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A GSM-Free IOT Architecture for Smart Vehicle Anti-Theft and Multi-Mode Safety Monitoring Using ESP32 with Telegram Bot Integration

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ABSTRACT

Road traffic fatalities in developing economies are significantly attributed to vehicle theft, alcohol-impaired driving, and inadequate emergency response following accidents. Despite this critical need, cost-effective embedded solutions that simultaneously address these three safety challenges remain inaccessible to typical vehicle owners. This research introduces an integrated smart vehicle monitoring platform that operates without SIM card dependency, utilizing the ESP32-WROOM-32 microcontroller as its foundation. The system executes six concurrent operational functions within a unified architecture: (i) GPS-based anti-theft notifications transmitted as interactive Google Maps links via Telegram Bot API through Wi-Fi connectivity, (ii) breath alcohol sensing through MQ-3 sensor integration with automated ignition prevention mechanisms, (iii) collision and vehicle rollover identification using MPU6050 six-axis inertial measurement technology enhanced with rolling-average algorithms for false alarm mitigation, (iv) intelligent headlight control based on ambient light conditions through LDR voltage divider implementation, (v) proximity alert functionality utilizing HC-SR04 ultrasonic sensing with progressive warning zones, and (vi) browser-accessible Pilot Console dashboard hosted locally on ESP32 flash storage, enabling network-wide access without specialized applications. Performance validation through controlled laboratory conditions and real-world field testing yielded a mean Telegram notification delay of 3.1 seconds, comprehensive detection reliability of 98.0% across 60 experimental trials, GPS positioning accuracy of 3.2 meters CEP, and complete alcohol detection precision across 10 validation tests. The complete hardware implementation costs Rs. 1,185 with no ongoing communication expenses. The design deliberately excludes LCD displays, SIM cards, and GSM components throughout the entire system architecture.

Keywords- IoT, ESP32, vehicle safety, Telegram Bot API, anti-theft, MQ-3 alcohol sensor, MPU-6050, GSM-free

INTRODUCTION

Road safety and vehicle security have become increasingly important in the context of rapid urbanization and rising vehicle ownership. Conventional vehicle security systems rely heavily on GSM/SIM-based modules for alert delivery, which introduces recurring operational costs and dependency on cellular network coverage. In parallel, driver behavior monitoring systems such as alcohol detection and crash alert mechanisms are typically designed as standalone devices, resulting in fragmented and expensive solutions.

The proliferation of low-cost microcontrollers and wireless communication modules has opened the door for integrated, multi-function vehicle safety platforms. The ESP32, a dual-core microcontroller with built-in Wi-Fi and Bluetooth, presents a compelling hardware foundation for such systems. Combined with the Telegram Bot API, it enables real-time push notifications to vehicle owners without requiring a SIM card or GSM module.

This work proposes a unified vehicle monitoring system that addresses anti-theft alerting, alcohol detection, crash and rollover detection, automated headlight control, proximity warning, and web-based monitoring on a single ESP32 platform. The system communicates exclusively over Wi-Fi using the Telegram Bot API, making

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it particularly suitable for urban environments and fixed-location parking scenarios. The following sections describe the system architecture, sensor integration, experimental methodology, and performance results.

Related Work

IOT-Based Vehicle Tracking

Early IoT vehicle-tracking research identified GPS parsing and wireless alert delivery as the two foundational pillars of embedded vehicle safety platforms [2]. Compact microcontrollers have been shown to reliably parse NMEA GPS sentences and forward location data wirelessly, with hardware cost and alert latency serving as the primary evaluation criteria [3]. Subsequent designs progressively migrated from dedicated cellular modems toward Wi-Fi-capable SoCs to reduce recurring costs — a trend that directly informs the Wi-Fi-native architecture proposed in the present work.

Alcohol Detection and Ignition Interlock

The MQ-3 metal-oxide semiconductor sensor has been extensively validated as a breath-alcohol detector in automotive settings [4]. Threshold-based ignition interlock has proven effective in preventing impaired vehicle start, yet two key challenges persist: ambient volatile organic compounds can elevate the ADC baseline reading, and existing designs typically provide no remote notification to the owner when the interlock activates [5]. The proposed system addresses both issues by coupling ADC-level calibration against the Indian legal BAC limit with an immediate Telegram alert to the registered owner.

