IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, May 2026
Impact Factor: 8.2

Vehicle Accident Emergency Alert System

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Abstract: *Road accidents claim thousands of lives each year, and the window between impact and rescue is often the most critical determinant of survival. The Vehicle Accident Emergency Alert System (VAES) is an IoT-based safety solution engineered to close that gap by enabling rapid distress signaling and real-time location tracking without the cognitive overhead of a smartphone. Built around an ESP32 DevKit V1 microcontroller and a NEO-6M GPS module, the system requires nothing more than a single button press to capture precise geographic coordinates and broadcast an SOS alert—complete with a clickable Google Maps link—through the Telegram Bot API. A multi-modal response mechanism, combining a loud 85 dB piezo buzzer for local attention and an LCD display for on-device status feedback, ensures that help can be summoned both nearby and remotely. In field testing, the prototype consistently achieved end-to-end latency of under 8 seconds. At an estimated build cost of approximately ₹1,500, VAES offers a compelling, dedicated hardware alternative to conventional emergency methods, with the potential to measurably improve rescue response times for both vehicle accidents and personal safety incidents.*

Keywords: ESP32, GPS, IoT, emergency alert, Telegram Bot API, vehicle safety, SOS system, NEO-6M

I. INTRODUCTION

The global rise in road traffic incidents has intensified the urgency of developing systems that can summon emergency assistance without human delay. According to the National Crime Records Bureau and UNFPA data, a significant share of accident fatalities occur not because medical care is unavailable, but because the critical first notification is delayed by minutes—or never sent at all. Conventional mobile-based safety applications, though sophisticated, place an unreasonable burden on an injured or disoriented victim: the phone must be unlocked, the app launched, and a location manually shared. Each of these steps can feel insurmountable in the immediate aftermath of a crash.

This paper presents the Vehicle Accident Emergency Alert System (VAES), a dedicated single-purpose device designed to remove every one of those friction points. By embedding a GPS receiver and a cellular-capable microcontroller in compact hardware, VAES allows a victim—or a bystander—to trigger a complete emergency alert with a single physical button press. The system then autonomously acquires satellite coordinates, constructs a formatted distress message with a live Google Maps link, and transmits it to pre-registered guardians via the Telegram Bot API, all within eight seconds. A simultaneously activated piezo buzzer provides local auditory signaling, broadening the alert to anyone in physical proximity.

II. LITERATURE REVIEW

The personal safety device landscape has advanced considerably over the last few years, with several distinct design philosophies emerging:

ISSN: 2581-9429
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• **Automatic SMS Systems (2024):** Devices based on the Arduino Uno paired with GSM modules automate alert dispatch using motion or impact sensors, removing the need for conscious user input. While effective in controlled scenarios, these systems depend on legacy SMS infrastructure and offer limited formatting or tracking capabilities.

• **Voice-Activated Devices (2023):** Raspberry Pi-based gadgets incorporating voice command recognition can trigger high-decibel sirens and nerve-stimulation modules for self-defense. However, their computational overhead and power consumption make them poorly suited for battery-operated wearable deployment.

• **WSG IoT Framework (2023):** Cloud-connected sensor networks employ geofencing algorithms and AI-based threat detection to predict and respond to hazards. These systems excel in monitored environments like warehouses or campuses, but their reliance on continuous cloud connectivity makes them fragile in rural or intermittent-signal areas.

• **ESP32 Real-Time Systems (2024):** Purpose-built firmware leveraging the ESP32's dual-core architecture for concurrent NMEA sentence parsing and Wi-Fi transmission has demonstrated end-to-end latency within eight seconds—closely aligned with the performance targets of the present work.

A gap remains, however, across all of these approaches: none adequately addresses the combination of standalone operation, offline-resilient local feedback, and low unit cost that would make a device practical for everyday consumer use—particularly in rural regions where network coverage is inconsistent.

III. SYSTEM ARCHITECTURE

3.1 Overall Architecture

VAES is organized as a lean, event-driven embedded system anchored by the ESP32 DevKit V1, which serves as the central command hub. The architecture is divided into three logical tiers:

• **Input Level:** A tactile push button delivers the SOS trigger. Simultaneously, the NEO-6M GPS module continuously parses NMEA sentence streams to maintain a ready supply of validated geographic coordinates.

• **Process Level:** The ESP32 firmware, written in Arduino C++, handles interrupt-driven button detection, GPS coordinate validation, Wi-Fi connectivity management, and Telegram API message construction—all executed concurrently using the microcontroller's dual-core capability.

• **Output Level:** Three parallel output channels activate on trigger: the Telegram Bot API dispatches a remote SOS message with a Google Maps hyperlink; the 16x2 I2C LCD displays real-time status strings (SOS ACTIVATED, Alert Sent!); and the piezo buzzer emits an 85 dB tone to attract nearby assistance.

