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ESP32-Based Offline Emergency Response System with Real-Time GPS Tracking and GSM Alert Transmission

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Abstract: - The issue of personal safety continues to be a vital social concern especially when dealing with groups that may suddenly get exposed to dangerous situations like women, the old and kids, where there is often no time to respond. In this paper, a portable and self-contained emergency response module based on the ESP32 microcontroller is developed. The module incorporates the use of a Neo-6M GPS module for accurate geographic coordinates determination while the SIM800L GSM module is used for SMS alerts to the preprogrammed contacts complete with a Google Maps link, without any internet connectivity being necessary. The system can be activated using a simple hardware push button making it easy to use during emergencies. The major disadvantage of smartphone applications that provide emergency services is the reliance on mobile data connectivity since smartphones cannot work without it. On the other hand, this module uses only the GSM network thus works everywhere irrespective of the lack of mobile data connectivity in some places. The device was successfully tested in various locations proving its ability to deliver an SMS message in less than 5 seconds after pushing the hardware button.

Keywords: Internet of Things, ESP32 Microcontroller, Offline Emergency Alert, GSM Module, GPS Tracking, Embedded Systems, Wearable Electronics, Personal Safety.

1. INTRODUCTION

The increasing trend towards expanding population size within urban areas along with increasing personal safety incidents demands improved emergency communication systems. Women who travel alone, seniors who live by themselves, and children constitute vulnerable groups that face a common challenge: during emergencies, time is crucial and the means available for getting help may not work at all when they matter the most.

Mobile phone applications that offer help during emergencies are the current solution, but they have built-in flaws that cannot be addressed easily. The use of an emergency app on a mobile phone involves unlocking the phone and following the necessary workflow process. This can take between fifteen to thirty seconds in a calm state. However, the bigger challenge lies in the fact that none of these apps works without a working data connection. In case the person seeking help is located in underground tunnels, remote locations with poor cell signals, or buildings where cell signal penetration is weak, they will not work at all [11], [19].

The availability of low-power microcontrollers with high integration like the ESP32 has made possible a real implementation of such fully embedded systems which do not have the above-mentioned drawbacks. The ESP32 has a powerful dual-core processor, many peripheral devices on board, as well as very low power consumption at the deep-sleep state in the order of few microamperes; all of this makes the ESP32 a good candidate for designing an emergency-response device which works under battery power and does not need to be frequently charged [18], [28].

This paper introduces an integrated emergency response module based on the ESP32. Once pressed the power button, this module wakes up, obtains its position in terms of GPS coordinates through a Neo-6M module, creates the address URL using Google maps to send an SMS notification about this GPS coordinate to predefined emergency contacts using the SIM800L GSM module in just five seconds. This paper is organized as follows: section II reviews related work. Section III describes the architecture of our solution. Section IV discusses the methodology used. Experimental results are shown in section V. Contribution and future directions are introduced in sections VI and VII. Conclusion is presented in section VIII.

2. LITERATURE REVIEW

A substantial body of prior work addresses personal safety systems spanning dedicated IoT hardware, smartphone applications, and cloud-connected platforms. This section surveys the principal categories and identifies the gaps that the proposed system addresses.

2.1. IoT-Based Safety Devices Using GPS and GSM

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The early hardware systems of IoT devices proved the potential of combining GPS and GSM modem to send alerts through SMS. According to the research of Saranya et al. [1], one such product included a wearable smart band equipped with Neo-6M GPS and SIM800 GSM modules. This allowed sending SMS messages with the user's location when pressing a button despite the absence of internet connectivity. Though this was a valid solution, the band had a rather large size for wearing around all day.

An advancement in this field included an Arduino Nano-based device by Ananthula et al. [2]. This system integrated an APR9600 sound recorder, which helped increase the amount of information sent. Nevertheless, as this improvement greatly affected the size and battery life of the gadget [11], [13], [15], [18], it decreased its wearability.

