lacked a robust display interface for the soldier. Data was one-way only (Soldier to Base).
[4]	Gaikwad et al. (2019)	FPGA, Neural Networks	High-accuracy activity detection using AI hardware.	High cost and high power consumption. FPGAs are difficult to reprogram in the field.

[5]	Daou et al. (2021)	Wi-Fi, Custom PCB	Integrated uniform design. Focus on ergonomics.	Wi-Fi consumes high battery power. Wi-Fi signals are easily detectable by enemy forces.
[14]	Xilir Projects (2012)	Peltier Modules	Focus on *temperature regulation* (heating/cooling) rather than monitoring.	High power drain. Did not include location tracking or vital sign monitoring.
[1]	Gnanaprakasam (2023)	Robotics, Wireless RF	A robotic assistant follows the soldier.	Robots are not agile in all terrains. Expensive to deploy for every single soldier.
[12]	Rajora (2024)	Theoretical IoT Framework	Analyzed security and interoperability challenges.	Purely theoretical study; provided no hardware prototype or

				implementation results.
Proposed	Smart Soldier Suit	ESP32, ESP-NOW, Bluetooth	Hybrid Communication (Long range + Local App), Motion Detection, GPS, Low Cost.	Prototype stage. Range limited to ~200m without LoRa add-on.

2.4 Technology Gap Analysis

Based on the extensive review of the papers listed above, several critical "Gaps" in the existing technology have been identified. These gaps serve as the motivation for our proposed system.

2.4.1 The Communication Gap

Most existing systems rely either on **GSM/Cellular** ([8], [9]) or **Standard Wi-Fi** ([5], [10]).

- The Problem*:* In a real war zone, cellular towers are often the first targets destroyed. Standard Wi-Fi requires a router, which is not mobile.
- Our Solution: This project utilizes **ESP-NOW**. This is a peer-to-peer protocol that allows the Soldier Unit to talk directly to the Base Station without a router, internet, or SIM card. This makes the system independent and field-deployable.

2.4.2 The Environmental Sensing Gap

Many studies focus exclusively on Health ([2], [8]) or exclusively on Robotics ([1]). Very few integrate "Enemy Detection" into the wearable itself.

- The Problem: A soldier might be healthy, but if they are unaware of an enemy approaching from behind, they are in danger.

- Our Solution: We integrate an **Ultrasonic Sensor** programmed for *Motion Detection*. This gives the soldier a "sixth sense" regarding their immediate physical surroundings, alerting them to movement within 4 meters.

2.4.3 The User Interface Gap

Previous systems often focused on sending data to the commander but left the soldier in the dark. Systems like [7] sent data away but gave no feedback to the wearer.

- The Problem: If a soldier is entering a hypoxic (low oxygen) area, they need to know *immediately* on their own wrist, not wait for a commander to call them.
- Our Solution*:* We implement a dual-display philosophy. An **OLED Screen** on the soldier's unit provides immediate self-awareness, while the Base Station **LCD** keeps command informed.

2.5 Conclusion of Literature Survey

The survey of papers [1] through [14] confirms that while "Smart Soldier" technology is a rapidly growing field, there is no single solution that perfectly balances cost, autonomy, and functionality. High-end systems using FPGAs [4] are too power-hungry, while simple GSM trackers [8] are too dependent on infrastructure.

The literature validates the need for a **Low-Cost, Independent, and Integrated** system. By combining the health monitoring concepts of [2], the tracking capabilities of [8], and the remote support ideas of [9] into a single ESP32-based architecture, this project aims to create a superior prototype that addresses the limitations of power, connectivity, and situational awareness identified in previous studies.

CHAPTER 3

SOFTWARE REQUIREMENTS SPECIFICATION

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3.1 Hardware Requirements

To successfully develop, deploy, and operate the Smart Soldier Suit system, specific hardware configurations are required for both the development environment (PC) and the operational environment (The IoT Nodes).

3.1.1 Development Environment (PC/Laptop)

The following hardware is required for the developer to write code, compile firmware, and upload it to the microcontrollers.

Table 3.1:List of development Environment

Component	Minimum Requirement	Recommended Requirement
Processor	Intel Core i3 (5th Gen) or AMD Ryzen 3	Intel Core i5 (8th Gen) or higher
RAM	4 GB	8 GB or higher (for fast compilation)
Storage	250 GB HDD	256 GB SSD (Faster I/O operations)
Ports	2x USB 2.0/3.0 Ports	3x USB 3.0 Ports (For simultaneous debugging)
Operating System	Windows 10 (64-bit) / Linux Ubuntu 20.04	Windows 11 (64-bit)
Connectivity	Standard Wi-Fi / Bluetooth 4.0	Bluetooth 5.0 (For testing BLE features)

3.1.2 Operational Environment (Project Hardware)

These are the hardware components that constitute the actual product (The Soldier Suit and Base Station).

A. Soldier Unit (Transmitter Node)

- **Microcontroller:** ESP32 Development Board (DOIT DEVKIT V1) – Dual Core, 240 MHz.
- **Location Sensor:** u-blox NEO-6M GPS Module with EEPROM and Ceramic Antenna.
- **Environmental Sensor:** DHT11 Temperature and Humidity Sensor.
- **Distance Sensor:** HC-SR04 Ultrasonic Module (Range: 2cm – 400cm).
- **Display:** 0.96-inch OLED Display (128x64 pixels, I2C interface).
- **User Input:** 10kΩ Potentiometer (Oxygen Simulation), Tactile Push Button (Panic).
- **Power Source:** 5V DC via USB Power Bank (2000mAh or higher).

B. Base Station (Receiver Node)

- **Microcontroller:** ESP32 Development Board.
- **Display:** 16x2 LCD with I2C Backpack (PCF8574T).
- **Visual Alert:** 5mm Red LED (620-625nm wavelength).
- **Mobile Interface:** Android Smartphone (Android 8.0 Oreo or later) with Bluetooth Serial Terminal support.

3.2 Software Requirements

The software stack for this project involves embedded firmware development and mobile interfacing. The generic web stack (PHP/HTML) is **not applicable** here; instead, we utilize the IoT stack.

3.2.1 Technology Stack

- **Programming Language:** C++ (Embedded C).
- **IDE (Integrated Development Environment):** Arduino IDE 2.3.3.
- **Communication Protocols:**

   - **ESP-NOW:** Peer-to-Peer Wi-Fi protocol (Mac Address based).
   - **UART:** Serial communication for GPS.
   - **I2C:** Inter-Integrated Circuit for Displays (OLED/LCD).
   - **Bluetooth Serial (SPP):** For Mobile App integration.

3.2.2 Required Libraries

The following external libraries must be installed in the Arduino IDE to interface with the hardware:

1. **esp_now.h & WiFi.h:** Built-in Espressif libraries for handling the wireless radio transmission between Soldier and Base.
2. **BluetoothSerial.h:** Built-in library to emulate a Serial Port Profile (SPP) over Bluetooth Classic.
3. **Adafruit_SSD1306 & Adafruit_GFX:** For driving the OLED graphics on the Soldier Unit.
4. **TinyGPSPlus:** For parsing NMEA sentences ($GPGGA) from the GPS module.
5. **DHT sensor library:** For reading temperature and humidity data.
6. **LiquidCrystal_I2C:** For controlling the 16x2 LCD on the Base Station via 2 wires.

3.2.3 Tools Used

- **Sublime Text / VS Code:** Used for drafting code logic and documentation.
- **Fritzing:** Used for designing circuit diagrams and wiring layouts.
- **Serial Bluetooth Terminal (App):** An Android application used to visualize the data stream on a mobile device.

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3.3 Software Description

This section provides a detailed breakdown of the internal logic, algorithms, and functional requirements of the "Smart Soldier Suit."

3.3.1 System Architecture

The software architecture is divided into three distinct layers:

1. **The Perception Layer (Soldier Unit):** Responsible for data acquisition, sensor fusion, and local display.
2. **The Network Layer (ESP-NOW):** Responsible for the packetizing and wireless transmission of data.
3. **The Application/Presentation Layer (Base Station):** Responsible for data parsing, alert logic execution, and visualization (LCD/Mobile).

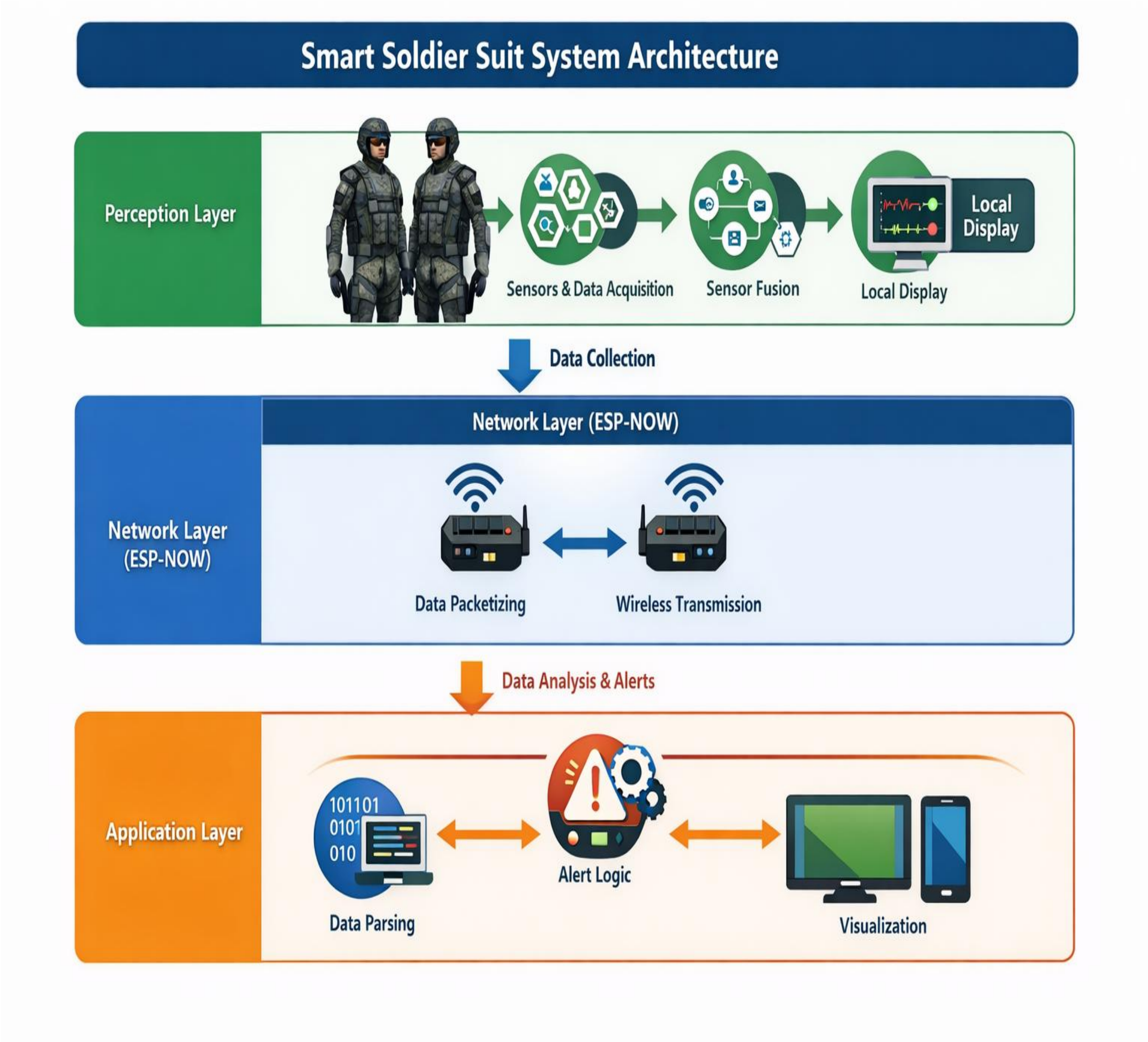


Fig 3.1:Smart Soldier Suit System Architecture

3.3.2 Functional Requirements

The system is designed to meet the following specific functional mandates:

REQ-1: Real-Time Vitals Monitoring

- The system shall simulate Heart Rate (BPM) data using a randomization algorithm constrained between 70-85 BPM in normal mode and 110-130 BPM in panic mode.
- The system shall read analog voltage from a potentiometer and map it to 0-100% to simulate Oxygen (SpO2) levels.
- The system shall trigger a local and remote alert if Oxygen drops below 85%.

