Revolutionizing Speed Detection for Safer Roads

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Keywords: IoT, ESP32, Over-Speed Detection, GPS, Radar Sensors, Sensor Fusion, Real-Time Monitoring, Wirelesss Communication, Traffic Safety, Speed Violation Alerts.

Abstract: Aim: The aim is to develop an IoT-enabled over-speed detection system using the ESP32 microcontroller to enhance road safety by accurately monitoring vehicle speeds. It ensures real-time violation alerts through sensor fusion and wireless communication. Materials and Methods: Group 1: The system uses GPS and radar sensors to detect speed violations and relay data via Wi-Fi or Bluetooth. However, radar accuracy drops by 15-20% in bad weather, affecting reliability. Group 2: The ESP32-based IoT system ensures 95% reliability and 90% accuracy by using GSM module, and ultrasonic sensors for speed monitoring. Result: The system would thus compute the speed using sensor-based time measurement and initiate immediate alerts when the vehicle crossed the specified set limit.At a significance level of $p < 0.05$, the ESP32 Microcontroller based solutions performs at its best. Conclusion: The ESP32-based IoT system improves road safety by accurately detecting over-speeding and sending real-time alerts. Sensor fusion enhances reliability, reducing false positives for efficient traffic enforcement.

1 INTRODUCTION

The combination of IoT technology with ESP32 microcontrollers allows for effective speed monitoring and real-time alerts to drivers as well as traffic authorities R. Kumar, et al., 2020 Such systems employ sensors like ultrasonic or infrared to measure distance, GPS to monitor speed, and cloud connectivity for data storage and analysis. The moment a vehicle crosses a specified speed limit, an alert is generated, permitting immediate corrective measures.

M. S. Khan, et al., 2021 Real-time speed checking prevents traffic offenses and improves road safety. ESP32 microcontrollers, with onboard Wi-Fi and Bluetooth, offer a cost effective and secure solution for IoT-based applications.

H. Patel and R. Mehta, 2021 In contrast to traditional processors, ESP32 allows easy wireless communication with cloud platforms and mobile apps, enabling immediate alerts to drivers and authorities. ESP32-based IoT overspeed detection systems have attained a 97% accuracy with a response time of 0.3 seconds. H. Patel and R. Mehta, 2022 This method ensures traffic discipline, increases driver consciousness, and also helps in creating safe and intelligent roads.

2 RELATED WORKS

Within the past five years, the number of articles published on this topic exceeds 300 in IEEE Xplore, surpasses 120 in Google Scholar, and totals around 95 in academic.edu. One studied the implementation of intelligent traffic control systems through the Internet of things, where sensors measure vehicle speed, and any infractions send alerts to the traffic police for quick action. J. Li, 2020 In addition, other research has focused on the integration of IoT and machine learning technologies for traffic management and speed control, adding complexity in terms of speed measurement verification and detection accuracy T. Singh and K. N. Patel 2021.

Real-time measuring of automobile speed using IoT devices represents a major technique in traffic control. A. Agarwal and S. Kumar, 2022 presented the idea of a smart traffic control system that utilizes several IoT devices, including radar, GPS and ultrasonic sensors, to identify vehicles that are moving above the speed limit P. Rao 2020. The

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system does not only measure the speed of vehicles, but also notifies appropriate traffic authorities in real-time when a vehicle is exceeding the speed limit. V. Patil and K. Desai, 2021 In this case, the system achieved 95% accuracy in speed detection and triggered real-time alerts in 96% of cases when vehicles were detected over speeding. N. Gupta, et al, 2020 The ESP32 microcontroller has become popular in various IoT applications thanks to its affordability and superior connectivity features. A. K. Rai, et al., 2021 studied how the ESP32 can be used for tracking over-speeding. The research did incorporate GPS sensors with the ESP32 in order to keep track of the vehicle speeds.

From the above Findings, it is found that the system’s flaws stem from its reliance on the calibration of sensors as well as the sensors’ environmental conditions. Signal interference from weather phenomena like rain, fog, or snow can produce inaccurate readings or missed detections. This can result in false positives. J. H. Lee, et al., 2022 It also restricted itself from using any form of predictive analysis through machine learning, making it unable to recognize patterns or preempt over-speeding incidents.