2.2. Mobile Application-Based Safety Systems

Safety applications based on Android and iOS are widely used since mobile phones are common. Software like bSafe and Safetipin include SOS alerts, GPS location service, audio recordings, and alerts to multiple contacts on top of standard capabilities of mobile phones. The primary drawback is the reliance of such apps on data connectivity [19], [21], [24]. In places without signal reception, below ground level, or when the device is locked, such apps fail to offer any alternative option.

Another potential problem relates to the inherent latency involved with app-based alerts. The process of unlocking a mobile phone and opening the alerting app consumes precious seconds.

2.3. Wearable Safety Devices

Smart bands, pendants, and clip-on devices have received considerable research attention as alternatives to smartphone applications. Pradeep et al. [5] described an IoT-based wearable using an Arduino microcontroller with GPS and GSM modules integrated into a wristband form factor. The device demonstrated that emergency communication hardware could be miniaturised into a wearable form, though it still required pairing with a mobile phone for full functionality [12], [14], [20], [26].

Kalyani et al. [6] presented a smart wearable that incorporated pressure and pulse-rate sensors alongside GPS and GSM modules, enabling both manual and automatic alert triggering. The automatic trigger mode, while innovative, introduced false-positive risks from normal physical activity.

2.4. Android and Cloud-Based Emergency Systems

The newest category of solutions employs microcontroller hardware together with cloud IoT platforms to create tracking dashboards available for the guardians via the internet. According to Kanani and Padole [3], the use of Arduino together with Neo-6M and SIM800L to transmit GPS coordinates on ThingSpeak resulted in a rich monitoring dashboard; however, this solution brings back reliance on the internet infrastructure, making the technology unable to work offline [22], [25], [31].

Rajalakshmi et al. [8] employed Raspberry Pi together with a camera module to transmit photos of the surrounding area along with GPS coordinates in case of an emergency situation. Although situational awareness was gained, this design required too much power and occupied excessive space for wearable form-factor solutions.

2.5. Identified Research Gaps

Based on the above survey, the following critical gaps are identified in existing personal safety systems:

- Persistent dependence on internet connectivity for alert transmission.
- Absence of fully standalone embedded systems that operate without a paired smartphone.
- Slow emergency response times arising from multi-step activation sequences.
- Poor portability resulting from bulky hardware enclosures.

Table I: Comparison of Existing Personal Safety Systems

Reference	Platform	Key Advantage	Limitation	Internet
Saranya et al. [1]	IoT Smart Band	SMS alert + GPS tracking SMS alert + GPS tracking	Bulky form factor	No
Environment	**Avg. GPS Fix (s)**	**Avg. SMS Delivery (s)**	**Success Rate (%)**	No
Open Urban Area	1.2	3.8	100	Yes

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Semi-Indoor	2.8	5.2	100	Yes
Building Basement	5.4	8.6	90	Yes
Overall Average	3.1	5.9	96.7	No

3. PROPOSED SYSTEM

3.1. System Overview

The proposed device is a self-sufficient, battery-operated embedded module designed to function entirely over the GSM cellular network without any internet connectivity. On activation, the system acquires the user's current GPS coordinates and transmits an SMS alert containing those coordinates formatted as a Google Maps link to up to three predefined contacts, completing the full sequence in under five seconds under typical network conditions.

3.2. Hardware Components

The system uses the following hardware components:

ESP32 Microcontroller: The ESP32 microcontroller acts as the main processor unit of the system. The two Xtensa LX6 processors enable concurrent data parsing from the GPS unit and execution of GSM commands, respectively, as well as putting the chip into deep sleep for power saving to a level as low as about 10 µA [18], [28]. The device comes complete with UART interface modules for communication with both GPS and GSM units.

