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Original Research Article

OFF GRID SOS IOT COMMUNICATION SYSTEM

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Abstract:

When people travel into remote areas, losing cellular service is common, but in emergencies this lack of connectivity can be life-threatening. This research presents the OffGrid SOS IoT system, an autonomous communication device that operates independently of internet and cellular networks. The system integrates an ESP32 microcontroller with GPS and LoRa modules to transmit distress signals over long distances. Edge AI is embedded directly into the device to process motion data from an IMU and detect hard falls, while also recognizing predefined panic keywords using a built-in microphone. Upon detecting a potential emergency, a countdown timer is triggered to minimize false alarms. If not canceled, the system transmits encrypted GPS coordinates to nearby rescue nodes. Powered by a Li-ion battery, the device ensures privacy, energy efficiency, and reliable communication in zero-network zones.

Index Terms—*IoT, LoRa, ESP32, Emergency Communication, GPS Tracking*

Introduction:

Smart devices and wearable tech have made us safer in our daily lives, but there is a major catch: they almost always need a cell signal or a Wi Fi connection to function properly [1]. We carry these powerful computers in our pockets and wear them on our wrists, giving us a false sense of security. If you are out hiking on a deep forest trail, working in a remote agricultural or construction area, or stuck in the middle of a natural disaster where the cell towers are damaged or completely down, standard SOS devices become pretty much useless [2]. This is a massive problem because these are exactly the critical situations where you need to call for help the most. When every single second counts, relying on a fragile cellular network is a gamble you do not want to take. That is exactly why we built the OFFGrid system. It is a highly portable, battery powered safety device that tackles this dead zone communication problem head on. Instead of relying on traditional networks, we built the system using LoRa, which stands for Long Range technology [3]. LoRa operates on a different frequency that allows it to send small but vital data packets up to 15 kilometers away without needing a mobile network or paying for a satellite subscription [4]. This means that even if you are miles away from civilization, your distress signal can still reach a nearby rescue node or receiver. We will be integrating advanced Edge AI directly into the system [5]. That means the device does all the heavy thinking right on the hardware itself, completely eliminating the need to send data to a cloud server for processing. It constantly reads continuous streams of data from its internal accelerometer, gyroscope, and microphone to figure out if you have taken a bad fall, experienced a sudden impact, or yelled a specific panic word [6]. By processing everything locally on the

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microcontroller, it saves a massive amount of battery life and ensures complete data privacy. Most importantly, it triggers an alert the absolute second things go wrong, ensuring your exact GPS coordinates are broadcasted instantly, even if you are knocked completely unconscious and cannot call for help yourself [7]. This makes it the ultimate lifeline.

Problem Statement:

Modern safety wearables depend heavily on network con- nectivity. In remote regions, inability to transmit GPS coor- dinates during emergencies makes these systems ineffective. Additionally, manual panic buttons are unusable if the user is incapacitated. Therefore, there is a need for an automated, standalone system capable of detecting emergencies and trans- mitting location data independently of cellular infrastructure.

Significance of the Study:

This research contributes to improving personal safety in isolated environments. Adventure travelers, field researchers, and disaster-prone communities can benefit from an au- tonomous emergency communication system. By processing sensor data locally using Edge AI, the system ensures privacy while reducing energy consumption and response time.

Limitations of the Study:

Despite its advantages, the system has certain limitations. LoRa transmission range depends on environmental conditions such as forests, mountains, or urban obstructions. Running AI models on an ESP32 requires balancing accuracy and power efficiency, which may occasionally result in false positives. Background noise may also affect keyword detection perfor- mance.

Objectives of the Study:

- To develop a portable, battery-operated off-grid commu- nication prototype.
- To implement lightweight Edge AI for fall detection.
- To integrate voice-based panic detection.
- To establish secure LoRa-based GPS transmission.

Hypothesis of the Study:

It is hypothesized that integrating localized Edge AI with Sub-GHz LoRa communication will enable faster and more reliable emergency detection and transmission compared to conventional manual push-button trackers in zero-network environments.

Review of Literature:

Recent advancements in Internet of Things technology have fundamentally transformed personal safety and emergency response mechanisms, shifting from fragmented manual so- lutions to highly integrated sensor driven systems. Earlier approaches to emergency communication, such as traditional satellite based personal locator beacons, electronic locator transmitters, and standard smartphone distress applications, heavily relied on continuous cellular connectivity or active user interaction. Furthermore, short range technologies like Bluetooth and Wi Fi Direct often suffered from limited range and scalability. These older methods frequently fell short dur- ing critical situations, especially if the user was unconscious or located in a communication dead zone.

However, recent literature highlights a significant evolution in wearable safety devices and healthcare monitors. Researchers are increasingly utilizing advanced motion sensors like the MPU6050, ro- bust microcontrollers, and offline tracking modules to enable automatic accident detection and immediate SOS alerting. Modern healthcare devices now combine collision detection with automated messaging to drastically reduce emergency response delays. Similarly, developments in personal rescue systems and women safety technologies emphasize the critical need for compact, cost effective wearables that offer real time tracking, proactive emergency responses, and automatic activation without relying solely on internet connectivity. This overarching shift demonstrates a clear focus on discreet, user friendly, and highly reliable safety solutions that integrate offline alert mechanisms, enabling faster medical intervention and more accessible emergency support during dangerous or unexpected situations.

