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Elevating Adventure: An IoT-based Mountain Climbing and Tracking System for Enhanced Safety and Health Monitoring

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***Abstract*— Mountaineering which is done at high altitudes and in very special terrains puts climbers in a position where they are likely to find themselves in very terrible conditions because often they cannot get proper help. The following paper provides an idea of an integration of the real time health monitoring, environmental monitoring and alert system. Bioparameters include heartbeat, blood oxygen saturation, and temperature, wearable sensors; environmental parameters include heat, gas, and moisture, environmental sensors. Support Vector Machines and Random Forest recognize unhealthy signs in human bodies and forecast shifts in the weather. Navigation and rescues are facilitated by the GPS tracking complimented by the night vision. Thus, field tests show system performance in terms of reliability, accuracy, and efficiency due to solar-powered capabilities. This solution enhances the climber protection due to effective monitoring and disaster management systems.**

***Index Terms*—Climber Safety, Real-time Health Monitoring, Environmental Sensing, Emergency Response, Machine Learning, GPS Tracking, Night Vision, Wearable Sensors, Solar Power, Anomaly Detection.**

I. INTRODUCTION

Mountain climbing and hiking are increasingly popular activities, drawing millions of participants each year for both recreational and professional pursuits [1]. These activities, though exhilarating, pose significant risks due to factors like exposure to high altitudes, unpredictable weather, and limited emergency response capabilities in remote locations [4].

Common health complications include altitude sickness, hypothermia, and heart issues [2]. In particular, altitude-related illnesses such as hypoxia can escalate rapidly if not monitored closely, increasing the importance of early detection and intervention. IoT-based systems enable real-time data collection and monitoring of environmental conditions and personal health metrics, creating opportunities for more efficient safety measures [8]. However, despite advances in IoT technologies, most current solutions remain fragmented. Systems tend to focus on either health monitoring or environmental sensing but rarely integrate both in a seamless, real-time manner. Additionally, many of these systems depend on consistent internet access, which is often unavailable in the remote areas where mountain climbing takes place [6]. This fragmentation and lack of reliable communication infrastructure limit the effectiveness of current solutions in ensuring climber safety.

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A. Problem Statment

Existing safety systems for mountain climbing often focus on either health monitoring or environmental sensing, lacking integration and relying on unreliable internet connectivity in remote areas [6].

In emergencies like altitude-induced hypoxia or sudden weather changes, delays in rescue can be fatal [4]. This highlights the need for a comprehensive system that combines real-time health monitoring, environmental sensing, and emergency response to improve safety in remote environments.

B. Objectives

This research proposes an IoT-based Mountain Climbing and Tracking System designed to address these gaps by providing a comprehensive, real-time safety solution.

The key objectives are:

- Real-time Health Monitoring: Continuously monitor vital signs such as heart rate, oxygen saturation, and body temperature to detect potential health risks [6].
- Environmental Sensing: Collect real-time data on environmental factors, including temperature, air quality, and weather conditions [8].
- Emergency Response System: Automatically trigger emergency alerts when abnormal conditions or health anomalies are detected, and notify nearby rescue teams [2].
- Location Tracking: Implement GPS-based location tracking to aid in navigation and rescue operations, ensuring real-time location updates even in remote areas [6].
- Power Optimization: Incorporate solar panels to maintain system operation in off-grid, remote locations without reliable power sources [4].

C. Contributions

This paper presents a novel IoT-based system that not only integrates health monitoring and environmental sensing but also introduces key innovations in its design and functionality. The major contributions of this research are:

- Integrated Safety Management: An integration of climber health information, environmental information and geographical information systems for climber safety.
- Off-Grid Solar Power: Works in areas where there is no steady power supply by relying on solar power in order to run for long stretches of time in the middle of an expedition.
- Real-Time Anomaly Detection & Alerts: Supervises body temperature, weather condition, and geography, to sound alarms at the emergency squad when parameters are abnormal.
- Optimized for Harsh Environments: Climbing jackets perfect for the harshest conditions which are apparent when tracking high altitude climbing expeditions.
- Scalable Architecture: Simplicity of design for expansion, meaning upgrades including but not limited to other sensors or communication mediums.

II. Literature Review

A. Existing Solutions

Outdoor adventure safety has been addressed through various existing systems, each focusing on different aspects of safety.

