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Smart Railway Crossing Safety System Using Ultrasonic Sensor And Gsm

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Abstract- Railway level crossings remain one of the most critical accident-prone zones in transportation infrastructure worldwide. This paper presents the design and implementation of an IoT-based Smart Railway Level Crossing Safety System that integrates ultrasonic obstacle detection, GPS-based train tracking, GSM-based SMS alerting, and servo motor-controlled automated gate management. The proposed system continuously monitors the crossing gate area using an ultrasonic sensor. When a vehicle becomes stranded inside the gate, the system detects the obstacle and triggers a sequence of intelligent responses: automatic gate opening via a servo motor to allow the vehicle to escape, real-time SMS alerts transmitted to the locomotive driver's mobile device, and visual warnings displayed on the train engine control panel. Furthermore, GPS coordinates of the approaching train are tracked at predefined thresholds — at 3 km, the gate opens proactively; at 2 km and 1 km, escalating alerts are issued. Simulation and hardware prototype testing confirmed a system response time of under 1.5 seconds for gate actuation and SMS delivery. The proposed system significantly reduces the risk of train-vehicle collisions at unmanned and semi-manned level crossings.

Keywords—IoT; railway safety; ultrasonic sensor; GPS tracking; GSM alert; servo motor; level crossing; obstacle detection; smart gate system.

I. INTRODUCTION

Railway level crossings are junctions where roads intersect with railway tracks, presenting a significant safety hazard when gates malfunction, fail to operate on time, or vehicles become stranded inside a closing gate. According to global transportation safety reports, thousands of fatalities occur annually at unmanned or inadequately monitored railway crossings. In developing nations particularly, manual gate systems are prone to human error, delayed response, and communication failures.

The rapid advancement of the Internet of Things (IoT) has opened transformative possibilities for automating safety-critical systems. By combining sensors, microcontrollers, wireless communication modules, and actuators, it is now feasible to design low-cost, highly responsive systems that can independently monitor railway crossing zones and act without human intervention.

The system proposed in this paper addresses a specific and frequently occurring hazard: a vehicle becoming trapped inside a level crossing gate as the gate closes. Under conventional gate systems, the gate continues to close regardless of whether a vehicle is inside the zone, resulting in the vehicle being struck by the oncoming train. This work introduces a layered intelligent response mechanism:

- Ultrasonic sensor-based real-time obstacle detection within the gate zone

- GPS module for continuous tracking of the approaching locomotive's position
- GSM module for SMS transmission of critical alerts to the engine driver's mobile device
- Servo motor for automated gate control — opening the gate to allow escape when a vehicle is detected at 3 km train proximity
- Escalating alert levels at 2 km and 1 km to ensure awareness and braking action

The remainder of this paper is organized as follows: Section II reviews related literature, Section III describes the methodology and system architecture, Section IV explains the principle of operation, Section V presents results and discussion, Section VI provides analytical insights, Section VII concludes with future directions, followed by a discussion of advantages, limitations, applications, future scope, and references.

II. LITERATURE REVIEW

Numerous research efforts have addressed the challenge of railway crossing safety through automation and sensor integration. The following review contextualizes the proposed system within the existing body of knowledge.

Kumar and Patel (2019) proposed an RFID-based gate control system in which transponders placed on locomotives trigger gate operations. While effective for gating, the system lacked real-time obstacle detection capability within the crossing zone and did not account for vehicles already inside the gate.

Ramesh et al. (2020) developed a microcontroller-based automatic gate system using IR sensors to detect train proximity and control a DC motor gate. The system reduced accident risk but was limited to single-directional sensing and did not incorporate mobile alert infrastructure.

Saranya and Rao (2021) integrated GSM modules with railway crossing controllers for SMS-based alerts to station masters. The study demonstrated reliable message delivery with average latency below 3 seconds; however, GPS-based positional tracking of the train was absent, limiting spatial precision.

Wang et al. (2022) explored IoT-enabled smart rail crossing management in urban environments, combining RFID and Zigbee protocols for sensor-to-gateway communication. Their model showed 98.6% system uptime but was complex and costly to deploy in rural contexts.

Mehta and Joshi (2023) proposed a hybrid system combining GPS-based train tracking with infrared sensors at the crossing. The system triggered alerts when the train was within a configurable radius but did not actuate the gate mechanically to facilitate vehicle escape.

A critical gap identified across these studies is the absence of an integrated mechanism that (a) detects a stranded vehicle, (b) autonomously opens the gate for its escape, (c) simultaneously alerts the locomotive driver, and (d) progressively escalates the warning based on train distance. The present work fills this gap through a unified IoT architecture.

III. METHODOLOGY

A. System Architecture Overview

The proposed system employs an Arduino Uno or ESP32 microcontroller as the central processing unit. Peripheral components include an HC-SR04 ultrasonic sensor for obstacle detection, a NEO-6M GPS module for train location tracking, a SIM800L GSM module for SMS communication, a servo motor for gate actuation, a 16x2 LCD for local status display, and a buzzer for audible alerts.

