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AlpineShield: Advanced Smart Jacket for Mountaineer Safety

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Abstract — **Smart jacket is an application designed to ensure the safety of mountaineers by continuously monitoring vital signs and environmental parameters in real time so that climbers can proactively manage their health and respond effectively to changing conditions. This work presents the development and evaluation of a smart jacket designed for mountain climbers, addressing the critical challenges of safety, environmental monitoring, and real-time communication in high-altitude terrains. The jacket integrates a network of embedded sensors to monitor vital signs, ambient temperature, and altitude, while incorporating Global Positioning System (GPS) module for real time location tracking and emergency alerts. The system aims to enhance climber safety through continuous health assessment and reliable connectivity in remote mountain environments. All biomedical and environmental sensors interact through the Espressif Systems Platform 32-bit (ESP32) module along with various sensors which offers a promising solution to address the challenge faced by them. The integration of GPS and Nordic Radio Frequency (NRF) modules facilitate communication and location tracking, allowing climbers to stay connected with support teams and receive assistance in case of emergencies. The jacket model design also plays a major role with its removable unique mini compartments for all hardware components. By providing this innovative solution which utilizes real time monitoring data, mountain climbers can mitigate risks, optimize their performance, and enjoy a safer and more fulfilling climbing experience amidst challenging environments.**

Keywords – Arduino Uno, Temperature sensor, Oxygen saturation, NRF Module, GSM Module.

I. INTRODUCTION

Mountaineering is a pursuit that brings climbers face-to-face with some of the most breathtaking landscapes on Earth. However, along with its exciting heights, it also poses various challenges that require careful preparation. It demands peak physical health due to its rough nature. It influences their performance, safety, and overall experience. It requires cardio-vascular endurance, muscular strength, and mental resilience. Any compromise in health can lead to accidents, injuries, or even fatalities. Mountaineers face a lot of health risks, including altitude sickness, hypothermia, and frostbite. These conditions are triggered by extreme environments like high altitudes and remote locations.

The surrounding weather also plays a vital role in mountain climbing. Climbers are constantly exposed to unexpected environmental conditions which include extreme temperatures, humidity, pressure difference and rapidly changing weather patterns. Extreme cold can lead to hypothermia, while intense heat can cause dehydration and heatstroke [1]. Moreover, sudden weather changes can increase the risk of avalanches, rockfalls, and other hazards, further risking climbers' safety. In 2009, Podolskiy and Komori reported on avalanche risks at the Manali Symposium, India [2]. Due to volcanic activity, human activities, natural decomposition of organic matter, and geological processes, trapped gases are released and these causes medical risks. In remote and dangerous terrains, access to medical assistance is limited or even nonexistent. Therefore, integrating advanced monitoring and sensing technologies into climbing equipment ensures climbers' safety and well being. There isn't readily available data on the overall death rate of mountain climbers worldwide throughout history. It's difficult to track because data on global climbing deaths is sparse due to underreporting, especially on less popular mountains.

Through this project, we aim to meet the unique needs of mountaineers by using advanced technology and engineering solutions. It emphasizes the integration of GPS modules to accurately point out the location of climbers, for rapid rescue operations. This system also comprises health monitoring sensors like EMG, ECG, heartbeat, blood pressure sensors that track vital signs such as heart rate, muscle activity, oxygen saturation, and body temperature. A Telegram bot is also programmed to act as a communication interface between the climber and the real-time monitoring system. The bot can send real-time notifications to the base camp about critical conditions. Though initially developed for mountaineering, our project has applications in various fields, including military operations, search and rescue missions, and industrial settings such as mining and offshore exploration. Our system can help in various situations where safety, communication, and knowing locations are very important. This project provides aid to mountaineers and outdoor enthusiasts with the tools and technologies which enhance their safety.