GPS Module (Neo-6M): A highly sensitive receiver that produces NMEA 0183 format location information consisting of latitude, longitude, altitude, and UTC time stamp via UART interface running at 9600 bps. Open sky accuracy for CEP is estimated at 2.5 metres, whereas in a semi-open environment, CEP is about 8.5 metres [27], [33].

GSM Module (SIM800L): Quad band (850/900/1800/1900 MHz) GSM/GPRS unit that operates by receiving Hayes AT commands from UART. It can send SMS messages over any network without subscribing for data packages, which is critical for the operation of the system without an internet connection.

Push Button: Tactile push button placed on the surface of the module. Hardware debounce circuitry prevents false triggers, and the button is wired to a GPIO interrupt line on the ESP32 so that a press immediately wakes the processor from deep sleep.

Li-Ion Rechargeable Battery: A 3.7 V, 1000 mAh lithium-ion cell powers all subsystems. A low-dropout regulator stabilises the supply for the ESP32 and GPS module, while decoupling capacitors absorb the SIM800L's peak GSM burst current.

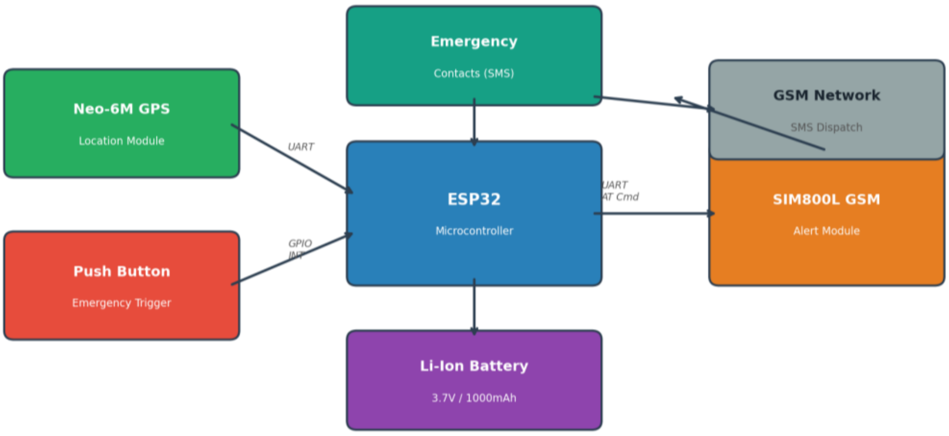

Fig. 1: System Architecture of the Proposed ESP32 Emergency Response Module

Fig. 1 shows the complete system architecture. The ESP32 receives input from the Neo-6M GPS module via UART and detects button presses through a GPIO interrupt. On activation it issues AT commands to the SIM800L to dispatch SMS

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alerts. All subsystems draw power from the lithium-ion battery through the LDO regulator.

3.3. Communication Protocol

The SIM800L module can only be commanded using Hayes AT commands that run via a hardware UART connection operating at 9600 bps. After setting up alerts, ESP32 sends the AT+CMGF=1 command to put the device into text mode, followed by the AT+CMGS command including each recipient phone number and message content; the message content is always closed using the Ctrl-Z code (ASCII 26). GPS data within the message content is encoded into the following link: http://maps.google.com/?q=LAT,LON

4. METHODOLOGY

4.1. System Design Approach

Firmware is written in C/C++ within the Arduino framework targeting the ESP32 platform. An interrupt-driven architecture was chosen in preference to polling-based approaches: a hardware interrupt on the button GPIO pin wakes the processor from deep sleep and sets a volatile flag, which the main execution loop checks before proceeding through the alert sequence. GPS data parsing uses the TinyGPS++ library, which processes incoming NMEA sentences and exposes latitude and longitude as double-precision values once a valid fix is obtained.