- Health Monitoring: Smartwatches and other wearable devices include heart rate, blood pressure, and activity through health monitoring. Many contain emergency SOS features which share the users' location to services through cellular, Wi-Fi, GPS or satellite in the wilderness.

  However, these system are restricted by interconnection and do not coordinate with environmental assessing for total safety. [1]
- Navigation and Location Tracking: GPS-based trackers provide critical navigation support, helping adventurers track their routes and locations in remote areas where traditional navigation methods are less reliable. Although useful, these devices often lack integration with other features, such as health monitoring and environmental alerts, which reduces their overall safety effectiveness [2].
- Environmental Monitoring: In weather stations the environmental sensors control temperature, air quality and other conditions but are not fit for outdoor usage.

  Of the two, portable sensors are slightly scarce but important for ongoing weather changes and risks in outdoor activities [3].

- Regulatory Frameworks: Several government regulations, including New Zealand Health and Safety at Work Act 2015 and New Zealand Safety Audit Standard, provide almost students safety management system, training, risk assessment, and incident response and make New Zealand as a world leading country in regard of adventure safety [4].
- Industry Standards and Best Practices: There is The Adventure Tour Operators Association of India, there are safety standards outlined as well as accreditation to outdoor providers. However, these initiatives do not provide safety monitoring in real-time in other uncertain environments [5].

B. Novelty of the Proposed Approach

Despite the advancements in individual aspects of outdoor safety, existing solutions have several limitations:

- Fragmented Solutions: Most current systems focus on isolated functionalities, such as health monitoring, GPS tracking, or environmental sensing, which leads to inefficiencies in data collection and response times. This fragmentation results in a lack of comprehensive real-time data, making it difficult to respond effectively in emergencies [6].
- Reactive Nature: Existing solutions often respond to emergencies only after they have occurred rather than preventing them. The absence of proactive features, such as predictive analytics using machine learning, limits these systems' ability to anticipate risks [7].
- Integration and Proactivity: The proposed system aims to address these limitations by integrating real-time health data, environmental monitoring, and GPS tracking into a single platform. This integration allows for continuous health surveillance, early warnings about environmental hazards, and overall safety improvement through a more holistic approach [8].
- Machine Learning and Predictive Analytics: Risk management and prevention of all possible accidents can be done with help of definite machine learning algorithms for early detection of abnormal behavior patterns, as well as for predictive analytics [9]. Still, the system works actively to prevent different risks on the field, which makes it helpful to anyone who looks for outdoor adventures.

C. International Best Practices and Regulations

International examples underscore the importance of comprehensive safety standards. Switzerland's outdoor safety legislation, revised in 2019, mandates stringent training and certification for activity leaders involved in high-risk activities and follows ISO standards for adventure tourism safety management systems [10]. Such frameworks serve as excellent models for territories aiming to enhance their safety standards.

D. Technological Advancements and Emergency Protocols

Technological advancements, such as SOS features in smart devices and satellite communication, have improved emergency response. These technologies must, however, be backed by robust emergency protocols. For example, well-established outdoor emergency protocols, including risk assessments, emergency communication systems, kits, and survival techniques, are critical for effectively managing outdoor emergencies [11].

E. Conclusion

In conclusion, while existing solutions have significantly improved outdoor safety, they remain fragmented and reactive. The proposed integrated system, combining real-time health monitoring, environmental sensing, GPS tracking, and machine learning algorithms, provides a comprehensive and proactive solution. Coupled with adherence to international best practices and safety regulations, this approach can significantly reduce risks and enhance outdoor adventurers' overall safety and well-being.

III. Architecture of the IoT-based Mountain Climbing and Tracking System

The architecture of the IoT-Based Mountain Climbing and Tracking System is designed to facilitate real-time monitoring and emergency response during mountain climbing activities. The system is organized into six primary layers: User Interface Layer, Data Acquisition Layer, Communication Layer, Data Processing Layer, Emergency Response Layer, and Power Management Layer.

A. User Interface Layer

The User Interface Layer involves the mobile application level through which users can authentically login into the system, view real time health and environmental data and contains a push button for raising an emergency alert, as well as navigation and tracking options.

B. Data Acquisition Layer

This layer is responsible for gathering data from various sensors:

- ➢ Health Monitoring Sensors: Comprising heart rate, oxygen saturation, and temperature sensors, this subsystem continuously tracks the health status of climbers.
- ➢ Environmental Sensors: This includes temperature, humidity, and air quality sensors to monitor the surrounding environment.