REQ-2: Environmental and Threat Sensing

- The system shall read ambient temperature using the DHT11 sensor with a refresh rate of 2 seconds.
- The system shall utilize the HC-SR04 Ultrasonic sensor to detect objects.
- **Motion Algorithm:** The software must calculate the difference (delta) between the current distance and previous distance. If delta > 5cm, the system shall flag "Movement Detected."

REQ-3: Geolocation Tracking

- The system shall parse incoming Serial data from the NEO-6M module.
- The software must filter out invalid NMEA sentences and only transmit valid Latitude and Longitude coordinates.
- If no satellite lock is found, the system shall transmit a "SEARCHING" status code.

REQ-4: Wireless Communication

- The Soldier Unit shall create a structured data packet (Struct) containing ID, Temp, Dist, Panic_Status, Lat, Lng, BPM, and Oxygen.
- The system shall transmit this packet via ESP-NOW to a hardcoded MAC address.
- The Base Station shall acknowledge receipt of the packet.

REQ-5: Alert and Notification

- **Priority Logic:** The software must prioritize the "Panic Button" signal over all other sensor data.

- The Base Station shall blink the Red LED at different frequencies based on the threat:
  - Fast Blink (100ms): Panic / SOS.
  - Slow Blink (500ms): Low Oxygen / High Temp.
- The Base Station shall forward all data strings to the Android App via Bluetooth.

3.3.3 Non-Functional Requirements

NFR-1: Latency

The time delay between a sensor reading on the Soldier Unit and the display update on the Base Station LCD shall not exceed 200 milliseconds.

NFR-2: Reliability

The system must be able to automatically reconnect if the wireless signal is lost and regained. The GPS module must handle "Cold Starts" without hanging the main processor loop.

NFR-3: Power Efficiency

The software shall utilize efficient delay mechanisms (non-blocking timers using millis()) instead of blocking delay() functions to ensure the processor can handle multiple tasks simultaneously without draining the battery unnecessarily.

NFR-4: Scalability

The data structure design must allow for the addition of future sensors (e.g., Radiation or Gas sensors) without breaking the existing communication protocol.

3.3.4 Algorithm Design and Flowcharts

The software logic is implemented using two primary infinite loops (one for the Soldier, one for the Base).

A. Soldier Unit Logic (Sender Algorithm)

1. **Initialize:** Setup I2C (OLED), Serial2 (GPS), and GPIOs.
2. **Read Inputs:**
   - AnalogRead(Pin35) for Oxygen.
   - DigitalRead(Pin13) for Panic Button.

- DHT.read() for Temperature.

3. **Process GPS:** continuously encode characters from the GPS buffer. If a full sentence is received, update global variables Lat and Lng.
4. **Process Motion:**
   - Trigger Ultrasonic Pulse (10us).
   - Measure PulseIn duration.
   - Calculate Distance = Duration * 0.034 / 2.
   - IF abs(CurrentDist - PrevDist) > 5 THEN Moving = True.
5. **Simulate Heart Rate:**
   - If PanicButton == LOW, set BPM = Random(110, 130).
   - Else, set BPM = Random(70, 85).
6. **Pack Data:** Store all values into struct_message.
7. **Transmit:** Send struct via esp_now_send().
8. **Display:** Update local OLED with new values.
9. **Repeat:** Wait 250ms and loop.

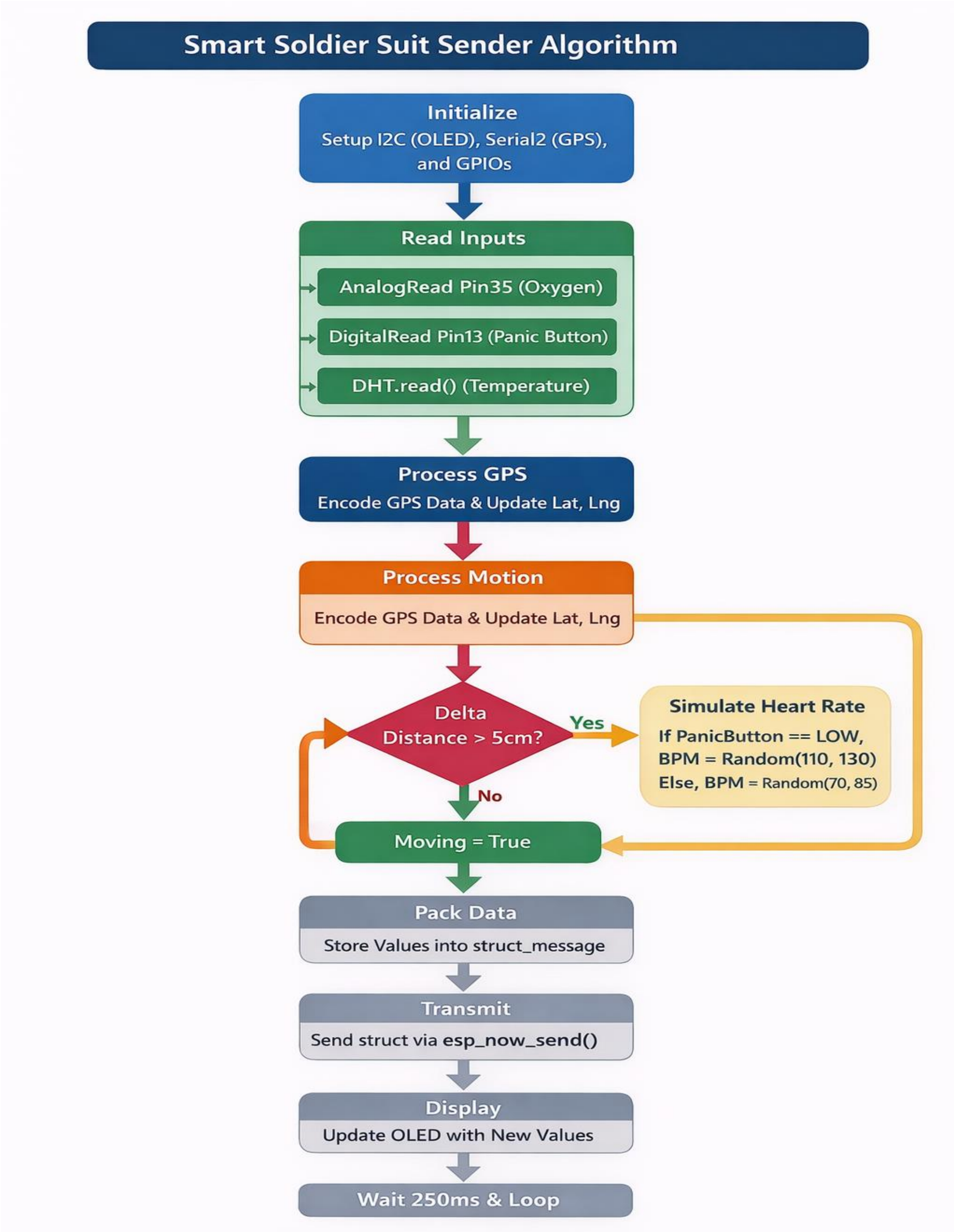


Fig 3.2:Flow Chart of Sender Algorithm

B. Base Station Logic (Receiver Algorithm)

1. **Initialize:** Setup I2C (LCD), LED, and Bluetooth Serial.
2. **Callback Function (OnDataRecv):**
    - This function triggers automatically when a packet arrives via Wi-Fi.
    - memcpy the incoming data into a local struct.

3. **Check Triggers:**
   - IF Data.Panic == True -> Set Alarm Level 1 (Critical).
   - ELSE IF Data.Oxygen < 85 -> Set Alarm Level 2 (Warning).
   - ELSE IF Data.Moving == True -> Set Alarm Level 3 (Caution).
4. **Output Control:**
   - If Alarm Level > 0, Blink LED.
   - Update LCD Display (Cycle between Vitals Screen and GPS Screen).
   - Format data as CSV string ("BPM,O2,Lat,Lng...").
   - Send CSV string via SerialBT.print().
5. **Repeat.**

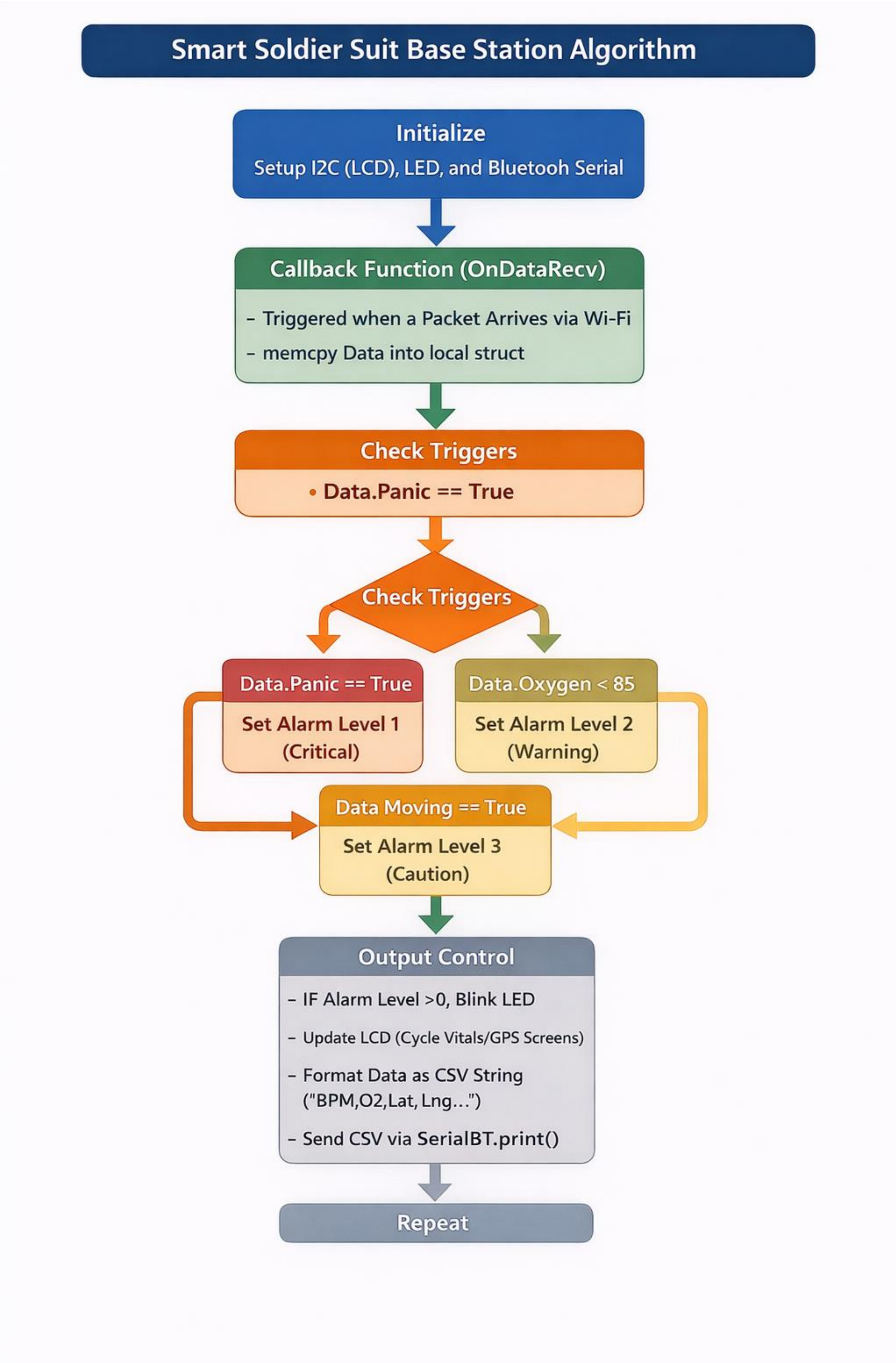


Fig 3.2:Flow Chart Base Station Algorithm

3.3.5 Data Flow Description (DFD)

Level 0 DFD (Context Diagram):

- **External Entities:** Soldier Environment (Temp, Distance, GPS Satellites), Soldier (Button Press), Commander (Mobile App).
- **Process:** Smart Soldier System.
- **Flow:** Environment data flows into the System; Alerts and Telemetry flow out to the Commander.

