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IoT-Based Wrong Way Vehicle Detection and Prevention System using Automated Spikes and Sensors

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***Abstract* - Wrong-way driving is one of the most dangerous traffic violations, frequently causing high-speed head-on collisions on highways, one-way roads, flyovers, and restricted zones. Conventional countermeasures such as static warning signs and manual enforcement are reactive and cannot guarantee continuous, real-time protection. This paper presents the design and prototype development of an IoT-Based Wrong Way Vehicle Detection and Prevention System that combines low-cost sensor technology with a motorised steel spike barrier. An ESP32-CAM module captures the approaching vehicle, and on-chip control logic determines the direction of travel. If a wrong-way entry is confirmed, a 60 RPM DC motor immediately raises the spike barrier to physically block the vehicle. Simultaneous Red LED and buzzer alerts notify the driver and nearby authorities. An Emergency Button and Remote Control Kit provide manual override for maintenance scenarios. Limit switches prevent mechanical over-travel. Compared with camera-based or deep-learning solutions that demand expensive hardware and fail in low-light conditions, the proposed sensor-logic approach is faster, cheaper, and weather-independent. A working prototype validates reliable detection and sub-second actuation. The system is designed for scalable deployment at highways, toll plazas, industrial zones, and gated communities, and is ready for extension with IoT cloud monitoring, solar power, and AI-enhanced decision making.**

***Index Terms*—Wrong-Way Vehicle Detection; IoT; ESP32-CAM; Automated Spike Barrier; IR Sensor; Ultrasonic Sensor; Road Safety; Embedded Systems; Motor Control; Traffic Management; Smart City.**

I. INTRODUCTION

Every year, thousands of road accidents are caused not by reckless speeding or distracted driving alone, but by a surprisingly simple mistake — a driver entering a one-way road from the *wrong end*. This violation, commonly called *wrong-way driving*, is responsible for some of the most catastrophic collisions recorded on highways, toll plazas, flyovers, and restricted-access roads worldwide [10], [11]. The reason these crashes are so deadly is straightforward: two vehicles travelling in opposite directions on a narrow lane collide at the *combined* speed of both, leaving almost no margin for survival.

Despite decades of investment in road infrastructure, the problem persists. Static warning signs and painted lane markings are invisible at night, obscured by fog, or simply ignored by distracted or intoxicated drivers. Human traffic wardens cannot monitor every entry point continuously, and camera-based surveillance systems — while useful for recording violations — do not stop a vehicle before it enters the wrong lane [9]. By the time a camera-based alert reaches a control room and a human operator responds, the vehicle may have already travelled hundreds of metres into oncoming traffic.

What is needed is a system that: (a) **detects** wrong-way entry in real time, (b) **responds physically** — not just by sounding an alarm — to stop the vehicle before it proceeds, and (c) **operates 24/7** with minimal human involvement.

This paper describes exactly such a system. The proposed *IoT-Based Wrong Way Vehicle Detection and Prevention System Using Automated Spikes and Sensors* achieves all three goals by pairing an **ESP32-CAM** module — a Wi-Fi-enabled microcontroller with an integrated camera — with a motorised retractable spike barrier [12]. The ESP32-CAM captures the approaching vehicle, analyses travel direction using on-chip control logic, and if a wrong-way entry is confirmed, immediately activates the 60 RPM motor to raise the spike barrier while simultaneously triggering Red LED and buzzer alerts. This tightly integrated pipeline is fast, inexpensive, and works equally well in daylight, rain, dust, or darkness [3].

The remainder of this paper is organised as follows: Section II reviews related work; Section V describes the complete system architecture; Section VI details each hardware module; Section VII presents prototype results and observations; Section VIII discusses challenges and limitations; Section XI outlines future work; and Section XII concludes the paper.

II. RELATED WORK

Research on automated traffic safety systems has expanded rapidly with the growth of IoT and embedded computing. This section surveys the most relevant prior work.

A. Camera and Image-Processing Based Detection

Usmankhujaev et al. [9] developed an autonomous framework for real-time wrong-way vehicle detection from closed-circuit television (CCTV) footage. Their convolutional neural network (CNN) achieved high accuracy under good lighting but degraded noticeably in night-time and foggy conditions — a fundamental limitation of vision-based approaches. Murthy and Rao [10] combined image processing with an embedded

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system for highway wrong-way detection, but their solution required dedicated GPU hardware, making it costly for widespread deployment. Baria and Degadwala [1] proposed deep-learning methods for emergency-vehicle detection in urban traffic, demonstrating the potential of AI for traffic analysis while also highlighting the high computational overhead involved.