II. RELATED WORKS

The research by Abeygunawardhana et al. [3] introduces a traveler-centric IoT system which includes both security monitoring and health monitoring features through a backpack design. The device operates through ESP32 hardware to run its solar powered LiPo battery which enables removable components because of its water-resistant design. Real-time monitoring with data storage together with decision making capabilities are enabled through a mobile app that operates through Firebase platform. The device features MQ gas sensors with LM-35 temperature sensors and BPM and temperature monitoring through a stethoscope sound detector. GPS tracking provides security features through its built-in theft prevention system. The IoT-based monitoring system for soldiers incorporates automatic bomb detection along with emergency notification systems and it incorporates health monitoring features [4]. The system consists of two main units: Soldier Unit having Arduino control mechanism with GPS, heartbeat and temperature detectors plus panic button and ESP32-camera for surveillance; Server Unit uses ThingSpeak real time monitoring together with cloud access features. Secure Wi-Fi communication lets soldiers upload videos and send hidden messages, and this overall improves safety and response during emergencies in addition to navigation assistance.

According to Tsao et al. Wu-Tso Elementary School in Taiwan adopted an IoT-based weather monitoring system to boost STEM education [5]. The system adopts MQTT data distribution protocol while integrating wind, temperature and humidity sensors to achieve efficient performance. Data exchange through Modbus protocol allows an Arduino MKR1000 to interact with the Raspberry Pi that manages web functionality and database operations. The webpage shows data which automatically renews its display every half hour. Future investigations target the improvement of scalability and efficiency to expand system applications. The IoT-based patient monitoring system operates during COVID-19 using MAX30100/MAX30102 together with DS18B20 and DHT11 sensors to monitor temperature and heart rate with oxygen levels and humidity [6]. The automated data acquisition through an ESP-32 microcontroller creates real-time remote tracking capabilities which is very beneficial for monitoring vulnerable patients.

A real-time health data collection and transmission occurs through an IoT-based monitoring system [7] which operates using Raspberry Pi 4B as the primary hardware. The health monitoring system incorporates three main components which include DS18B20, MAX30100, and SIM7600E. Secure storage occurs through the MySQL database and real-time monitoring and alerts emerge through the mobile application. Through this system patients benefit from both distant medical choices and crisis response capabilities for patients who need regular health checks. The IoT-based remote patient monitoring system [8] utilizes the combination of MAX30102 sensors with AD8232 sensors and NCIT for non-contact health tracking. The system uses NodeMCU for real-time telemedicine monitoring purposes. The ECG diagnostic accuracy reaches 97.81% through an advanced machine learning system based on ANN. Patients have access to proactive healthcare services combined with early medical intervention because of the system structure [9].

Paper [10] presents an IoT-based WBAN technology which enables real-time health assessment for rescue teams operating during flood and wildfires. The system employs MAX30102 for oxygen and heart rate measurement and AD8232 for ECG detection as well as NCIT for temperature measurement through Body Data Coordinator to gateway communication. EdgeX Foundry operates at the edge level to process sensor data before forwarding information to cloud storage analysis. Testing blood pressure trends becomes possible through time series analysis along with the forecasting model fbProphet which provides early opportunities for health interventions during rescue missions. Work [11] by Rajesh Kumar Garg et al. examines Wireless Sensor Networks for physical parameter observation through "Smart-Dust" sensors. The research evaluates how WSNs use efficient power methods and examines how these methods function in avalanche-dangerous zones. WSARE presents a rescue system with LoRa combined with satellite modems and sensors that monitor OSR beside body temperature and ECG and HR and RR and PRQ. The hardware installation features both Arduino Mega and communication modules.

Paper [12] introduces an IoT-based system designed exclusively for monitoring soldiers' health and safety during missions. It includes technologies like ESP32, smart sensors, GPS, and M-health systems. The system's architecture includes a Soldier Unit and a Server Unit which does communication via an IoT module. The Soldier Unit combines heartbeat and temperature sensors, a panic button, and a Peltier crystal for monitoring the body activities. These sensors gather crucial data and send to the Server Unit for processing to which it displays the information on an LCD display through the ThingSpeak app. Additionally the system also incorporates an ESP32-camera module for wireless communication facilities. Mohit et. al [13] developed an IoT healthcare system incorporating ESP32 together with Raspberry Pi for continuous vital signs tracking. The Wi-Fi transmission of data reaches a web server while MQTT facilitates swift server communication from the Raspberry Pi-based server to enable prompt doctor alerts.

