

# Next-Gen Soldier Monitoring System: A Wearable Vest with Intelligent Sensing and Automated Heat-Cold Regulation for Battlefield Vital Health Tracking

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## ABSTRACT:

Current battlefield environments expose soldiers to extreme weather, toxic gases, and intense physical exertion, increasing risks to health and mission performance. This paper presents a Next-Generation Soldier Monitoring System in the form of a smart wearable vest designed to continuously track both physiological and environmental parameters. The system integrates biometric sensors to measure heart rate, body temperature, and stress levels, along with environmental sensors for ambient temperature, humidity, and toxic gas detection. Data is processed using an Arduino Uno and transmitted wirelessly via an ESP32 module to remote monitoring stations. To enhance soldier comfort, the vest incorporates an adaptive thermoregulation mechanism using a heating element for cold conditions and a Peltier module for cooling in high temperatures. Additionally, a discreet haptic alert system notifies soldiers of critical conditions or threats. The proposed system aims to improve soldier safety, endurance, and operational efficiency in challenging battlefield scenarios.

**Keywords:** Wearable health monitoring, Biomedical sensors, Heart rate monitoring, Toxic gas detection, Internet of Things (IoT), Arduino Uno

**How to cite this article:** Baskar J, Kumar US, Paveethrashri K, Gayathri D., Next-Gen Soldier Monitoring System: A Wearable Vest with Intelligent Sensing and Automated Heat-Cold Regulation for Battlefield Vital Health Tracking. *Int J Drug Deliv Technol.* 2026;16(42s): 986-992; DOI: 10.25258/ijddt.16.42s.107

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## 1. INTRODUCTION

The soldiers operating in battle environments are usually subjected to adverse climatic situations, toxic gases, and immense physical and psychological stresses. Such conditions tend to impact their physiological stability, stamina, and operational capabilities. Efficient regulation of core body temperature and consistent tracking of all essential physiological parameters become necessary to avoid conditions such as heat exhaustion, hypothermia, excessive fatigue, and any other medical emergencies that may arise during battles. Several breakthroughs made in wearables and embedded devices have helped create some highly useful monitoring systems for soldiers. However, there is a general lack of integration between various aspects in most soldier wearable devices available in the current market. This leads to a reduction in their practicality due to the inability of the device to provide real-time monitoring while adjusting to different environments at the same time. In addition to this, traditional alerts are generally auditory in nature, which becomes a drawback while trying to remain unnoticed. Several studies have addressed different angles in this research domain. The researchers Mitsik and Byrdina [2] introduced wearable smart clothes

incorporating Peltier elements to regulate upper body temperature. Also, Poikayil et al. [3] offered a design of a jacket embedded with Peltier elements for temperature regulation based on user command input. Moreover, Sergi et al. [5] designed Internet-of-Things (IoT) devices for monitoring heat stress in the industrial environment. Nevertheless, no research has been performed on a unified platform for multi-parameter monitoring of health status, thermal regulation, gas concentration measurement, and silent alerts. To fill these gaps, this study has proposed an intelligent vest which incorporates monitoring health status, adaptive thermal regulation, and alert functions. The vest will continually sense the vital signs including heart rate, body temperature, and stress levels; at the same time, environmental temperature, humidity level, and poisonous gases will be monitored with environmental sensors. Temperature will be regulated automatically according to the sensed data, where heating will be utilized for cold environments and the cooling function using Peltier elements for hot environments. Finally, communication is performed wirelessly through the ESP32 microcontroller module.