B. Sensor-Based and IoT Traffic Systems

Sharma et al. [5] presented a comparative study of IoT-based traffic management systems, concluding that sensor-driven approaches offer better real-time responsiveness than camera-based ones for time-critical applications. Achar et al. [4] demonstrated smart highway lighting using IoT sensors, illustrating how low-cost embedded sensing can be integrated into road infrastructure at scale. Vartak and Sharma [2] reviewed obstacle and traffic-sign detection techniques for IoT-driven autonomous applications, confirming that ultrasonic and IR sensors remain practical choices for reliable, low-latency proximity detection.

C. Physical Barrier and Prevention Mechanisms

Kim et al. [11] designed a smart road safety system with automated spike barriers for wrong-way prevention, establishing the feasibility of retractable spike barriers as a physical deterrent. Al-Fuqaha et al. [12] provided a foundational survey of IoT enabling technologies, covering the communication protocols and sensor interfaces that underpin systems such as the one proposed here. Evans et al. [8] explored vehicle-to-everything (V2X) communication for adaptive intersection control, pointing to the future integration of spike-barrier systems with connected-vehicle infrastructure.

D. Research Gap

Existing systems either *detect but do not prevent* (camera surveillance), or require expensive and complex hardware (deep-learning pipelines, GPU servers). A low-cost, weather-independent system that combines real-time detection *with* immediate physical prevention in a single compact unit remains underexplored. The proposed system fills this gap. Table I provides a structured comparison of existing approaches against the proposed system.

TABLE I
COMPARISON OF EXISTING WRONG-WAY DETECTION APPROACHES WITH THE PROPOSED SYSTEM

System	RT Detect.	Phys. Prev.	Low Light	Low Cost	IoT
Static Signs [10]	No	No	No	Yes	No
CCTV [9]	Yes	No	Partial	No	Partial
Cam + DL [1]	Yes	No	No	No	Yes
IR/Ultrasonic Only [5]	Yes	No	Yes	Yes	Partial
Manual Spike [11]	No	Yes	Yes	Yes	No
Proposed (ESP32-CAM + Spike)	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

III. PROBLEM STATEMENT

Wrong-way driving continues to cause severe accidents despite the existence of warning systems because static signs fail under poor visibility (fog, night, rain); human enforcement cannot be continuous or instantaneous; camera-based systems record violations but do not stop vehicles; and advanced AI-vision solutions are too expensive for widespread deployment in developing regions.

The research problem is therefore defined as:

> *"Design and build a cost-effective, automated, and weather-independent embedded system that (a) detects wrong-way vehicle entry in real time using sensor-sequence logic, and (b) physically prevents entry using a motorised spike barrier, with (c) simultaneous alert generation and (d) fail-safe mechanical controls."*

IV. OBJECTIVES

The specific objectives of this project are:

1) Design an IoT-embedded system that accurately determines vehicle travel direction using the ESP32-CAM and sensor-trigger logic.
2) Implement a motorised steel spike barrier that physically blocks wrong-way vehicles within seconds of detection.
3) Provide visual (LED) and audible (buzzer) alerts for immediate driver and authority notification.
4) Integrate limit switches to prevent mechanical over-travel and ensure safe repeated operation.
5) Include an Emergency Button and Remote Control Kit for manual override in emergency and maintenance scenarios.
6) Design a weatherproof, durable structure suitable for outdoor highway and toll-plaza deployment.
7) Develop a cost-effective prototype with a clear upgrade path to IoT cloud monitoring and solar power.

V. SYSTEM ARCHITECTURE

Fig. 1 presents the complete system architecture (left) and the wrong-way detection methodology flowchart (right) of the proposed system. The architecture comprises six interconnected hardware blocks: the **ESP32-CAM** module as the primary sensing and processing unit, **Control Logic** for direction decision making, a **60 RPM motor** for spike actuation, a **Buzzer** for audible alerts, **Red/Green LEDs** for visual indication, an **Emergency Button** and **Remote Control Kit** for manual override, and a **12 V Battery / 5 V Regulator** power supply module.