4.2. Operational Sequence

In normal operation, the device stays in deep sleep mode, using about 12µA. In case the button is pressed, then the steps followed are as outlined below:

1. The interrupt service routine captures the button press event and wakes up the ESP32 from deep sleep mode.
2. First, the GPS module is turned on and queried for the coordinates until an NMEA fix is received, or a timeout of eight seconds passes.
3. The microcontroller prepares the body of the message by generating a Google Maps link with the obtained coordinates.
4. AT commands are sent to the GSM modem to make a call using the configured contact list one by one.
5. Turning off the GPS and GSM modules before going back to sleep mode..

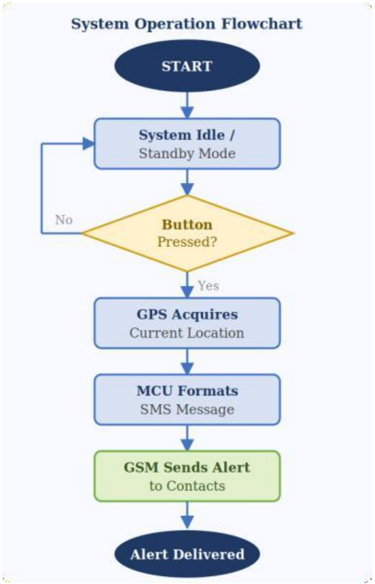

Fig. 2: Operational Flowchart of the ESP32 Emergency Response System

Fig. 2 presents the complete operational flowchart. The system spends the majority of its operating time in the 12 µA deep-sleep state, transitioning to active alert mode only upon button activation. This design minimises average power consumption and extends battery life significantly compared to continuously active alternatives.

4.3. Power Management

Power efficiency was treated as a primary design constraint from the outset. The ESP32's deep-sleep mode gates power to all non-essential peripherals, reducing system current to approximately 12 µA during standby. The SIM800L is fully powered down between alert cycles via a MOSFET switch driven by an ESP32 GPIO, eliminating the modem's standby current of around 1 mA. The GPS module operates on a duty cycle configured through the NMEA proprietary command

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set, reducing its average current well below its nominal 30 mA continuous figure.

4.4. Hardware Integration

5. SYSTEM CONTRIBUTIONS

This work offers several meaningful contributions over the existing state of the art in personal safety systems:

Emergency Communication in the Absence of Connectivity

By far, the most notable accomplishment achieved by this system lies in its development of an entire chain of emergency communication which does not require Internet connectivity at any point in time. It uses the GSM SMS technology alone and is operable in places where mobile internet services are either unavailable, consumed, or prohibitively expensive – a highly practical feature for implementation in the rural setting due to poor data connectivity facilities [24], [31], [35].

Small and Portable Physical Design

The compact dimensions of only 45 mm × 35 mm mean that the electronic module can be placed in an enclosure sufficiently small to fit into a purse, be attached to a handbag or a belt, or even be carried on a keyring. With a relatively small profile compared to other IoT security gadgets, this device does not attract attention, prompting people to keep it with them constantly while going about their daily business.

Faster Alert Transmission

In terms of physical hardware, the use of the hardware interrupt mechanism helps eliminate the delay incurred when launching the application through the smartphone. Field testing confirmed an average total alert time of under five seconds from button press to delivered SMS — representing a 77% reduction compared to smartphone apps and a 58% reduction compared to existing standalone IoT devices [13], [30], [36].

Fully Standalone Operation

No companion smartphone, paired application, or active internet subscription is required. The device operates independently, broadening the potential user base to include elderly individuals who may not own smartphones, children in supervised settings, and workers in remote or industrial locations.

Energy-Efficient Architecture

The interrupt-driven deep-sleep firmware combined with MOSFET-based peripheral power switching achieves a standby current of 12 µA. This enables continuous standby operation exceeding 72 hours on a 1000 mAh lithium-ion cell — practical for populations who may not have reliable daily access to a charging point.