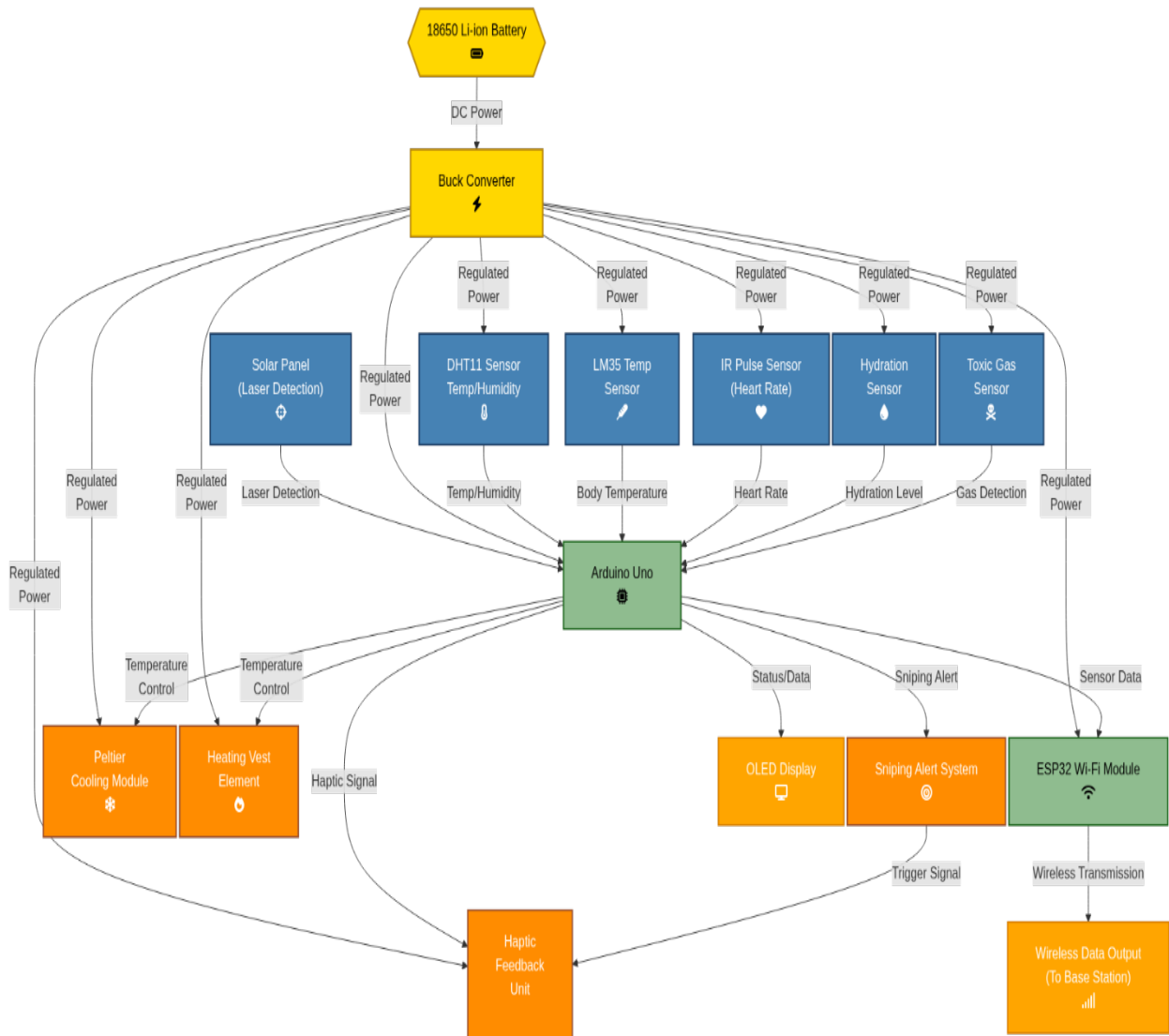


Figure 1 Block diagram

## 2. METHODOLOGY

This part provides details on the architecture, hardware implementation, and software programming of the intelligent soldier vest design. The system is developed based on a modular architecture combining different modules of sensing, processing, actuation, and communication.