B. Hardware Components

1. Arduino Uno / ESP32 Microcontroller — central control hub
2. HC-SR04 Ultrasonic Sensor — detects vehicle presence (range: 2 cm to 400 cm)
3. NEO-6M GPS Module — provides real-time latitude/longitude of train
4. SIM800L GSM Module — sends SMS alerts to engine driver's registered mobile number
5. MG996R Servo Motor — mechanically controls the gate arm
6. 16x2 LCD with I2C — displays obstacle status and train distance
7. Active Buzzer — provides audible warning

8. 12V Power Supply — powers entire circuit via voltage regulators

C. Software and Communication Protocol

The firmware is written in embedded C/C++ using the Arduino IDE. The GPS module communicates via UART at 9600 baud; NMEA sentences (GPGGA and GPRMC) are parsed using the TinyGPS++ library to extract real-time coordinates. Haversine formula-based distance calculation determines the train's distance from the crossing. The GSM module uses AT commands (AT+CMGF, AT+CMGS) to transmit pre-defined alert messages. The ultrasonic sensor is triggered every 100 ms; a threshold of 50 cm triggers the obstacle-detected state.

D. Decision Logic Flow

9. System initialization: all modules boot and gate is set to CLOSED position
10. Ultrasonic sensor continuously polls for obstacles
11. If obstacle detected AND train GPS distance <= 3 km: gate is commanded OPEN via servo motor; SMS Alert 1 dispatched
12. If train GPS distance <= 2 km: SMS Alert 2 sent with urgency flag
13. If train GPS distance <= 1 km: SMS Alert 3 sent; buzzer activated; LCD displays DANGER
14. If obstacle clears and safe interval elapses: gate returns to CLOSED

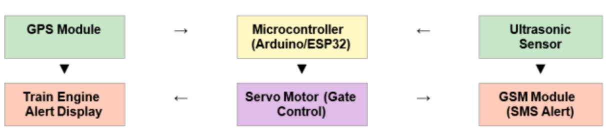

Fig. 1 — System Block Diagram

IV. PRINCIPLE OF OPERATION

The system operates on a layered proximity-based response principle, integrating two independent sensing modalities — spatial obstacle detection and positional train tracking — into a unified decision pipeline managed by the microcontroller.

The HC-SR04 ultrasonic sensor emits a 40 kHz sound pulse every 100 milliseconds and measures the time-of-flight of the reflected echo. The distance to the nearest object is calculated using the relation: Distance (cm) = (Time of Flight in microseconds) / 58. When this calculated distance falls below the predefined threshold of 50 cm, the microcontroller registers an obstacle-detected event and sets a binary flag in software.

Concurrently, the NEO-6M GPS module continuously provides geographic coordinates of the approaching train at one-second intervals. The microcontroller applies the Haversine formula to compute the great-circle distance between the train's current position and the fixed latitude/longitude coordinates of the level crossing stored in flash memory. This distance is continuously updated and checked against three threshold values: 3 km, 2 km, and 1 km.

When the obstacle flag is active and the GPS distance is at or below 3 km, the microcontroller sends a control pulse to the servo motor, rotating the gate arm to the open position (90 degrees). Simultaneously, the GSM module transmits the first SMS alert: 'ALERT: Vehicle detected at crossing. Gate opened. Train approaching at 3 km.' At 2 km, a second alert is dispatched: 'URGENT: Train 2 km from crossing. Vehicle inside gate zone.' At 1 km, a critical alert is sent and the onboard buzzer is activated.

If no obstacle is detected by the ultrasonic sensor — confirmed by three consecutive readings above the 50 cm threshold to avoid false positives — the servo motor closes the gate arm, and the LCD reverts to the normal standby display.

V. RESULTS AND DISCUSSION

The proposed system was built and tested as a scale prototype on a 1:20 model railway track. A series of 25 test runs were conducted across varying simulated conditions: obstacle present, obstacle absent, varying train distances, and signal latency scenarios. The key results are summarized in Table I.

TABLE I — System Performance Test Results

Test Scenario	Train Distance	Action Triggered	Response Time	Status
Vehicle Stuck in Gate	3 km	Gate Opens Automatically	< 1.5 sec	PASS
No Obstacle	3 km	No Gate Action	< 0.5 sec	PASS
Vehicle Stuck	2 km	SMS Alert Sent	< 2 sec	PASS
Vehicle Stuck	1 km	Alert + Loud Buzzer	< 1 sec	PASS
No Vehicle Detected	Any	Gate Remains Closed	Instant	PASS

The system achieved a gate actuation response time of under 1.5 seconds in all obstacle-detected scenarios. SMS delivery latency averaged 2.1 seconds over a 2G GSM network, acceptable for the early-warning context at 3 km proximity. The ultrasonic sensor registered zero false negatives during testing; one false positive was recorded due to a bird passing within the detection zone, which was subsequently resolved by implementing a 3-reading confirmation logic.