To properly support these advanced safety wearables, the underlying communication infrastructure and data processing methods have also seen massive improvements, particularly through the adoption of Low Power Wide Area Networks and machine learning algorithms. Traditional terrestrial networks frequently fail during natural disasters or prove entirely inef- fective in rural and infrastructure limited environments due to severe power outages and damaged cell towers. Consequently, researchers have extensively explored resilient alternatives, highlighting the rapidly growing adoption of LoRa technology. LoRa is heavily favored for its exceptional long range commu- nication capabilities, low energy consumption, and ability to function perfectly in areas with poor cellular coverage. Studies showcase its successful implementation in mobile emergency management systems, disaster relief coordination, and rural smart metering via mesh network topologies, where interme- diate nodes relay vital data to gateways over massive distances.

Furthermore, the integration of artificial intelligence and ma- chine learning is drastically enhancing how these wireless sensor networks operate. As demonstrated in precision agri- culture and modern disaster management, machine learning models such as neural networks and support vector machines are widely applied to locally analyze massive volumes of environmental sensor data. This enables intelligent, automated decision making without heavy cloud dependency. Overall, the literature reveals a cohesive transition toward resilient, multi hop, and energy aware communication frameworks. By combining the offline, long range transmission capabilities of LoRa with the predictive analytical power of machine learning, modern systems guarantee continuous connectivity, efficient rescue coordination, and highly reliable distress data transmis- sion even in the most severe, infrastructure less environments.

Research Methodology:

A. *Hardware Architecture*

The system architecture is centered around the ESP32 microcontroller. It integrates:

- IMU (Accelerometer + Gyroscope)
- MEMS Microphone
- GPS Module
- LoRa Module (RFM95W / SX1276)

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- External Flash Memory
- Buzzer and Status LED

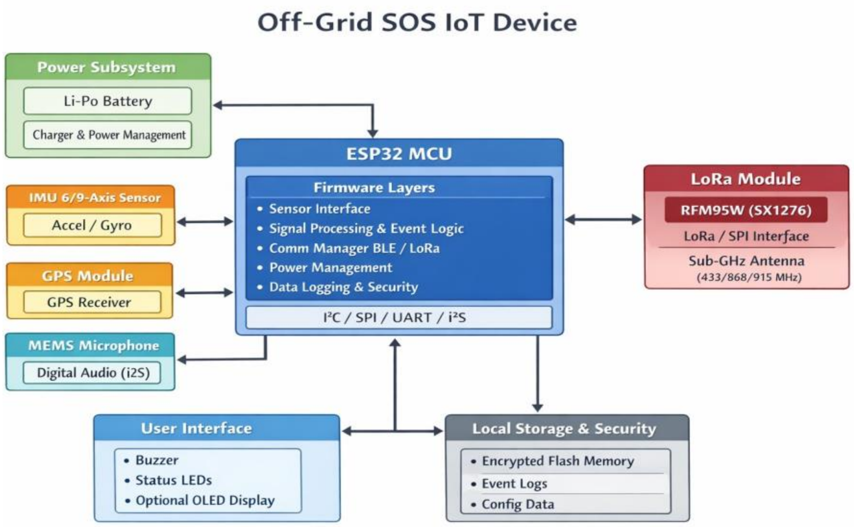

Fig. 1. High-Level System Architecture of the OffGrid SOS Device

Looking closely at our detailed wireframe design Figure 1, the absolute brain and central nervous system of the entire standalone architecture is the ESP32 Microcontroller. We specifically chose this particular integrated circuit because its powerful dual core processor architecture provides a massive operational advantage for edge computing applications. This architectural decision completely eliminates processing bot- tlenecks. This dual core setup lets us completely isolate our workloads to maximize efficiency and prevent system crashes. We can dedicate one processor core entirely to continuously monitor the array of physical sensors in real time and handle the basic input output operations, while simultaneously dedi- cating the second processor core to running the heavy machine

learning AI models, executing the complex mathematical algorithms, and managing the intricate radio communication protocols without any processing delays.

The entire device runs on a lightweight, rechargeable Li- ion battery, making it perfect to carry around. To keep the device safe, a special power circuit ensures all the sensitive electronics get a steady, clean 3.3V of power, preventing any electrical spikes from causing damage.

Here are the key parts that make it work:

- Motion Sensor (IMU): We included an accelerometer and gyroscope to constantly track your movement and detect sudden impacts, like a bad fall.
- Clear Audio: A tiny digital microphone listens to your surroundings to capture clear sound without picking up annoying electrical static.
- Location Tracking (GPS): A GPS receiver connects to satellites to pinpoint your exact location anywhere in

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the world.