### 2.1. System Architecture

The four major subsystems in the system include sensing unit, processing and control unit, thermal regulation and alert unit, and communication unit. The subsystems work together to detect health parameters of the soldier, monitor the environment, automatically regulate the body temperature and offer alerts during extreme situations. In the sensing unit, different sensors used for continuous monitoring include biomedical sensors such as heart rate pulse sensor, LM35 sensor to measure temperature of the body and the vest, GSR sensor to evaluate stress using skin conductivity, environmental sensors such as DHT11 sensor to measure temperature and humidity, and gas detection sensor to identify the presence of any dangerous gases.

For data collection and processing, an Arduino Uno microcontroller serves as the processing and control unit. An ESP32 module enables wireless communication between the vest and a remote monitoring station.

### 2.2. Hardware Implementation

This hardware setup incorporates various sensors, controllers, actuators, communication, and power management devices on a small, wearable system. The main controller used is the Arduino Uno microcontroller that takes care of acquiring data, making decisions, and managing thermal regulation. This is coupled with an ESP32 module that offers wireless communication using Wi-Fi.

Vital biological factors will be measured using specific biomedical sensors such as the infrared pulse sensor for measuring the heart rate, LM35 sensor for measuring body and vest temperature, and GSR sensor for measuring stress levels. Ambient temperature and humidity will be measured using DHT11 sensor while toxic gases will be measured using a gas sensor.

Temperature regulation is carried out using two different modules. One is a heating element in the vest which generates heat when the body temperature is low. On the other hand, cooling is done by the Peltier module using an L298N motor driver.

A cooling fan increases the efficiency of heat transfer from the Peltier module. The alarm and display module includes a haptic feedback module that gives silent feedback through touch, as well as an OLED screen that displays live values from the sensor readings. The whole system runs on 18650 rechargeable lithium-ion batteries with a buck converter for voltage regulation.

### 2.3. Circuit Design

An Arduino Uno microcontroller acts as the main controller of the system that uses a regulated supply of voltage that comes from the buck converter running from the lithium-ion battery. A common ground is used

for all sensors and peripheral modules for correct referencing. The IR pulse, LM35, and the GSR sensors are connected to analog inputs of the controller, while the DHT11 uses a digital input with single wire communication.

Thermal regulation circuit connects the heating element to an output that is controlled through a switching device. The Peltier module is powered through an L298N motor driver circuit so that the microcontroller can be protected from high current draws. A cooling fan is connected to the motor driver circuit. The tactile feedback module is connected to a digital output of the controller, whereas the OLED display is connected using I<sup>2</sup>C interface. The ESP32 board is connected to the Arduino Uno through serial interface.