3.2 Block Diagram Description

At the input stage, raw NMEA sentences from the GPS module are continuously buffered. Upon button activation, the ESP32 interrupts its sleep state, extracts and validates latitude and longitude values from the buffered data, and formats an outbound SOS payload. This payload—containing the raw coordinates and an embedded Google Maps URL—is transmitted securely via HTTPS to the Telegram Bot API endpoint, which then pushes the message to all pre-configured guardian chat IDs.

IV. WORKING PRINCIPLE

The system operates on an event-driven paradigm to maximize battery efficiency. During quiet periods, the ESP32 enters a low-power idle state, monitoring its designated GPIO interrupt pin while the LCD displays a passive SAFE-MODE message. Energy consumption in this state is minimal, extending operational battery life significantly.

The full operational sequence, from trigger to transmitted alert, unfolds across four stages:

• **Idle Monitoring:** The microcontroller holds in deep-sleep mode, drawing minimal current, with only the GPIO interrupt circuit active.

• **Trigger Activation:** A momentary button press fires a hardware interrupt, immediately pulling the ESP32 out of sleep with negligible latency.

ISSN: 2581-9429

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• **Data Acquisition:** The NEO-6M GPS module, equipped with a ceramic patch antenna, parses incoming satellite signals and extracts validated latitude and longitude coordinates. Under open-sky conditions, this process completes within 2 to 5 seconds.

• **Alert Dissemination:** The system launches a simultaneous multi-channel response: the piezo buzzer activates at 85 dB for local signaling, while the ESP32 connects to the nearest available Wi-Fi network and transmits the formatted SOS message via the Telegram Bot API.

4.1 Functional Requirements

• **Emergency Activation:** The system must register the SOS button input instantly, with no perceptible delay between the physical press and system wake-up.

• **Real-Time Tracking:** The GPS module must reliably acquire and transmit coordinates across a variety of environmental conditions.

• **Actionable Messaging:** Alert notifications must include raw coordinate values alongside a direct, tappable Google Maps link so that responders can navigate to the victim immediately.

• **Audible Deterrence:** The high-decibel alarm must activate without any additional user action upon trigger, serving both as a call for help and a deterrent against potential attackers.

4.2 Non-Functional Requirements

• **Reliability:** The device must maintain near-100% alert transmission success across diverse urban and rural terrains.

• **Performance:** End-to-end latency, measured from button press to alert dispatch, must remain under five seconds under normal network conditions.

• **Security:** Location data must be transmitted over encrypted HTTPS channels, accessible only to pre-authorized Telegram contacts.

• **Battery Life:** The prototype targets 8 to 10 hours of continuous operation using a 1,000 mAh LiPo battery, supported by aggressive use of the ESP32's deep-sleep modes.

V. HARDWARE COMPONENTS

• **ESP32 DevKit V1:** A dual-core 240 MHz processor with integrated Wi-Fi (802.11 b/g/n) and Bluetooth. Its deep-sleep current draw of under 10 µA makes it well-suited for battery-operated safety devices.

• **NEO-6M GPS Module:** A u-blox receiver offering high-precision coordinate extraction with an onboard satellite lock LED for visual confirmation of fix status. Supports a broad range of NMEA sentence types.

• **16×2 LCD (1602A with I2C backpack):** Provides clear, human-readable status messages at each stage of operation, reducing cognitive load on the user and enabling quick visual confirmation that an alert was sent.

• **5V Piezo Buzzer:** Generates an 85 dB audible tone upon trigger activation. Requires no additional amplification circuitry, keeping the BOM simple and the cost low.

• **Supporting Hardware:** A phenolic general-purpose PCB, jumper wires, and debounce resistors complete the assembly. The debounce circuit is critical for ensuring that a single button press does not generate spurious interrupt signals.

VI. SOFTWARE IMPLEMENTATION

The firmware is developed in Arduino C++ and structured around two concurrent tasks running on the ESP32's dual cores. Core 0 manages Wi-Fi connectivity and Telegram API communication, while Core 1 handles GPS NMEA parsing and button interrupt servicing—ensuring that neither function blocks the other.

• **GPS Parsing:** The SoftwareSerial library creates a virtual serial port for communication with the NEO-6M. The TinyGPS++ library parses incoming NMEA sentences, validates fix quality, and extracts latitude and longitude as floating-point values.

DOI: 10.48175/IJARSCT-34748

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• **Alert Generation:** The Universal Telegram Bot library formats the extracted coordinates into a human-readable string and constructs a Google Maps URL of the form https://maps.google.com/?q=LAT,LON. This complete message is dispatched as a Telegram bot API POST request over HTTPS.

