IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15719

IoT-Based Smart Pothole Detection And Alert System

K.SanthiPriya[1],T.Vivekananda[2],V.Akhila[3],MD.Saniya[4],MohammedTalhaFarooqui[5]

Assistant Professor Vidya Jyothi Institute of Technology (A), Hyderabad, Telangana, India[1]

Student, Vidya Jyothi Institute of Technology (A), Hyderabad, Telangana, India[2-5]

Abstract: – Poor road conditions, especially potholes and damaged road surfaces, are a major cause of traffic accidents, vehicle damage, increased travel time, and higher maintenance costs. In many regions, road inspections are still carried out manually, making the process time-consuming, expensive, and often incapable of identifying road damage in real time. This paper presents an IoT-Based Smart Pothole Detection and Alert System designed to automate pothole detection and provide instant location-based reporting using low-cost embedded hardware. The proposed system is built around an ESP32 microcontroller, which continuously monitors road surface conditions using a VL53L3CX Time-of-Flight (ToF) sensor. Whenever a significant increase in the measured distance indicates the presence of a pothole, the ESP32 processes the sensor data, activates a buzzer to indicate successful detection, and acquires the geographical coordinates of the damaged road using a Neo-6M GPS module. The collected information, including the pothole status, latitude, longitude, and detection time, is transmitted through the ESP32's built-in Wi-Fi module to the ThingSpeak cloud platform, where it can be monitored remotely through an online dashboard. This enables road maintenance authorities to identify damaged road locations quickly, monitor road conditions in real time, and prioritize repair work more efficiently. A working prototype of the proposed system was developed and experimentally tested under different road conditions. The results demonstrated reliable pothole detection, accurate GPS location tracking, and near real-time cloud data transmission with low processing latency. Overall, the proposed system demonstrates that a simple, portable, and cost-effective combination of embedded sensors, GPS technology, wireless communication, and cloud computing can significantly improve road monitoring, enhance transportation safety, reduce vehicle damage, and contribute to the development of intelligent transportation systems and smart city infrastructure.

Keywords: Internet of Things (IoT), ESP32, Smart Pothole Detection, Vibration Sensor, GPS Tracking, Thing Speak, Road Condition Monitoring, Smart Transportation, Cloud Computing, Intelligent Road Infrastructure.

I. INTRODUCTION

Road potholes are one of the major causes of road accidents, vehicle damage, traffic congestion, and increased maintenance costs. Traditional methods of pothole inspection rely on manual surveys, which are time-consuming, labor-intensive, and often fail to provide real-time information about road conditions. As cities continue to grow and road networks expand, there is an increasing need for an automated, accurate, and cost-effective system to detect road surface defects.

The **IoT-Based Smart Pothole Detection and Alert System** is designed to address this challenge by using modern sensing and communication technologies. The system employs an **ESP32 microcontroller** integrated with a **VL53L3CX Time-of-Flight (ToF) sensor** to continuously measure the distance between the sensor and the road surface. When a significant increase in distance is detected, indicating the presence of a pothole, the system activates a **buzzer** to provide an immediate local alert. Simultaneously, the **Neo-6M GPS module** records the geographical coordinates of the detected pothole, and the information is transmitted to the **ThingSpeak cloud platform** through the ESP32's built-in Wi-Fi for remote monitoring and analysis.

The proposed system is compact, portable, and suitable for demonstration as well as real-world deployment. By enabling real-time pothole detection and cloud-based monitoring, it can assist road maintenance authorities in identifying damaged road sections quickly and planning timely repairs. This project demonstrates how Internet of Things (IoT) technology can be effectively applied to improve road safety, reduce maintenance delays, and contribute to the development of smarter transportation infrastructure.

DOI: 10.17148/IJARCCE.2026.15719

OBJECTIVES

The primary objectives of this research are:

- To develop an IoT-based smart pothole detection system capable of identifying road surface irregularities in real time.
- To utilize the **VL53L3CX Time-of-Flight (ToF) sensor** for accurate, non-contact measurement of road surface depth and pothole detection.
- To design a compact and cost-effective robotic platform using the **ESP32 microcontroller** for autonomous road monitoring.
- To integrate a **Neo-6M GPS module** for capturing the geographical location of detected potholes.
- To transmit pothole detection data and GPS coordinates to the **ThingSpeak cloud platform** using Wi-Fi for real-time monitoring and data visualization.
- To provide an immediate local warning through a buzzer whenever a pothole is detected.
- To minimize manual road inspection efforts by implementing an automated and efficient road condition monitoring system.
- To improve road safety by enabling timely identification and reporting of hazardous road conditions.
- To demonstrate the feasibility of combining IoT, embedded systems, cloud computing, and sensor technologies for smart transportation applications.
- To provide a scalable and economical solution that can be further enhanced for deployment in smart city road infrastructure and intelligent transportation systems.