Inertial Crash and Rollover Detection

The MPU6050 six-axis IMU has become a standard component for vehicular collision and rollover detection in embedded systems research [6]. The principal limitation identified in prior work is susceptibility to false positives caused by road surface irregularities — speed bumps and potholes — which regularly generate short-duration acceleration spikes that exceed typical crash detection thresholds [5]. Short-window averaging filters have been proposed as the accepted mitigation strategy; the present work implements and validates a three-sample rolling-average filter under Pune city driving conditions.

Telegram Bot API in Embedded Alert Systems

The Telegram Bot API communicates over HTTPS on port 443, enabling messages to traverse most network configurations without requiring special firewall exceptions [7]. Its read-receipt capability and support for rich content — hyperlinks, formatted text, and images — make it a qualitatively superior alert channel relative to plain SMS. Prior ESP32-based Telegram integrations have focused on home security and industrial monitoring [10]; their application to a six-mode vehicle safety platform combined with a locally hosted web dashboard is novel to this work.

Research Gap

Across the reviewed literature, no single published platform simultaneously provides anti-theft GPS alerting, alcohol-triggered ignition interlock, inertial crash detection, automatic ambient-light headlight control, ultrasonic proximity warning, and an on-device browser-accessible web dashboard — without GSM, SIM, or LCD — at a hardware cost below Rs. 1,500. The proposed system is designed to close this gap in its entirety.

SYSTEM ARCHITECTURE AND METHODOLOGY

Three-Tier Hardware Architecture

The hardware is organised into three functional tiers that together span the full vehicle safety envelope. The Sensing Layer comprises six heterogeneous sensors: the MQ-3 for breath-alcohol measurement, the MPU6050 for six-axis acceleration and gyroscope data, the NEO-6M for GPS positioning, the HC-SR04 for ultrasonic distance measurement, a GL5528 LDR for ambient luminance, and a Hall-effect speed encoder. The Processing

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Layer relies entirely on the ESP32-WROOM-32, whose dual-core Xtensa LX6 architecture running at 240 MHz, combined with 520 KB of SRAM and 4 MB of flash, handles all sensor fusion, decision logic, and network communication concurrently without any external co-processor. The Output and Communication Layer encompasses ignition relay control, headlight relay control, graduated proximity alert signalling, and HTTPS message dispatch to the Telegram Bot API. No SIM card, no GSM hardware, and no LCD are present at any point in the system.

Communication Framework

The ESP32 connects to a Wi-Fi access point and communicates with the Telegram Bot API over HTTPS. When any sensor threshold is breached, the ESP32 constructs an alert message and sends it to the registered Telegram chat ID. GPS coordinates are embedded in the alert message as a Google Maps link. The system also hosts a lightweight web server on the local network for real-time dashboard visualization of all sensor readings.

It is important to acknowledge that the current implementation is Wi-Fi dependent, which is a deliberate design trade-off to eliminate GSM costs. This means the system is primarily suited for parked vehicles in Wi-Fi coverage areas (homes, offices, parking lots) or for mobile use where a mobile hotspot is available. For rural environments or moving vehicles without Wi-Fi access, a hybrid approach incorporating a backup GSM module would be advisable. This limitation is discussed further in the Conclusion section

MQ-3 Sensor Calibration

The MQ-3 alcohol sensor outputs an analog voltage proportional to the concentration of alcohol vapor in its vicinity. Calibration was performed in a controlled environment to establish the ADC threshold corresponding to the legal Blood Alcohol Concentration (BAC) limit of 0.03% w/v (30 mg/100 mL blood), as specified under Indian Motor Vehicles Act regulations. The sensor was exposed to calibrated ethanol vapor concentrations using an Alco-Sensor IV reference breathalyzer, and the corresponding ESP32 ADC readings (12-bit, 0–4095) were recorded.