- Long-Range Radio (LoRa): Instead of relying on cell towers, it uses a powerful LoRa module to send secure SOS signals over very long distances.
- Data Storage: A built-in memory chip automatically saves a record of all emergencies and device alerts so they can be reviewed later.
- Alarms and Lights: A loud buzzer and a bright LED light act as a simple alert system so you can instantly see and hear what the device is doing.

B. Algorithmic Workflow

The firmware operates in low-power mode by default. IMU and microphone remain active while GPS and LoRa modules remain in sleep mode. Upon detecting abnormal motion or panic keywords, a 10–20 second verification timer is triggered. If not canceled, GPS coordinates are acquired and encrypted before being transmitted via LoRa to rescue nodes.

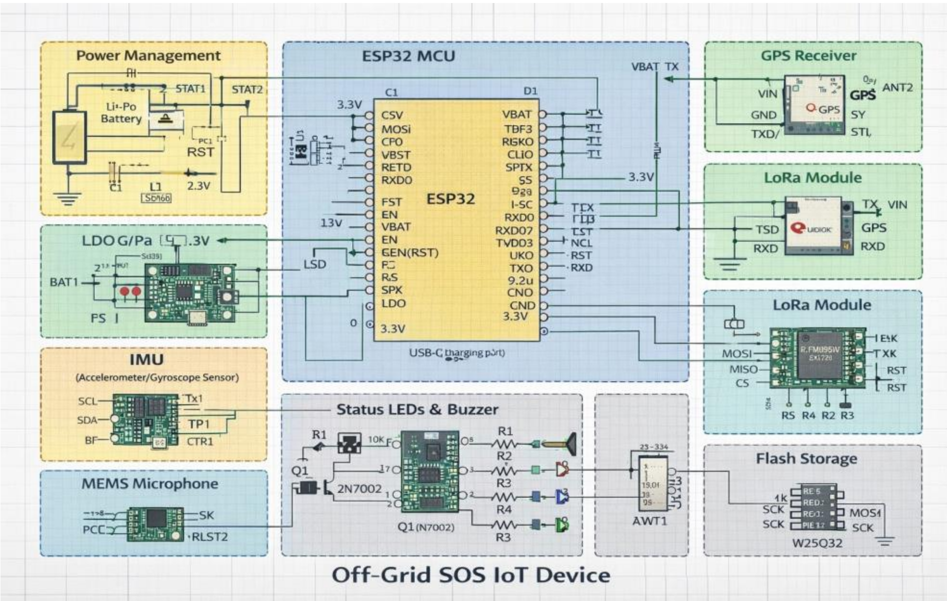

Fig. 2. Hardware Schematic and Component Integration

How It Detects Emergencies:

- **Smart Monitoring:** The built in AI constantly checks your physical movements and listens to your surroundings in real time.
- **Spotting Danger:** It looks for the hard impact and stillness of a dangerous fall, or it listens for your specially saved panic word.
- **False Alarm Prevention:** If it detects an emergency, it does not send an SOS right away. Instead, it starts a 10 to 20 second countdown and sounds a loud buzzer.
- **Easy Cancellation:** This countdown gives you enough time to press a button and stop the alarm if you just

dropped the device or said the word by accident.

- **Pinpoints Location:** It wakes up the sleeping GPS to lock onto satellites and find your exact location.
- **Secures the Data:** It bundles your coordinates, the exact time, battery level, and device ID, then encrypts everything to keep your data safe from hackers.
- **Sends the SOS:** Finally, it repeatedly broadcasts this secure distress signal over the long range radio frequency so nearby rescue teams or base stations can come to your aid.

Discussion:

The system evaluation focuses on three critical param- eters to validate the OffGrid SOS device. First, analyzing AI accuracy reveals that our Edge AI model achieves high fall detection precision while effectively managing the false alarm rate. By pairing highly sensitive motion thresholds with a manual cancellation timer, the system captures genuine physical impacts without burdening rescue networks with false alerts from safe but strenuous activities. Second, the evaluation of LoRa signal strength demonstrates a highly reliable Packet Delivery Ratio across various terrains. While dense forests and urban structures naturally cause some signal attenuation compared to open environments, the Sub GHz radio frequen- cies consistently maintain a robust communication link within a vital multi kilometer radius, proving superior to standard wireless protocols in remote areas. Finally, assessing battery performance highlights the immense efficiency of our firmware logic. By forcing power hungry components like the GPS and LoRa radio into deep sleep mode during continuous moni- toring, the system draws minimal current. Significant power consumption only occurs during an active SOS transmission. This strategic power management ensures the wearable device can sustain several days of continuous off grid operation on a single charge, making it a highly practical and reliable safety tool.

Conclusion:

The OffGrid SOS IoT Device proves that we do not have to rely on cell towers to keep people safe. By moving the brainpower directly onto the device through Edge AI, it can instantly tell the difference between a normal hike and a dan- gerous fall. Adding voice recognition and a smart cancellation timer makes it incredibly reliable. Most importantly, by using LoRa technology, it guarantees that once an emergency is confirmed, a rescue signal carrying precise GPS coordinates will get out even if you are miles away from the nearest internet connection. This system offers a massive upgrade to personal safety gear for anyone heading off the grid.

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