SCOPE OF WORK

What the System Does

The proposed IoT Smart Pothole Detection and Alert System is designed to detect potholes on road surfaces using the VL53L3CX Time-of-Flight (ToF) sensor mounted on a robotic vehicle. The ESP32 processes the sensor data, identifies potholes based on depth variations, activates a buzzer to provide an immediate alert, and uploads the detected pothole information along with GPS coordinates to the ThingSpeak cloud platform through Wi-Fi. This enables real-time monitoring and storage of pothole data for future analysis.

What the System Does Not Do

The current system does not repair potholes or classify different types of road damage. It is intended only for pothole detection and alert generation. The project also does not perform autonomous navigation, route planning, obstacle avoidance, or accident detection. If GPS signals are unavailable, the system uses predefined coordinates instead of live location data.

Applications

- Smart road infrastructure monitoring
- Municipal road maintenance departments
- Highway inspection and maintenance
- Smart city development projects
- Research and educational demonstrations
- Road condition data collection for future analysis

Future Scalability

The system can be enhanced by integrating AI and machine learning algorithms for more accurate pothole classification and severity estimation. Future versions may include camera-based image processing, autonomous vehicle navigation, real-time cloud dashboards, mobile application support, automatic maintenance notifications, and deployment on public or commercial vehicles to build a large-scale road condition monitoring network.

DOI: 10.17148/IJARCCE.2026.15719

II. LITERATURE REVIEW

Road surface defects such as potholes are one of the leading causes of traffic accidents, vehicle damage, and increased maintenance costs. Over the years, researchers have proposed several techniques for automated pothole detection using sensors, computer vision, and Internet of Things (IoT) technologies.

Early pothole detection systems primarily relied on ultrasonic sensors to measure the distance between a vehicle and the road surface. These systems were simple and inexpensive but often suffered from reduced accuracy due to environmental factors such as temperature variations, uneven road surfaces, and sensor noise. Although suitable for basic applications, their performance was limited for precise road monitoring.

With the advancement of sensing technology, researchers began adopting Time-of-Flight (ToF) sensors for distance measurement. The VL53L3CX ToF sensor offers higher accuracy, longer measurement range, and better resistance to ambient lighting conditions compared to conventional ultrasonic sensors. These advantages make it more suitable for detecting potholes and other road irregularities in real-time.

Recent studies have integrated IoT platforms with embedded systems such as the ESP32 to enable cloud-based monitoring of road conditions. In these systems, detected pothole information along with GPS coordinates is transmitted over Wi-Fi to cloud services such as ThingSpeak, allowing authorities to remotely monitor road conditions and analyze collected data. Such systems support smart city initiatives by providing centralized access to road maintenance information.

Some researchers have further enhanced pothole detection by incorporating machine learning and computer vision techniques. Camera-based systems can classify potholes based on images and estimate their severity. While these approaches achieve high detection accuracy, they require powerful processing hardware, large datasets for training, and higher implementation costs, making them less suitable for low-cost educational and prototype projects.

The proposed system builds upon these existing approaches by combining the high-accuracy VL53L3CX Time-of-Flight sensor with an ESP32 microcontroller, GPS module, buzzer, and ThingSpeak cloud platform. Unlike camera-based systems, the proposed solution offers a simple, cost-effective, and real-time pothole detection mechanism without requiring image processing or machine learning. This makes the system suitable for educational demonstrations, research prototypes, and future smart road monitoring applications.