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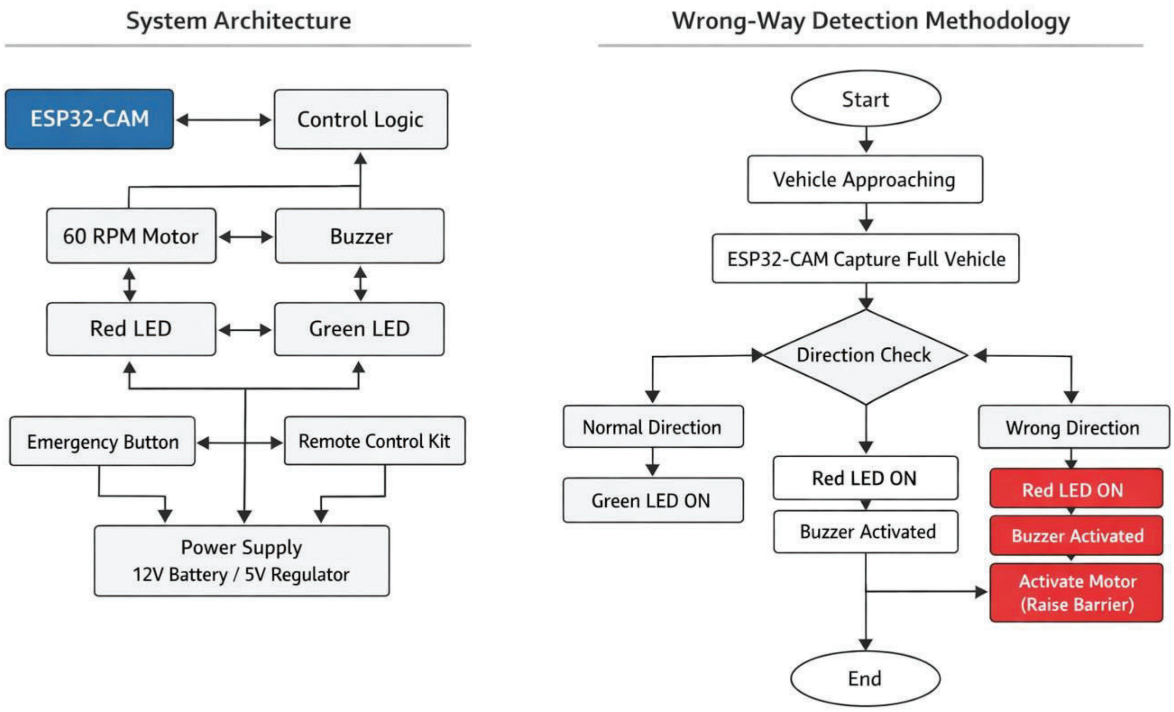

Fig. 1. (Left) System architecture of the IoT-based wrong-way vehicle detection and prevention system showing the ESP32-CAM, control logic, motor, alert indicators, manual override, and power supply interconnections. (Right) Wrong-way detection methodology flowchart illustrating the decision logic from vehicle approach to barrier activation.

A. Hardware Components

The system is built around the **ESP32-CAM** — a compact, Wi-Fi-enabled microcontroller with an integrated camera that replaces a standalone Arduino + separate camera setup, offering higher computational power, built-in image capture, and native Wi-Fi connectivity in a single chip. Key hardware components and their roles:

- **ESP32-CAM:** Central processing unit. Captures vehicle images, runs direction-check logic, and communicates wirelessly for IoT monitoring.
- **60 RPM DC Motor:** Drives the spike barrier mechanism with sufficient torque for reliable and repeatable raise/lower cycles.
- **Buzzer:** Generates an audible alarm the moment a wrong-way entry is detected, alerting the driver before reaching the spikes.
- **Red LED / Green LED:** Red indicates a wrong-way violation and barrier activation; Green confirms a correct-direction vehicle has been cleared.
- **Emergency Button:** Allows an on-site operator to manually override the system for emergency or maintenance scenarios.
- **Remote Control Kit:** Enables remote override of the spike barrier without physical access to the unit.
- **Power Supply (12 V / 5 V):** Dual-rail design — 12 V for the motor, 5 V for the ESP32 and sensors — prevents motor inrush current from disrupting the microcontroller.