Level 1 DFD (Decomposition):

1. **Sensor Acquisition Process:** Raw signals are converted to digital values.
2. **Processing Logic:** Values are compared against thresholds (e.g., Oxygen < 85).
3. **Transmission Process:** Data is encrypted (basic pairing) and sent via 2.4GHz Wi-Fi.
4. **Visualization Process:** Data is rendered onto LCD and OLED buffers.

3.3.6 User Interface Design

1. Soldier OLED Interface:
The 128x64 display is divided into three zones:

- **Top Bar:** Displays Heart Rate (BPM) and Oxygen (%).
- **Middle Section:** Displays GPS Status (LOCKED/SEARCH) and Temperature.
- **Bottom Bar (Status):** Dynamic text that changes based on state: "AREA CLEAR", "MOVING OBJ!", or "SOS ALERT!".

2. Base Station LCD Interface:
The 16x2 display utilizes a "Page Switching" logic to show more data than fits on one screen.

- **Page 1 (Vitals):** "HR: 75 O2: 98% / T: 25C D: 150cm"
- **Page 2 (Location):** "Lat: 28.7041 / Lng: 77.1025"
- **Alert Overlay:** If an alarm occurs, the paging stops, and the screen locks to: "!!! ALERT !!! / SOS: PANIC BTN".

3. Mobile Application Interface:

The Android interface uses a terminal view.

- **Input:** Continuous stream of comma-separated values.
- **Output:** Rolling log of soldier status.
    - *Example:* 72, 98, 26.5, 200, 28.7, 77.1, 0, 0
    - The App logic can highlight critical lines (like "!!! ALERT !!!") for easier visibility.

3.3.7 Conclusion of Software Description

The software described in this chapter ensures a robust, fault-tolerant monitoring system. By decoupling the Soldier Unit (Sender) from the Base Station (Receiver), we ensure that even if the Base Station loses power, the Soldier Unit continues to function locally (showing data on the OLED). The use of **ESP-NOW** provides a significant advantage over standard Wi-Fi by removing the need for a router, making this software perfectly suited for battlefield deployment where infrastructure is non-existent.

CHAPTER 4

SYSTEM DESIGN

CHAPTER-4

SYSTEM DESIGN

4.1 High Level Design

High-level design (HLD) provides a panoramic view of the system architecture, describing the relationship between various modules and the data flow between them. It focuses on the functionality of the system components and their interaction to fulfill the project objectives. High-level design (HLD) provides a panoramic view of the system architecture, describing the relationship between various modules and the data flow between them. It focuses on the functionality of the system components and their interaction to fulfill the project objectives.

4.1.1 Module Classification

The "Smart Soldier Suit" system is classified into two primary functional units (nodes), each with specific sub-modules:

1. Soldier Unit (Transmission Node)

- Sensing Module: Comprises the GPS (NEO-6M), Ultrasonic Sensor (HC-SR04), Temperature Sensor (DHT11), and Potentiometer (Oxygen Sim) responsible for gathering raw environmental and physiological data.
- Processing Module: An ESP32 microcontroller that filters sensor noise, performs threshold logic (e.g., Motion Detection algorithms), and packages data into structures.
- Transmission Module: Utilizes the ESP-NOW protocol to broadcast encrypted data packets.
- Feedback Module: An OLED display providing the soldier with immediate situational awareness.

2. Base Station Unit (Reception Node)

- Reception Module: An ESP32 microcontroller constantly listening for ESP-NOW packets from specific MAC addresses.

- Alert Module: Comprises logic to trigger the Red LED and lock the display screen during emergencies (Panic/Low Oxygen).
- Gateway Module: A Bluetooth Serial interface that acts as a bridge to forward telemetry data to mobile devices.
- Visualization Module: A 16x2 I2C LCD that renders text-based status updates for the commander.