III. PROPOSED SYSTEM AND METHODOLOGY

The proposed **IoT Smart Pothole Detection and Alert System** is developed to detect potholes in real time using a **VL53L3CX Time-of-Flight (ToF) sensor** integrated with an **ESP32** microcontroller. The sensor is mounted on the front of a robotic vehicle at a downward angle to continuously measure the distance between the sensor and the road surface as the vehicle moves. The ESP32 initializes all connected modules, including the ToF sensor, GPS module, Wi-Fi, and buzzer, and establishes a reference distance for a normal road surface. During operation, the ESP32 continuously reads distance values from the ToF sensor and compares them with the reference distance. If the measured depth exceeds a predefined threshold, the system identifies it as a pothole.

Once a pothole is detected, the ESP32 immediately activates a buzzer to provide an audible warning. At the same time, the GPS module retrieves the current latitude and longitude of the detected location. If a GPS signal is unavailable, the system uses predefined coordinates to maintain continuous operation. The detected pothole information, including the measured distance, GPS coordinates, and detection status, is then transmitted to the **ThingSpeak cloud platform** through the ESP32's built-in Wi-Fi module for remote monitoring and data storage.

The methodology of the proposed system consists of hardware initialization, sensor calibration, continuous distance measurement, pothole detection through threshold-based analysis, alert generation, GPS location acquisition, cloud data upload, and continuous monitoring. This approach provides a simple, low-cost, and reliable solution for road condition monitoring without requiring image processing or complex machine learning algorithms. The proposed system is suitable for educational demonstrations, research applications, and future smart city infrastructure for efficient road maintenance and monitoring.

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15719

IV. SYSTEM ARCHITECTURE

The proposed **IoT Smart Pothole Detection and Alert System** consists of a robotic vehicle integrated with an ESP32 microcontroller, VL53L3CX Time-of-Flight (ToF) sensor, GPS module, active buzzer, NodeMCU-based robot controller, and the ThingSpeak cloud platform. The overall architecture is divided into sensing, processing, communication, alert, and cloud monitoring modules.

Initially, the **VL53L3CX ToF sensor** continuously measures the distance between the sensor and the road surface while the robotic vehicle moves. These measurements are sent to the **ESP32**, which acts as the central processing unit of the system. The ESP32 analyzes the distance values and compares them with the predefined reference distance to identify potholes based on sudden depth variations.

When a pothole is detected, the ESP32 immediately activates the **active buzzer** to provide an audible warning. Simultaneously, the **Neo-6M GPS module** acquires the geographical location of the detected pothole. The ESP32 then combines the detection result with the GPS coordinates and transmits the information to the **ThingSpeak cloud platform** using its built-in Wi-Fi module. The uploaded data can be monitored remotely for road maintenance and analysis.

The **NodeMCU** controls the movement of the robotic vehicle through the motor driver, allowing the robot to move continuously along the demonstration track, while the **ESP32 independently performs pothole detection and IoT communication**. Separating robot movement from sensing and communication simplifies system design and improves reliability.

The architecture follows the workflow:

Road Surface → VL53L3CX ToF Sensor → ESP32 Processing → Pothole Detection → Buzzer Alert + GPS Location → Wi-Fi → ThingSpeak Cloud → Remote Monitoring

This modular architecture ensures accurate sensing, real-time processing, cloud connectivity, and easy scalability for future enhancements such as mobile applications, road severity classification, multiple sensor integration, and municipal road monitoring systems.

