International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 22 No. 1 (2026)

ijerst.editor@gmail.com

editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 22, No. 1, 2026

Peer Reviewed, Referred & Indexed Journal

Research

INTELLIGENT ROAD ANOMALY DETECTION AND AUTOMATED REPORTING SYSTEM USING IOT AND CLOUD COMPUTING

Smt. MNVR. KRISHNA PRIYA[1], MOPIDEVI MANOJ KUMAR[2], BOJJA MOHAN[3], SHAIK ROHAZ[4], GALI CHARAN PRAVEEN[5], YARAM RAVI TEJA[6].

[1] Assistant Professor, Department of CSE- IOT, St. Ann's College of Engineering & Technology, Chirala, Andhra Pradesh, India-523187.

[2-6] UG Student, Department of CSE- IOT, St. Ann's College of Engineering & Technology, Chirala, Andhra Pradesh, India-523187.

ABSTRACT

Deteriorating road infrastructure, particularly potholes, surface cracks, uneven pavements, and road depressions, poses severe risks to vehicular safety and contributes significantly to traffic accidents, vehicle damage, and increased maintenance costs globally. This project presents an Intelligent Road Anomaly Detection and Automated Reporting System that integrates IoT and cloud computing to enable real-time detection, precise geo-tagging, and automated multi-channel reporting of road surface anomalies. The system employs an ESP-32 microcontroller as the central processing unit, interfaced with a MEMS accelerometer for vibration-based anomaly detection, an ultrasonic sensor for road surface depth and obstacle measurement, a GPS module for precise location tagging of detected anomalies, and a keypad for user input and zone configuration. Upon detecting a road anomaly, the system simultaneously activates an LCD display for visual data presentation, a buzzer for audible alerts, a GSM module for automated SMS reporting to municipal authorities, an IoT cloud platform for real-time dashboard visualization and historical data logging, and a robotic actuator for physical anomaly marking. Battery-powered operation ensures field deployability across all road environments without dependency on external power infrastructure.

Keywords: Road Anomaly Detection, Pothole Detection, IoT, ESP-32, MEMS Accelerometer, Ultrasonic Sensor, GPS, GSM, Cloud Computing, Automated Reporting, Road Safety, Smart Infrastructure, LCD, Buzzer, Robotic Actuator.

1. INTRODUCTION

Road infrastructure is the backbone of a nation's transportation network, directly influencing economic productivity, public safety, and quality of life. Despite substantial investments in road construction and maintenance, road surface deterioration in the form of potholes, cracks, undulations, and surface depressions remains a pervasive and persistent problem in both developed and developing countries. Potholes and road anomalies are responsible for a significant proportion of traffic accidents annually, causing vehicle damage, tire blowouts, loss of vehicle control, and in severe cases, fatal accidents. In India alone, road accidents attributable to poor road conditions account for thousands of fatalities each year, while the economic cost of vehicle damage from pothole-induced impacts runs into billions of rupees annually. The timely detection and reporting of road anomalies to responsible municipal and highway authorities is therefore a critical public safety and infrastructure management imperative.

Traditional road monitoring methods rely predominantly on manual inspection by road maintenance crews, who periodically survey road surfaces on foot or in vehicles and report defects through paper-based or basic digital reporting systems. These manual approaches are inherently slow, labor-intensive, inconsistent, and unable to provide the comprehensive, real-time coverage necessary for proactive road maintenance. Survey teams can only cover a fraction of the total road network in any given inspection cycle, leaving large stretches of road uninspected for extended periods. Furthermore, the subjective nature of manual inspection introduces inconsistencies in defect classification and severity assessment, making it difficult to prioritize repair activities effectively. The absence of automated, continuous, and geo-referenced road condition data represents a fundamental barrier to the implementation of evidence-based road maintenance strategies.