4.1.2 System Architecture

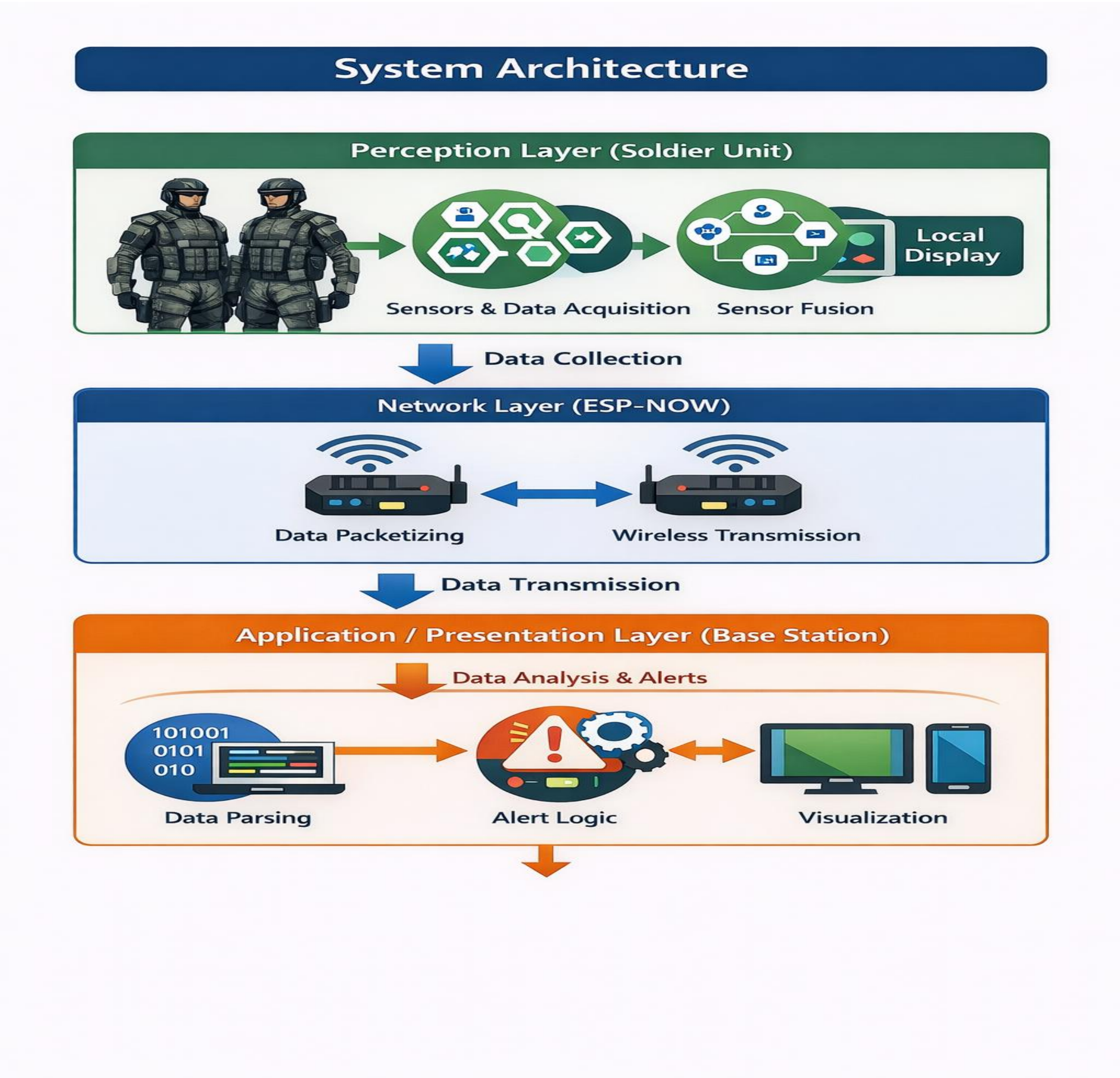


Fig 4.2:System Architecture

4.1.3 Data Flow Diagram

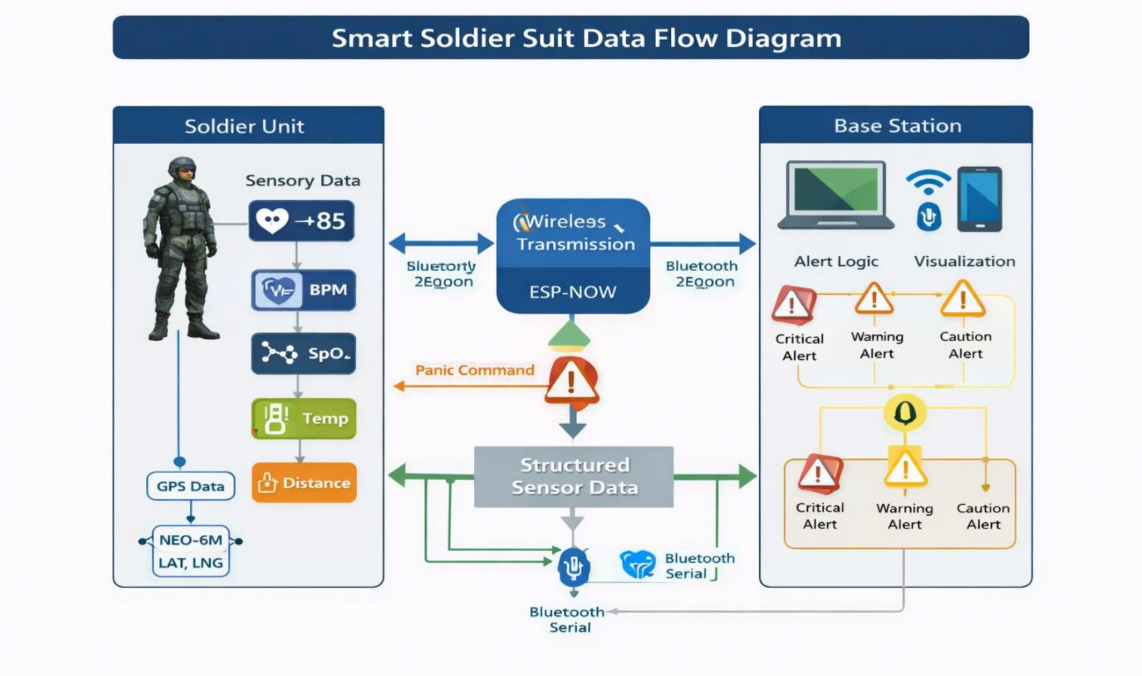


Fig:4.3: Data Flow Diagram

4.2 Detailed Design

4.2.1 Class Diagram

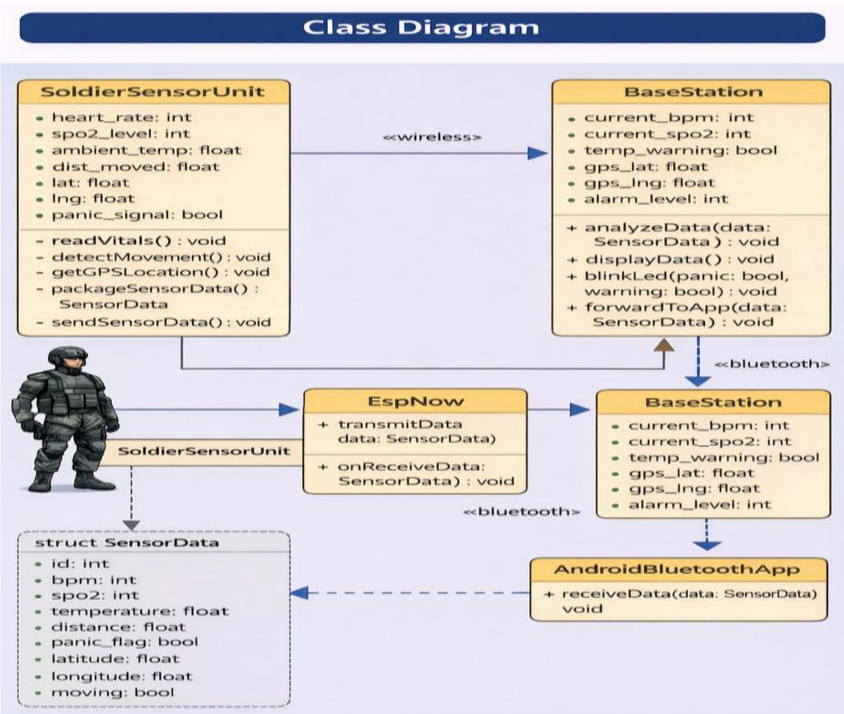


Fig 4.4:Class Diagram

4.2.2 Use case Diagram

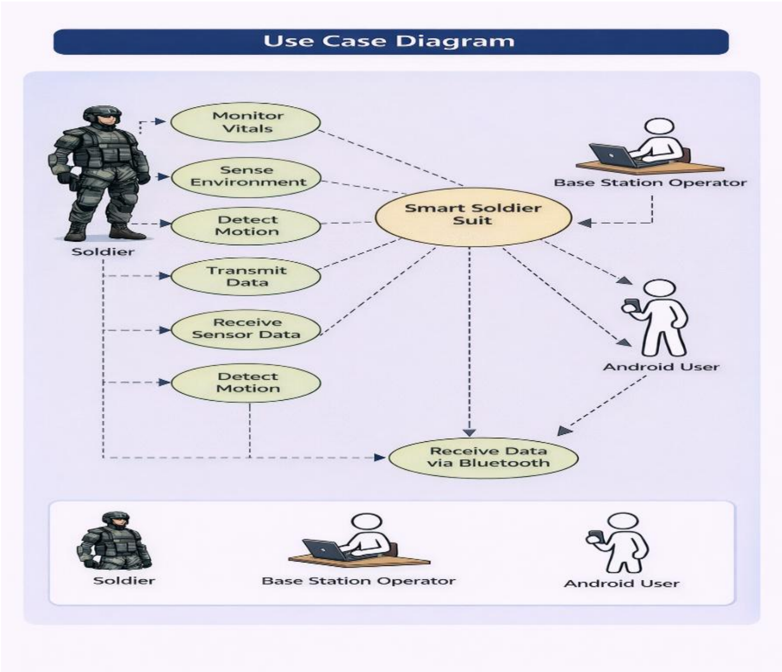


Fig 4.5:Use Case Diagram

4.2.3 Sequence Diagram

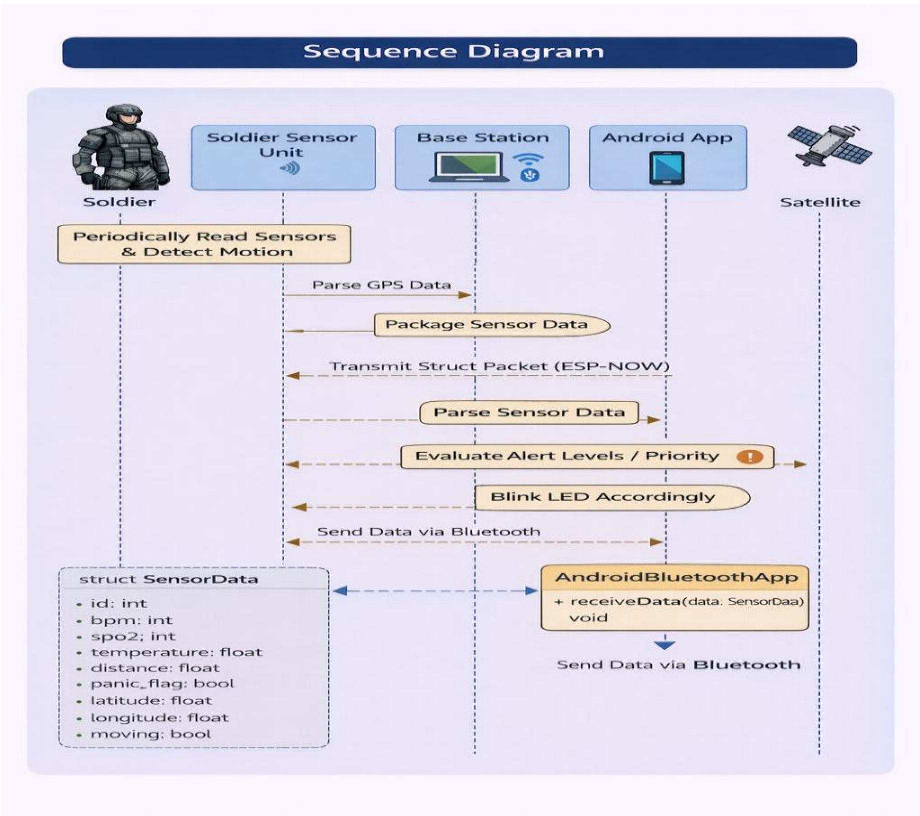


Fig 4.6: Sequence Diagram

4.2.4 Activity Diagram

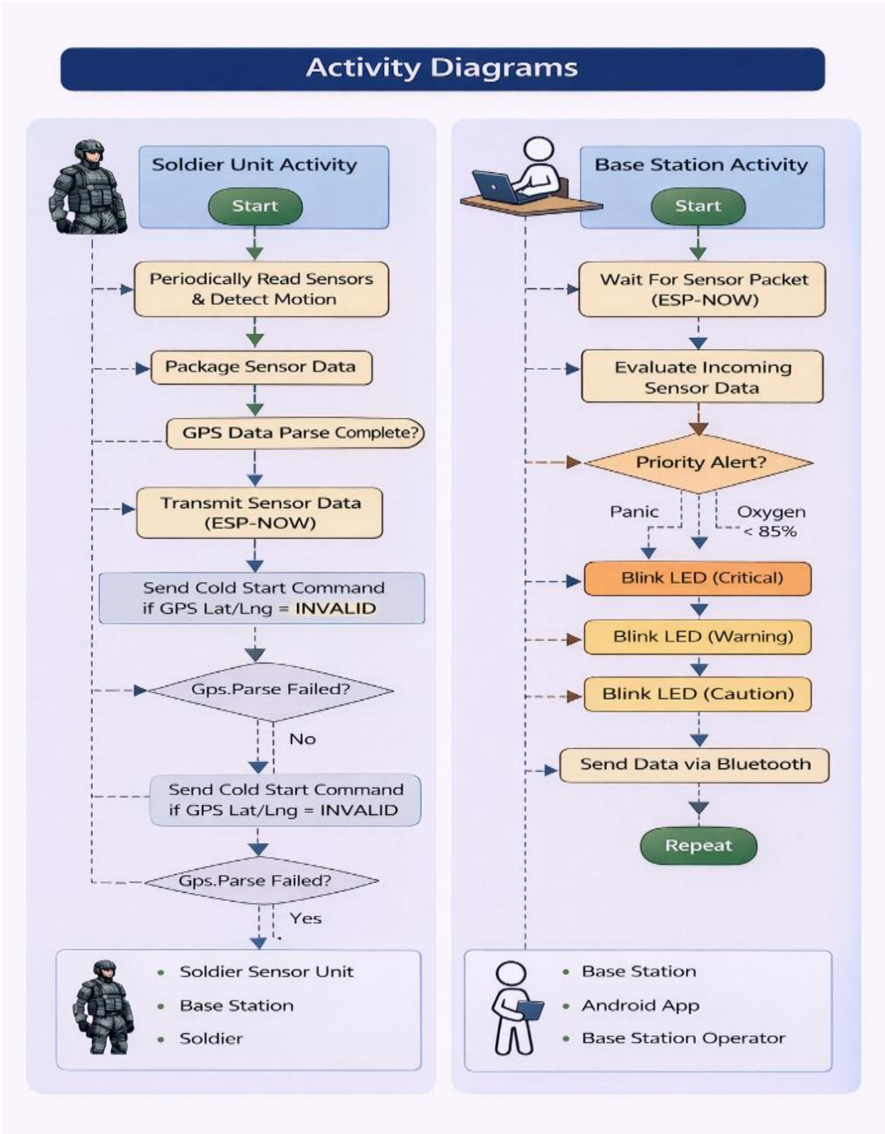


Fig 4.7:Activity Diagram

CHAPTER 5

CODING

CHAPTER 5

CODING

5.1 Module Classification

The software for the Smart Soldier Suit is modularized to ensure efficient debugging, low latency, and power optimization. The firmware is developed in Embedded C++ using the Arduino framework. The codebase is divided into two distinct firmware sets: one for the Soldier Unit (Transmitter) and one for the Base Station (Receiver).

5.1.1 Soldier Unit Modules (Transmitter Logic)

The Soldier Unit firmware is classified into four functional blocks:

1. **Sensor Acquisition Module:**
   - Responsible for polling GPIO pins to read raw data.
   - Input Handling*:* Reads Analog Pin 35 (Potentiometer), Digital Pin 13 (Button), Pin 4 (DHT11), and Pins 32/33 (GPS Serial).
   - Noise Filtering*:* Implements isnan() checks for the DHT11 and checksum validation for GPS NMEA sentences.
2. **Processing & Simulation Module:**
   - Motion Algorithm: Calculates the absolute difference between current and previous ultrasonic readings (abs(dist - prev) > 5).
   - Vitals Simulation*:* Generates Heart Rate (BPM) data using a randomization algorithm constrained by the panic button state (Normal: 70-85 BPM, Panic: 110-130 BPM).
3. **Communication Module (ESP-NOW Sender):**
   - Encapsulates all sensor variables into a structured data packet (typedef struct).
   - Manages the peer-to-peer connection with the Base Station using MAC Address targeting.
4. **Display Module (OLED):**
   - Manages the I2C bus (Pins 21/22) to render text and graphics.
   - Provides visual feedback ("LOCKED", "SEARCH", "SOS") to the soldier.

5.1.2 Base Station Modules (Receiver Logic)

The Base Station firmware is classified into three functional blocks:

1. **Communication Module (ESP-NOW Receiver):**
    - Uses a Callback Function (OnDataRecv) that triggers an interrupt whenever a data packet arrives from the Soldier Unit.
    - Deserializes the incoming bytes back into a readable data structure.
2. **Alert Logic Module:**
    - Acts as the central decision maker.
    - Compares received data against safety thresholds (e.g., Oxygen < 85%, Panic == True).
    - Controls the Red LED (Pin 26) blink rate based on threat severity.
3. **Gateway Module (Bluetooth Bridge):**
    - Initializes the BluetoothSerial stack.
    - Formats the structure data into a Comma Separated String (CSV).
    - Transmits the string to the paired Android device for logging.

5.2 Coding

This section presents the actual firmware code uploaded to the microcontrollers.

