IES International Journal of Multidisciplinary Engineering Research

GPS Geofencing based Automatic Speed Control System for School Zone Safety

Govind P S[1], Selvin Xavier [2], Swathy E S[3], Ummer Sinan[4], Anitha Mathew[5]

[1,2,3,4]*Students, Department of EEE, IES College of Engineering Chittilapilly, Kerala, India.*

[5]*Assistant Professor, EEE, IES College of Engineering Chittilapilly, Kerala, India.*

Email_id: govindps434@gmail.com, swathyes57@gmail.com, selvinxavier054@gmail.com, ummersinan195@gmail.com, anithamathew@iesce.info

Abstract

Speeding near school premises continues to be a major contributor to road accidents, even with the presence of conventional preventive measures such as signboards, speed bumps, and surveillance by traffic personnel. To address the shortcomings of these traditional systems, this paper proposes an automated speed regulation solution that leverages GPS-based geofencing to identify school zones and regulate vehicle speed without relying solely on driver awareness. The system incorporates an ESP32 microcontroller, GPS receiver, display indicators, and alert mechanisms to continuously track the vehicle's location and determine when it enters a predefined geofenced region. Once inside a school zone, the controller activates visual and audible warnings and restricts vehicle speed through a dedicated control interface. The prototype was evaluated through simulation and preliminary testing, demonstrating accurate zone identification, minimal response delay, and a framework scalable to multiple sensitive locations. The proposed system offers a cost-efficient, low-power, and easily deployable solution that can enhance safety near educational institutions and can be further extended to hospitals, residential neighborhoods, and other restricted areas. The work aligns with the emerging objectives of intelligent transportation systems and smart mobility infrastructure.

Keywords: GPS, Geofencing, School Zone Safety, ESP32, Speed Control, Intelligent Transportation System.

DOI: https://doi.org/10.5281/zenodo.18857815

1. Introduction

Ensuring road safety in areas surrounding schools is a critical concern for transportation authorities, as children and pedestrians remain highly vulnerable to traffic-related incidents. A significant number of accidents near educational institutions are directly linked to vehicles exceeding the permissible speed limits. Although preventive measures such as warning boards, rumble strips, and manual enforcement exist, their effectiveness is often reduced due to driver negligence, visibility issues, and inconsistent monitoring.

Recent advancements in satellite navigation and embedded electronics provide an opportunity to automate speed control based on a vehicle's real-time position. GPS technology combined with geofencing allows the creation of virtual boundaries around sensitive zones, enabling automated detection when a vehicle enters or exits these regions. Once the vehicle crosses into a geofenced school zone, automated control actions can be triggered without relying on external roadside infrastructure.

Microcontrollers like the ESP32 have made it feasible to integrate location processing, decision-making, wireless communication, and control actuation in a compact, low-cost platform. These capabilities support the development of intelligent vehicle systems that can contribute to improved compliance with speed regulations.

This work presents the design and implementation of a GPS-enabled geofencing system intended to automatically regulate vehicle speed in school zones. The system combines real-time GPS tracking, embedded algorithms, driver alert mechanisms, and a speed-limiting interface to form a comprehensive solution. The primary contributions of the study include a modular hardware design, an efficient geofencing algorithm suitable for low-cost GPS modules, and prototype validation through simulation-based analysis.The overall objective is to provide an affordable and adaptable platform for enhancing safety around schools, while laying a foundation for integration into smart city and intelligent transportation frameworks.

2. Objectives

The primary aim of this project is to develop an automated speed regulation system that utilizes GPS-based geofencing to accurately identify school zones and enforce compliance with safe speed limits. The system seeks to significantly reduce over speeding incidents near schools and enhance pedestrian safety by shifting from manual, driver-dependent enforcement to an automated regulation system.