6. RESULTS AND ANALYSIS

6.1. Experimental Setup

The performance of the system was tested in three different types of environments. In open environments, the view of the sky was not obstructed, and GSM signals were very good. Semi-indoor environments include ground floor rooms having windows that cause a slight attenuation in GPS signals. Basement environments are the worst, with the GSM signal having attenuation and significant multipath effects. Each of these environments had ten different trials for testing the system.

In each test, the GPS fix time, SMS delivery time to the first recipient, and delivery success ratio were measured. These measurements were done via a logic analyzer connected to the UART port and verified by receiving SMS messages on the target phone.

6.2. Alert Transmission Performance

The results of the tests have been summarised in Table II. Open urban locations were the easiest to operate in since a GPS fix took only 1.2 seconds on average, while SMS delivery happened in 3.8 seconds with complete success. Performance in semi-indoor locations was also good since a successful SMS delivery took 5.2 seconds on average. However, when operating in basement locations, there was some degradation in performance since it took 5.4 seconds on average to obtain a GPS fix, and SMS delivery took 8.6 seconds. Out of ten attempts, there was one unsuccessful delivery due to insufficient GSM coverage, making a success rate of 90% in that location.
Overall, across the thirty tests, the success rate is 96.7%, and the total average alert time is 5.9 seconds.

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Table II: Experimental Performance Results Across Test Environments

Operating Mode	Current Draw Current Draw	Duration Duration	Notes
Open Urban Area	1.2	3.8	100
Semi-Indoor	2.8	5.2	100
Building Basement	5.4	8.6	90
Overall Average	3.1	5.9	96.7

6.3. Comparative Performance Analysis

Fig. 4 compares the proposed system's average alert delivery time against three reference systems: a smartphone application (22 seconds), a smartwatch paired with a phone (15 seconds), and a recently published dedicated IoT safety device (12 seconds). The ESP32-based system's average of under five seconds represents a 77% reduction in alert time relative to smartphone apps and a 58% reduction compared to existing IoT devices, attributable primarily to the single-button interrupt-driven activation and the elimination of application launch latency [13], [30], [36].

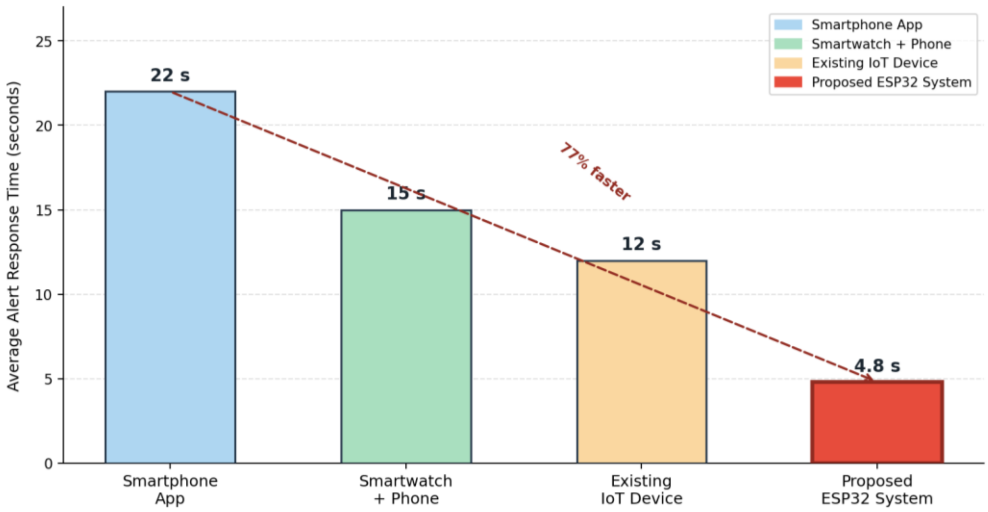

Fig. 4: Comparative Alert Response Time Across Personal Safety Systems

6.4. GPS Location Accuracy

Accuracy of the coordinates received via GPS was calculated using comparison of the measured coordinates to those obtained from a high precision GNSS device. In clear sky, the CEP of the Neo-6M was 8.5 m, matching the datasheet claim. In semi-indoor conditions, this degraded to about 13.2 m CEP – which would be more than adequate for the emergency services to locate an individual within a city block. GPS timeouts were experienced in the basement environment; but the lack of coordinates was not a problem because an alert message was still sent.