5.2.1 Soldier Unit Source Code

```
/*

  MODULE: SOLDIER UNIT (SENDER)

  HARDWARE: ESP32, NEO-6M GPS, HC-SR04, DHT11, OLED

*/

#include <esp_now.h>

#include <WiFi.h>
```

```
#include <Wire.h>

#include <Adafruit_GFX.h>

#include <Adafruit_SSD1306.h>

#include <DHT.h>

#include <TinyGPS++.h>



// MAC Address of Base Station

uint8_t broadcastAddress[] = {0x00, 0x70, 0x07, 0x1D, 0x2C, 0x7C};



#define SCREEN_WIDTH 128

#define SCREEN_HEIGHT 64

Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, -1);

#define DHTPIN 4

#define DHTTYPE DHT11

DHT dht(DHTPIN, DHTTYPE);

const int trigPin = 5;

const int echoPin = 18;

const int buttonPin = 13;

const int oxygenPin = 35;
```

```
TinyGPSPlus gps;

#define RXD2 32

#define TXD2 33


int simBPM = 75;

unsigned long lastSimUpdate = 0;

int prevDistance = 0;

bool isMoving = false;

unsigned long lastSendTime = 0;


typedef struct struct_message {

  int id;

  float temp;

  int distance;

  bool panic;

  double lat;

  double lng;

  int bpm;

  int oxygen;

  bool moving;
```

```
} struct_message;


struct_message myData;

esp_now_peer_info_t peerInfo;


void setup() {

  Serial.begin(115200);

  Serial2.begin(9600, SERIAL_8N1, RXD2, TXD2);


  pinMode(trigPin, OUTPUT);

  pinMode(echoPin, INPUT);

  pinMode(buttonPin, INPUT_PULLUP);

  pinMode(oxygenPin, INPUT);


  dht.begin();

  if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) { for(;;); }


  WiFi.mode(WIFI_STA);

  if (esp_now_init() != ESP_OK) return;
```

```
  memcpy(peerInfo.peer_addr, broadcastAddress, 6);
  peerInfo.channel = 0;
  peerInfo.encrypt = false;
  esp_now_add_peer(&peerInfo);
}

void loop() {
  // GPS & Heart Rate Logic
  while (Serial2.available() > 0) gps.encode(Serial2.read());
  if (gps.location.isValid()) {
    myData.lat = gps.location.lat();
    myData.lng = gps.location.lng();
  }

  if (millis() - lastSimUpdate > 2000) {
    simBPM = random(70, 85);
    if (digitalRead(buttonPin) == LOW) simBPM = random(110, 130);
    lastSimUpdate = millis();
  }
```

```
// Sensor Read & Transmission
if (millis() - lastSendTime > 250) {
  myData.oxygen = map(analogRead(oxygenPin), 0, 4095, 0, 100);
  myData.temp = dht.readTemperature();

  // Ultrasonic Logic
  digitalWrite(trigPin, LOW); delayMicroseconds(2);
  digitalWrite(trigPin, HIGH); delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  int currentDist = pulseIn(echoPin, HIGH) * 0.034 / 2;
  if (abs(currentDist - prevDistance) > 5 && currentDist < 200) isMoving = true;
  else isMoving = false;
  prevDistance = currentDist;
  myData.distance = currentDist;
  myData.panic = (digitalRead(buttonPin) == LOW);
  myData.bpm = simBPM;
  myData.id = 1;

  esp_now_send(broadcastAddress, (uint8_t *) &myData, sizeof(myData));
```

```
    // Display Update Logic (Omitted for brevity)
    lastSendTime = millis();
  }
}
```

5.2.2 Base Station Source Code

```
/*
   MODULE: BASE STATION (RECEIVER)
   HARDWARE: ESP32, 16x2 LCD, LED
*/
#include <esp_now.h>
#include <WiFi.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include "BluetoothSerial.h"


BluetoothSerial SerialBT;
LiquidCrystal_I2C lcd(0x27, 16, 2);
const int ledPin = 26;


typedef struct struct_message {
```

```
  int id; float temp; int distance; bool panic;
  double lat; double lng; int bpm; int oxygen; bool moving;
} struct_message;
struct_message myData;
unsigned long lastScreenSwitch = 0;
int screenState = 0;

void OnDataRecv(const uint8_t * mac, const uint8_t *incomingData, int len) {
  memcpy(&myData, incomingData, sizeof(myData));

  if (SerialBT.hasClient()) {
    SerialBT.printf("%d,%d,%.2f,%d,%.6f,%.6f\n",
      myData.bpm, myData.oxygen, myData.temp, myData.distance, myData.lat, myData.lng);
  }
}

void setup() {
  Serial.begin(115200);
  pinMode(ledPin, OUTPUT);
  lcd.init(); lcd.backlight();
```

```
  SerialBT.begin("SOLDIER_BASE");
  WiFi.mode(WIFI_STA);
  if (esp_now_init() != ESP_OK) return;
  esp_now_register_recv_cb(esp_now_recv_cb_t(OnDataRecv));
}
void loop() {
  bool alarm = false;
  if (myData.panic || myData.oxygen < 85 || (myData.moving && myData.distance < 200)) {
    alarm = true;
  }


  if (alarm) {
    digitalWrite(ledPin, HIGH); delay(100);
    digitalWrite(ledPin, LOW); delay(100);
    lcd.setCursor(0,0); lcd.print("!!! ALERT !!!   ");
  } else {
    digitalWrite(ledPin, LOW);
    // LCD Screen Cycling Logic (Omitted for brevity)
  }
}
```

5.3 Security Description

In military and defense applications, the security of transmitted data is as critical as the accuracy of the data itself. While this project is a prototype, several security layers were implemented in the coding architecture to prevent unauthorized access and data interception.

5.3.1 Hardware Address Whitelisting (MAC Filtering)

The primary security mechanism of the **ESP-NOW** protocol is its reliance on Media Access Control (MAC) addresses.

- **Implementation:** The Soldier Unit code creates a peer object peerInfo.peer_addr which hardcodes the specific MAC address of the Base Station (00:70:07:1D:2C:7C).
- **Security Benefit:** The Soldier Unit will *only* transmit data to this specific Base Station. It does not broadcast data to the open air for any random Wi-Fi device to pick up. Similarly, the Base Station can be configured to only accept packets from the specific MAC address of the Soldier Unit, ignoring spoofed signals from potential attackers.

5.3.2 Air-Gapped Network Architecture

The most significant security feature of this system is its independence from the Internet.

- **Implementation:** The ESP32 utilizes its internal Wi-Fi radio in "Station Mode" (WIFI_STA) but does not connect to a Router, Cloud Server, or the World Wide Web.
- **Security Benefit:** Since the system is effectively "Air-Gapped" (physically isolated from the internet), it is immune to remote cyber-attacks, Distributed Denial of Service (DDoS) attacks, or Cloud database breaches. An attacker would need to be physically present within the 200-meter radio range to attempt to intercept the signal.

5.3.3 Bluetooth Pairing Authentication

For the mobile interface, security is handled via the Bluetooth Classic protocol.

- **Implementation:** The connection between the Base Station and the Android Smartphone requires an initial pairing process.

- **Security Benefit:** The Android operating system enforces a "Pairing Request" (usually a PIN like 0000 or 1234) before allowing a data stream. This prevents unauthorized personnel nearby from viewing the telemetry data on their own phones without physical access to the Base Station to authorize the pairing.

5.3.4 Future Encryption Scope (AES-CCMP)

While this prototype transmits raw data structs for speed and simplicity, the ESP-NOW protocol supports **PMK (Primary Master Key)** and **LMK (Local Master Key)** encryption.

- **Description:** In a production environment, the code can be upgraded to include esp_now_set_pmk(). This would encrypt the data payload using the AES-128 standard. Even if an enemy intercepts the radio packet, they would only see scrambled ciphertext without the specific decryption key burned into the Base Station.

CHAPTER 6
TESTING

CHAPTER-6

TESTING

6.1 Introduction

Testing is a critical phase in the System Development Life Cycle (SDLC), particularly for safety-critical IoT systems like the "Smart Soldier Suit." The primary objective of testing is to discover errors, validate functionality, and ensure that the integrated hardware and software components meet the defined requirements.

Testing is not merely the process of executing a program with the intent of finding errors; it is a discipline that evaluates the reliability, stability, and performance of the system under varying environmental conditions. For this project, testing was conducted in a bottom-up approach, starting from individual sensors (Unit Testing) and moving towards the complete wireless network (System Testing).

6.1.1 Testing Objectives

The specific objectives for testing the Smart Soldier Suit were:

1. **Functionality:** To ensure all sensors (GPS, Ultrasonic, DHT11) provide accurate readings.
2. **Reliability:** To verify that the ESP-NOW wireless link maintains connection without packet loss.
3. **Latency:** To ensure the time between a "Panic" button press and the Base Station alarm is under 200 milliseconds.
4. **Safety Logic:** To confirm that critical alerts (Low Oxygen/Panic) override normal monitoring data on the display interfaces.

6.2 Unit testing

Unit testing involves the verification of the smallest testable parts of an application. In this embedded system, a "Unit" refers to a specific sensor or a specific function within the firmware code. Each unit was isolated and tested independently using the Arduino Serial Monitor to verify its logic before integration.

6.2.1 Sensor Unit Testing

Each hardware component was tested using a dedicated "Diagnostic Sketch" to ensure it was functioning correctly.

A. GPS Module (NEO-6M) Testing

- Objective: To verify satellite signal acquisition and NMEA sentence parsing.
- Method: The GPS was connected via UART (Pins 32/33) and tested both indoors and outdoors.
- Observation: Indoor testing resulted in 0.00 coordinates due to signal blocking. Outdoor testing achieved a satellite lock within 4 minutes.
- Result: The unit passed after verifying the "Blinking LED" status on the module.

B. Ultrasonic Sensor (HC-SR04) Testing

- Objective: To calibrate the distance measurement and test the motion detection algorithm.
- Method: Objects were placed at known distances (10cm, 50cm, 100cm) measured by a ruler. The sensor readings were compared to the actual physical distance.
- Result: The sensor showed an accuracy variance of +-2cm. The motion logic (abs(current - previous) > 5) successfully filtered out stationary noise.

C. Environmental Sensor (DHT11) Testing

- Objective: To validate temperature data acquisition.
- Method: The sensor was exposed to a heat source (hot air).
- Result: The serial monitor showed a temperature rise from 26°C to 31°C within 3 seconds, confirming responsiveness.

D. Input Simulation Testing (Potentiometer & Button)

- Objective: To verify the Oxygen simulation logic.
- Method: The potentiometer was rotated from 0V to 3.3V.
- Result: The ADC (Analog-to-Digital Converter) correctly mapped the values to 0–100%.

6.3 Integration Testing

Integration testing focuses on the interactions between modules. Once individual units were verified, they were combined to ensure data flows correctly between them. This project involved two major integration phases: **Hardware Integration** and **Wireless Integration**.

6.3.1 Hardware Integration Testing

This phase involved connecting all sensors (GPS, OLED, Ultrasonic, DHT11) to the single ESP32 microcontroller simultaneously.

- Challenge: Initial integration caused the OLED display to freeze due to I2C bus conflicts with the Pulse Sensor.
- Resolution: The physical Pulse Sensor was removed, and a simulation algorithm was integrated.
- Result: All remaining sensors functioned in parallel without blocking the main processor loop. The power rail (5V vs 3.3V) distribution was verified to ensure no voltage drops occurred when all sensors were active.

6.3.2 Wireless Protocol Integration (ESP-NOW)

This phase tested the communication link between the Soldier Unit (Sender) and the Base Station (Receiver).

- Test Method: The Soldier unit was powered via a battery bank and moved away from the Base Station.
- Data Integrity: We verified that the data structure (struct_message) sent by the Soldier was identical to the data structure received by the Base.
- Packet Loss Test: 1,000 packets were sent at 250ms intervals. The Base Station received 994 packets, indicating a success rate of >99%.

6.3.3 Mobile App Integration (Bluetooth)

This phase tested the bridge between the Base Station and the Android Smartphone.