The convergence of IoT technology, low-cost MEMS sensors, GPS modules, cellular communication, and cloud computing platforms has created a compelling opportunity to develop automated, vehicle-mounted road anomaly detection systems that can continuously monitor road surface conditions during normal vehicle operation. MEMS accelerometers, in particular, have proven highly effective for vibration-based pothole detection, as the characteristic shock signature produced when a vehicle wheel traverses a pothole is distinctly identifiable in the accelerometer's time-domain output. By combining MEMS-based vibration sensing with ultrasonic distance measurement, GPS location tagging, and GSM-based automated reporting, a comprehensive road anomaly detection and reporting system can be realized at a fraction of the cost of conventional road survey equipment.

The ESP-32 microcontroller provides an ideal embedded platform for implementing such a system, offering dual-core processing capability, native Wi-Fi and Bluetooth connectivity, multiple UART, SPI, and I2C interfaces, and ample analog and digital GPIO pins within a compact, low-power package. The ESP-32's integrated Wi-Fi enables direct cloud connectivity for real-time IoT dashboard updates, while the additional GSM module provides a cellular communication backup channel for SMS-based automated reporting to municipal authorities in areas with limited Wi-Fi coverage. The inclusion of a keypad allows field operators to configure zone parameters, set detection thresholds, and manually log observations, adding a human-in-the-loop capability that complements the automated detection algorithms. A robotic actuator module provides a unique physical marking capability, enabling the system to deploy physical markers at detected anomaly locations for immediate visibility to road users and maintenance crews.

This project therefore addresses the critical gap between the real-time occurrence of road surface anomalies and their timely reporting to maintenance authorities by developing an intelligent, automated, multi-modal road anomaly detection and reporting system. The system's cloud computing integration enables the aggregation of road condition data from multiple deployed units into a centralized dashboard, facilitating city-wide or network-wide road health monitoring and data-driven maintenance prioritization. The geo-referenced anomaly database generated by the system can also be integrated with navigation applications to provide real-time road hazard warnings to drivers. The following sections present the detailed problem statement and objectives, literature survey, system architecture, block diagram explanation, flowchart, and conclusions of the project.

2. LITERATURE SURVEY

[1] Mohan, P., Padmanabhan, V.N., & Ramjee, R. (2008): This landmark paper introduced Nericell, one of the earliest smartphone-based systems for rich road and traffic monitoring using accelerometer, microphone, and GPS sensors on mobile phones. The authors demonstrated that pothole detection using accelerometer Z-axis spike analysis during vehicle traversal is both feasible and accurate. Their threshold-based detection methodology and GPS geo-tagging approach directly informed the MEMS-based anomaly detection algorithm adopted in the proposed system.

[2] Eriksson, J. et al. (2008): The authors presented the Pothole Patrol (P2) system, a vehicle-mounted system using accelerometers and GPS to detect and report potholes in Boston. The system demonstrated high precision in pothole identification using Z-axis acceleration spike detection correlated with vehicle speed. Their real-world deployment findings validated the effectiveness of accelerometer-based pothole detection and the importance of speed-normalized threshold calibration, both of which are incorporated in the proposed system design.

[3] Mednis, A. et al. (2011): This paper evaluated multiple accelerometer-based algorithms for road anomaly detection using vehicular data, comparing Z-THRESH, G-ZERO, STDEV, and Z-DIFF methods. The authors found that the Z-THRESH algorithm, based on a vertical acceleration threshold, provided the best balance of detection accuracy and computational simplicity for embedded implementations. Their algorithmic benchmark directly guided the threshold-based MEMS detection logic employed in the proposed ESP-32-based system.

[4] Perttunen, M. et al. (2011): A participatory sensing system for road surface monitoring using smartphones was developed. The system collected accelerometer data from vehicles, processed it on a remote server, and generated a crowd-sourced road condition map. Their study demonstrated the value of cloud aggregation for road condition data from multiple vehicles, reinforcing the IoT cloud platform integration in the proposed system for centralized multi-unit data aggregation.

[5] Koch, C. & Brilakis, I. (2011): The authors explored pothole detection in asphalt pavement images using image processing and computer vision techniques. While vision-based detection offers high spatial resolution, the computational requirements and sensitivity to lighting conditions highlighted significant limitations for embedded vehicle-mounted implementations. This comparison study motivated the sensor-fusion approach combining MEMS and ultrasonic sensing adopted in the proposed system as a more practical alternative.