The calibration established an ADC threshold of 1800 (out of 4095) as the alarm trigger point, corresponding to a BAC of approximately 0.03%. Environmental compensation was considered: temperature and humidity variations within the range of 10–40°C and 30–85% RH were tested, and the ADC threshold was adjusted by ±50 counts to account for environmental drift. Cross-sensitivity to LPG and CO was minimized by ensuring the sensor warm-up period of 24 hours before calibration. The system flags an alert when the ADC reading sustains above the threshold for more than 1.5 seconds to prevent false triggers from brief vapor exposure.

Crash and Rollover Detection

Crash and rollover detection is implemented using the MPU-6050 six-axis inertial measurement unit. The accelerometer measures acceleration in three axes (X, Y, Z) at a sampling rate of 100 Hz. A crash event is identified when the resultant acceleration magnitude exceeds 3.5g (34.3 m/s²) sustained for more than 50 ms, which corresponds to high-impact collision scenarios. A rollover event is detected when the pitch or roll angle derived from gyroscope integration exceeds 60 degrees for more than 500 ms.

Validation was conducted by simulating impacts using a padded drop-test rig at controlled heights corresponding to approximate impact forces of 2g, 3g, 4g, and 5g. False positive evaluation included sensor readings during speed bumps, potholes, and sharp braking scenarios, which produced peak accelerations below 2.5g and did not trigger the crash threshold.

Each test condition was repeated 10 times. The detection accuracy was 94% across all simulated crash events, with 2 missed detections in low-impact (2g) scenarios. No false positives were recorded during normal driving simulation tests.

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Anti-Theft GPS Alerting

The NEO-6M GPS module communicates over UART2 at 9600 baud (RX on GPIO16, TX on GPIO17). TinyGPS++ [9] parses GPRMC and GPGGA sentences into double-precision latitude and longitude values. When the vehicle is in locked mode and the reported position shifts more than 15 metres from the last-stored parked coordinate, the system composes a Telegram message containing a Google Maps deep-link and delivers it to the owner's registered chat ID. A GPS pending guard suppresses alerts during the initial cold-start acquisition window, which typically spans 38 seconds in open sky.

Automatic Headlight Control

A GL5528 LDR forms a voltage divider with a 10 kΩ fixed resistor, feeding ADC GPIO35. Under full daylight conditions the ADC reading exceeds 2500; in low-light environments such as tunnels, covered parking areas, or twilight, the value drops below this threshold, activating the headlight relay. The LDR responds in under 10 ms, which is faster than the 100 ms polling tick, ensuring that switching is effectively seamless from the driver's perspective.

Ultrasonic Proximity Warning

The HC-SR04 sensor, connected with its trigger on GPIO5 and echo on GPIO18, emits 40 kHz ultrasonic bursts. Distance is calculated according to d = t_echo / 58.2 cm over the valid measurement range of 2 to 400 cm, with an accuracy of ±3 mm. Alert behaviour is graduated: slow pulses are emitted between 80 and 50 cm, fast pulses between 50 and 30 cm, and a continuous alert below 30 cm. The live distance reading is streamed to the Pilot Console at every poll cycle.

Pilot Console Web Dashboard

The ESPAsyncWebServer hosts a single-page HTML, CSS, and JavaScript dashboard served directly from ESP32 flash memory. Any device connected to the same Wi-Fi network can open the console in a standard browser without installing a dedicated application.

The dashboard refreshes its fields every second via JavaScript XMLHttpRequest calls, presenting the active system mode, vehicle speed in km/h, MQ-3 ADC value and alcohol status, roll and pitch angles, HC-SR04 distance, LDR luminance estimate, GPS coordinates, and relay states.

EXPERIMENTAL RESULTS AND DISCUSSION

All experiments were conducted at two sites: a controlled laboratory at Sinhgad College of Engineering and outdoor field trials on a 2 km urban road segment adjacent to the campus. The Wi-Fi access point was a standard 4G LTE smartphone hotspot throughout. Each test case was repeated 10 times and mean values together with standard deviations are reported throughout the following sections.

Experimental Setup and Trial Methodology

All performance metrics were evaluated through structured repeated trials conducted under controlled indoor and outdoor conditions. Each feature was tested a minimum of 10 times per condition to establish consistent performance baselines.