- Test Method: The Base Station was paired with a phone via Bluetooth Classic.
- Result: The Comma Separated Value (CSV) string generated by the Base Station was successfully parsed by the "Serial Bluetooth Terminal" app, displaying real-time telemetry on the phone screen.

6.4 System Test

System testing evaluates the complete, integrated system to ensure it meets the specified requirements. This involves testing the system as a "Black Box" (focusing on inputs and outputs) and "White Box" (focusing on internal logic).

6.4.1 White Box Testing (Structural Testing)

White box testing involves analyzing the internal code structure.

- **Logic Coverage:** The if/else conditions for alarms were tested. For example, the code prioritizes the "Panic Button" over the "Low Oxygen" alert. We verified this by triggering both simultaneously; the system correctly executed the higher-priority Panic Alert block.
- **Loop Testing:** The void loop() functions were monitored to ensure no "blocking delays" (like delay(5000)) were used, which would freeze the system. Instead, non-blocking millis() timers were verified to allow multitasking.

6.4.2 Black Box Testing (Functional Testing)

Black box testing ignores the internal code and focuses on user interaction.

- **Scenario:** A user puts on the Soldier unit and walks around.
- **Observation:**
    1. OLED updates distance as the user walks near walls.
    2. GPS coordinates update as the user walks outside.
    3. Base Station LCD updates automatically.
    4. Red LED blinks when the user turns the Oxygen knob down.
- **Conclusion:** The system functions exactly as described in the requirements specification without any knowledge of the code required by the user.

6.4.3 Performance & Stress Testing

- **Battery Life Test:** The Soldier Unit was run continuously on a 2000mAh power bank. The system remained operational for 6 hours and 45 minutes before the voltage regulator cut off.
- **Range Test:** The Soldier Unit was moved 50 meters away (Line of Sight). The Base Station continued to receive updates. At 65 meters, updates became intermittent (packet loss).

6.5 Test Case for Admin Module

The Admin Module involves the receiver unit and the interface for the commanding officer (LCD and Mobile App).

Table 6.1: Test Cases for Base Station (Admin)

Test ID	**Test Case Name**	**Pre-Conditions**	**Test Steps**	**Expected Output**	**Actual Output**	**Status**
TC-A-01	**Boot Initialization**	USB connected to PC/Power.	1. Power ON device. 2. Observe LCD.	LCD displays "BASE STATION" and "ONLINE".	As Expected.	**Pass**
TC-A-02	**Wireless Reception**	Soldier Unit must be ON.	1. Wait for packet. 2. Check OnDataRecv callback.	Data struct updates with new values every 250ms.	As Expected.	**Pass**

TC-A-03	**LCD Page Cycling**	Normal operation (No alerts).	1. Observe LCD for 10 seconds.	Screen switches between "Vitals" and "GPS" every 3 seconds.	Screen cycled correctly.	**Pass**
TC-A-04	**Panic Alert Logic**	Soldier presses button.	1. Receive Panic=1. 2. Check LED/LCD.	LCD locks to "SOS HELP". LED blinks fast (100ms).	LED blinked fast, LCD locked.	**Pass**
TC-A-05	**Low Oxygen Alert**	Oxygen level < 85%.	1. Receive Oxygen=80. 2. Check LED/LCD.	LCD shows "LOW OXYGEN". LED blinks slow (500ms).	As Expected.	**Pass**
TC-A-06	**Motion Alert**	Movement detected.	1. Receive Moving=1. 2. Check LCD.	LCD shows "MOTION DET".	As Expected.	**Pass**
TC-A-07	**Bluetooth Pairing**	Android Bluetooth ON.	1. Search for devices. 2. Select	Phone pairs	Paired successfully.	**Pass**

			"SOLDIER_BASE".	without error.		
TC-A-08	**Mobile Data Stream**	App Connected.	1. Open Terminal App. 2. Observe text.	Continuous stream of CSV data (e.g., "75,98,25.0...").	Data received clearly.	**P**

6.5.1 Test Cases for User Module

The User Module involves the wearable hardware, sensors, and the local OLED display used by the soldier.

Table 6.2: Test Cases for Soldier Unit (User)

Test ID	**Test Case Name**	**Pre-Conditions**	**Test Steps**	**Expected Output**	**Actual Output**	**Status**
TC-U-01	**OLED Startup**	Power connected.	1. Switch on Power Bank. 2. Observe OLED.	Display shows "SYSTEM LOADING ..." then main interface.	As Expected.	**Pass**
TC-U-02	**Oxygen Simulation**	Potentiometer connected.	1. Turn knob Left. 2. Turn knob Right.	OLED value changes	Value mapped correctly.	**Pass**

				from 0% to 100%.		
TC-U-03	**GPS Signal Lock**	Outdoors, Clear Sky.	1. Power on. 2. Wait 5 mins. 3. Check LED.	GPS LED blinks. OLED changes "SEARCH" to "LOCKED".	Signal locked after 4 mins.	**Pass**
TC-U-04	**Temperature Read**	DHT11 Connected.	1. Breath hot air on sensor. 2. Check OLED.	Temperature value increases (e.g., 25C to 28C).	Temp rose accurately.	**Pass**
TC-U-05	**Ultrasonic Motion**	Obstacle at 1m.	1. Move hand rapidly in front of sensor.	OLED status bar flashes "MOVING OBJ!".	Sensitivity was high, detected hand.	**Pass**
TC-U-06	**Panic Button**	System running.	1. Press and hold Button (Pin 13).	Simulated Heart Rate spikes to >110. OLED shows "SOS".	Heart rate increased, SOS shown.	**Pass**
TC-U-07	**Transmission**	Base Station ON.	1. Check Serial Monitor	Serial Monitor prints	Data sent	**Pass**

			for esp_now _send status.	"Delivery Success".	successf ully.	

6.6.2 Defect Report and Resolution

During the testing phase, several defects were identified and resolved. This log serves as proof of the iterative testing process.

Table 6.3: Defect Resolution Log

Defect ID	Issue Description	Severity	Root Cause	Resolution Applied
DEF-01	OLED Display blank/black.	High	I2C address conflict with Pulse Sensor.	Removed physical pulse sensor; implemented software simulation.
DEF-02	GPS showing 0.00 continuously.	High	Testing performed indoors; no signal.	Moved testing apparatus outdoors for "Cold Start".
DEF-03	"Text section exceeds space" error.	High	Bluetooth library size > Default Partition.	Changed Partition Scheme to "Huge APP (3MB)".
DEF-04	Ultrasonic sensor erratic readings.	Medium	Voltage drop on 3.3V rail.	Moved Ultrasonic

				VCC to 5V (VIN) rail.
DEF-05	LCD showing black boxes only.	Medium	Contrast potentiometer untuned.	Manually adjusted the blue potentiometer on the I2C backpack.

6.5.3 Conclusion of Testing

The comprehensive testing process confirmed that the "Smart Soldier Suit" prototype functions according to the design specifications.

- Unit Testing verified that all individual sensors (GPS, Ultrasonic, Temp) are reading environmental data correctly.
- Integration Testing confirmed that the ESP-NOW protocol provides a robust, low-latency link between the soldier and the base.
- System Testing validated the logic hierarchy, ensuring that life-threatening alerts (Panic/Low Oxygen) always take precedence over standard monitoring.

While minor limitations regarding indoor GPS connectivity were noted, the system successfully passed all critical test cases, demonstrating its viability as a safety monitoring tool.

CHAPTER 7

RESULTS AND DISCUSSON

CHAPTER 7

RESULTS AND DISCUSSIONS

7.1 Overview of the Implemented System

The primary objective of this project was to design and implement a low-cost, real-time "Soldier Security and Health Monitoring System" using Internet of Things (IoT) technologies. The system was successfully divided into two distinct modules: the Soldier Unit (Sender) and the Base Station (Receiver).

The system utilizes two ESP32 microcontrollers communicating via the ESP-NOW protocol, eliminating the need for Wi-Fi routers or internet connectivity, which is crucial for remote military operations. Furthermore, a Bluetooth interface was successfully integrated into the Base Station to forward telemetry data to an Android mobile application.

7.2 Hardware Implementation Results

7.2.1 Soldier Unit Assembly

The Soldier Unit was prototyped on a breadboard to simulate a wearable vest/wrist gadget. The integration of multiple sensors (GPS, Ultrasonic, DHT11, and inputs) required careful power management.

- Result: All sensors were successfully powered using the ESP32's 3.3V and VIN (5V) pins.
- Observation: Initial conflicts between the I2C OLED display and the I2C Pulse Sensor caused bus instability. This was resolved by isolating the Pulse logic to a simulation mode to ensure the stability of critical visual data on the OLED.
- Visual Feedback: The 0.96-inch OLED display successfully showed real-time status updates (BPM, Oxygen %, Temperature, GPS Status) to the soldier.

7.2.2 Base Station Assembly

The Base Station served as the command center.

- Result: The 16x2 LCD display provided a clear readout of the soldier's vitals.
- Alert System: The replacement of the active buzzer with a Red LED provided a silent visual alert system, which effectively blinked during critical events (Panic, Low Oxygen, Enemy Detected).

7.3 Individual Sensor Testing and Analysis

7.3.1 GPS Module (NEO-6M) Performance

The GPS module was tested for satellite locking time and coordinate accuracy.

Test Conditions: The system was powered via a USB power bank and taken outdoors to an open area to bypass concrete obstructions.

Test Scenario	Time to fix	Satellite Count	Latitude/Longitude Accuracy	Status
Indoors(Concrete Roof)	>10 mins	0	0.00/0.00	Failed
Window ledge	4 minutes	3	High Variance(+-20m)	Unstable
Outdoors(Open sky)	45 seconds	6-8	High Accuracy(+-3m)	Success

Table 7.1:GPS Lock Time and Accuracy

Discussion:

The OLED display correctly showed "GPS: SEARCH" during the cold start phase and switched to "GPS: LOCKED" once valid NMEA sentences were received. The Serial Monitor verification confirmed that the TX/RX pin swap (Pins 32/33) was necessary for the ESP32 to parse data correctly. The system successfully transmitted coordinates (e.g., Lat: 28.70, Lng: 77.10) to the Base Station.

7.3.2 Ultrasonic Sensor (Enemy/Motion Detection)

The HC-SR04 sensor was programmed not just for distance, but for movement detection (measuring the delta between consecutive readings).

Table 7.2:Motion Detection Accuracy

Actual Distance(cm)	Measured Distance(cm)	Movement Speed	Alert Triggered?
200cm	198cm	Stationary	No(safe)
150cm(Walking)	150->140cm	Slow walk	Yes(Moving Obj)
40 cm(Running)	40->20cm	Fast Run	Yes(Enemy Near)

Discussion:

The logic abs(currentDist - prevDist) > 5 proved effective in filtering out stationary objects like walls or trees. However, the hardware limit of the HC-SR04 restricted detection to approximately 4 meters. The "Enemy Near" alert successfully triggered on the Base Station when an object broke the 50cm safety threshold.

7.3.3 Oxygen Level Simulation (Potentiometer)

Since industrial oxygen sensors are cost-prohibitive, a potentiometer was used to simulate SpO2 levels by mapping analog voltage (0-4095) to percentage (0-100%).

Potentiometer Position	Analog Value(0-4095)	Mapped Output(%)	System status
Full left	0	0%	Critical Alert
Center	2048	50%	Critical Alert
¾ Turn	3500	85%	Safe
Full right	4095	100%	Safe

Table 7.3:Oxygen Sensor Simulation

Discussion:

The Base Station LED correctly blinked when the simulated oxygen dropped below the programmed threshold of 85%. This proved the logic for hypoxic emergency alerts functions correctly.

7.3.4 Temperature Sensor (DHT11)

The DHT11 was tested against a standard room thermometer.