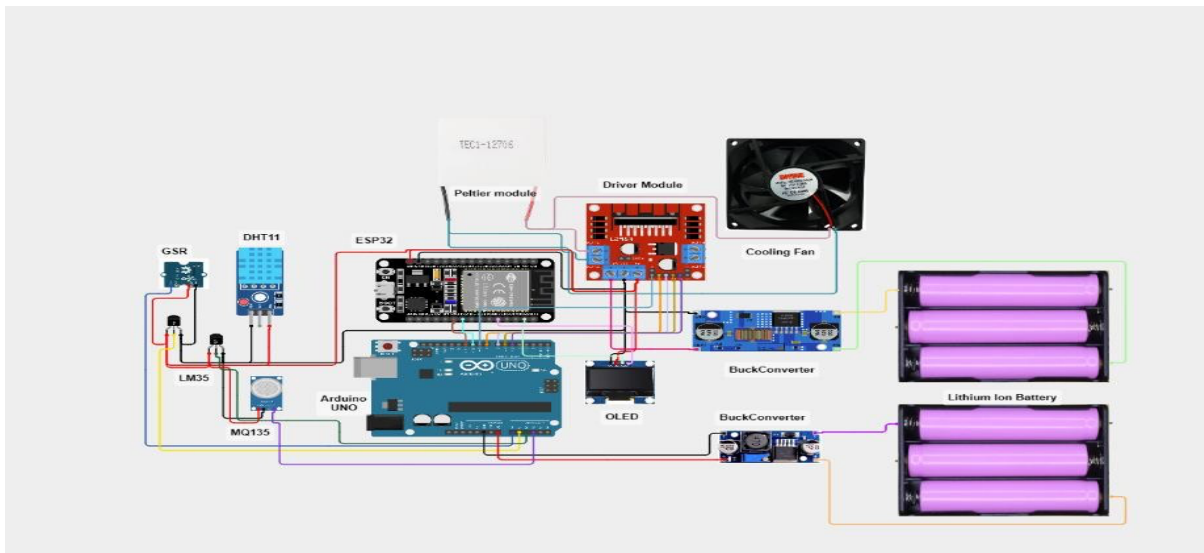


Figure 2 Circuit design

### 2.4. System Firmware Development and Control Algorithm

Firmware development of the system is done using the Arduino IDE with Embedded C/C++ programming language. Standard library files are used for the sensors including DHT11, LM35, IR pulse, gas sensor, OLED display, and ESP32 Wi-Fi interface. The Arduino Uno regularly samples the data from different sensors in real time. Sensor data are processed, filtered, and converted to physical values including heart rate, body temperature, environmental temperature and humidity, and concentration of the gas.

The adaptive control algorithm helps maintain temperature automatically in the vest. In case of temperature going below the lower threshold value, the heater is turned on. The Peltier cooling module is activated when temperature goes above the upper threshold limit using the motor driver circuit. Threshold control allows efficient and effective thermal regulation.

The software system constantly monitors the sensor output for any critical values like abnormal heart rate, high level of stress, and presence of toxic gases in the environment. Upon detecting such values, the system raises an alert using the haptic feedback system. The processed sensor output is transmitted wirelessly using the ESP32 module to the external monitoring system.

## 3. RESULTS AND DISCUSSION

The proposed Next-Generation Soldier Monitoring System has been developed as a working prototype in the form of a wearable vest and experimentally tested under controlled laboratory conditions. The primary purpose of such a system is to determine its ability to accurately monitor physiological and environmental parameters and adaptively regulate thermal comfort along with detecting any threats during combat operations.

# RESEARCH PAPER

## 3.1. Automatic Temperature Detection and Adaptive Thermal

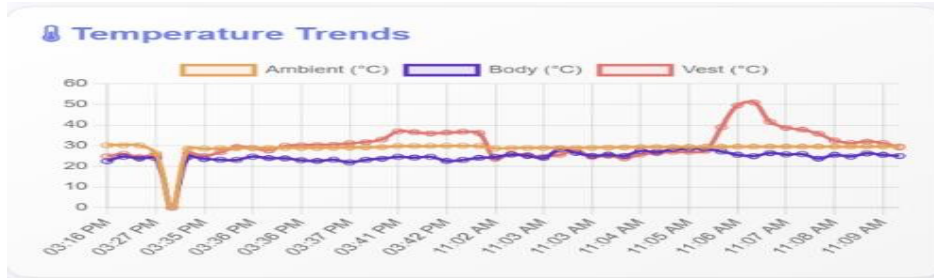


FIGURE 3.1 Ambient, Body and vest Temperature Variation

### Regulation

The automatic detection of temperatures of the body/vest and the environment is done through sensors LM35 and DHT11 respectively. In case the temperature of the body and/or the vest drops below a pre-defined lower limit, the system switches on the heating system causing an automatic increase in vest temperature, thereby protecting the soldiers from hypothermia due to cold climate. The heating system stops automatically as soon as the temperature reaches the desired level. If the ambient temperature goes above the upper pre-defined

limit, the cooling process is activated through a Peltier device causing a reduction in internal heat of the vest.

### 3.2. Humidity Trend Analysis

Ambient humidity data was collected through the usage of DHT11 sensors to analyze the effect of ambient humidity on soldier health and comfort. The humidity trend reflects that the sensors worked properly to detect all changes in environmental parameters over time. Humidity analysis is necessary to assess the severity of the environment and facilitate informed decisions about operation in various climate zones.