To achieve this, the project focuses on several key objectives: first, the Design of the Embedded Hardware Platform is necessary to develop a complete and reliable architecture centered around the ESP32 microcontroller, ensuring stable power delivery, accurate data acquisition, and seamless integration of components like the GPS module, display, and speed-control interface for continuous real-time operation. Second, the Development of the Geofencing Algorithm requires designing a robust decision-making algorithm to compare real-time GPS coordinates with predefined zone boundaries, accurately detecting zone entry and exit, even with typical GPS errors, for reliable, safety-critical identification. Third, the Implementation of Automatic Speed Regulation involves integrating a speed-control mechanism that becomes active inside a school zone, triggering visual and audible warnings for the driver and generating control signals to interface with a motor driver or speed governor to automatically limit speed. Fourth, Simulation and Functional Testing must be performed using realistic coordinates to evaluate key performance parameters like detection accuracy, responsiveness, and system stability, validating the design's feasibility before full hardware field testing. Finally, Ensuring Scalability and Practical Deploy ability is a long-term objective to build a modular system capable of supporting multiple geofenced zones without significant hardware changes, with the goal of extending the system to other sensitive areas (like hospitals or residential neighborhoods) and integrating it with IoT platforms for centralized monitoring and data logging.

3. Methodology

The development of the GPS-based geofencing speed control system followed a structured methodological approach that ensured a smooth transition from conceptual design to a functional prototype. The initial stage involved a detailed analysis of system requirements, where the functional expectations—such as continuous vehicle tracking, reliable school-zone detection, automatic activation of warnings, and speed regulation—were clearly established. Alongside these, non-functional aspects including low power consumption, affordability, scalability to multiple zones, and compatibility with standard vehicle electrical systems were also considered essential. Typical scenarios of vehicles approaching, entering, traveling through, and exiting school zones were studied to determine the operational conditions under which the system should perform consistently and accurately.

Based on the identified requirements, the hardware architecture was designed around the ESP32 microcontroller, which serves as the central processing unit. The ESP32 was selected for its robust processing capabilities, integrated communication features, and suitability for real-time embedded applications. It was interfaced with a GPS module to acquire continuous latitude and longitude data, an OLED display to provide driver feedback, and a set of LEDs and a buzzer for immediate visual and audible alerts. A DC–DC buck converter based on the LM2596 was used to step down the 12-volt supply typically available in vehicles to the required 5-volt and 3.3-volt levels needed by the electronics. All components were integrated on a prototype board and enclosed in a compact casing suitable for installation either inside a vehicle or on a demonstration model.

The core of the system lies in the geofencing and speed-control algorithm implemented within the ESP32. Predefined school-zone coordinates and boundary radii were stored in the controller's memory. As the GPS module streamed real-time positional data, the controller continuously calculated the distance between the vehicle's current position and the geofenced zone using a geographic distance formula. If the calculated distance fell within the defined radius, the system interpreted this as entry into the school zone and immediately activated the warning indicators. At the same time, the controller issued a control signal to a motor driver or speed-governing interface, effectively limiting the vehicle or model's maximum speed to a safe level. When the vehicle left the defined geofence, the system automatically deactivated the warnings and restored the vehicle to normal operating conditions. To ensure stability near zone boundaries, hysteresis was incorporated into the detection logic to avoid rapid switching due to minor GPS fluctuations.

Firmware for the system was developed in C/C++ using either the Arduino IDE or the ESP-IDF environment. The software handled tasks such as parsing NMEA GPS data, evaluating geofence conditions, updating the display and alerts, and issuing control commands to the speed-regulating module. Error-handling routines were included to maintain system stability during temporary GPS signal loss or momentary noise in the input data. Care was taken to structure the firmware using non-blocking loops to ensure that all system tasks executed smoothly and consistently in real time.

For evaluation, the completed prototype was tested on a small-scale vehicle model or a controlled test bench capable of simulating vehicle speed. Real and simulated GPS data were used to emulate entry and exit from school zones. Throughout testing, data related to GPS coordinates, transition timings, alert activations, and speed-governing responses were recorded and analyzed. These results were used to refine the algorithm parameters, improve detection accuracy, and verify that the system responds reliably under practical operating conditions. The methodology ensured that the final prototype offered a stable, scalable, and effective solution for automated speed regulation in sensitive areas.