An IoT-based automated healthcare system depends on Arduino to provide live health tracking along with disease identification functions that minimize patient visits to medical facilities [14]. The system connects heartbeat with temperature measurement and EEG sensors through AD8232 which delivers better ECG outcomes. An ESP8266 Wi-Fi module enables data transmission from RS232 to both PCs and mobile applications. The disease prediction module uses symptoms to produce results with better accuracy since it requires more data. The platform implements PHP and SQL systems that maintain cloud storage and perform analysis to deliver physicians the capability of real-time health monitoring. Through its Arduino-based setup the system regulates driver ECG monitoring in real time for safety prevention against accidents [15]. The system acquires heart potential measurements through an AD8232 ECG module with three leads and executes its readings every 10 seconds. The system uses Arduino to detect abnormalities which then activates both an alarm system and sends CAN bus signals to start vehicle braking which decreases vehicle speed. The inexpensive system improves both traffic safety and optimizes heart signal detection time between operations.

The patient monitoring system based on wireless sensor networks utilizes AODV and DSR routing protocols modified with AODV-M1 and AODV-M2 to boost rural healthcare operations [16]. Test results demonstrated that AODV-M2 achieved the highest performance metrics among the conducted evaluations. Future development will focus on broadening the patient monitoring system capabilities to enhance rural healthcare services. The system in [17] uses an Arduino Uno platform in which RC522 RFID together with L298N motor driver and Ublox NEO 6M GPS elements implement speed limit control features. The system first accesses GPS data while RFID serves as backup data and regulates motor speed through PWM technology. The system protects RFID UID data using DES encryption and operates through a restricted zone function which disables motor functions within defined areas. The application reads NMEA-formatted GPS data to establish safe speed limits for proper control.

Scientists have developed a liquid-solid triboelectric nanogenerator to harvest energy from water movement according to research [18]. Each droplet produces electric power at a rate of 99.1μA together with 9.55μW. Applications in smart home and IoT technologies gain potential from the self-powered rain-responsive window-closing mechanism operated by the device. Revathy and Greeshma [19] developed an IoT wearable device for fertility monitoring which uses flex and temperature sensors to track abdomen thickness alongside body temperature. An Arduino Uno controls the data stream for the system while its SVM algorithm identifies ovulation patterns accurately 92% of the time. DNA encryption combined with Huffman compression offers secure transmission of data through which doctors can remotely access patient records to decrease hospital visits and treatment-related stress for infertile women.

III. PROPOSED SYSTEM

This work is intended to improve mountaineer safety through real-time health and environmental monitoring. It combines several sensors to monitor heart rate, body temperature, pulse rate, atmospheric pressure, and oxygen saturation, providing constant health monitoring. The microcontroller processes and sends the information to a Telegram bot, enabling caretakers and base stations to remotely monitor the climber's condition. In the event of a life-threatening health incident, an emergency buzzer sends out an alarm, allowing for instant help. This system also includes ECG and EMG sensors to monitor heart activity and muscle effort, providing information on the physical state of the climber. The system also includes an environmental monitoring module that continuously monitors atmospheric pressure, temperature, humidity, and altitude, providing critical information for predicting weather changes. The GPS module provides real-time location tracking, and an automated emergency alert system alerts caretakers and base stations in case environmental conditions reach safety limits. Through the convergence of health tracking, environmental monitoring, and instant alerts, the suggested system presents an all-round and proactive protection solution, ensuring greater security and situational intelligence for mountaineers in perilous environments. Fig. 1 shows the component level representation of the proposed system.