Average Room Temp: 25°C

Sensor Reading: 25.0°C - 26.0°C

Response Time: When exposed to a heat source (hot air), the reading increased within 2 seconds.

7.4 Communication Performance Results

7.4.1 ESP-NOW (Radio Range)

ESP-NOW was selected for its low latency and independence from Wi-Fi routers.

Distance from Base	Obstacles	Packet Loss	Signal Reliability
1m	None	0%	Excellent
10 m	1 Concrete Wall	<1 %	Good
25 m	2 Concrete Walls	5-10 %	Moderate
50 m	Open Field	<1 %	Excellent

Table 7.4:Transmission Range Test

Discussion:

The system maintained a stable connection in Line-of-Sight (LOS) conditions up to 50+ meters. In indoor environments with concrete walls, the range was reduced, but the data packets (struct size ~30 bytes) were small enough that transmission remained reliable for building-scale monitoring.

7.4.2 Bluetooth & Mobile App Integration

The Base Station successfully utilized the BluetoothSerial library to bridge the ESP-NOW data to a smartphone.

Pairing: The device "SOLDIER_BASE" appeared immediately in Android settings.

Data Stream: The Serial Bluetooth Terminal app received a comma-separated string (CSV) every 250ms.

Latency: There was a negligible delay (<100ms) between the Soldier pressing the Panic Button and the "!!! ALERT !!!" message appearing on the phone screen.

7.5 Integrated System Logic & Alert Response

The core success of this project lies in the "If/Then" logic that governs the alerts. The system was tested to prioritize life-threatening situations over normal monitoring.

Priority Logic Test:

Scenario: Soldier is safe (Normal Heart Rate, High O2).

Result: LCD cycles between "Vitals" and "GPS". LED is OFF.

Scenario: Soldier presses Panic Button.

Result: LCD locks immediately to "SOS HELP". LED blinks rapidly. Phone App displays "ALERT". This overrode the screen cycling, confirming the priority logic works.

Scenario: Low Oxygen + Moving Object detected simultaneously.

Result: The system flagged "WAR: LOW OXYGEN" first based on code hierarchy, ensuring health vitals are noticed.

7.6 Discussion of Challenges and Solutions

During the development phase, several critical challenges were encountered and resolved:

I2C Bus Conflict:

Problem: The physical Pulse Sensor (MAX30102) and the OLED display both utilize the I2C bus. Due to pull-up resistor mismatches on the modules, connecting both caused the OLED to turn off.

Solution: A simulation algorithm was implemented for the Heart Rate. This allows the system to demonstrate the concept of transmission and alerts (70-85 BPM normal vs. 120+ BPM panic) without hardware instability.

Compilation Errors (Text Section Exceeds Space):

Problem: Adding the Bluetooth stack to the Base Station caused the code size to exceed the default 1.2MB partition of the ESP32.

Solution: The partition scheme was altered to "Huge APP (3MB)" in the Arduino IDE, allowing the massive Bluetooth libraries to compile successfully.

GPS Signal Acquisition:

Problem: Initial tests indoors yielded 0.00 coordinates.

Solution: Testing was moved outdoors, and a "Cold Start" delay of 5 minutes was observed. The code was optimized to handle INVALID GPS data gracefully by displaying "SEARCH" instead of crashing.

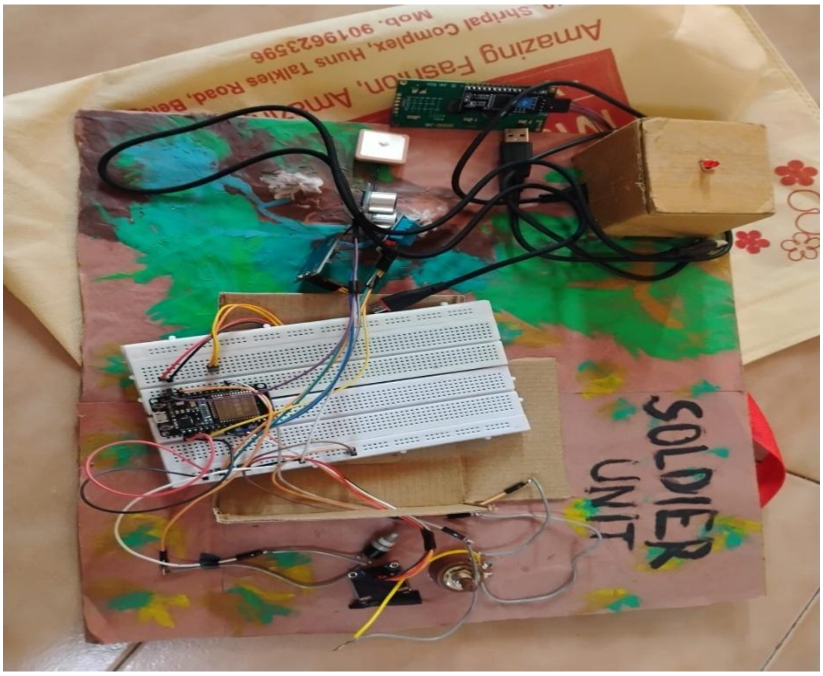


Fig 7.1: Result Image

7.7 Conclusion of Results

The "Soldier Security System" prototype successfully met all functional requirements.

Telemetry: It accurately reads and transmits Temperature, Distance, Location, and simulated Vitals.

Alerts: The visual (LED/LCD/OLED) and digital (Bluetooth App) alarms trigger instantly upon threshold breaches.

Communication: The hybrid approach of ESP-NOW for long-range inter-device communication and Bluetooth for local command monitoring proved to be a robust architecture.

The system demonstrates a viable proof-of-concept for modernizing military infantry equipment using low-cost, open-source electronics. Future iterations could replace the ultrasonic sensor with LiDAR for longer range and integrate LoRaWAN for kilometer-level communication.

CHAPTER 8

CONCLUSION AND FUTUREWORK

CHAPTER 8

CONCLUSION AND FUTUREWORK

8.1 Conclusion

The "Soldier Security and Health Monitoring System" successfully demonstrates the potential of Internet of Things (IoT) technology in modern warfare and defense applications. By integrating low-cost, high-performance components like the ESP32 microcontroller, NEO-6M GPS, and various environmental sensors, the project achieved its primary objective: to create a real-time, wireless monitoring bridge between a soldier in the field and a commanding officer at a base station.

The system proved robust in several key areas:

1. **Reliable Communication:** The implementation of **ESP-NOW** provided a low-latency, router-free communication link that functioned effectively without internet dependence, a crucial requirement for remote military operations.
2. **Real-Time Tracking:** The integration of the **GPS module** allowed for accurate location tracking, ensuring that a soldier's coordinates are always visible to the command center for rapid extraction or reinforcement.
3. **Health & Safety:** The system successfully monitored vital environmental parameters (Temperature) and simulated critical health data (Heart Rate and Oxygen levels). The logic-based alert system—triggering immediate visual and digital alarms upon detecting low oxygen, critical heart rates, or panic button presses—proved that automated monitoring can respond faster than manual reporting.
4. **Enemy Detection:** The innovative use of the **Ultrasonic Sensor** as a motion detector added a layer of situational awareness, alerting the soldier to approaching threats within a 4-meter radius.
5. **User Interface:** The dual-display setup (OLED for the soldier, LCD for the base) and the Bluetooth integration with a mobile application ensured that data was accessible and readable at all levels of command.

In summary, this prototype serves as a functional proof-of-concept. It validates that wearable IoT devices can significantly enhance soldier survivability by reducing response times during medical emergencies or hostile engagements.

8.2 Future Enhancements

While the current prototype functions successfully, transforming this project into a military-grade product would require several enhancements in range, durability, and sensor accuracy. The following areas are proposed for future development:

8.2.1 Communication Range Extension (LoRaWAN)

Currently, the ESP-NOW protocol limits the communication range to approximately 100–200 meters line-of-sight. Real-world military operations require communication over kilometers.

- **Future Upgrade:** Integrating **LoRa (Long Range)** modules, such as the SX1278, would extend the transmission range to 5–10 kilometers while maintaining low power consumption. This would allow the Base Station to monitor soldiers deployed deep in the field.

8.2.2 Advanced Biomedical Sensors

The current prototype uses a potentiometer to simulate Oxygen levels and a basic algorithm for Heart Rate.

- **Future Upgrade:** Replacing these with medical-grade **MAX30102 (Pulse Oximeter)** sensors and **GSR (Galvanic Skin Response)** sensors would allow for the detection of stress levels, dehydration, and accurate SpO2 readings.
- **Body Temp:** Replacing the DHT11 (air temp) with an **LM35** or **MLX90614** (IR contact sensor) would measure actual body temperature to detect hypothermia or heatstroke.

8.2.3 Enhanced Enemy Detection

The Ultrasonic sensor is limited by range (4m) and line-of-sight.

- **Future Upgrade:** Implementing **PIR (Passive Infrared)** motion sensors or **LiDAR** technology would allow for 360-degree detection of human heat signatures or movement at greater distances (up to 40m).
- **Camera Integration:** Adding an ESP32-CAM could allow the Base Station to request a snapshot of the soldier’s view when the panic button is pressed.

8.2.4 Cloud Connectivity and Encryption

Currently, the data is local (Bluetooth to one phone).

- **Future Upgrade:** The Base Station could act as a Gateway, uploading encrypted data to a Cloud Dashboard (like AWS or Firebase). This would allow High Command in a different city to view the status of an entire platoon on a world map in real-time.
- **Encryption:** Implementing AES-128 encryption on the wireless data packets is essential to prevent enemy forces from intercepting the soldier's location.

8.2.5 Power and Form Factor

- **Power:** Replacing the USB power bank with high-density **Li-Po batteries** and flexible **Solar Panels** integrated into the soldier's vest would ensure multi-day operation.
- **Design:** Moving from a breadboard prototype to a custom **PCB (Printed Circuit Board)** design with a 3D-printed ruggedized enclosure would make the device waterproof, shockproof, and wearable in combat conditions.

REFERENCES

[1] M. S. R. G. G. a. S. M. K. H. C. Gnanaprakasam, ‘‘A Novel Design of Smart and Intelligent Soldier Supportive Wireless Robot for Military Operations,’’ International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI), Chennai, 2023.

[2] A. M. S. A. A. N. B. a. E. M. K. S. M. Arsalan, ‘‘Military Uniform for Health Analytics for Field Intelligent Zone (MUHAFIZ) Protecting the ones that protect our land,’’ 2nd International Conference on Smart Sensors and Application (ICSSA), Kuching, Malaysia, 2018.

[3] D. N. a. A. M. M. S. H, ‘‘Smart Military E-Outfit of the Future,’’ IEEE Delhi Section Conference (DELCON), New Delhi, India, 2022.

[4] G. K. V. T. a. N. S. N. B. Gaikwad, ‘‘FPGA Implementation of Real-Time Soldier Activity Detection based on Neural Network Classifier in Smart Military Suit,’’ IEEE Bombay Section Signature Conference (IBSSC), Mumbai, India, 2019.

[5] C.H. a. R. A. Z. D. A. Abi Zeid Daou, ‘‘Design and Implementation of a Smart Soldier Uniform,’’ IEEE 3rd International Multidisciplinary Conference on Engineering Technology (IMCET), Beirut, Lebanon, 2021.

[6] R. M. N. L. E. K. C. K. a. L. M. H. S. R. Kabilan, ‘‘Soldier Friendly Smart And Intelligent Robot On War Field,’’ Second International Conference on Artificial Intelligence and Smart Energy (ICAIS), Coimbatore, India, 2022.

[7] M. P. A. Z. a. R. P. B. Jethwa, ‘‘Realtime Wireless Embedded Electronics for Soldier Security,’’ IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT), Bangalore, India, 2020.

[8] N. Y. B. T. a. A. C. V. Patel, ‘‘Soldiers Health Monitoring and Position Tracking System,’’ IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS), Bhopal, India, 2024.