4. System Design

The proposed system is developed as a compact embedded unit capable of automatically detecting school zones and regulating vehicle speed based on real-time GPS information. Its architecture integrates sensing, processing, alerting, and actuation functions into a unified platform that can be installed inside a vehicle or a prototype model. At the heart of the design is the ESP32 microcontroller, chosen for its processing power, integrated communication interfaces, and suitability for real-time embedded applications. The microcontroller continuously receives latitude and longitude data from the GPS module, which operates with an active antenna to ensure stable satellite reception and consistent coordinate updates during vehicle movement.

Power for all components is supplied through an LM2596 DC–DC buck converter, which steps down a standard 12-volt vehicle or battery input to regulated 5-volt and 3.3-volt lines. These supply rails ensure reliable operation of the microcontroller, GPS unit, OLED display, and the alerting peripherals. The user interface is designed to provide immediate feedback to the driver through a small OLED display that presents zone status, coordinates, or warning messages, while LEDs and a buzzer offer quick visual and audible indications when the vehicle enters a restricted school zone. The system housing is compact and robust, enabling it to be mounted inside a dashboard or on a vehicle prototype without requiring significant structural modifications.

The control pathway begins with the acquisition of GPS data, which the ESP32 interprets to determine whether the vehicle has entered a predefined geofence boundary. As soon as the controller identifies the vehicle's presence within a school zone, it activates the warning indicators and sends a speed-limiting signal to the motor driver or speed governor interface. This signal constrains the maximum permissible speed of the vehicle or model motor, ensuring that it cannot accelerate beyond the safe limit configured for that zone. When the vehicle moves out of the geofenced area, the controller automatically restores normal mode, deactivating warnings and releasing the speed restriction. The data flow between sensing, decision-making, and actuation is organized to maintain low latency and high reliability, ensuring that the system responds almost instantaneously to changes in vehicle position. The modularity of the overall design allows additional zones, communication interfaces, or sensors to be added without altering the core architecture. This makes the system adaptable for broader deployment in intelligent transportation frameworks, supporting applications such as automated safety enforcement in hospitals, residential zones, or construction areas.

4.1 Block Diagram

Systems Used : The GPS Geofencing-Based Automatic Speed Control System consists of five interconnected units: the Power Supply, which uses an LM2596 DC–DC Buck Converter to step down the 12 V source to regulated 5 V and 3.3 V lines ; the GPS Module (NEO-6M / NEO-M8N), which takes 3.3 V / 5 V input and outputs serial NMEA data to the ESP32's UART RX pin ; the ESP32 Microcontroller (the Central Control Unit), which processes the GPS data using the geofencing and speed-control logic and outputs control signals via I2C to the OLED Display, GPIO to the LEDs and Buzzer, and PWM/Digital Output to the Motor Driver or Speed Governor ; the User Interface/Alert Unit (OLED Display, LED Indicators, and Buzzer), which provides immediate feedback on zone status, messages, and warnings ; and finally, the Speed Control Actuator (Motor Driver / ECU Interface / Speed Governor), which receives the control signal from the ESP32 to limit the vehicle or motor speed within the school zone.