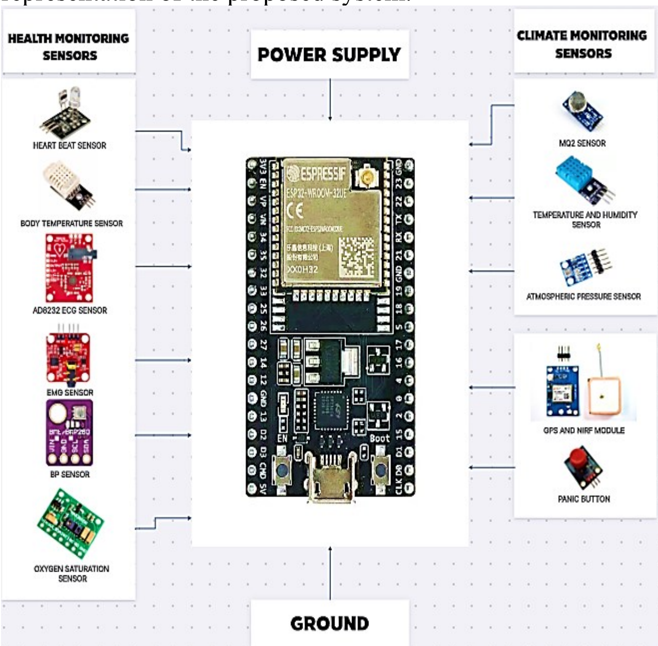

Fig. 1. Component Diagram of Proposed System

IV. DESIGN AND IMPLEMENTATION

A. Hardware Components

i. Espressif Systems Platform 32-bit

ESP32 is a microprocessor chip that provides integrated Wi-Fi along with Bluetooth connectivity for IoT devices. Its low power consumption during analog to digital conversions as well as computation and level thresholds, robust design and high level of integration makes it perfect for developing a system for checking the health and atmospheric conditions of a mountaineer.

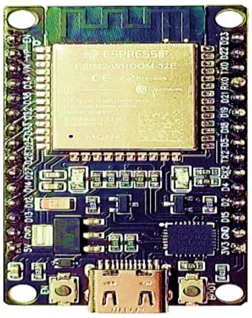

Fig. 2. ESP32

ii. Digital Barometric Pressure Sensors

The BMP180 is a digital barometric pressure sensor which has high precision and low power consumption which is ideal for mobile applications. It measures the pressure ranging from 300 to 1100 hPa, which can be used to determine altitude up to approximately 9000 m. The BMP180 communicates via the I2C interface, commonly used in microcontrollers, making it a favorite for weather stations and altitude tracking projects. The BMP280 is an advanced barometric pressure sensor designed for high accuracy and low power consumption, suitable for mobile applications. It measures atmospheric pressure within the range of 300 to 1100 hPa, which can be used for various applications like weather forecasting or altitude tracking with a precision of ±1 hPa.

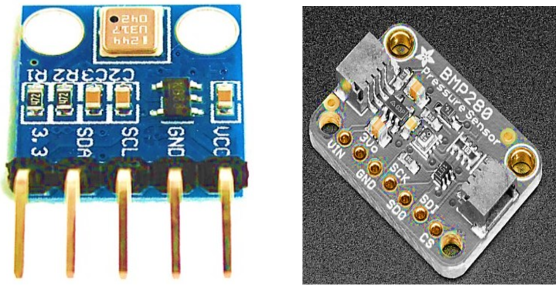

Fig. 3. Pressure Sensors

iii. *EMG Sensor*

The EMG sensor is used for the detection of electrical activity from a muscle by placing conductive pads on the skin. It reads the total activity, which is considered as a noise signal since it is composed of many random impulses. It contains a signal processing hardware that can convert these noise signals into a voltage level, such that the level is related to the amount of effort being used to activate the muscle. This sensor can be used to detect damage to the mountaineer's muscles by monitoring the conditions of fatigue in the muscle during isotonic contraction using two electrodes to measure the EMG signals. This system enables real time monitoring of injuries sustained by mountaineers during their trek.