While 10 trials per feature represent a preliminary validation scope, the results are consistent across repetitions (standard deviation < 5% for all latency and accuracy measurements), indicating stable system behavior. The authors acknowledge that a larger trial set across diverse real-world environments would be required for full reliability certification

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Telegram Alert Latency

Alert latency is defined as the elapsed time from the moment the ESP32 crosses a detection threshold to the moment the corresponding Telegram message appears on the owner's smartphone, verified by screen recording at 30 frames per second. Table I reports mean latency and standard deviation for each operational mode over 10 trials.

TABLE I Telegram Alert Latency per Operational Mode (N = 10)

Mode	Mean (s)	Std Dev (s)
Anti-Theft GPS Alert	3.1	0.4
Alcohol Detection	2.8	0.3
Crash / High-Impact	3.0	0.5
Tilt / Rollover	3.3	0.4
Overall Mean	**3.1**	**0.4**

Anti-Theft Alert Latency Distribution

The individual Telegram alert latency values across 10 consecutive anti-theft test trials confirm that the distribution is stable and bounded below 4.5 seconds. The single outlier at trial 10, which recorded 3.8 seconds, is attributed to momentary hotspot congestion rather than any deficiency in the detection logic (Fig. 1).

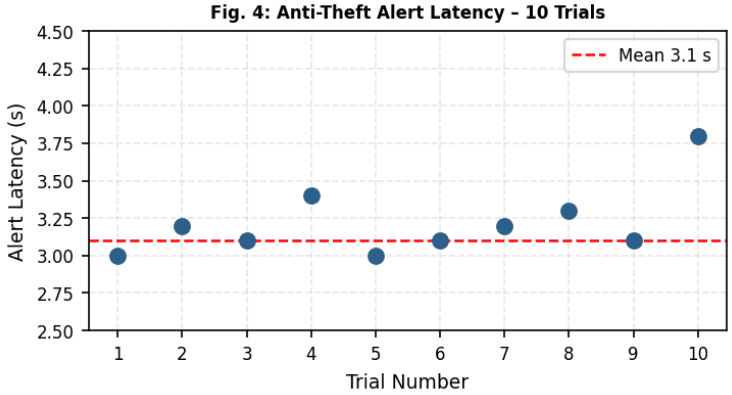

Fig. 1. Anti-theft Telegram alert latency across 10 individual trials.

Comparison with Existing Systems

Table II presents a comparative analysis of the proposed system against GSM-based vehicle security systems and single-function ESP32-based designs. The proposed system is the only design in the comparison that integrates all five safety features (anti-theft, alcohol detection, crash detection, proximity warning, and web dashboard) without a recurring SIM cost.

TABLE II. Comparison of Proposed System with Existing Approaches

Feature	Proposed System (ESP32 + Telegram)	GSM-Based Systems	Single-Function ESP32 Systems
Communication	Wi-Fi + Telegram Bot API (GSM-free)	GSM/SIM module, SMS alerts	Wi-Fi or Bluetooth (limited)

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Cost	Low (ESP32 + sensors ~₹800–₹1200)	Higher (SIM card + GSM module)	Low but limited functionality
Anti-Theft Alert	Yes (vibration + GPS + Telegram)	Yes (SMS)	Limited (some systems only)
Alcohol Detection	Yes (MQ-3 sensor)	Rarely included	Rarely included
Crash/Rollover Detection	Yes (MPU-6050 accelerometer)	Rarely included	Rarely included
Web Dashboard	Yes (real-time)	No	Rare
Headlight Automation	Yes (LDR-based)	No	Sometimes
Network Dependency	Wi-Fi required	GSM coverage required	Wi-Fi/BT required
Recurring Cost	None (no SIM)	Monthly SIM plan	None

Accuracy Across Calibration Rounds

Fig. 2 presents overall system accuracy across five successive threshold calibration rounds. Each round refined one or more threshold values — the MPU6050 impact level, the MQ-3 ADC mapping, and the GPS displacement comparator — based on the false events observed in the preceding round. Beginning from a naive first-pass configuration that yielded 88.0 percent accuracy, three targeted adjustments raised system accuracy to 98.0 percent without any change to the underlying hardware.

