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Identification of Victims Buried Under Avalanches

Ajin kumar J[1], Mohamed Barakathulla L[3], Pravin M[4], Ayappan G[2], Dr. M Pachhaiammal @Priya[5]
Department of Computer and Communication Engineering, Sri Sairam Institute of Technology West Tambaram, Chennai, Tamil Nadu, India

Abstract: An avalanche accident is a very hazardous incident, usually involving complete burial in compacted snow with reduced breathing capability and an acute reduction of available oxygen. The probability of survival decreases greatly with every minute of burial, and there is a marked drop beyond the first fifteen minutes. Conventional methods of avalanche rescue rely on the detection of the victim by radio beacons or reflectors. These methods do not provide any information on the physiological state of the buried victim. In this regard, rescue teams cannot access medical condition awareness as to which victim is in urgent need at the moment when multiple-victim avalanche situations arise. This paper proposes a wearable avalanche victim identification device that integrates a MAX30102 pulse oximeter sensor for detecting oxygen saturation and heart rate measurement, NEO-6M GPS module for acquiring geolocation, ESP32 microcontroller for signal processing, and SX1278 LoRa transceiver for long-range multi-hop wireless communication. The device automatically increases its transmission frequency when oxygen saturation falls below a threshold, indicating hypoxia. The experimental results report reliable physiological monitoring and long-range communication in mountainous terrain, with very effective support for rescue prioritization.
Keywords: Pulse oximetry, oxygen saturation, heart rate, multi hop communication, Lora transceiver.

I. INTRODUCTION

Avalanches happen when layers of accumulated snow on a slope lose their cohesion and slide downhill at high speeds, often with one or more skiers, hikers, or mountaineers caught and moved along with the snow. Once buried in the snow, the victim's chest movements are severely limited by the weight of compacted snow layers. The small volume of the air pocket surrounding the nose and mouth becomes rapidly depleted of oxygen and is gradually replaced by carbon dioxide. The literature suggests that survival probability remains high for the first fifteen minutes of burial but decreases significantly thereafter, notably beyond thirty-five minutes, when hypoxia and cardiac arrest become inevitable. The present rescue systems, namely, avalanche transceivers and RECCO reflectors, help the rescue teams locate the places of the victims but fail to provide information about whether the victim is still alive or is in a state of critical respiratory distress. In the case of multiple victims, the lack of physiological information results in random sequencing of the rescues, which can lead to wasting precious time on rescuing the already dead while a potentially survivable casualty continues to deteriorate. A device that can offer physiological monitoring and simultaneous location tracking becomes very critical in improving the survival rates of victims. Triggers for avalanches include natural events such as heavy snowfall, rapid warming, or vibrations, but many incidents clearly occur during adventure sports or military patrol operations in high-altitude regions. With increasing tourism in mountainous areas and with armed forces operating in often-remote, high-elevation terrains, the potential for avalanche exposure increases and continues to rise worldwide. Factors contributing to the severity of an avalanche event include snow density, terrain slope, wind deposition, temperature gradients, and rock or vegetation cover. These environmental factors create unstable and dynamic collapse points within the snowpack. Because avalanches can travel at speeds well over 80 km/h, individuals caught in the flow often have little chance to maneuver or escape. As the snow around the victim settles after burial, it becomes much harder than ice and may attain densities which prevent the expansion of the lungs. He or she may remain conscious for a period of minutes with feelings of panic, hyperventilation and finally blackout as oxygen is depleted. The complete lack of movement and inability to see the casualty from outside make it almost impossible for rescuers to ascertain whether the victim is alive. Rescues are critically dependent upon stability of environmental conditions since further avalanches are common during the period following the original event. Rescue groups may also be confronted by extreme cold, darkness and inaccessibility, delaying recovery attempts. Avalanche survival research emphasizes repeatedly that time is the most crucial factor. When there are multiple victims, simply reducing search time does not suffice. Medical triage is required. Absence of physiological monitoring within currently available avalanche safety systems forces rescuers to make decisions based on luck or subjective judgment. A technological system capable of independent monitoring and broadcasting the health condition of a buried victim enables objective, data-driven decisions. The paper, therefore, focuses on bridging this gap by introducing a wearable sensing and communication system that functions despite cold weather, low oxygen environments, and absence of external networking infrastructure.