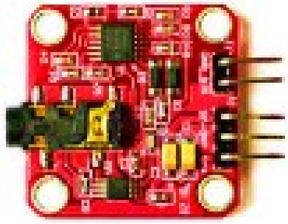

Fig. 4. EMG Sensor

iv. Finger Heartbeat Detection sensor

The KY-039 Finger Heartbeat Detection Sensor utilizes a bright infrared LED and a phototransistor to monitor the pulse of a finger, with a red LED flashing in sync with each heartbeat. Placing a finger between the IR LED and the phototransistor enables pulse detection at the signal output. In the phototransistor, increased current correlates with higher applied control voltage, the same way as in a standard transistor. Here, incident light acts as the control voltage. Higher light intensity leads to greater current flow. For optimal heartbeat detection, positioning the sensor over a larger blood vessel is recommended. Adjusting the sensor on the fingertip can enhance signal reception as well.

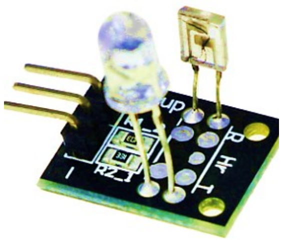

Fig. 5. Finger Heartbeat Sensor

v. *ECG Sensor*

The AD8232 chip is great for measuring bio-signals like ECG in noisy environments. It's a compact package that combines signal conditioning, amplification, and filtering. This simplifies signal capture for microcontrollers or ADCs. Its features include a high-pass filter to remove motion artifacts and electrode potential, a single-stage high gain and high-pass filtering for efficiency, customizable low pass filtering for noise reduction, and an amplifier for applications like right leg drive. It also has a fast restore function for quick recovery after signal disturbances and works well in various temperature ranges. Overall, it's perfect for wearable health tech and medical monitoring systems.

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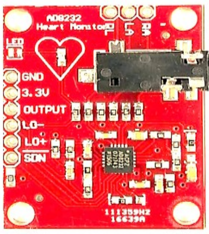

Fig. 6. ECG Sensor

vi. *Temperature/Humidity Sensor*

The DHT11 sensor is a digital temperature and humidity sensor. It includes a resistive type humidity measurement component, an NTC temperature measurement component and a high performance 8-bit microcontroller, which provides digital signal output. The sensor can measure temperature from 0°C to 50°C and humidity from 20% to 90% with an accuracy of ±1°C and ±1%. This sensor can be easily interfaced with any microcontroller such as Arduino, Raspberry Pi etc. to measure humidity and temperature instantaneously as the sensor communicates using a single wire digital interface. Also, DHT22 is a low cost, low power, and easily integrable digital sensor that measures temperature and humidity using a thermistor and capacitive humidity sensor. It transmits data to a microcontroller or microcomputer via a proprietary 1-wire communication protocol, eliminating the need for analog input pins. Compact and energy efficient, the DHT22 can send data over distances up to 20 meters, making it ideal for various environmental monitoring applications

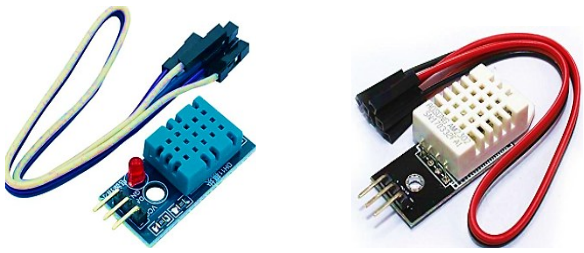

Fig. 7. Temperature/Humidity Sensor

vii. *Gas Sensor*

The MQ-2 sensor is a gas sensor used to detect various gases such as methane, propane, butane, alcohol, smoke, and carbon monoxide in the air. MQ2 is a metal oxide semiconductor type gas sensor. It works on the principle of semiconductor conductivity, where the resistance of its sensing element changes in the presence of different gases. This change in resistance is converted into an electrical signal that can be measured and interpreted by a microcontroller or other electronic devices. This sensor works on 5V DC voltage. It can detect gases in the concentration of range 200 to 10000ppm. It is often used in gas leakage detection systems, industrial safety applications, fire detection systems, and air quality monitoring devices. Its compact size, low cost, and ability to detect a range of gases make it a versatile choice.