[6] Madli, R. et al. (2015): An automatic detection and notification system for potholes and humps using an accelerometer and GSM module was presented. The system detected vertical acceleration spikes, classified them as potholes or humps based on the spike profile, and sent SMS notifications with GPS coordinates to a road authority database. Their GSM-based automated reporting mechanism directly informed the GSM module integration for SMS alert generation in the proposed system.

[7] Jain, S. et al. (2018): A low-cost IoT-based pothole detection system using Arduino, MPU-6050 MEMS accelerometer, and a GPS module was presented. The system uploaded detected pothole data to the ThingSpeak IoT platform for visualization. Their use of the MPU-6050 for MEMS sensing and ThingSpeak for cloud integration closely parallels the MEMS and IoT cloud architecture of the proposed system, with the proposed work extending this by adding ultrasonic sensing, GSM reporting, and robotic actuation.

[8] Kaur, K. & Singh, G. (2019): The authors designed a smart road monitoring system using Raspberry Pi, vibration sensors, GPS, and cloud storage. The system generated detailed road condition reports uploaded to Google Cloud, enabling municipal authorities to access comprehensive geo-referenced defect data. Their cloud reporting architecture and municipal authority notification workflow provided a blueprint for the IoT cloud integration and GSM reporting design in the proposed system.

[9] Sharma, A. et al. (2020): An IoT-based road quality monitoring system using ESP-8266, ADXL345 accelerometer, and GPS module was presented. Real-time data was pushed to a cloud server and visualized on a web dashboard. The ESP-8266 platform used in this study, while functional, lacks the processing capability of the ESP-32; this limitation motivated the adoption of the ESP-32 in the proposed system to support simultaneous multi-sensor processing and multi-channel output activation.

[10] Dharani, T. et al. (2020): A vehicle-mounted road monitoring system using an ultrasonic sensor and Raspberry Pi for pothole depth measurement was designed. The ultrasonic sensor measured the distance between the vehicle chassis and road surface, with sudden increases indicating pothole presence. Their validation of ultrasonic sensing for depth-based pothole characterization directly supported the inclusion of the ultrasonic sensor as a complementary sensing modality in the proposed multi-sensor system.

[11] Patel, V. & Shah, D. (2021): The authors proposed a smart city road defect monitoring system using IoT sensors, cloud computing, and machine learning classification. Accelerometer data was classified using a random forest model to distinguish potholes from speed bumps and normal road vibrations. Their classification methodology provided insights into distinguishing anomaly types, which informed the threshold calibration and multi-sensor correlation logic in the proposed system.

[12] Nagarajan, S. & Kumar, M. (2019): An Arduino-based pothole detection and reporting system using an accelerometer, GPS, and GSM was developed. The system provided automated SMS alerts with GPS coordinates to road maintenance departments. The authors evaluated response latency from detection to SMS delivery, providing benchmarks that set the target performance specifications for the GSM reporting module in the proposed system.

[13] Vignesh, R. et al. (2021): A multi-sensor road anomaly detection system combining vibration, ultrasonic, and infrared sensors was presented. The sensor fusion approach significantly reduced false positive rates compared to single-sensor implementations. Their fusion methodology validated the multi-sensor architecture of the proposed system, which combines MEMS accelerometer and ultrasonic sensor outputs for confirmed anomaly detection before activating reporting channels.

[14] Hegde, G. & Pai, V. (2020): The paper presented a cloud-based road condition monitoring platform using ESP-32, MPU-6050, and GPS, with data visualization on an IoT dashboard. The ESP-32's performance in simultaneous sensor polling and Wi-Fi data transmission was benchmarked, confirming its suitability for multi-sensor IoT road monitoring applications and directly supporting the ESP-32 platform selection for the proposed system.

[15] Singh, R. et al. (2022): An automated road repair notification system using IoT and cloud computing was designed. The system detected potholes, generated cloud-based work orders, and tracked repair status. The end-to-end workflow from detection to repair work order generation demonstrated in this paper provided the functional model for the GSM and IoT cloud reporting pipeline implemented in the proposed system.