II. OBJECTIVES

This research work is primarily focused on the design and realization of a wearable avalanche survival monitoring system that effectively detects the status of the buried victims to aid in rescue priority. The proposed system should measure oxygen saturation and heart rate continuously, establish the location of the victim using GPS, and transmit such information through a long-range LoRa mesh network. Such a device needs to be power-effective with very low power consumption and switch into an emergency transmission mode whenever hypoxia is detected, thereby notifying the rescue teams about the critical state of the victim. In the end, the solution will provide the possibility to achieve rescue prioritization during multi-casualty avalanche events based on the basis of data. The system should be compact, weightless enough to be worn during snow activities, resistant to cold-induced battery degradation, and functional in the presence of atmospheric interference and terrain shadowing. The system should require no manual input from the victim, as physical incapacitation is expected. Critical thresholds about SpO_2 level and pulse patterns should be processed autonomously, enabling the device to answer to emergencies independently, even when the wearer is unconscious.

III. LITERATURE REVIEW

In the case of avalanche burial, the restricted chest expansion and rapid depletion of oxygen make hypoxia the most important cause of death in otherwise not fatally traumatized survivors. Pulse oximetry refers to the non-invasive monitoring of arterial blood oxygen saturation. Photoplethysmographic-based measurement is reliable, and MAX30102 is used in a wide range of wearable medical devices, since it integrates LED drivers, a photodiode for detection, and amplification into one single element. Cold conditions decrease peripheral blood flow, but appropriate digital filtering allows a stable estimation of SpO_2 even in low-perfusion states. GPS-based geolocation must therefore be implemented to determine the approximate position of victims. The actual snow cover weakens the GNSS reception, but even intermittent or last-known coordinate information will substantially reduce search regions when trying to rescue subjects. The most serious problem associated with mountainous terrain is wireless communication, where classical networks are usually not available. LoRa, based on chirp spread spectrum modulation, guarantees long-range, low-power transmission, and can perform effectively in multi-hop mesh configurations, enabling data relaying across obstructed areas. Existing avalanche rescue tools only support location detection and not physiological condition awareness. Physiological condition monitoring is of primary importance during a multi-casualty rescue for prioritization of victims. The integration of physiological monitoring and long-range communication represents the missing component in current avalanche safety systems.

IV. EXISTING SYSTEM

The conventional methodology of avalanche rescue involves beacon searching, probing, and excavation, in that order. Avalanche beacons operate to transmit and receive in the frequency band of 457 kHz; thus, rescuers can locate victims by triangulation. While efficient for location, these devices cannot provide information whether a victim is breathing or in cardiac instability. RECCO reflectors are even more limited, reflecting radar signals from search equipment without any sort of electronic sensing or communication. Probing techniques are slow, labor-intensive, and yield no diagnostic data. Search dogs are effective in odor-based detection but are subject to weather, exhaustion, limited deployment time, and handler availability.

They all have one fundamental limitation in common: no physiological information. Thus, victims who are already in irreversible respiratory failure may be subjected to immediate rescue efforts while a still-survivable victim remains buried. In high-casualty avalanche scenarios-which is not uncommon in mountaineering expeditions and military patrols-this inherent inability to perform triage can lead directly to preventable deaths. The problem is not the skill or training of the rescuers but rather the absence of real-time medical telemetry to inform management decisions.

V. PROPOSED SYSTEM

The proposed system undertakes physiological and positional monitoring using a compact, wearable device. At the heart of this system lies the MAX30102 pulse oximeter, which measures dynamic patterns of light absorption produced by oxygenated and deoxygenated haemoglobin to calculate arterial oxygen saturation and pulse rate. These two measurements are considered vital signs that provide critical indicators of respiratory function and cardiovascular stability. The NEO-6M GPS module captures real-time geospatial data that can still provide useful localization breadcrumbs even when there is partial loss of signal.