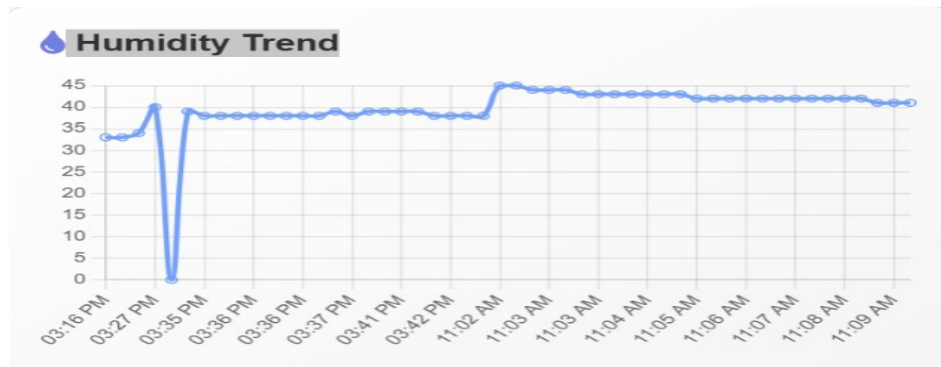


FIGURE 3.2 Humidity variation graph

### 3.3. Pulse (Heart Rate) Trend Analysis

Heart rate analysis was conducted through the usage of IR pulse sensors. Pulse data reflects variations in heart rate associated with physiological activities. This trend indicates that the heart rate sensor worked properly to detect heart rate changes and monitor health conditions. This test proves that the sensor can detect all irregularities of heart rates for further medical assistance.

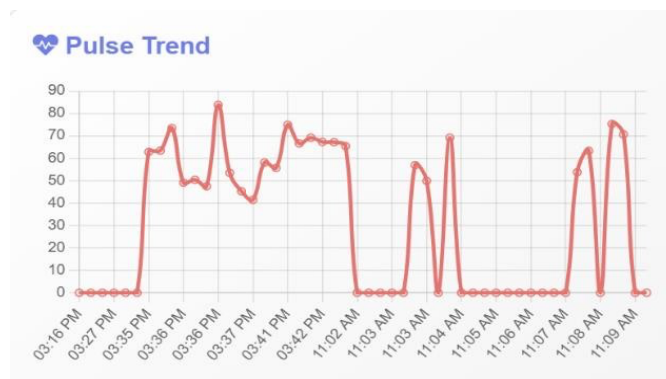


FIGURE 3.3 Heart rate (Pulse) Variation over time

### 3.4. GSR (Stress Level) Trend Analysis

Physiological stress data collection was carried out using the GSR sensor to assess variations in the level of stress. GSR trends show variations associated with the change of stress levels. The results prove that the system is capable of analysing stress and fatigue, which are important factors affecting soldier operations.

