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ORIGINAL CONTRIBUTION

SMART GEO-FENCING AND REAL-TIME DISTANCE MONITORING SYSTEM USING GPS, GSM AND ESP32

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ABSTRACT

Geo-fencing enables the definition of virtual geographical boundaries for automated monitoring and alert generation. This paper presents a portable real-time geo-fencing system integrating a Neo-6M GPS receiver, ESP32 microcontroller, SIM800L GSM module, OLED display, buzzer, and battery-based power supply. The system acquires GPS coordinates and calculates the distance from a predefined geo-fence centre using the Haversine formula to determine the current zone status. A ± 5 m hysteresis band is incorporated to minimize false boundary transitions caused by GPS fluctuations. On detecting a confirmed violation, the ESP32 activates a local buzzer and transmits an SMS through the GSM module using AT commands, with a 60 s alert cooldown to prevent repeated notifications. The reported prototype achieved approximately ± 3.2 m average distance error, 100% violation detection across 10 trials, SMS delivery within 3 s, and approximately 4.5 h of operation under the stated test condition. The system demonstrates a low-cost and portable approach for outdoor real-time monitoring.

KEYWORDS: Geo-fencing, Haversine formula, real-time monitoring, boundary detection, GPS-based tracking.

1. INTRODUCTION

Geo-fencing defines a virtual geographical boundary around a physical location and triggers an automated response when a tracked object enters or leaves the defined region. The availability of low-cost GNSS receivers and embedded controllers has enabled its application in vehicle, asset and personal monitoring. However, positioning uncertainty, energy consumption and intermittent location measurements remain important challenges for reliable geo-fencing [1]–[4].

Conventional tracking systems often rely on smartphones, cloud platforms or commercial trackers, which may require continuous Internet connectivity or dedicated infrastructure. GPS-GSM architectures provide a practical

alternative by acquiring geographical coordinates locally and transmitting alerts through cellular networks [5], [6]. Nevertheless, GPS fluctuations near a geo-fence boundary can produce repeated or incorrect state transitions. Özdemir and Tuğrul investigated this issue and demonstrated the use of moving-average and Kalman filtering approaches for improving GPS-based geofencing accuracy [2].

To address this practical limitation, the proposed system integrates GPS positioning, Haversine-based distance calculation, boundary hysteresis and GSM-based notification within a compact ESP32-based architecture. A ± 5 m hysteresis band is used to reduce false boundary transitions, while an OLED display and local buzzer provide immediate on-site status and warning indication.

SMS notification enables remote alerting without requiring continuous Internet connectivity.

The remainder of this paper is organized as follows: Section II presents the literature review; Section III describes the proposed system and hardware architecture; Section IV presents the methodology; Section V discusses implementation; Section VI presents the experimental results and discussion; Sections VII and VIII describe applications and future scope, respectively; and Section IX concludes the paper.

2. LITERATURE REVIEW

Geo-fencing has been widely investigated for location-based services. Garzon and Elbehery examined reliable geofencing for proactive services and identified positioning accuracy and energy consumption as important factors affecting reliability [1]. Garzon, Arbuzin and Küpper further proposed a geofence reliability index for evaluating the performance of continuous geographical zone matching [3].

Özdemir and Tuğrul investigated real-time GPS-based geofencing using moving-average filtering, Kalman filtering and logistic regression to reduce positioning errors [2]. Their study demonstrates that GPS uncertainty can directly affect boundary decisions. Nguyen and Krumm addressed another reliability issue associated with sparse location measurements, where an object may cross a geo-fence without a recorded position inside the boundary. Their approach uses short-term location prediction to improve activation reliability [4].

GPS-GSM architectures have also been applied to real-time tracking. Lee, Tewolde and Kwon demonstrated a GPS/GSM/GPRS vehicle-tracking system integrated with a smartphone application [5], while Fleischer *et al.* developed a GPS/GSM-based tracking and alert system for commercial inter-city buses [6]. These studies establish the feasibility of combining positioning with cellular communication for real-time monitoring.