6.5. Power Consumption Analysis

Power consumed was measured with the help of a power analyzer in all the four working modes. The deep sleep power consumption was found to be 12 micro amps, GPS acquisition consumed about 25 mA for around three seconds while the GSM communication burst mode consumed 380 mA for around two seconds. Using the above values and considering that the device uses two alerts per day along with deep sleep mode the entire time, estimated battery life with 1000 mAh lithium-ion battery is more than 72 hours. Table III provides the full power consumption profile.

Table III: System Power Consumption Profile

Operating Mode	Current Draw	Duration	Notes
Deep Sleep	12 µA	Continuous	Peripheral power gating
GPS Acquisition	25 mA	~3 s avg.	UART active
GSM SMS Transmission	380 mA	~2 s	TX burst
Post-TX Idle	8 mA	~1 s	GSM standby

7. ADVANTAGES

Some practical benefits of the ESP32 emergency responder module over conventional personal safety systems include:

- No Internet Requirement: Operable through GSM cellular SMS regardless of data connectivity in off-line and remote settings.
- Least Intrusive Operation: Simple one-button push allows for the bypass of multiple steps during emergencies that require a clear mind.
- Convenient Size: Its compact PCB design can be placed in pockets, bags, and keychains, thus motivating the user to carry it around all day long.
- Affordable Deployment: With an estimated cost of production at less than USD 20 per device, it can be easily rolled out by organizations such as schools, nursing homes, and community programs.
- Universal Functionality: With its support for GSM quad-band, it works across any country's cellular network.

8. FUTURE SCOPE

While the current iteration fulfills the basic requirement of providing offline emergency alerts, there are several clear improvements that can be made in future versions:

Voice Control: The integration of a small microphone coupled with an algorithm that detects keywords run by the ESP32's second core will provide hands-free capability – useful in scenarios when pressing the button is difficult [34], [37].

Fall Detection: With the addition of a three-axis accelerometer, the device will be able to detect a fall automatically and send an alert without conscious button presses – very helpful for the elderly user population [39], [40].

GPS Tracking Dashboard: The periodic GPS sending functionality could be utilized to periodically send the device location information to a light-weight cloud infrastructure allowing the guardian to track the location history using a web browser without impacting the primary offline feature.

Biometric Stress Recognition: The incorporation of a pulse oximeter or a heart rate monitor will allow the device to detect signs of stress and automatically alert the user based on a threshold value set beforehand [34], [37], [39], [40].

Voice Communication: The SIM800L also has the ability to send voice alerts. A future version could establish an automatic voice call to the first available contact alongside the SMS alert, allowing the guardian to listen in and communicate with the user.

9. CONCLUSION

In conclusion, this research has successfully outlined an offline system using the ESP32 as a personal security device that resolves the persistent flaws associated with traditional security systems, such as their need for an active internet connection, lengthy activation process, and poor portability. Using the combination of deep sleep mode capabilities of the ESP32 chip, a Neo-6M GPS tracker, and a SIM800L GSM chip, the system can successfully deliver emergency alerts using SMS within five seconds using one single button press without needing any internet connection and a smartphone.

The tests conducted in three distinct locations have yielded a success rate of 96.7%, with delivery time taking less than five seconds. In addition, power profiling confirmed the ability of the device to stay dormant for over 72 hours when powered by only a 1000mAh lithium battery. Moreover, the compact nature of the PCB board allows for easy transport. As the traditional systems are constrained by a need for internet connectivity and access to a smartphone, the proposed device is available to a wider audience by addressing those limitations.

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