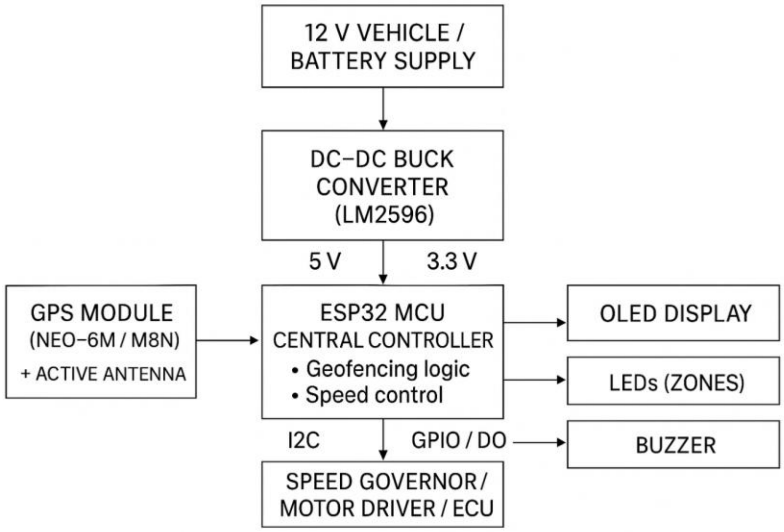

Figure 1: Block Diagram

4.2 Working Principle

The system's operational principle is based on the continuous, closed-loop location awareness of the vehicle and the autonomous execution of control signals required to enforce speed limits within sensitive zones. The GPS module serves as the primary sensor, constantly streaming real-time geographic data (latitude, longitude, and speed) to the ESP32 microcontroller via a dedicated communication channel like UART. The ESP32 acts as the Central Processing Unit, where an embedded decision algorithm (often utilizing the Haversine formula) repeatedly calculates the precise distance between the vehicle's current position and the known central coordinate of the school zone. This calculated distance is then critically compared against the zone's defined geofence radius. Upon confirming a zone entry event—which occurs when the distance is less than the radius—the system initiates a coordinated response: simultaneously activating visual and audible warnings (via the OLED display, LEDs, and buzzer) to alert the driver, and, most importantly, generating a control signal (such as a PWM or digital output) directed toward the Motor Driver or Speed Governor Interface. This signal automatically commands the vehicle's engine control unit (ECU) to limit the maximum speed smoothly, ensuring the vehicle remains within a safe, regulated threshold throughout the geofenced area. To maintain stability and prevent the system from rapidly toggling states due to minor GPS signal fluctuations near the boundary, a hysteresis margin is factored into the distance calculation; only when the vehicle's position exceeds the radius plus this margin is the zone exit event confirmed, leading to the disengagement of the speed limiting signal and the restoration of unrestricted speed control. This integrated cycle ensures timely feedback and automated regulation without requiring manual intervention, making the system a reliable safety mechanism.

4.3 Simulation Diagram

The simulation diagram gives a clear and complete virtual view of how the GPS-based school-zone speed control system works. It lets us test the entire setup before moving on to the real hardware. The diagram shows how all the major components ESP-32 microcontroller, GPS module, OLED display, LEDs, buzzer, and the speed-control actuator are connected and interact with each other inside the simulation environment.

In this virtual setup, the GPS block provides sample latitude and longitude values that act like real GPS readings. These values are sent to the ESP-32, which runs the geofencing algorithm to check the vehicle's location. Depending on whether the system detects entry into a school zone, presence inside it, or exit from the restricted area, the controller triggers different responses. The LEDs indicate the zone status, the buzzer gives an audible warning, and the OLED display shows messages related to speed limits or alerts. The simulated speed-control actuator shows how the controller would actually regulate the vehicle's speed in a real-world situation.

The diagram also shows how the power supply is arranged, clearly marking the regulated 3.3 V and 5 V lines that feed the different modules. This ensures that every component receives the correct voltage. The signal connections between modules are also well represented, making it easy to confirm that data flows properly from the GPS module to the ESP-32 and then to the output devices.

By watching how the LEDs turn on, how the buzzer behaves, and how the display updates during the simulation, we can verify that the control logic is working as intended. This testing phase helps catch wiring mistakes, logic errors, or communication issues early, ensuring the system will function reliably once it is implemented on actual hardware.