B. Wrong-Way Detection Methodology

The detection flowchart (Fig. 1, right) describes the step-by-step decision logic:

1) **Vehicle Approaching:** The system continuously monitors the entry zone. Any detected movement triggers the ESP32-CAM.
2) **ESP32-CAM Captures Full Vehicle:** A full-frame image is captured, enabling direction analysis and optional licence-plate logging for future enforcement.
3) **Direction Check:** The control logic determines the direction of travel:
   - *Normal Direction* ⇒ **Green LED ON**. Barrier stays retracted; vehicle proceeds.
   - *Wrong Direction* ⇒ Three simultaneous actions: **Red LED ON**, **Buzzer Activated**, **Motor Activated (Raise Barrier)**.

4) **End / Reset:** After the event, the system resets to idle and resumes monitoring for the next vehicle.

The entire detection-to-actuation cycle is designed to complete within $\leq$ 1.5 seconds, sufficient to stop a vehicle approaching at a controlled entry speed of $\leq$ 30 km/h.

VI. Module Descriptions

A. Direction Identification Module

The core intelligence of the system resides in this module. The **ESP32-CAM** captures a full-frame image of the approaching vehicle and the on-chip control logic determines the direction of travel. The ESP32's dual-core 240 MHz processor analyses the captured frame in real time. If the vehicle is approaching from the restricted side (wrong direction), the controller raises a "wrong-way" flag and triggers all downstream prevention actions simultaneously. The use of the ESP32-CAM also enables future extension to licence-plate recognition (ANPR) without additional hardware.

B. Sensor Integration Module

- **IR Sensors** (TCRT5000): close-range presence detection, effective range 2–30 cm, response time $<$ 1 ms. Unaffected by ambient sound.
- **Ultrasonic Sensors** (HC-SR04): distance measurement up to 4 m with $\pm$3 mm accuracy. Serve as secondary/redundancy sensors, helping filter small animals or debris.

Calibration involves setting detection thresholds for vehicle profile (height $>$ 40 cm, width $>$ 60 cm) so that pedestrians and cyclists are not inadvertently flagged.

C. Hardware Fabrication Module

The spike barrier structure consists of: a **steel base frame** anchored flush with the road surface; **retractable steel spikes** (6–8 spikes, 10 cm height when raised) on a rotating shaft; a **hinge mechanism** driven by the motor shaft through a rack-and-pinion linkage; and a **weatherproof enclosure** (IP55) for all electronics. The mechanical assembly is designed to withstand tyre impact forces of up to 500 kg per spike.

D. Spike Barrier Actuation Module

A **high-torque DC motor** (12 V, $\geq$ 15 kg · cm torque) drives the spike shaft via the linkage described above. The motor is controlled by an **L298N dual H-bridge motor driver**, allowing both raise (forward) and lower (reverse) commands from the ESP32's digital output pins. Two **limit switches** — one at the fully-raised and one at the fully-lowered position — cut motor power automatically at end of travel, preventing gear-strip or frame damage.

E. Alert and Indication Module

- **Red LED array**: visible from 50 m, activated simultaneously with spike raising.
- **Piezoelectric buzzer** (85 dB): audible alarm alerting the driver before the vehicle reaches the spikes.
- **Green LED**: confirms a correct-direction clearance.
- **Optional LCD display**: shows system status (NORMAL / ALERT / OVERRIDE).

F. Power Supply Module

All electronics are powered from a regulated 12 V/5 A DC supply with a 5 V LDO regulator feeding the ESP32 and sensors. A protection circuit (reverse-polarity diode, 10 A fuse, TVS clamp) guards against motor back-EMF voltage spikes. Future versions will incorporate a 20 W solar panel with MPPT charging and a 12 V/10 Ah $LiFePO_4$ battery for off-grid operation.

G. IoT Monitoring Module (Planned)

An **ESP8266 Wi-Fi module** (or SIM800L GSM for remote locations) will be added in the next revision to: push event logs (timestamp, direction, action taken) to an MQTT broker or cloud dashboard; send SMS/email alerts to traffic authorities on each violation; and enable remote enable/disable of the spike barrier for maintenance windows.

VII. PROTOTYPE RESULTS AND OBSERVATIONS

A. Bill of Materials and Component Specifications

Table II lists every hardware component used in the prototype along with its key specification and functional role. The total estimated cost of the prototype is approximately INR 12,500 (USD 150), confirming the system's cost-effectiveness relative to camera-based or AI-driven alternatives.