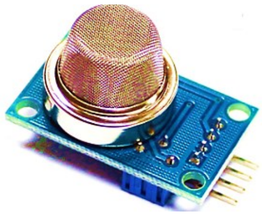

Fig. 8. Gas Sensor

viii. *GSM Module*

The NEO-6M GPS module is widely used across industries and applications that require accurate positioning, navigation, and geographic data acquisition. Its compact size, low power consumption, and high accuracy make it a popular choice for a variety of electronic projects and devices. It is used in GPS navigation devices for vehicles, boats, drones, and aircraft for accurate positioning and navigation.

Fig. 9. GSM Module

ix. *Oxygen Saturation Sensor*

SpO2 measures the percentage of oxygen in your blood, crucial for keeping your body functioning properly. A healthy SpO2 level typically falls between 96% and 99%, indicating that your blood is effectively carrying oxygen. When SpO2 levels drop too low, a condition called hypoxemia can occur, which might cause symptoms like shortness of breath or cyanosis, where the skin takes on a bluish tint. If left unchecked, hypoxemia can lead to hypoxia, where body tissues don't receive enough oxygen, potentially leading to serious health issues. Monitoring SpO2 is important for maintaining good health and catching problems early.

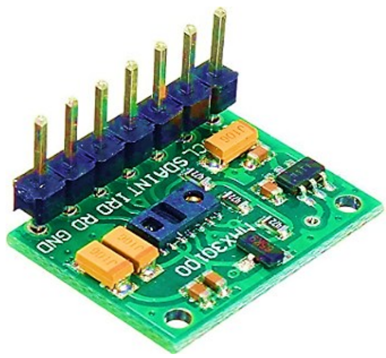

Fig. 10. Oxygen Saturation Sensor

V. RESULTS AND DISCUSSIONS

The top view of circuit implementation is shown in Fig. 11. The microcontroller controls all the health monitoring Sensors and sends the data to the caretaker through the NRF module. A buzzer is there for an emergency signal to send the signal to the caretaker in case if any health emergency occurs.

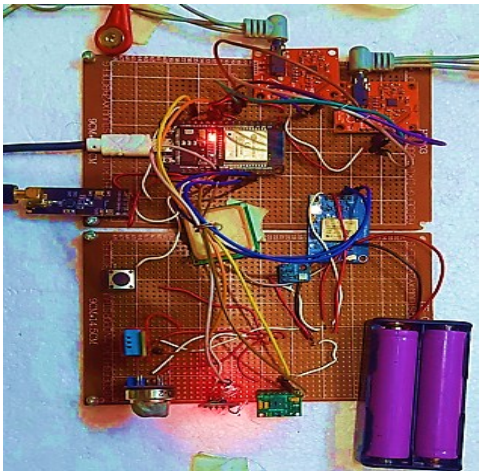

Fig. 11. Circuit Implementation

The data monitored by the system includes the heart rate, body and atmospheric temperature, pulse rate, atmospheric and body pressure, and real time location of the climber, ensuring a through tracking system. This system is vital in extreme conditions where health and location data need to be transmitted continuously for the climber's safety.

A. Health Monitoring

Fig. 12 shows the serial monitor's output. The real time results recorded display the climber's body temperature, heart rate, atmospheric pressure, and oxygen saturation (SpO2). For instance, at 19:33:22, the body temperature reads 69.00°F, heart rate 114.07 BPM, body pressure 130.00 hPa, and SpO2 98.00These values are sent regularly to the Telegram bot, for the constant communication of the climber's condition to the base station as well as the caretaker in case of emergencies.