For indoor environments, Pešić *et al.* developed GEMAT, an IoT-based security geo-fencing framework using Bluetooth Low Energy micro-location tracking [7]. This highlights the

limitations of GPS in obstructed environments and the need for alternative positioning technologies.

The reviewed studies indicate requirements for reliable positioning, reduced boundary fluctuations, timely alerts and efficient operation. The proposed prototype addresses these requirements through a low-cost ESP32-based GPS-GSM architecture integrating Haversine distance estimation, ± 5 m boundary hysteresis, OLED and buzzer indication, and cellular SMS notification.

3. PROPOSED SYSTEM

3.1. System Architecture

The proposed system is organized into four functional layers: sensing, processing, output and alert, and power.

Layer 1—Sensing Layer: The Neo-6M GPS module continuously acquires satellite signals and generates NMEA data at 9600 baud, including latitude, longitude, altitude, speed and satellite count. The NodeMCU receives the serial data and uses the TinyGPS++ library for parsing.

Layer 2—Processing Layer: The NodeMCU ESP8266 executes the main firmware, processes the GPS data, calculates the distance from the geo-fence centre using the Haversine formula, and compares it with the configured radius to determine the zone status.

Layer 3—Output and Alert Layer: The OLED displays GPS coordinates, distance, zone status and alert information. The buzzer activates during an outside-zone condition, while the SIM800L sends an SMS containing the current coordinates. The outputs are reset when the device returns to the safe zone.

Layer 4—Power Layer: A 7.4 V nominal 18650 battery pack supplies the system through an XL4016 buck converter, which regulates the voltage to 5 V. The NodeMCU's onboard 3.3 V regulator supplies the GPS and OLED modules.

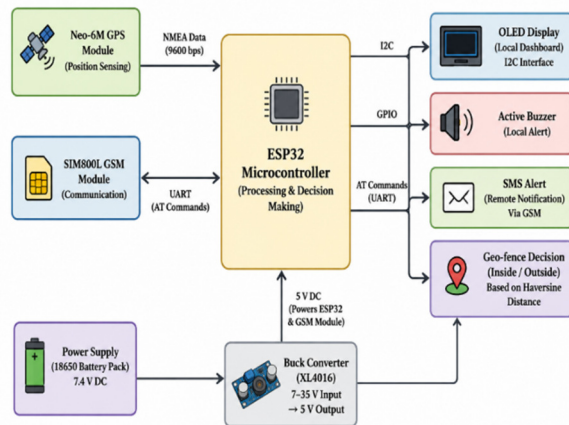


Figure 1: System Architecture of the Proposed Geo-Fencing System

The architecture illustrates the integration of the Neo-6M GPS, ESP32, SIM800L, OLED and buzzer for real-time position monitoring and alert generation. The ESP32 processes GPS data, performs Haversine-based geo-fence decisions, and controls local and GSM-based notifications.

3.2. Hardware Components

Table I:

Component	Function	Reported Specification
ESP32	Central processing	Dual-core Xtensa LX6, up to 240 MHz, 520 KB SRAM, Wi-Fi/Bluetooth
Neo-6M GPS	Position acquisition	u-blox 6 engine, approximately 2.5 m CEP specification, 9600-baud NMEA
SIM800L GSM	Remote alert	Quad-band 850/900/1800/1900 MHz, AT-command-based SMS
OLED Display	Local dashboard	128×64, SSD1306, I2C, 0.96 in.

18650 Battery Pack	Portable power	3.7 V × 2, approximately 5000 mAh stated capacity
Active Buzzer	Local warning	5 V active buzzer
Buck Converter	Power regulation	XL4016-based, stated 7–35 V input range

3.3. Monitoring Interface

The OLED interface displays live monitoring information including latitude, longitude, calculated distance, zone status, SMS status and satellite information. The supplied prototype demonstration showed an example coordinate of 22.052341 latitude and 88.114253 longitude, a calculated distance of 43.7 m, an INSIDE ZONE status, SMS status and seven satellites.