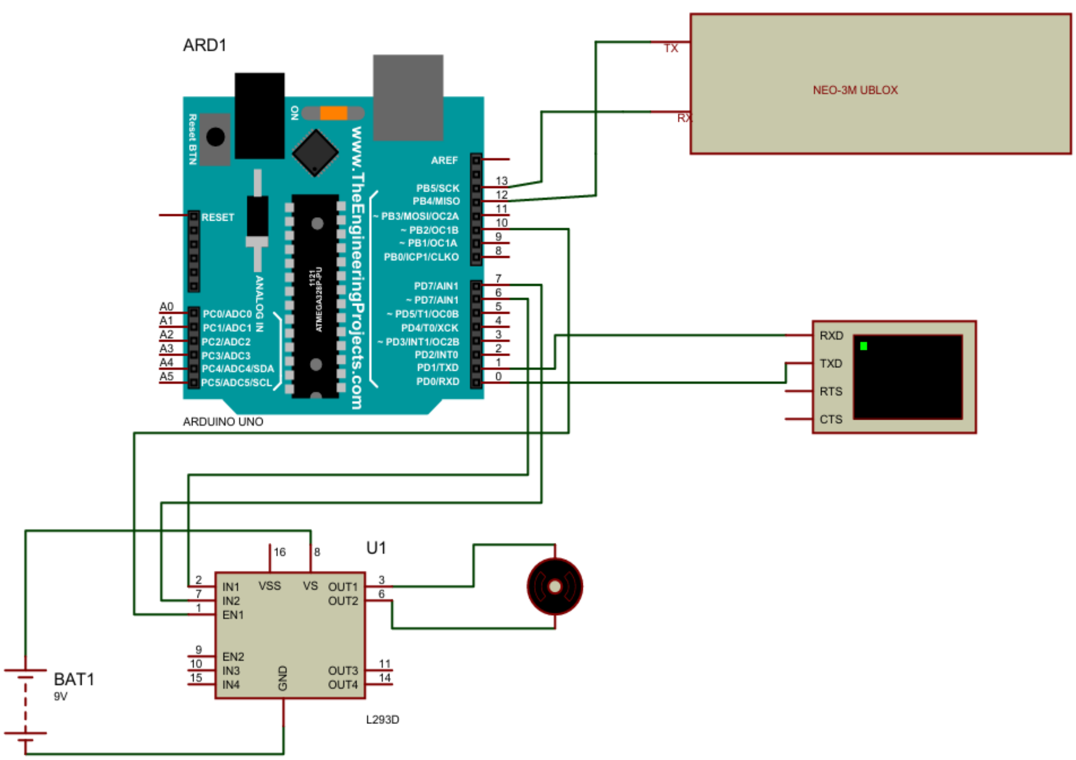

Figure 2: Simulation Diagram

5. Conclusion

The development of a GPS-based geofencing system for automatic speed regulation in school zones demonstrates practical and effective approach to improving road safety in sensitive areas. By integrating real-time

GPS tracking with an embedded decision-making algorithm, the system is able to accurately identify when a vehicle enters or exits a predefined school zone and respond immediately by activating warning indicators and limiting vehicle speed. The prototype successfully shows that even with low-cost GPS modules and readily available microcontroller hardware, reliable geofence detection and responsive speed control can be achieved with minimal latency. The use of an ESP32 based architecture ensures that all sensing, processing, and control tasks occur seamlessly, providing a stable and autonomous mechanism for enforcing safe driving speeds without relying on continuous driver attention or external enforcement measures.

Simulation and controlled testing confirm that the system can distinguish restricted zones with good precision and maintain stable performance despite minor GPS variations. The modular design, efficient power management, and compatibility with standard vehicle systems make the solution both scalable and practical for broader deployment. Overall, the work establishes a strong foundation for the adoption of GPS-enabled automated safety mechanisms in school zones, contributing to the wider objective of developing intelligent transportation systems capable of enhancing public safety and reducing accident risks, especially in areas frequented by children and pedestrians.