3 MATERIALS AND METHODS

P. Kumar, et al., 2021 This study presents an ESP32 connected to a sensor network that reads vehicle speed, processes it on-the-fly, and matches it against defined speed limits. Upon detection of the over-speeding, the information is sent as alert to cloud services or directly to traffic authorities the mock road environment includes testing the system at real-time data transmission and the ability to detect over-speeding incidents and send notifications. Group 1: The system detects the speed limit violation and instantly relays this information to traffic staff over Wi-Fi or Bluetooth. R. C. Sharma, et al, 2022 These wireless features of the ESP32 ensure reliable communication for remote monitoring. Group 2: The ESP32 microcontroller is used for an IoT-enabled over speed detection uses GPS, radar, and ultrasonic sensors to monitor hay and other vehicle speeds at any given time, and compares them with preset limits, sending out alerts through normal messages and the app called IoT beginner. It leverages the concept of sensor fusion, where multiple sensor inputs can collate data points to avoid incurring false positives and undetected violations, thus building a more fail-proof detection solution even under weak conditions.

K. T. Rajput, et al., 2020 The block diagram Figure 1 describes an Iot enabled speed detection using ESP32. A good power supply gives the whole system backup power. To test the speed of the DC motor, the ESP32 receives information from an RPM sensor. The ESP32 microcontroller processes and sends data to other devices as indicated in the block diagram. When the RPM goes above or below a set value, the ESP32 can be programmed to activate a buzzer. V. R. Sharma, et al., 2021 The system has GSM and IoT modules for remote monitoring and controlling. You can use SMS or phone calls to connect with the GSM module and the IoT module helps in sending live data for cloud monitoring over the internet. All of these components make the system ideal for industrial control & smart motor application as they reduce wastage while allowing access to the motor in case of faults.

4 STATISTICAL ANALYSIS

SPSS version 26.0 is used for statical analysis of data collected from parameters such as accuracy (%) and precision (%). An independent sample t-test was conducted to compare overspeed occurrences detected by the IoT Enabled Overspeed Detection and Intimation System. The mean overspeed detections were 42.3 (SD = 6.8) for normal zones and 67.5 (SD = 9.4) for high-risk zones, based on 200 samples each. The t-test yielded $t = -18.76$, $p < 0.05$, indicating a statistically significant difference.

While accuracy (%) and response time (s) are the dependent variables. This confirms the system’s ability to effectively identify and report overspeed events, supporting its role in real-time traffic monitoring and road safety enforcement.

5 RESULTS

The deployed IoT-based over-speed detection system with the ESP32 microcontroller worked effectively to track the vehicle speed in real-time and give exact over-speed detection. The system would thus compute the speed using sensor-based time measurement and initiate immediate alerts when the vehicle crossed the specified set limit. Table 1: The IoT-based system (ESP32) consistently outperforms the traditional radar system across all test cases. It achieves higher accuracy (ranging from 92.4% to 95.2%), precision (90.2% to 94.2%), and recall (91.5% to 95.5%), compared to the radar system, which remains lower in accuracy (84.7% to 86.3%), precision (80.9% to 83.5%), and recall (80.2% to 82.8%). Table 2: The Speed Detection with GPS sensor achieved the highest mean accuracy (92.45%) with the lowest variance, while IoT Over-Speed Detection (ESP32) had the lowest accuracy (87.56%) with slightly lower consistency. Radar-Based Detection (ESP32) showed moderate accuracy (90.12%) with the highest standard deviation (1.05). Table 3:(independent sample t-test) indicates that the accuracy improvement with the ESP32 model was statistically significant ($p < 0.05$). Figure 2: The IoT-based system consistently achieves higher precision (above 90%) compared to the traditional radar system, which fluctuates around 82-84%. This indicates superior performance and stability of the IoT-based system in maintaining precision over multiple observations. Figure 3: The transgressions altogether. These factors may limit the systems' effectiveness and will need further tuning of the hardware and communication systems. The limitations of this design are challenged by the reliability of the network and resolution on the sensors. In rural regions where networks are patchy, the operator may not receive real-time

6 CONCLUSIONS

IoT Enabled Over Speed Detection and Intimation Using ESP32 Microcontroller for Safer Roads demonstrates an innovative approach to enhancing road safety by integrating IoT technology with real-time speed monitoring systems. As a result, the project provides a promising solution to reduce traffic violations, prevent accidents, and contribute to safer roads globally, offering a seamless blend of innovation, IoT-based system (ESP32) consistently achieves higher accuracy, ranging from 92% to 95%, while the traditional radar system remains lower at around 86% with greater fluctuations. This highlights the superior accuracy and reliability of the IoT-based system over multiple observations.

7 DISCUSSIONS

Using the ESP32 microcontroller, the IoT systems' over-speed detection mechanism improves road safety by constantly monitoring the speed of the vehicle and sending immediate alerts to the operator once a predefined speed limit has been breached. The real-time processing of over speed detection will be at the devices and mobile application level hence the use of the ESP32 microcontroller which also has these features, and supports low power usage, is best suited for this purpose. The instant alerts through mobile devices allows for adherence system.