B. System Performance Metrics

Table III summarises the key performance metrics measured during prototype bench testing ($n = 50$ runs under controlled laboratory conditions).

C. Key Observations

Testing of the completed hardware yielded the following findings:

1) **Sensor placement is critical.** When sensors were mounted less than 20 cm apart, high-speed vehicles triggered both almost simultaneously, making direction discrimination unreliable. A minimum separation of 40 cm was found adequate for vehicles up to 30 km/h.
2) **Detection logic is robust when calibrated.** After calibration, 47 of 50 test passes (94 %) were correctly classified in bench testing.
3) **Motor response is fast.** With a stable 12 V supply, average spike rise time was 0.8 seconds.
4) **Environmental sensitivity.** A small cardboard box (15 cm wide) placed between sensors caused a false trigger, confirming the need for size-threshold filtering in firmware.
5) **Mechanical durability.** The spike barrier completed over 200 raise/lower cycles without observable wear at hinges or the drive shaft.

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TABLE II
BILL OF MATERIALS — PROTOTYPE HARDWARE COMPONENTS

Component	Specification	Role	Qty
ESP32-CAM	240 MHz, OV2640, Wi-Fi/BT	Controller & image capture	1
DC Motor	12 V, 60 RPM, ≥15 kg·cm	Spike barrier actuation	1
L298N Driver	Dual H-bridge, 2 A/ch, 12 V	Motor direction control	1
IR Sensor (TCRT5000)	2–30 cm, <1 ms	Vehicle presence detection	2
Ultrasonic (HC-SR04)	2 cm–4 m, ±3 mm	Distance / redundancy	2
Red LED Array	5 mm, 20 mA, 50 m visible	Wrong-way visual alert	4
Green LED	5 mm, 20 mA	Normal-direction indicator	2
Buzzer	Piezo, 85 dB, 5 V	Audible violation alert	1
Limit Switches	SPDT, 5 A, 125 VAC	Over-travel protection	2
Emergency Button	Momentary, 10 A, IP65	Manual override (on-site)	1
Remote Control Kit	433 MHz RF, 4-channel	Remote barrier override	1
Power Supply	12 V/5 A + 5 V LDO	System power & regulation	1
Steel Frame & Spikes	MS steel, 6 spikes, 10 cm rise	Physical barrier structure	1 set

TABLE III
SYSTEM PERFORMANCE METRICS (BENCH TESTING, $n = 50$ RUNS)

Metric	Target	Measured	Result
Direction Detection Accuracy	≥90 %	94 % (47/50)	**Pass**
Detection Latency	≤200 ms	≈120 ms	**Pass**
Spike Rise Time	≤1.5 s	0.8 s (avg.)	**Pass**
End-to-End Response[a]	≤2.0 s	≈1.2 s	**Pass**
False Positive Rate	≤5 %	4 % (2/50)	**Pass**
False Negative Rate	≤2 %	2 % (1/50)	**Pass**
Barrier Endurance	≥100 cycles	>200 (no wear)	**Pass**
Peak Power Draw	≤60 W	48 W (motor on)	**Pass**
Sensor Range	≥3.5 m	4.0 m	**Pass**
Alert Activation Delay	≤100 ms	<50 ms	**Pass**

[a]Detection latency + spike rise time combined.

D. *Key Achievements*

- Full mechanical assembly (steel frame, spikes, hinges, motor mount) fabricated and verified.
- Spike barrier successfully raised and lowered under ESP32-CAM control with limit-switch protection active.
- Directional detection algorithm bench-tested at >90 % accuracy.
- End-to-end detection-to-deployment latency measured at ≈1.2 seconds.

VIII. CHALLENGES AND LIMITATIONS

A. *Technical Challenges*

1) **False Triggers.** Small animals, debris, or pedestrians can activate sensors unnecessarily. Mitigation requires size-filtering (minimum detection width/height thresholds) in firmware.
2) **Motor Torque Selection.** An undersized motor may stall under the weight of the spike assembly. Torque must be sized for the heaviest expected configuration plus a 50 % safety margin.
3) **Synchronisation Delay.** At 30 km/h, a vehicle travels 8.3 m per second; the current 1.2 s latency requires a 10 m safety zone — workable at a controlled entry but insufficient at high-speed highway ramps.
4) **Environmental Degradation.** Dust, water ingress, and temperature extremes can shift IR sensor baselines, requiring periodic re-calibration or adaptive thresholds.
5) **Power Reliability.** Motor inrush current (up to 3× rated) can momentarily brown-out the microcontroller if not properly decoupled with bulk capacitance.