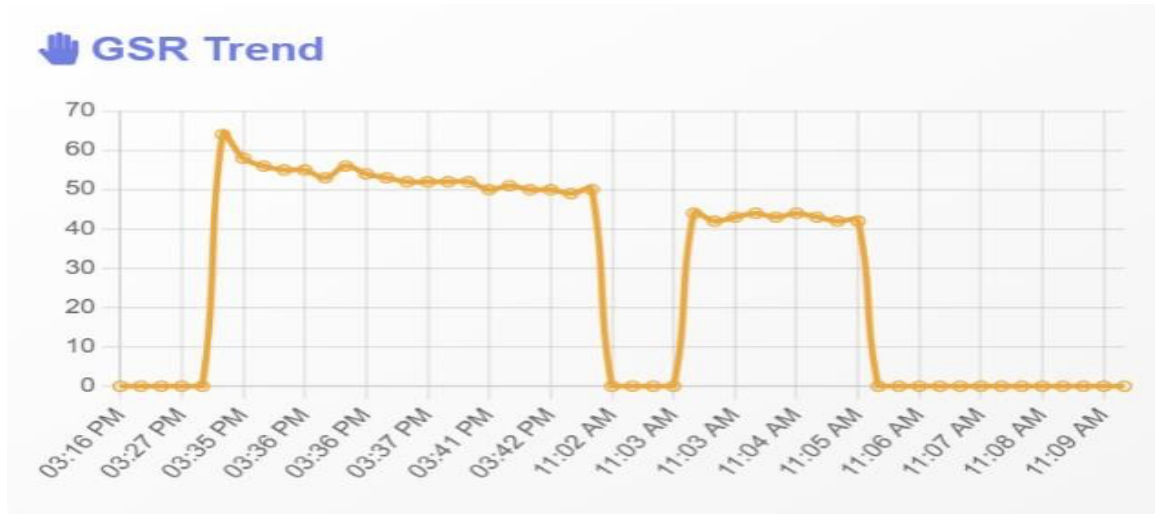


FIGURE 3.4 Galvanic skin response analysis

### 3.5. Analysis of Toxic Gas Detection Module

To check the working of the gas detection module, the sensor was exposed to a set number of hazardous gases. Whenever the level of gas crossed the predefined threshold value, a warning was automatically generated by the system, and the warning message was notified on the OLED screen along with haptic feedback for silent alerting of the soldier. It proves the gas detection capability and alert generation capability of the system.

### 3.6. Analysis of Sniper (Laser) Detection Module

For sniper detection, the system uses a laser-sensing mechanism through a solar panel. Whenever the laser alerting using haptic feedback is possible.

light falls on the solar panel, it triggers the sniper detection and generates silent haptic alert for the soldier.

### 3.7. Discussion about System Performance

Experimental analysis of the system verifies that the suggested intelligent soldier vest is a fully autonomous sensor-based wearable system which is capable of physiological monitoring, environmental sensing, temperature regulation, toxic gas detection and sniper detection with no delays at all. Real-time data acquisition and transfer through the wireless module i.e., ESP32 is done for real-time monitoring and silent

Parameter	Sensor / Module	Status
Heart Rate Monitoring	IR Pulse Sensor	Functional
Body Temperature	LM35 Sensor	Accurate
Stress Level (GSR)	GSR Sensor	Functional
Ambient Temp & Humidity	DHT11 Sensor	Stable
Toxic Gas Detection	Gas Sensor (MQ-series)	Threshold-triggered
Thermal Heating	Embedded Heating Element	Functional
Active Cooling	Peltier Module + L298N	Functional
Silent Alert	Haptic Feedback Unit	Functional
Wireless Transmission	ESP32 Wi-Fi Module	Real-time
Power Management	18650 Li-ion + Buck Conv.	Stable

Table 1. System parameter performance summary

In conclusion, the developed system shows robustness, flexibility, and practicality for military applications of

the future generation, providing better security and safety for soldiers. This project addresses existing gaps

in related research fields by creating an all-inclusive wearable device which incorporates multi-parameter physiological monitoring, adaptive temperature management, environment monitoring for gases, and intelligent alerts.

#### 4. CONCLUSION

This paper described the design of a Next-Generation Intelligent Soldier Monitoring System which is based on the development of a wearable smart vest that aims to improve soldier safety and comfort in challenging environments. The designed system provides integrated capabilities of physiological and environmental monitoring and adaptive regulation of thermal comfort level together with haptic-based silent alert mechanisms.

Specifically, the proposed smart vest includes sensors that allow for the monitoring of the vital health parameters like heart rate, body temperature, and stress level, as well as the environmental factors such as ambient temperature and humidity, toxic gas levels. The system allows for automatic thermal regulation based on sensor values with the heating element being used during cold periods while the Peltier-based cooling module operates during hot periods. The use of the haptic alerts enables delivery of alerts silently.

The prototype was tested experimentally, showing high-quality operation of the sensors, adaptation to the thermal regime, and energy management. This modular approach makes the device scalable and enables the addition of new functionality in the future, which makes the device suitable for military wearables in the next generation. Future research directions include AI/ML integration for analytics, location tracking based on GPS, cloud-based storage of acquired data, and communication protocols.

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