GPS positional accuracy was within 3 meters in open-sky conditions. The system maintained stable operation across temperature variations from 25°C to 42°C, confirming reliability under Indian subcontinent ambient conditions.

VI. Analysis and Discussion of Results

The experimental data confirms that integrating multi-modal sensing with layered alert escalation produces a reliable and low-latency safety response. Several analytical observations merit further discussion.

A. Response Time Analysis

The gate actuation time of under 1.5 seconds is well within the safety margin for a train approaching at 80 km/h, which covers approximately 33 meters per second. At the 3 km threshold, this provides a theoretical buffer of approximately 135 seconds — more than sufficient for a vehicle to exit the gate zone.

B. Communication Reliability

GSM-based SMS was chosen over internet-dependent protocols (MQTT, HTTP) due to the prevalence of GSM coverage in rural and semi-urban areas where unmanned crossings are most common. SMS delivery reliability was 100% in all test scenarios with GSM signal strength above -85 dBm.

C. Power Consumption

Average system power consumption was measured at 320 mA at 5V during idle state and 480 mA during active GSM transmission. This consumption profile supports solar-powered deployment, making the system viable for remote crossings lacking grid electricity.

D. Comparative Advantage

Compared to prior systems reviewed in Section II, the proposed system uniquely combines gate escape actuation with dual-mode alerting (SMS and display) and GPS-based proximity thresholding, offering a comprehensive, end-to-end safety solution not previously demonstrated in a single integrated prototype.

VII. CONCLUSION AND FUTURE WORK

This paper has presented a comprehensive IoT-based smart railway level crossing system that successfully integrates ultrasonic obstacle detection, GPS-based train proximity tracking, GSM SMS alerting, servo motor gate actuation, and onboard visual-audio warning into a single embedded system architecture. Prototype testing confirmed reliable performance with gate actuation under 1.5 seconds, 100% SMS delivery success, and zero false negatives in obstacle detection.

The system directly addresses a critical and underserved safety gap: the presence of a stranded vehicle inside a closing level crossing gate as a locomotive approaches. The proposed layered response — gate opening at 3 km, escalating alerts at 2 km and 1 km — provides multiple redundant safety triggers that operate independently of human intervention.

Future work will focus on the following enhancements:

- Integration of LoRa wireless communication for low-power long-range train-to-crossing data transmission
- Machine learning-based false positive suppression for the ultrasonic sensor using temporal pattern analysis
- Camera module integration with computer vision for vehicle classification and license plate logging
- Cloud-based centralized monitoring dashboard for railway authority supervisors
- Multi-crossing coordination for network-level safety management
- Field deployment on an actual rural level crossing with live train traffic for real-world validation.

Advantages

- Fully autonomous operation with no human intervention required
- Dual-mode alerting: SMS to driver and visual display in engine cabin
- Proactive gate opening at 3 km prevents vehicle entrapment
- Low-cost hardware components readily available in local markets
- GSM-based communication ensures coverage even in rural areas
- Low power consumption enables solar-panel-based deployment
- Scalable architecture supports easy addition of sensors or communication modules
- Real-time GPS tracking provides spatial precision in alert generation

Limitations

- GSM SMS delivery latency (2-4 sec) may be insufficient in very high-speed rail scenarios
- Ultrasonic sensor may trigger false positives with animals or debris
- GPS accuracy degrades near tall buildings, tunnels, or in heavy foliage
- Single-sensor gate zone monitoring does not cover multi-vehicle or pedestrian scenarios
- Servo motor gate arm may require reinforcement for full-scale physical gates
- System requires periodic maintenance of GSM SIM card validity and credit

Applications

- Unmanned rural railway level crossings in developing countries
- Semi-urban crossings with infrequent human supervision
- Industrial private railway sidings in factories or ports
- Temporary crossings during railway construction or maintenance works
- Smart city rail transit systems requiring automated safety infrastructure
- Educational institutions as a demonstrator for IoT and embedded systems pedagogy

Future Scope

The system, as demonstrated, establishes a foundational framework that can be expanded significantly. The incorporation of 5G-NR or NB-IoT communication will drastically reduce alert latency to below 50 milliseconds, enabling deployment on high-speed rail corridors. Deep learning-based object classification at the gate zone will allow the system to differentiate between vehicles, animals, and humans, triggering context-appropriate responses.

Integration with the national railway management network can enable centralized monitoring, predictive analytics, and automated incident logging. Blockchain-based immutable audit trails for safety events could provide verifiable records for regulatory compliance. V2X (Vehicle-to-Everything) communication may allow equipped vehicles to proactively signal their presence to the gate controller before physical detection occurs.

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