6. Future Scope

The proposed GPS-based geofencing system offers a strong foundation for further development into a fully automated and intelligent speed control solution suitable for real-world vehicle applications. One of the most significant future enhancements involves integrating the system directly with a vehicle's electronic control unit (ECU) or an approved speed-governing mechanism, enabling precise and fully automated speed limitation without relying solely on alerts or external motor drivers. Conducting large-scale on-road testing across various school zones and traffic conditions will be crucial for validating performance under real-world influences such as urban canyons, fluctuating satellite signals, dense traffic, and varying weather conditions. These field studies will help refine geofence radii, response thresholds, and hysteresis margins to ensure consistent operation in diverse environments.

Future improvements may also include incorporating wireless communication capabilities using Wi-Fi, LoRa, or cellular IoT modules. Such connectivity would enable remote configuration of school-zone coordinates, cloud-based storage of vehicle logs, and centralized monitoring by authorities or fleet operators. A companion web or mobile application could further enhance usability by enabling dynamic updates of restricted zones, visualization of vehicle movements, and generation of safety or compliance reports without physical access to the device. To improve detection accuracy, especially in dense urban areas, the system can be expanded to utilize more advanced positioning technologies such as Differential GPS, inertial measurement units, or map-matching algorithms that improve the reliability of location data in signal-challenged regions.

Additionally, integrating machine learning models can support predictive safety features, such as identifying patterns of risky driver behavior or adjusting speed limits dynamically based on traffic density, time of day, or environmental conditions. These intelligent enhancements would transform the system from a localized safety tool into a comprehensive smart transportation component. As smart city initiatives increasingly emphasize data-driven management of mobility and safety, the proposed geofencing-based speed regulation system has strong potential to evolve into a standardized solution for improving safety not only around schools but in hospitals, residential communities, construction zones, and other sensitive locations.

10. References

[1]. J. Baidya, S. Roy, and K. Gupta. (2024) “Smart GPS Based Vehicle Speed Limit Controller on Zone Identification Using Geo-Fencing Algorithm,” in Proceedings of 2024 IEEE International Conference on Intelligent Transportation.

[2]. M. Rahman, S. Khan, and P. Saha. (2019) “Real Time Tracking System Using GPS and Geo-fencing with Error Reduction Filters,” IEEE Sensors Journal, vol. 19, no. 7, pp. 2345–2358.

[3]. K. P. Singh, A. K. Verma, and R. Kumar. (2021) “Intelligent Transportation Systems: Overview and Future Perspectives,” IEEE Access, vol. 9, pp. 15827–15846.

[4]. H. Wang, Z. Liu, and J. Chen. (2019) “Advances in GPS-Based Vehicle Tracking Systems,” IEEE Transactions on Vehicular Technology, vol. 68, no. 4, pp. 3421–3435.

[5]. L. Chen, S. Park, and M. Davis. (2020) “Behavioural Impact of Automated Enforcement Systems,” Transportation Research Record, vol. 2674, no. 7, pp. 294–305.

[6]. E. Norbert, B. Johannes, and M. Keller. (2020) “GPS Accuracy Improvements in Urban Environments,” IEEE Access, vol. 8, pp. 56789–56812.

[7]. J. Lee, K. Park, and S. Kang. (2021) “IoT Integration in Vehicular Control Systems,” IEEE Internet of Things Journal, vol. 8, no. 6, pp. 4532–4549.

[8]. A. Garcia and C. Lopez. (2022) “Geofencing Technology in Vehicular Networks: A Comprehensive Review,” Journal of Intelligent Transportation Systems, vol. 23, no. 2, pp. 112–135.

[9]. P. Kumar, M. Singh, and R. Sharma. (2019) “Cost-Effective Vehicle Tracking Using Consumer-Grade GPS Modules,” IEEE Transactions on Consumer Electronics, vol. 65, no. 2, pp. 201–210.

[10]. T. Green, M. Brown, and J. Smith. (2020) “Environmental Impact of Optimized Vehicle Speed Control,” Journal of Environmental Engineering, vol. 146, no. 8, pp. 04020066-1–04020066-12.