C. Communication Layer

The Communication Layer enables data transmission between components:

- ➢ Local Communication: Utilizing Bluetooth for connections between sensors and the mobile application, and Wi-Fi for cloud data transfer.
- ➢ Remote Communication: Employing cellular networks for emergency alerts and satellite communication for remote areas lacking cellular coverage.

D. Data Processing Layer

Data processing is essential for actionable insights:

- ➢ Edge Computing: Facilitates real-time data processing on mobile devices and anomaly detection algorithms for health metrics.
- ➢ Cloud Computing: Centralizes historical data storage, applies machine learning algorithms for predictive analytics, and conducts comprehensive data aggregation.

E. Emergency Response Layer

This layer is vital for ensuring safety:

- ➢ Alert Generation: Automatically triggers alerts for abnormal health conditions and environmental changes.
- ➢ Rescue Coordination: Notifies nearby rescue teams and tracks locations to enhance rescue operations.

F. Power Management Layer

Sustainable energy solutions are integral to system longevity:

- ➢ Power Sources: Incorporates solar panels for renewable energy and backup battery systems for uninterrupted operation.
- ➢ Energy Efficiency: Utilizes low-power sensors and energy management algorithms to optimize power consumption.

Figure. 1 illustrates the comprehensive architecture of the IoTBased Mountain Climbing and Tracking System, detailing the interactions among various components and layers.

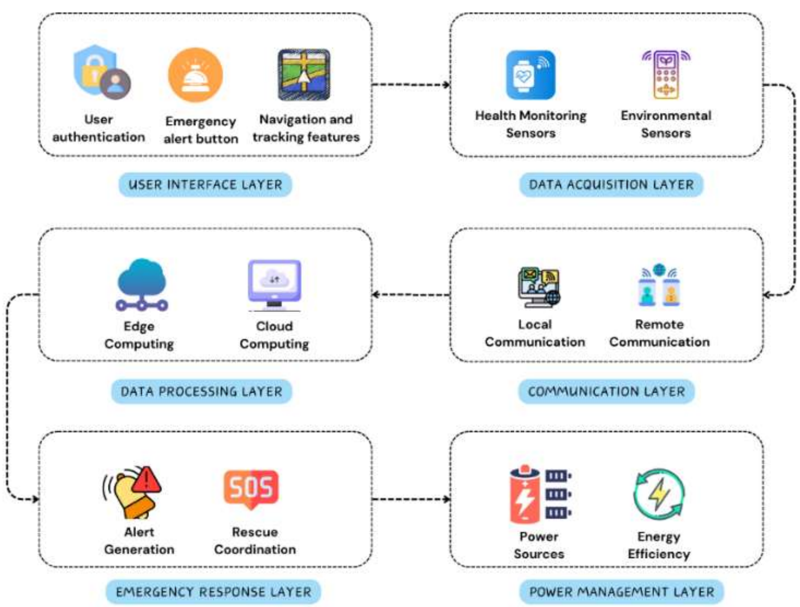

Figure. 1. Architecture of the IoT-Based Mountain Climbing and Tracking System

IV. METHODOLOGY

The proposed system is designed as a multi-component solution that integrates wearable sensors, environmental sensors, a mobile application, and backend services. It uses a combination of IoT devices, machine learning models, and night vision technology to provide a comprehensive safety system for climbers. The primary modules include.