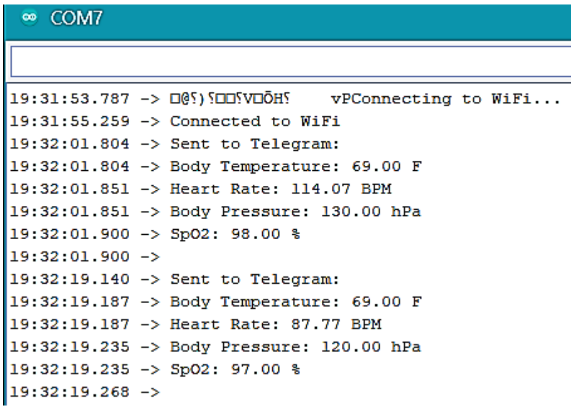

Fig. 12. Health Monitoring Serial Monitor Display

B. Telegram Bot Messages for Health Monitoring

The Telegram bot, named "Mountain Saver" receives and records the climber's health parameters at continuous intervals. The values are almost similar to those shown in the serial monitor which confirms the successful data transmission from the microcontroller. The variations in body pressure exhibit the system's ability to track real time health fluctuations. Fig. 13 shows the messages using Telegram Bot.

Fig. 13. Health Monitoring using Telegram Bot

C. ECG Result

The ECG module tracks the climber's heart activity, with electrodes attached at specific points on the body. Fig.14 shows the ECG waveform of the climber.

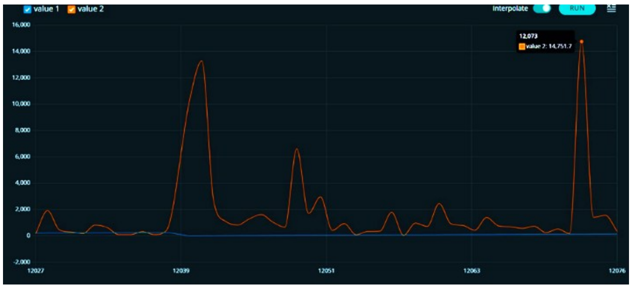

Fig. 14. ECG Waveform

D. EMG Waveforms

The EMG sensor captures muscle activity, explicitly contraction and relaxation, essential for monitoring physical exertion. The health data and real time location are relayed to the caretaker and base camp through the NRF module, ensuring assistance in the event of an emergency. The graph shows two conditions: resting and working. During resting periods, the EMG reading is relatively the same which indicates stable conditions in the first graph. However, during physical exertion like climbing or muscle activity, the second graph shows corresponding spikes.

Fig. 15. EMG Results: Resting & Working Conditions

E. Weather Monitoring

Fig. 16 shows the weather conditions in serial monitors. Atmospheric pressure fluctuates from 332.82 hPa to 714.25 hPa, indicating significant changes in weather conditions or elevation. Temperature readings range between 27.80°C and 29.40°C. Humidity levels vary from 47% to 52%. The altitude readings show a broad range, from 2053.94 meters to 8063.21 meters, likely due to changes in mountain altitudes.

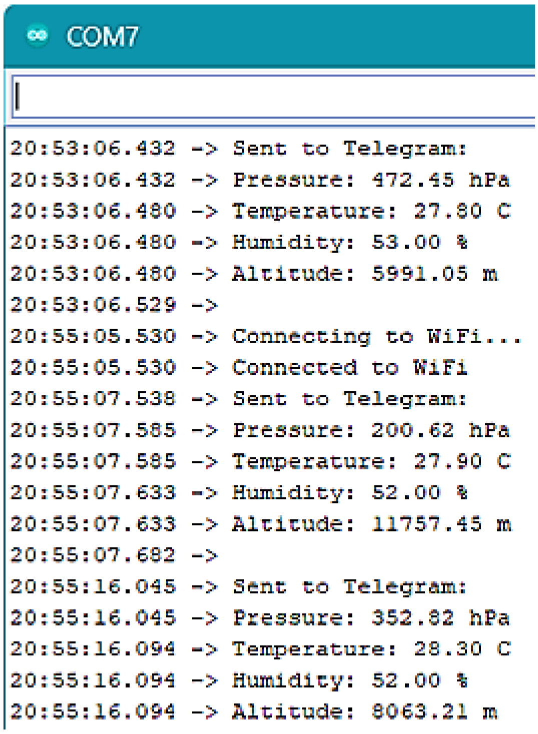

Fig. 16. Weather Condition in Serial Monitor

Also, the Telegram bot forwards individual messages containing atmospheric pressure, temperature, humidity, and altitude values. Fig. 17 shows the Telegram messages.