4. METHODOLOGY

4.1. GPS Coordinate Acquisition

After initialization, the Neo-6M continuously provides NMEA positioning data at 9600 baud. The ESP32 parses the received data using the TinyGPS++ library and extracts latitude and longitude for distance calculation.

4.2. Haversine Distance Calculation

Since GPS coordinates represent positions on the Earth's surface, the Haversine formula is used to determine the distance between the current position and the geo-fence centre: where is the calculated distance, m is the Earth's mean radius, ϕ_1 and ϕ_2 are the latitudes, and $\Delta\lambda$ are the latitude and longitude differences in radians. The TinyGPS++ distance Between () function can perform the corresponding calculation.

$$a = \sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1) \cos(\phi_2) \sin^2\left(\frac{\Delta\lambda}{2}\right) \quad (1)$$

$$c = 2 \operatorname{atan2}(\sqrt{a}, \sqrt{1-a}) \quad (2)$$

$$d = R c \quad (3)$$

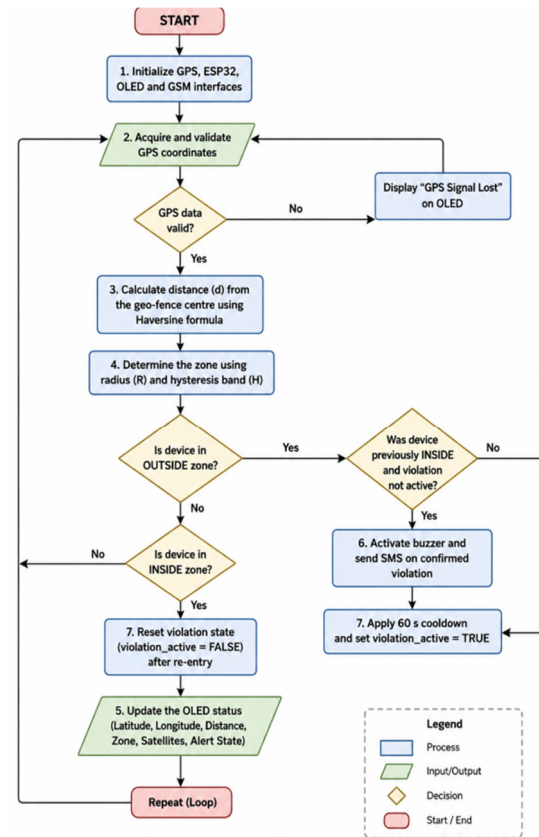
4.3. Geo-Fence Decision

Let denote the configured geo-fence radius and the calculated distance. The zone is classified as INSIDE when and OUTSIDE when. A ± 5 m hysteresis band is applied to reduce repeated state transitions caused by GPS fluctuations near the boundary.

4.4. Alert Generation

For a confirmed boundary violation, the ESP32 activates the buzzer and commands the SIM800L to transmit an SMS using AT commands. The modem is configured using AT+CMGF=1 and AT+CMGS. A 60 s cooldown prevents repeated alerts while the device remains outside the geo-fence.

4.5. Overall Algorithm



5. IMPLEMENTATION

The prototype integrates the Neo-6M GPS, ESP32, OLED, SIM800L and buzzer into a portable monitoring unit. GPS data are parsed using TinyGPS++, while Adafruit SSD1306, Adafruit GFX and Wire.h support OLED and I2C operation; SoftwareSerial is used for GPS/GSM communication. The SIM800L transmits boundary violation SMS alerts through AT commands, while the buzzer provides local notification. Two 18650 cells with approximately 5000 mAh combined capacity and a buck converter provide portable regulated power. The core alert function operates without continuous Wi-Fi or cloud connectivity, although GSM coverage is required for SMS transmission.