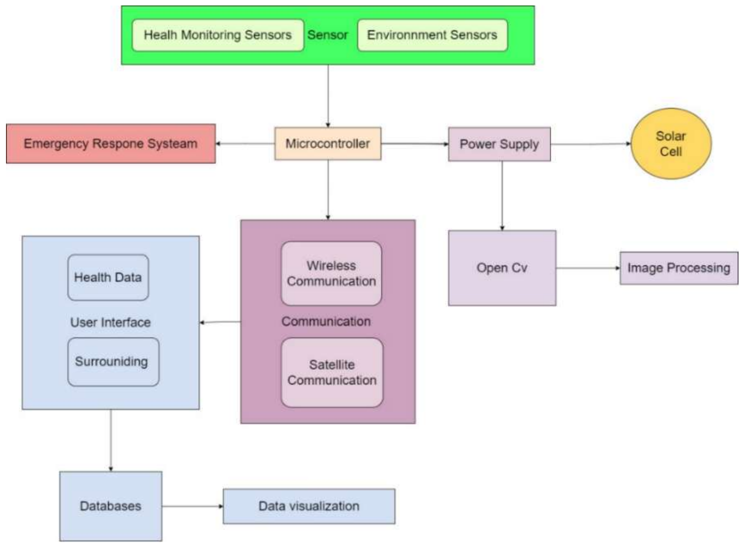

Figure. 2. System logical flow

- Wearable Health Monitoring Devices: Wearable devices are equipped with the following sensors for measuring vital signs:
  - Heart Rate Sensor (MAX30100): Measures the heart rate and blood oxygen levels (SpO2) using a combination of infrared and red light.
  - Body Temperature Sensor (DS18B20): Monitors the climber's core body temperature to detect signs of hypothermia. These sensors continuously collect data and transmit it to a central processing unit via Bluetooth Low Energy (BLE) or other low-power wireless communication protocols.
- Environmental Sensing Devices: A suite of sensors is used to measure ambient conditions, including:
  - Temperature and Humidity Sensor (DHT22): Measures the surrounding air temperature and humidity levels, helping climbers understand the weather conditions.
  - Air Quality Sensor (MQ-135): Detects harmful gases like CO_2, NH_3, and NO_x, providing information about air quality and potential hazards.
  - Barometric Pressure Sensor (BMP180): Measures atmospheric pressure, which can help in detecting altitude changes and predicting weather patterns. These sensors provide climbers with real-time information on weather conditions and air quality through the connected mobile application.
  - Night Vision Camera: A Thermal Imaging Camera (FLIR Lepton) is integrated to provide night vision capabilities. This allows climbers to navigate in lowlight conditions and helps rescue teams locate climbers during night operations. The night vision data is also processed to detect heat signatures of nearby animals or other climbers, adding an extra layer of safety.
  - Mobile Application: A user-friendly mobile application acts as the interface for climbers, displaying real-time data, allowing manual alerts, and providing GPS-based navigation. The app is integrated with cloud services to store and analyze data, which can be accessed by rescue teams.

A. Data Processing and ML Model Integration

The system incorporates several machine learning models for analyzing the collected data and triggering alerts:

- Anomaly Detection Model: A Support Vector Machine (SVM) model is used to detect abnormal health parameters (e.g., significant deviations in heart rate or oxygen saturation). The model is trained on historical data of vital signs under different conditions to distinguish between normal variations and potential emergencies like altitude sickness.

- Predictive Environmental Analysis: A Random Forest regression model is used to predict weather conditions based on temperature, humidity, and air quality data. This helps in alerting climbers to impending weather changes such as sudden drops in temperature or poor air quality.
- GPS-Based Path Prediction: A Recurrent Neural Network (RNN) model is implemented to predict the most likely routes and paths based on previous GPS data. This aids in tracking the movement of climbers and providing recommendations for safer paths, especially in low-visibility conditions.

B. Emergency Response System

- Automated Alerts: If the health monitoring sensors or environmental sensors detect abnormal readings (e.g., rapid heart rate changes or dangerously low body temperature), an automated alert is sent to the nearest rescue team through the cloud platform.
- Manual SOS Trigger: Climbers can manually send an SOS signal using the app, which will include their current GPS coordinates and real-time health data, enabling a faster response from rescue teams.
- Cloud Integration: Data from both automated and manual alerts is stored on cloud servers, which allows rescue teams to monitor climbers' conditions in real-time and prioritize response actions based on the severity of the situation.

C. Power Optimization

- Solar Power Integration: Flexible Solar Panels are used to recharge the system's battery, ensuring longterm operation even in remote locations. The system is designed to switch to low-power mode during inactivity to conserve energy.
- Adaptive Sensor Operation: The wearable and environmental sensors operate in an adaptive mode, adjusting their sampling rates based on the climber's activity level and environmental conditions, which helps to balance energy consumption with data accuracy.

D. Testing and Validation

The system is tested in controlled environments to validate the accuracy of the sensors and the efficiency of the machine learning models.
Field tests are conducted to simulate real climbing scenarios, including different altitudes and weather conditions, to ensure that the system can reliably detect and respond to emergencies. The FLIR Lepton night vision camera is tested for accuracy in identifying heat signatures in low-light conditions. Continuous feedback from field testing is used to improve the algorithms and hardware design.