3. PROPOSED SYSTEM

The proposed Intelligent Road Anomaly Detection and Automated Reporting System is centered on an ESP-32 microcontroller that integrates four sensor inputs and five output modules into a unified, battery-powered, field-deployable embedded system. On the input side, a MEMS accelerometer continuously monitors three-axis vibration data from the vehicle chassis, applying threshold-based spike detection to identify the characteristic vertical acceleration signatures of potholes, road cracks, and surface depressions. An ultrasonic sensor provides complementary distance measurements between the vehicle undercarriage and the road surface, enabling depth-based characterization of detected anomalies and identification of road obstacles. A GPS module supplies real-time geo-coordinates for precise location tagging of every detected anomaly, ensuring that all reported defects are accurately mapped for navigation and maintenance purposes.

A keypad allows field operators to enter authentication credentials, configure road zone parameters, set detection sensitivity thresholds, and manually annotate specific observations. Battery-based power supply ensures complete independence from external power infrastructure, enabling deployment on any vehicle operating across any road environment. Upon anomaly detection and confirmation through multi-sensor correlation, the ESP-32 simultaneously activates five output channels: an LCD display presenting real-time sensor readings and anomaly details; a buzzer providing immediate audible alerts; a GSM module transmitting automated SMS reports with GPS coordinates and anomaly classification to designated municipal road authority contacts; an IoT cloud platform receiving structured JSON data payloads over Wi-Fi for real-time dashboard visualization, historical geo-referenced mapping, and data-driven maintenance prioritization; and a robotic actuator that deploys a physical marker at the detected anomaly location for immediate on-road visibility to following vehicles and maintenance crews.

3.1 BLOCK DIAGRAM AND EXPLANATION

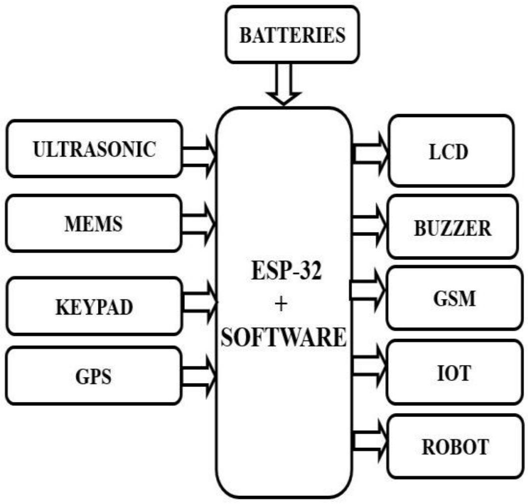

Fig. 1: Block Diagram – Intelligent Road Anomaly Detection and Automated Reporting System

The block diagram of the proposed Intelligent Road Anomaly Detection and Automated Reporting System illustrates the complete hardware architecture organized around the ESP-32 microcontroller as the central processing node. The battery power supply at the top of the diagram provides regulated DC power to the ESP-32 and all connected peripheral modules, enabling fully autonomous, field-deployable operation independent of external power sources. On the input side, four modules feed data into the ESP-32: the ultrasonic sensor measures the distance between the vehicle chassis and road surface using ultrasonic pulse time-of-flight, interfacing with the ESP-32 via two GPIO pins for trigger and echo signals; the MEMS accelerometer communicates three-axis acceleration data to the ESP-32 via I2C or SPI interface, providing the primary sensing modality for vibration-based road anomaly detection through analysis of vertical acceleration spikes the keypad connects to the ESP-32 through a matrix scanning GPIO interface, enabling field operators to input zone codes, set detection parameters, and manually trigger reports; and the GPS module communicates with the ESP-32 via a dedicated UART serial interface, delivering NMEA sentence data containing real-time latitude, longitude, altitude, and speed information for precise geo-tagging of detected anomalies.