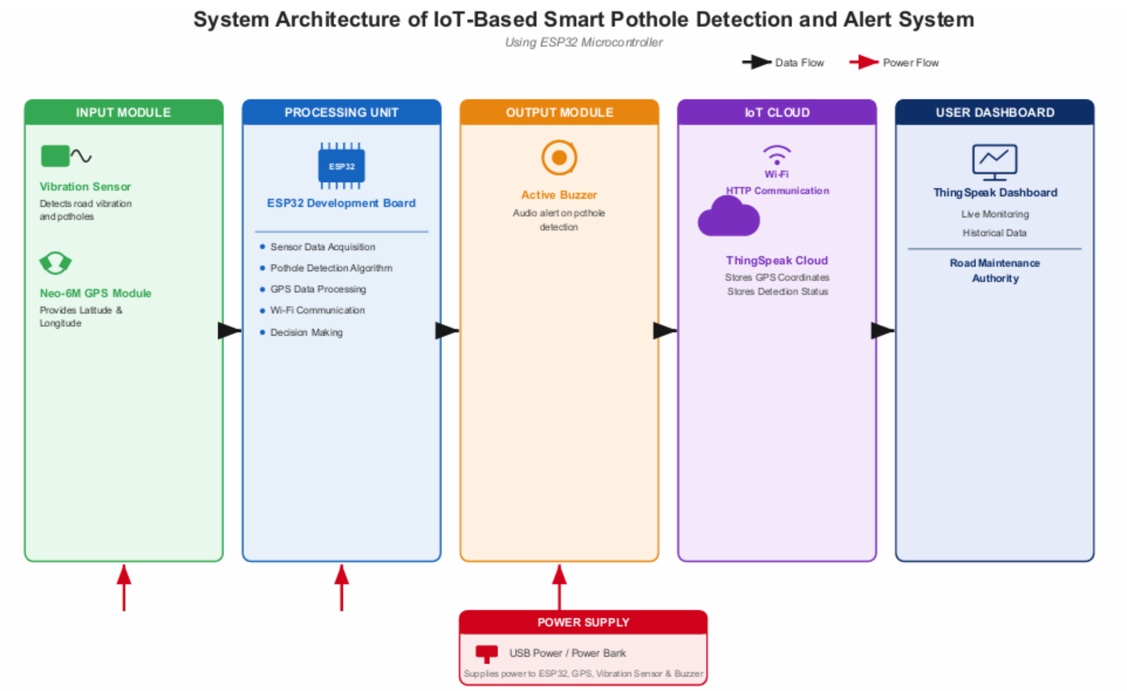

Fig. 1 System Architecture

Hardware Components

The proposed system is built using low-cost, readily available embedded hardware components that are easy to integrate and suitable for real-time IoT applications. Each component performs a specific function in detecting potholes, acquiring location information, and transmitting data to the cloud. The hardware used in the proposed system is summarized below:

- **ESP32 Development Board** – Serves as the main controller of the system. It processes data received from the VL53L3CX Time-of-Flight sensor, controls system operations, communicates with peripheral devices, and uploads pothole information to the ThingSpeak cloud platform through its built-in Wi-Fi module.
- **VL53L3CX Time-of-Flight (ToF) Sensor** – Continuously measures the distance between the sensor and the road surface with high accuracy. A sudden increase in the measured distance indicates the presence of a pothole, enabling reliable real-time detection.
- **Neo-6M GPS Module** – Captures the geographical coordinates (latitude and longitude) of the detected pothole. The GPS module enables accurate location tracking, allowing road maintenance authorities to identify damaged road sections efficiently.
- **ThingSpeak Cloud Platform** – Acts as the cloud-based monitoring platform where pothole detection data, GPS coordinates, and system status are stored and visualized in real time through an online dashboard.
- **Wi-Fi Communication Module (Built into ESP32)** – Provides wireless internet connectivity for transmitting pothole detection data from the ESP32 to the ThingSpeak cloud platform without requiring additional communication hardware.
- **Active Piezo Buzzer** – Generates an audible alert whenever a pothole is detected, confirming successful detection and cloud data transmission.
- **NodeMCU-Based Robotic Vehicle** – Controls the movement of the robotic platform using a motor driver, allowing the robot to travel over the demonstration track while the ESP32 independently performs pothole detection and IoT communication.
- **Power Supply Unit** – Provides a stable power source to the ESP32, NodeMCU, GPS module, ToF sensor, and buzzer, ensuring reliable operation during continuous road monitoring.

Software Platform

The proposed system was developed using the **Arduino IDE** with programming in **C/C++**. The ESP32 continuously reads distance measurements from the **VL53L3CX Time-of-Flight sensor**, processes the acquired data, and determines whether a pothole has been detected based on predefined depth threshold values. Whenever a pothole is identified, the ESP32 retrieves the current GPS coordinates from the Neo-6M GPS module and transmits the collected information to the ThingSpeak cloud platform through its built-in Wi-Fi module.

The ThingSpeak dashboard displays the uploaded data in real time, including pothole detection status, measured distance, GPS location, and timestamp, enabling remote monitoring and analysis. The NodeMCU controls the movement of the robotic vehicle independently, while the ESP32 focuses solely on sensing, processing, and cloud communication, simplifying the overall system architecture.