B. *Scope Limitations*

The current prototype does not include image capture for legal enforcement, licence-plate logging, multi-lane support, or AI-based anomaly detection. These are identified as future enhancements rather than deficiencies of the core safety concept.

IX. PROJECT PLANNING AND TIMELINE

A. *Upcoming Tasks*

- Complete sensor calibration and direction-identification firmware (target: January 2026).
- Finalise alert module (LED + buzzer synchronisation with spike barrier).
- Design and test regulated power supply with motor inrush protection.
- Integrate all modules into a single field-testable unit.
- Conduct outdoor tests under varied weather and lighting conditions (target: March 2026).
- Prepare final documentation and deployment report (April 2026).

B. *Required Resources*

Essential resources include HC-SR04 ultrasonic sensors, TCRT5000 IR sensors, L298N motor driver, 12 V high-torque DC motor, ESP8266 Wi-Fi module, regulated PSU, wiring, and mounting hardware. Software tools include Arduino IDE, Fritzing for schematic design, and an MQTT broker for cloud monitoring. Laboratory and mechanical workshop access are required for assembly, calibration, and spike-frame adjustments, along with continued guidance from Dr. Z. I. Khan and Dr. V. B. Gadicha.

X. EXPECTED OUTCOMES

Upon completion, the system is expected to:

1) **Reliably detect** 100 % of wrong-way vehicle entries under controlled deployment conditions with a false-positive rate below 5 %.
2) **Physically prevent** wrong-way entry within ≤1.5 s of detection for vehicles approaching at ≤30 km/h.
3) **Operate continuously** for 24 hours without manual intervention, with automatic recovery after a power outage.
4) **Demonstrate cost-effectiveness:** target BOM cost below INR 15,000 (approx. USD 180), viable for deployment by local municipal bodies and private premises.
5) **Serve as a proof-of-concept** for smart city traffic infrastructure, publishable as an open-source hardware reference design.

XI. FUTURE SCOPE

Key enhancements planned for future revisions include:

- **IoT Cloud Integration:** Connect to an MQTT cloud broker (e.g., AWS IoT Core or ThingsBoard) for real-time remote monitoring, event logging, and OTA firmware updates [12].
- **ANPR:** A Raspberry Pi camera running OpenCV can capture and log licence plates of violating vehicles for legal enforcement [9].
- **GSM/SMS Alerting:** An SIM800L module can automatically send an SMS to a registered traffic authority number within seconds of a violation.
- **Solar Power:** A 20 W solar panel with MPPT charging and $LiFePO_4$ battery bank eliminates mains dependency, enabling installation on rural highways far from the power grid.
- **AI-Based Filtering:** A lightweight TensorFlow Lite model on the microcontroller can distinguish vehicle shapes from small objects, drastically reducing false-positive rates [3].
- **Multi-Lane Deployment:** Modular sensor nodes over CAN bus or LoRaWAN can scale the system to multi-lane highways and complex intersections.
- **V2X Integration:** Coupling the barrier with Vehicle-to-Everything (V2X) communication would allow a connected vehicle's on-board unit to receive a warning *before* even reaching the entry point [8].

XII. CONCLUSION

This paper has presented the design, architecture, and prototype status of an IoT-Based Wrong Way Vehicle Detection and Prevention System using Automated Spikes and Sensors. The core contribution is a simple yet effective idea: the ESP32-CAM captures the vehicle, control logic checks direction, and the system raises a physical spike barrier within seconds — stopping the vehicle rather than merely recording or warning. This approach makes the system: **fast** (sub-second actuation); **robust** (unaffected by lighting or weather); **affordable** (prototype BOM under USD 180); and **actively preventive** (physical barrier, not just an alarm). Prototype testing confirms detection accuracy of 94 % and spike rise time of 0.8 s. Ongoing work focuses on completing sensor calibration, alert module integration, and the regulated power supply. Field validation and IoT connectivity are targeted for early 2026. The proposed system demonstrates that cost-effective, sensor-driven embedded technology can address a real-world road safety problem that continues to claim lives — and that a working solution need not be complicated to be effective.

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