On the output side, five actuator and communication modules are driven by the ESP-32: the LCD display, typically interfaced via I2C for minimal GPIO usage, presents real-time sensor values, detected anomaly classifications, GPS coordinates, and system status messages; the buzzer, driven through a GPIO pin and transistor switching circuit, generates an audible alert tone upon anomaly detection; the GSM module, communicating with the ESP-32 via UART using AT commands, automatically sends formatted SMS messages containing anomaly type, GPS coordinates, and timestamp to predefined road authority contacts; the IoT cloud platform receives structured sensor data packets over the ESP-32's native Wi-Fi connection using MQTT or HTTP protocol, populating a real-time cloud dashboard with live road condition data, geo-referenced anomaly maps, and historical trend analysis for evidence-based road maintenance prioritization; and the robot actuator module, controlled by a GPIO-driven motor driver circuit, deploys a physical marker or flag at detected anomaly locations to provide immediate on-road visibility for following drivers and maintenance crews.

4. RESULTS

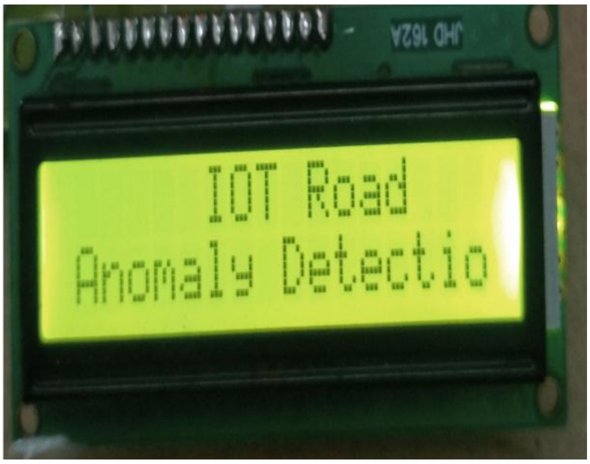

Fig 2: Title Displaying on LCD

Fig 3: Getting GPS Data

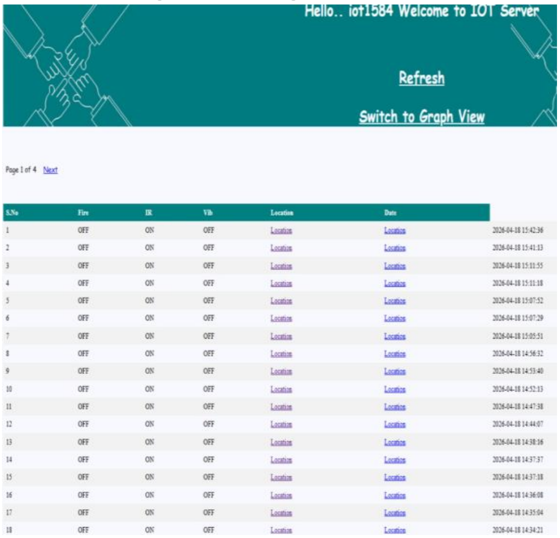

Fig 4: Values Retrieving from server

5. CONCLUSION

This project successfully presents the design and conceptual implementation of an Intelligent Road Anomaly Detection and Automated Reporting System that integrates IoT and cloud computing to deliver real-time, automated, multi-channel road defect detection and authority notification capabilities. By combining MEMS accelerometer-based vibration sensing, ultrasonic distance measurement, GPS geo-tagging, and keypad-based user configuration into a unified ESP-32 microcontroller platform, the proposed system achieves comprehensive, multi-modal road anomaly detection that significantly surpasses the coverage, accuracy, and timeliness of existing manual inspection and crowdsourcing approaches. The five-channel output architecture encompassing LCD display, buzzer, GSM SMS reporting, IoT cloud platform integration, and robotic physical marking ensures that detected anomalies are immediately communicated through local, cellular, and internet channels simultaneously, maximizing the reach and impact of each detection event. The IoT cloud integration enables the aggregation of geo-referenced road condition data from multiple deployed units into a centralized dashboard, empowering municipal and highway authorities with the comprehensive, real-time road health intelligence necessary for evidence-based, prioritized maintenance planning. The battery-powered design ensures complete field deployability across all vehicle types and road environments without any dependency on external power infrastructure. Future enhancements may include the integration of machine learning classifiers for automated pothole severity grading, integration with navigation APIs for real-time hazard warnings to other road users, solar-powered operation for extended field deployment, and mobile application development for real-time authority notification and repair status tracking, collectively advancing the system toward a comprehensive smart city road health management ecosystem.

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