The ESP32 microcontroller acts as the processing hub, from which PPG waveforms are interpreted, oxygen saturation is calculated using ratio-of-ratios computations, heart rate variability is monitored, and telemetry packets are prepared. The SX1278 LoRa module executes the transmission of telemetry in a mesh network topology, allowing long-range, multi-hop communication over complex terrain where direct communications with the rescue base might not be possible.

If the measured SpO_2 falls below a critical threshold indicative of hypoxic distress, the system automatically switches to emergency broadcast mode, increasing the frequency of transmissions to urgently draw attention to the condition of the victim.

This automatic triage signaling is important because the buried victim may, at any time, become unconscious and thus unable to initiate help. The automated detection of the emergency removes dependence on manual calls for help and ensures that the rescue operation is informed by objective medical urgency.

VI. METHODOLOGY

The system continuously measures physiological and positional data while wirelessly sending it using a long-range wireless network. The MAX30102 uses absorbed red and infrared light to generate photoplethysmographic waveforms. Oxygen saturation is determined by the ratio between pulsatile and baseline absorption signals using:

$$SpO_2 = A - (B \times R)$$

where R is the ratio of light absorption at the two wavelengths. Heart rate is calculated by measuring the interval between systolic pulse peaks:

$$HR = 60 / T$$

Filtering and processing of raw sensor data by the ESP32 microcontroller updates GPS coordinates and formats the values as compact telemetry packets. The SX1278 LoRa transceiver sends these packets over a mesh network, where surrounding nodes forward the signal toward a rescue base station. Should oxygen saturation fall below a critical threshold, the device switches to high-frequency emergency burst transmission to indicate medical urgency. This ensures that the device will continue its operation autonomously without the need for physical activation by the buried victim.

VII. IMPLEMENTATION

The hardware setup consists of the MAX30102 pulse oximeter, NEO-6M GPS module, ESP32 microcontroller, and SX1278 LoRa transceiver powered by a rechargeable lithium-ion battery. The ESP32 manages data acquisition, signal filtering, emergency detection, and communication scheduling. LoRa communication parameters are configured to favor range and robustness rather than data rate, allowing reliable operation in obstructed mountainous regions. Power efficiency is maintained by placing the microcontroller into deep-sleep mode between measurements, extending battery life during prolonged burial scenarios. Field evaluations demonstrated stable SpO_2 and heart rate measurement, reliable GPS coordinate retention, and multi-kilometer LoRa transmission performance, validating the system’s applicability for real avalanche rescue support.

VIII. CONCLUSION

This paper presents an innovative solution to the vital challenge of identifying and prioritizing avalanche victims based on physiological condition. The proposed wearable device for avalanche victim identification includes the MAX30102 pulse oximeter, NEO-6M GPS module, ESP32 microcontroller, and SX1278 LoRa transceiver, which together ensure reliable continuous health monitoring and geolocation tracking even in the harshest mountain environments. If signs of hypoxia are detected, the system autonomously increases transmission frequency, thus communicating medical urgency promptly to rescue teams, in turn allowing more effective data-driven decision-making in the process of multi-victim avalanche rescues.

This system represents a significant improvement over traditional avalanche rescue tools, which largely do not possess health status awareness, by virtue of its integration of physiological monitoring with long-range, low-power communication in a rugged, wearable form factor. Field evaluations have demonstrated the feasibility of reliable SpO_2 and heart rate monitoring, stable GPS data retention, and multi-kilometer LoRa communication performance that validates the device's potential to improve survival outcomes in real-world avalanche scenarios.

In the future, further power consumption optimization of the system, refining the triage algorithm in cases of multiple victims, and integration with existing avalanche rescue infrastructures could lead to further improvements. It has the potential to revolutionize avalanche rescue operations by providing rescue teams with objective real-time health data, thus increasing the chances of survival and reducing the possibility of preventable deaths in such high-risk environs.

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