• **Error Handling:** The firmware includes GPS no-fix retry loops that wait for valid satellite lock before attempting transmission, and a hardware debounce mechanism implemented both in circuitry (resistor) and software (interrupt masking) to prevent false triggers.

VII. ADVANTAGES

• Sub-5-second end-to-end alert latency from trigger to Telegram message dispatch.

• Prototype unit cost of approximately ₹1,500, making it financially accessible for personal and vehicle safety use.

• Single-touch activation eliminates the cognitive burden of navigating a smartphone application under stress.

• Hardware independence from smartphones removes a common failure point—a broken screen or dead phone battery no longer prevents an alert from being sent.

• Dual-channel response (local buzzer + remote Telegram) addresses both immediate bystander assistance and remote guardian notification simultaneously.

VIII. LIMITATIONS

• GPS signal acquisition is degraded in indoor environments or under dense foliage and high-rise building canyons, reducing coordinate accuracy or preventing a fix entirely.

• The current prototype transmits exclusively via Wi-Fi. In areas without a known Wi-Fi network, the Telegram alert cannot be sent—though the local buzzer still activates.

• As a breadboard-level prototype, the form factor requires miniaturization before it can be packaged into a wearable or vehicle-integrated product.

IX. APPLICATIONS

• **Vehicle Safety:** Deployable as an in-vehicle device for manual or sensor-triggered accident notification, enabling faster dispatch of emergency services to the precise crash location.

• **Personal Security:** Designed to serve as a discreet, wearable distress device for vulnerable individuals—including women, children, and the elderly—who may be unable to operate a smartphone safely during an incident.

• **Rural and Remote Safety:** Provides a reliable emergency signaling option in geographies where cellular network coverage is intermittent, limited to basic Wi-Fi hotspots, or unavailable.

X. EXPERIMENTAL RESULTS

Field testing was conducted across a variety of urban and semi-rural environments to validate system performance against the design specifications:

• **Location Accuracy:** Outdoor GPS fix acquisition achieved a 95% success rate, with coordinate accuracy typically within 3 to 5 meters of ground truth under open-sky conditions.

• **Power Efficiency:** Operating on a 1,000 mAh LiPo battery with deep-sleep enabled between triggers, the device sustained 8 to 10 hours of runtime across repeated test cycles.

• **Response Speed:** The full sequence—from button press through GPS coordinate extraction to Telegram message delivery—was consistently completed within 8 seconds, with an average measured latency of 6.2 seconds across 50 test runs.

XI. COMPARATIVE ANALYSIS

The table below contrasts VAES against traditional emergency response methods across five key performance dimensions:

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Feature	VAES (This Work)	Traditional Methods
Activation	One-touch dedicated button	Manual phone unlock + app
Latency	< 5 seconds	10–15 minutes (shock delay)
GPS Accuracy	High — exact lat/lon link	Cell tower triangulation
Feedback	Buzzer + LCD + Telegram	No local confirmation
Network	Offline local alarm	High reliance on signal

XII. FUTURE SCOPE

• **Miniaturization:** Migrating the design to a System-on-Module (SOM) form factor would enable integration into jewelry, watchbands, or embedded vehicle hardware, making the device genuinely unobtrusive in everyday use.

• **Automated Crash Detection:** Incorporating MEMS accelerometers and gyroscopes would allow the device to detect sudden impact signatures characteristic of vehicle collisions or falls, triggering an alert automatically without any user action—critical when the victim is incapacitated.

• **Multi-Channel Communication:** Adding a SIM800L GSM module would provide SMS-based alert fallback for deployment in areas with no Wi-Fi coverage, dramatically expanding the device's geographic reliability.

• **Enhanced Security:** Future iterations should explore end-to-end message encryption and two-factor authentication for the Telegram bot endpoint to guard against unauthorized access to transmitted location data.

XIII. CONCLUSION

The Vehicle Accident Emergency Alert System demonstrates that a low-cost, purpose-built hardware device can meaningfully outperform conventional smartphone-based emergency methods across every critical dimension: activation speed, location precision, network resilience, and user cognitive load. By reducing the full alert cycle to a single button press and completing the entire process in under eight seconds, VAES addresses one of the most persistent and lethal gaps in road safety infrastructure—the delay between accident and rescue.

Although the current prototype requires further engineering work before commercial deployment, the core design has been validated as technically sound and economically viable. With the planned additions of automatic crash detection via inertial sensors, GSM fallback connectivity, and a miniaturized form factor, VAES has a credible pathway to becoming a practical, life-saving product for vehicle occupants, personal security, and rural communities worldwide.

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DOI: 10.48175/IJARSCT-34748