Fig. 17. Weather Condition using Telegram Bot

F. Emergency Message

Fig. 18 shows the emergency message alert to the corresponding care takers. Based on the defined thresholds, the health monitoring system must evaluate. When limits are exceeded by these values an automatic alert is transmitted to rescue personnel. Racks in our device contain an activation button which sends quick alerts to rescue teams when climbers experience illness.

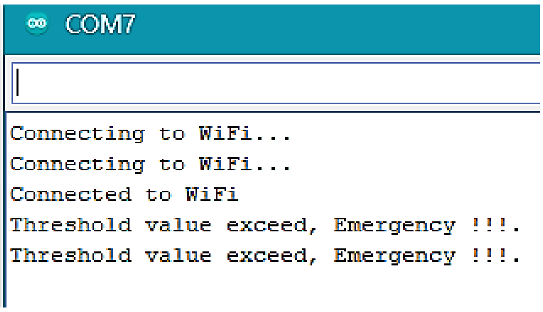

Fig. 18. Emergency Message Alert

G. GPS Navigation

The serial monitor captures the system's connection to Wi-Fi and its response to threshold violations. When the sensor detects environmental conditions that exceed a preset threshold, triggering an emergency alert, displaying the message: "Threshold value exceed, Emergency!!!" This function is designed to detect critical conditions, indicating risks for mountain climbers. The emergency alert is configured to send the notification to the Telegram bot, informing the user, caretaker and base camp in real time, which enhances safety during expedition. Fig. 19 and 20 show the latitudes and longitudes using serial monitor and GPS navigation.

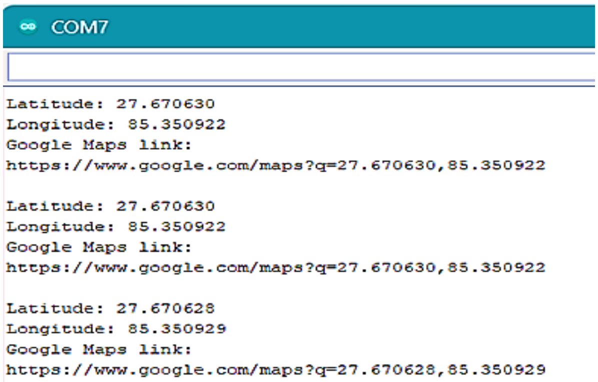

Fig. 19. Location using Serial Monitor

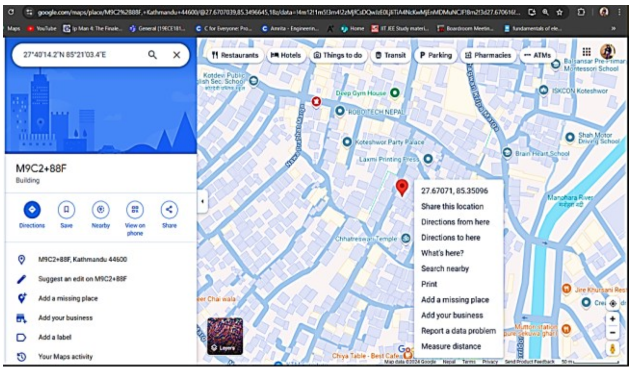

Fig. 20. GPS Location

VI. CONCLUSION

The proposed prototype will help the climber and as well as safeguard of the mountaineers to track the health condition of the climber along with the real time data transmission system has proven potential to decrease mortality rates through live monitoring by safeguards who inspect health records alongside geographical position and atmospheric information. The safeguards in the base can track the health and real time location of the mountaineers along with the environmental condition of the mountains. The current NRF module in the system holds a major limitation because its wireless communication range proves insufficient when operating in mountainous environments. The LoRa module demonstrates superior performance in distance coverage and environmental efficiency, so it seems like a better wireless communication choice for this purpose. The jacket should integrate camera technology to generate live video feedback that will help rescue teams during operations. The system transforms into a dependable security companion for mountaineers through these upgrades which enables better response together with improved preparedness during emergency situations.

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