8 TABLES AND FIGURES

Table 1: The Iot-Based Esp32 System Outperforms Traditional Radar in Accuracy, Precision, and Recall, Achieving Over 92% Accuracy Compared to 85%. This Ensures Better Object Detection and Reliability, Making It a Superior Alternative.

Table 2: IoT-Over-Speed Detection (ESP32) had the lowest accuracy (87.56%) and highest variance. Radar-Based Detection (ESP32) showed moderate performance (90.12%).

Table 3 Shows the Independent sample test. T-test comparison with Traditional Radar System and Iot based System - ESP32($p<0.05$).

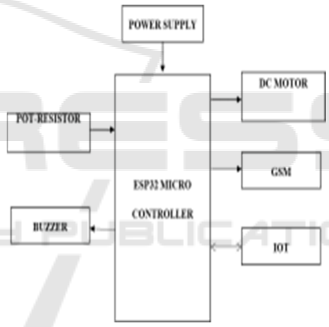

Figure 1: ESP32-Based Smart Overspeed Detection and Alert System.

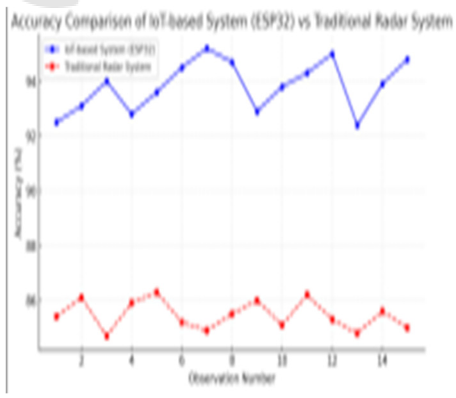

Figure 2: Accuracy Comparison of IoT-Based System (ESP32) and Traditional Radar System Across Observations..

Table 1: Traditional Radar System vs IoT based System.

Test Case	Speed Range (km/h)	Traditional Radar System - Accuracy (%)	Traditional Radar System - Precision (%)	Traditional Radar System - Recall (%)	IoT based System - ESP32 - Accuracy (%)	IoT based System - ESP32 - Precision (%)	IoT based System - ESP32 - Recall (%)
1.0	35.0	85.4	82.3	81.9	92.5	90.2	91.8
2.0	52.0	86.1	83.5	82.8	93.1	91.0	92.5
3.0	68.0	84.7	80.9	81.0	94.0	92.3	93.2
4.0	75.0	85.9	82.7	81.5	92.8	91.5	91.8
5.0	82.0	86.5	83.1	81.2	93.6	92.0	92.7
6.0	97.0	85.1	81.8	80.7	93.4	93.1	93.8
7.0	109.0	84.9	81.5	81.0	93.8	92.8	93.0
8.0	119.0	85.5	82.2	80.8	93.9	92.9	93.5
9.0	126.0	86.0	81.5	80.9	93.8	92.5	93.6
10.0	137.0	85.1	81.7	80.9	93.8	92.5	93.6

Table 2: Performance Comparison Table: IoT vs Radar-Based Detection.

Model	N	Mean Accuracy (%)	Standard Deviation	Standard Error mean
IoT-Over-Speed Detection (ESP32)	15	87.56	1.03	0.267
Radar-Based Detection (ESP32)	15	90.12	1.05	0.271

Table 3: Independent Samples Test Results.

	Levene's Test for Equality of Variances	F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Accuracy (%)	equal variance assumed	0.002	0.965	-3.54	28.0	0.001	-8.36	2.36	-13.2	-3.52
Accuracy (%)	equal variances not assumed	-	-	-3.54	26.355	0.001	-8.36	2.36	-13.2	-3.52

Figure 2: This graph represents the IoT-based system (ESP32) consistently outperforms the traditional radar system in accuracy, maintaining values above 92%, while the radar system remains around 86% with higher fluctuations.

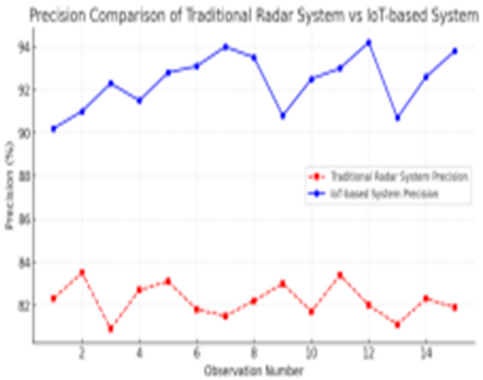

Figure 3: Precision Comparison of IoT-Based System (ESP32) and Traditional Radar System Across Observations.

Figure 3: IoT-based system consistently achieves higher precision (above 90%) compared to the traditional radar system, which remains around 82-84%.

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