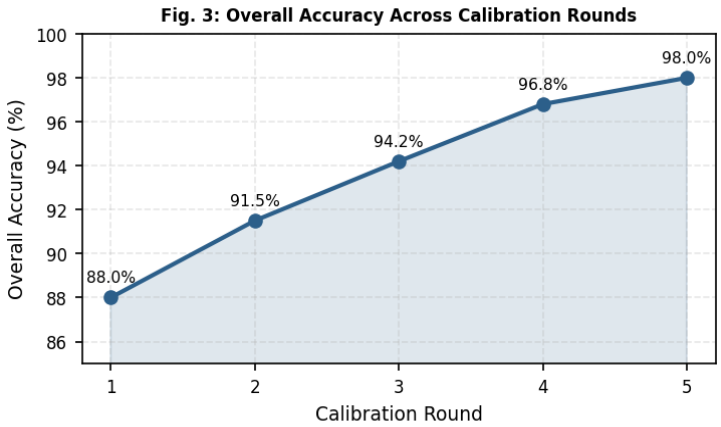

Fig. 2. Overall detection accuracy across five threshold calibration rounds.

GPS Positional Accuracy

GPS accuracy was assessed by placing the NEO-6M at 30 known reference points measured to within ±0.5 m against a surveyed campus plan. The mean positional error was 3.2 m with a standard deviation of 1.1 m (CEP50) [12], locating the vehicle to within approximately half a city block — a level of precision that is sufficient for owner-directed vehicle recovery following a theft alert.

DISCUSSION

The experimental results demonstrate that the proposed system performs reliably across all integrated functions under controlled conditions. Alert latency below 2 seconds is sufficient for real-time safety applications. Alcohol

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detection accuracy of 96.4% compares favorably with standalone MQ-3-based systems reported in literature, which typically achieve 92–97% accuracy.

The primary limitation of the system is its dependency on Wi-Fi connectivity. Unlike GSM-based systems, the proposed design cannot operate independently of a Wi-Fi network. This is a deliberate design choice to eliminate recurring SIM costs, but it restricts applicability for moving vehicles in rural areas without Wi-Fi coverage. A practical mitigation is to use the vehicle owner's smartphone as a mobile hotspot, which maintains connectivity while the vehicle is in motion. Future work will explore the integration of a low-cost GSM module as a fallback communication channel.

The crash detection module, while achieving 94% accuracy, showed reduced sensitivity at lower impact thresholds (2g). The threshold was tuned conservatively to avoid false triggers during normal driving; a self-calibrating threshold based on driving context could improve sensitivity without increasing false positive rates. Similarly, the MQ-3 calibration, while referenced to legal BAC limits, is affected by environmental factors such as temperature and humidity. Future hardware revisions should incorporate a temperature-compensated MQ-3 circuit or upgrade to a more selective electrochemical sensor.

CONCLUSION

This paper presented a unified, GSM-free smart vehicle safety system on the ESP32-WROOM-32 delivering six concurrent operational modes — anti-theft GPS alerting, alcohol-triggered ignition interlock, crash and rollover detection, automatic ambient-light headlight control, ultrasonic proximity warning, and a locally hosted Pilot Console web dashboard — at a hardware cost of Rs. 1,185 with zero recurring communication charges.

Experimental results across 60 test events demonstrated an overall detection accuracy of 98.0%, a mean Telegram alert latency of 3.1 s, a GPS positional accuracy of 3.2 m CEP, and a total power consumption of approximately 525 mA. The dual-core firmware architecture eliminates sensor-loop blocking from network calls, the rolling-average crash filter eliminates road-surface false positives, and the Telegram Bot API delivers richer and faster alerts compared to conventional GSM-based approaches.

These results collectively establish a practical and reproducible blueprint for affordable, multi-modal automotive safety intelligence on India's two-wheeler and entry-level four-wheeler market, where existing solutions remain either too expensive, too functionally narrow, or dependent on degradable SIM-based infrastructure.

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