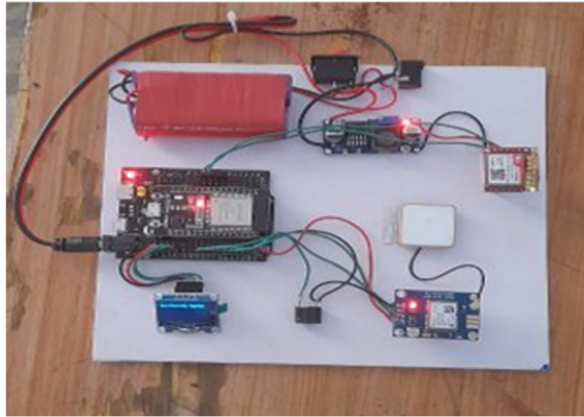


Figure 2: Hardware Prototype of the model

6. RESULTS AND DISCUSSION

The supplied prototype evaluation reports an average GPS distance error of approximately ± 3.2 m. Six individual distance-error values presented in the project material were 2.8 m, 3.5 m, 3.1 m, 2.9 m, 3.8 m and 3.0 m. These values demonstrate the expected metre-level variation associated with outdoor GPS measurements.

Table II: Reported Prototype Performance

Parameter	Reported Result
Average Distance Error	± 3.2 m
Violation Detection Rate	100% of reported trials
SMS Delivery Time	<3 s after boundary crossing
Battery Endurance	Approximately 4.5 h
Boundary Hysteresis	Approximately ± 5 m
SMS Cooldown Period	60 s

The ten-trial test sequence showed correct operation: Trials 1–3 produced no alerts inside the zone, Trials 4–6 and 10 generated SMS alerts during boundary crossings, and Trials 7–9 correctly reset the violation state after re-entry.

The approximately 4.5 h battery endurance limits continuous deployment. Performance also depends on satellite visibility and cellular availability, with a reported GPS cold-start delay of 30–60 s and support for a single geo-fence zone. The OLED provided continuous local monitoring of position, distance and zone status, while the buzzer supplied an immediate on-site warning during violations. The ± 5 m hysteresis reduced repeated state transitions caused by GPS fluctuations near the boundary. The combined GPS-GSM architecture therefore provides a practical low-cost solution for portable outdoor monitoring and real-time alert generation.

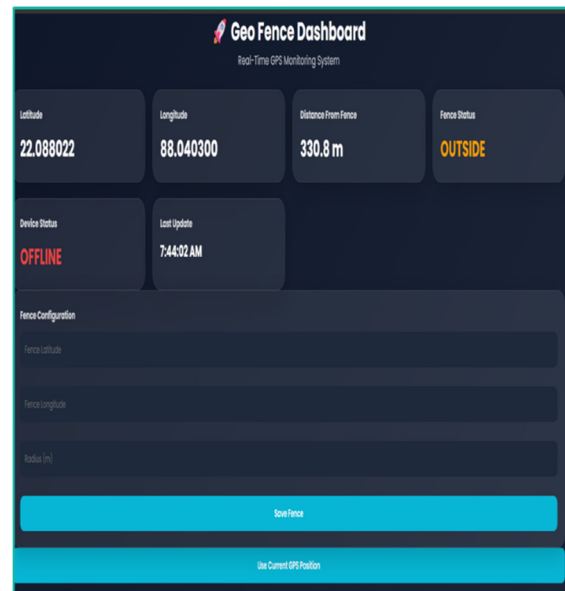


Figure 3: Real-time Geo-Fence Dashboard displaying GPS coordinates, distance from the defined fence, zone status, device status, and fence configuration controls.

The dashboard provides a real-time interface for monitoring the device position and geofence status. It also allows the user to configure the fence coordinates and radius and save or update the monitoring region.

7. CONCLUSION

This paper presented a portable ESP32-based geofencing system integrating GPS positioning, Haversine distance calculation, ± 5 m hysteresis, OLED monitoring, buzzer indication and GSM-SMS alerts. The reported prototype achieved ± 3.2 m average distance error, 100% detection across 10 trials, SMS delivery within 3 s and approximately 4.5 h battery operation. The integration of local and cellular alerts enables rapid response without continuous Internet connectivity. The proposed low-cost architecture is suitable for practical outdoor monitoring where

portability, real-time boundary detection and immediate notification are required. Future work includes GPS filtering, multi-zone operation, predictive detection and improved power management.

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