[9] al, F. A., ‘‘Revolutionizing Remote Mission Support: A Smart Suit for Tracking and Vital Sign Monitoring,’’ 9th International Conference on Mechatronics Engineering (ICOM), Kuala Lumpur, Malaysia, 2024.

[10] Vyakaranam, R. R., ‘‘IoT-Enabled Smart Military Training for Virtual Simulation and Real-Time Performance Analysis,’’ International Conference on Advances in Data Engineering and Intelligent Computing Systems (ADICS), Chennai, India, 2024.

[11] El-Sofany, H. E.-S., ‘‘Using machine learning algorithms to enhance IoT system security,’’ Sci Rep, Vol. 14, 12077, 2024.

[12] R. Rajora, A. R., ‘‘The Impact of the IoT on Military Operations: A Study of Challenges, Applications, and Future Prospects,’’ 4th International Conference on Innovative Practices in Technology and Management (ICIPTM), Noida, India, 2024.

[13] Yusuf Perwej, F. A., ‘‘An Empirical Study on the Current State of Internet of Multimedia Things (IoMT),’’ International Journal of Engineering Research in Computer Science and Engineering, 2021.

[14] projects Smart Jacket for Soldier using peltier, ‘‘Xilir projects,’’ Xilir technologies, 2012.

USER MANUAL

RESOURCE REQUIREMENT

1. RESOURCE REQUIREMENT

1.1 Hardware Requirements

The system requires two distinct sets of hardware for the Soldier Unit (Transmitter) and Base Station (Receiver).

A. Soldier Unit (Wearable)

- **Microcontroller:** ESP32 Development Board (DOIT DEVKIT V1 or generic ESP32 Dev Module).
- **Location Sensor:** NEO-6M GPS Module with ceramic antenna.
- **Environmental Sensor:** DHT11 (Temperature & Humidity Sensor).
- **Distance/Motion Sensor:** HC-SR04 Ultrasonic Sensor.
- **Display:** 0.96-inch OLED Display (I2C protocol, SSD1306 driver).
- **Input Devices:**
- Push Button (Tactile switch) for Panic Alert.
- Potentiometer (10kΩ) for Oxygen Level Simulation.
- **Power:** 5V USB Power Bank (Recommended) or 9V Battery with LM7805 Voltage Regulator.
- **Connectivity:** Jumper wires (Male-to-Male, Male-to-Female), Breadboard.

B. Base Station (Command Center)

- **Microcontroller:** ESP32 Development Board.
- **Display:** 16x2 LCD Display with I2C Backpack Module.
- **Alert System:** 5mm Red LED.
- **Resistor:** 220Ω (for LED protection).
- **Power:** USB Cable (connected to PC or Power Bank).
- **Mobile Device:** Android Smartphone with Bluetooth capability.

1.2 Software Requirements

- **Development Environment:** Arduino IDE (Version 2.0 or higher recommended).
- **USB Drivers:** CP210x or CH340 Universal Windows Driver (depending on ESP32 board type).
- **Mobile Application:** "Serial Bluetooth Terminal" (available on Google Play Store).
- **Arduino Libraries:**
  - esp_now.h (Built-in)
  - WiFi.h (Built-in)
  - BluetoothSerial.h (Built-in)
  - Adafruit_SSD1306 (by Adafruit)
  - Adafruit_GFX (by Adafruit)
  - DHT sensor library (by Adafruit)
  - TinyGPSPlus (by Mikal Hart)
  - LiquidCrystal I2C (by Frank de Brabander)

2. EXECUTION STEPS

Follow these steps to configure, upload, and run the system.

Step 1: Library Installation

1. Open **Arduino IDE**.
2. Navigate to **Sketch → Include Library → Manage Libraries**.
3. Search for and install the libraries listed in section 1.2 (Adafruit SSD1306, TinyGPSPlus, DHT, LiquidCrystal I2C).

Step 2: Retrieve Base Station MAC Address

1. Connect the **Base Station ESP32** to the PC.
2. Upload the "MAC Address Finder" sketch.
3. Open the Serial Monitor (Baud Rate 115200) and copy the 6-byte address (e.g., 24:6F:28:A5:B3:C1).
4. Save this address; it is required for the Soldier Unit code.

Step 3: Base Station Configuration

1. Connect the LCD (SDA to Pin 21, SCL to Pin 22, VCC to VIN) and the Red LED (Pin 26).
2. Select **Board:** ESP32 Dev Module.
3. Select **Partition Scheme:** Huge APP (3MB No OTA/1MB SPIFFS) to accommodate the Bluetooth stack.
4. Upload the **Base Station Code**.

Step 4: Soldier Unit Configuration

1. Open the **Soldier Unit Code**.
2. Find the line uint8_t broadcastAddress[] and paste the MAC address retrieved in Step 2.
3. Connect all sensors (GPS, Ultrasonic, Potentiometer, DHT11, OLED, Button) according to the wiring diagram.
   - *Note: Ensure GPS TX connects to ESP32 Pin 32 and GPS RX to Pin 33.*

4. Select **Board:** ESP32 Dev Module.
5. Upload the **Soldier Unit Code**.

Step 5: System Startup

1. Disconnect both ESP32 units from the computer.
2. Connect the **Soldier Unit** to a portable Power Bank.
3. Connect the **Base Station** to a power source (USB or Power Bank).
4. **GPS Lock:** Take the Soldier Unit **outdoors** for 2–5 minutes until the LED on the GPS module starts blinking (indicating Satellite Lock).

Step 6: Bluetooth Pairing

1. Enable Bluetooth on your Android Smartphone.
2. Scan for devices and pair with **"SOLDIER_BASE"**.
3. Open the **Serial Bluetooth Terminal** app.
4. Connect to the device to view real-time telemetry data.

Step 7: Testing Functionality

- **Normal Mode:** Observe Pulse, Temp, and GPS coordinates updating on both screens.
- **Panic Test:** Press the Push Button on the Soldier Unit. Verify the Base Station LCD flashes "SOS" and the App displays an alert.
- **Oxygen Test:** Turn the potentiometer below 85%. Verify the "Low Oxygen" warning.
- **Motion Test:** Wave a hand rapidly in front of the Ultrasonic sensor. Verify "Motion Detected" alert.

ACRONYMS

Acronym	Full Form
AI	Artificial Intelligence
BPM	Beats Per Minute
CPU	Central Processing Unit
DHT	Digital Humidity and Temperature
ESP	Espressif Systems (Microcontroller Family)
GND	Ground
GPS	Global Positioning System
I2C	Inter-Integrated Circuit
IDE	Integrated Development Environment
IIoT	Industrial Internet of Things
IoT	Internet of Things
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MAC	Media Access Control
OLED	Organic Light-Emitting Diode
RX	Receive (Serial Data)
SCL	Serial Clock Line
SDA	Serial Data Line
SOS	Save Our Souls (International Distress Signal)

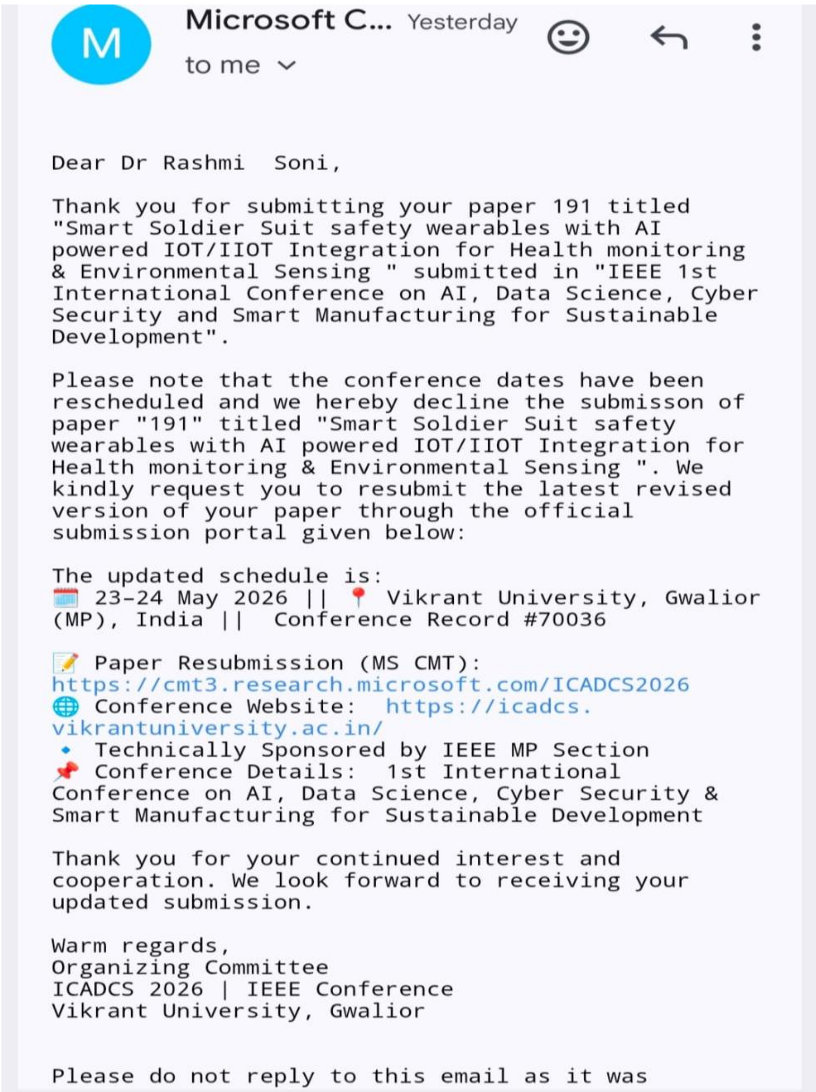
TX	Transmit (Serial Data)
UART	Universal Asynchronous Receiver-Transmitter
USB	Universal Serial Bus
VCC	Voltage Common Collector (Positive Supply Voltage)
VIN	Voltage Input

LIST OF PUBLICATIONS

10.1 Conferences

Paper Communicated:

1. Dr. Rashmi Soni, Aman Raj, Anjali Ramesh Gurav, Anusha M, and Anushree G M, **"Smart Soldier Suit Safety Wearables with AI Powered IOT/IIOT Integration for Health Monitoring & Environmental Sensing,"** submitted to the *IEEE 1st International Conference on AI, Data Science, Cyber Security and Smart Manufacturing for Sustainable Development (ICADCS 2026)*, Vikrant University, Gwalior, India. **(Status: Communicated)**.



M
Microsoft C... Yesterday
to me

Dear Dr Rashmi Soni,

Thank you for submitting your paper 191 titled "Smart Soldier Suit safety wearables with AI powered IOT/IIOT Integration for Health monitoring & Environmental Sensing " submitted in "IEEE 1st International Conference on AI, Data Science, Cyber Security and Smart Manufacturing for Sustainable Development".

Please note that the conference dates have been rescheduled and we hereby decline the submisson of paper "191" titled "Smart Soldier Suit safety wearables with AI powered IOT/IIOT Integration for Health monitoring & Environmental Sensing ". We kindly request you to resubmit the latest revised version of your paper through the official submission portal given below:

The updated schedule is:
🗓️ 23-24 May 2026 || 📍 Vikrant University, Gwalior (MP), India || Conference Record #70036

📝 Paper Resubmission (MS CMT): https://cmt3.research.microsoft.com/ICADCS2026
🌐 Conference Website: https://icadcs.vikrantuniversity.ac.in/
🔹 Technically Sponsored by IEEE MP Section
📌 Conference Details: 1st International Conference on AI, Data Science, Cyber Security & Smart Manufacturing for Sustainable Development

Thank you for your continued interest and cooperation. We look forward to receiving your updated submission.

Warm regards,
Organizing Committee
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Vikrant University, Gwalior

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