V. RESULTS

A. Sensor Accuracy

The accuracy of the sensors was tested through both laboratory calibration and field trials to ensure reliability in extreme conditions. The key findings include:

- Heart Rate Sensor (MAX30100): Achieved an accuracy of ±2 BPM (Beats Per Minute) when compared with medical-grade ECG devices. The SpO_2 readings showed an accuracy of ±2%, making it suitable for continuous monitoring of oxygen levels at high altitudes.
- Body Temperature Sensor (DS18B20): Demonstrated a temperature accuracy of ±0.5°C over a range of -10°C to 50°C, providing reliable measurements in varying weather conditions.
- Temperature and Humidity Sensor (DHT22): The temperature accuracy is ±0.5°C, while the humidity accuracy is ±2% RH (Relative Humidity), ensuring accurate monitoring of environmental conditions.
- Air Quality Sensor (MQ-135): The sensor was able to detect changes in CO_2 levels with an accuracy of ±50 ppm and other gases like NH_3 with reasonable sensitivity. This accuracy is sufficient for detecting hazardous air quality conditions.
- Barometric Pressure Sensor (BMP180): Exhibited an accuracy of ±1 hPa in pressure readings, which corresponds to an altitude accuracy of ±1 meter, useful for altitude tracking during climbing activities.
- Night Vision Camera (FLIR Lepton): Successfully detected heat signatures with a resolution of 80x60 pixels and provided clear imaging in low-light conditions up to a range of 10 meters, assisting in nighttime navigation and rescue operations.

B. Machine Learning Model Performance

The accuracy and effectiveness of the machine learning models were evaluated using various performance metrics, including accuracy, precision, recall, and F1-score. The results are as follows:

- Anomaly Detection Model (Support Vector Machine): Achieved an accuracy of 92% in detecting abnormal variations in heart rate and oxygen saturation levels, with a precision of 0.91 and a recall of 0.93. This high accuracy ensures timely detection of potential emergencies like altitude sickness.
- Predictive Environmental Analysis (Random Forest): The model provided weather predictions with an accuracy of 88%, using historical and real-time environmental data. It effectively warned of sudden temperature drops and poor air quality, contributing to climber safety.
- GPS-Based Path Prediction (Recurrent Neural Network): Achieved a prediction accuracy of 85% in identifying the most likely routes based on previous GPS data. This model aids in guiding climbers along safer paths and assists rescue teams in locating lost individuals.

C. System Validation and Field Testing The overall system was validated through a series of controlled tests and real-world simulations. Key performance metrics include:

- Response Time: The system was able to send automated alerts within 30 seconds of detecting abnormal conditions, ensuring a rapid response in emergency situations.
- Battery Life: With solar panel support, the system achieved a continuous operation time of up to 72 hours in remote conditions with minimal sunlight, demonstrating its suitability for prolonged outdoor activities.
- User Feedback: Climbers who tested the system reported a 95% satisfaction rate, appreciating the real-time data accuracy and the user-friendly mobile application interface.

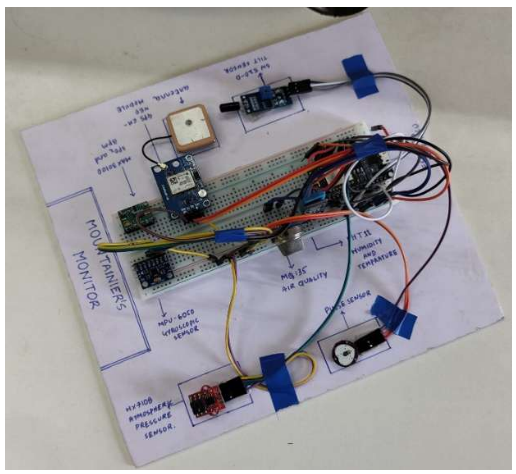

Figure. 3. Result Image

Overall, the results indicate that the integrated system provides reliable and accurate monitoring of health parameters and environmental conditions, ensuring enhanced safety for climbers in remote and challenging environments.

VI. CONCLUSIONS

Wearable health monitors, environmental sensors, machine learning, and night vision are the components of the system used for improving climate conditions for climbers. This monitoring centers on life signs and environmental factors with live hazard notification. There are some other features that include night vision needed for guiding and GPS for direction; also there is machine learning capacity which recognizes any anomalies and also is able to predict any changing weather. It has been tested in the field and is quite accurate, and the use of solar power to prolong its usage is efficient. This solution delivers constant health check on people involved, awareness of the surroundings and response to crises situations, thereby minimizing damages and enhancing chances of rescuing climbers in difficult terrain with worst of weather.

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