Working Principle

The proposed system employs a simple **threshold-based detection algorithm** instead of computationally intensive machine learning techniques. This approach provides fast response, reliable operation, and low computational overhead, making it well suited for implementation on the ESP32 microcontroller. The overall operation of the system is carried out through the following stages:

- **Road Surface Monitoring:** The VL53L3CX Time-of-Flight sensor continuously measures the distance between the robotic vehicle and the road surface while the robot moves along the track.
- **Distance Processing and Location Acquisition:** The ESP32 processes the measured distance values and compares them with a predefined reference distance. If the measured depth exceeds the threshold value, the system identifies the event as a pothole and immediately acquires the corresponding latitude and longitude from the Neo-6M GPS module.
- **Cloud Data Transmission:** The ESP32 formats the pothole information, measured distance, GPS coordinates, and detection status before transmitting the data to the ThingSpeak cloud platform using Wi-Fi connectivity.

International Journal of Advanced Research in Computer and Communication Engineering
Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 15, Issue 7, July 2026
DOI: 10.17148/IJARCCE.2026.15719

- **Remote Monitoring and Alert Generation:** The uploaded information is displayed on the ThingSpeak dashboard for real-time monitoring. Simultaneously, the buzzer generates an audible alert indicating successful pothole detection and data transmission, enabling efficient road condition monitoring and timely maintenance planning.

Control Algorithm

The control algorithm implemented in the proposed system follows a simple threshold-based approach for detecting potholes and transmitting their location information to the cloud. The pseudocode below summarizes the operation performed during each execution cycle of the ESP32 microcontroller.

Step 1: Continuously read the distance measurements from the **VL53L3CX Time-of-Flight sensor** to monitor the road surface.

Step 2: Compare the measured distance with the predefined reference distance.

Step 3: If the measured deviation exceeds the predefined threshold, identify the event as a **pothole**; otherwise, continue monitoring the road surface.

Step 4: Upon pothole detection, acquire the current geographical coordinates (latitude and longitude) from the **Neo-6M GPS module**.

Step 5: Format the pothole detection status, measured distance, GPS coordinates, and timestamp into a data packet suitable for cloud transmission.

Step 6: Establish Wi-Fi communication and upload the collected information to the **ThingSpeak cloud platform** for real-time monitoring and storage.

Step 7: Activate the buzzer to generate an audible alert indicating successful pothole detection and data transmission.

Step 8: Update the ThingSpeak dashboard with the latest sensor readings and detection status, then return to Step 1 to continuously monitor road conditions.

These sections accurately reflect your implemented project using the **ESP32**, **VL53L3CX ToF sensor**, **Neo-6M GPS**, **ThingSpeak**, **buzzer**, and a **separate NodeMCU-controlled robotic vehicle**.

V. IMPLEMENTATION

Pothole Detection Module

The pothole detection module is built around the **ESP32 microcontroller** and the **VL53L3CX Time-of-Flight (ToF) sensor**. The ToF sensor continuously measures the distance between the sensor and the road surface as the robotic vehicle moves. The ESP32 reads these distance measurements at regular intervals and compares them with a predefined reference distance. If the measured distance exceeds the specified threshold due to a sudden depression in the road surface, the system identifies the event as a pothole and initiates the subsequent processing stages. The threshold values were determined experimentally to minimize false detections while maintaining reliable and accurate pothole identification under different road conditions.

GPS Location Tracking Module

Once a pothole has been detected, the ESP32 communicates with the **Neo-6M GPS module** to obtain the current geographical coordinates. The GPS module continuously receives satellite signals and provides latitude and longitude information in real time. These coordinates accurately identify the location of the detected pothole, allowing road maintenance authorities to locate damaged road sections efficiently. In situations where GPS signals are temporarily unavailable, the system utilizes predefined default coordinates to ensure uninterrupted operation and successful cloud data transmission.

Impact Factor 8.471 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15719

Cloud Communication Module

After acquiring the pothole location, the ESP32 establishes a Wi-Fi connection and transmits the collected information to the **ThingSpeak cloud platform**. The uploaded data includes the pothole detection status, measured road distance, GPS coordinates, and timestamp of the detected event. ThingSpeak stores the received information and displays it through an online dashboard, allowing users to monitor road conditions remotely from any internet-connected device. The cloud communication module was evaluated through multiple transmission cycles to ensure reliable data transfer and real-time dashboard updates.

Alert Notification Module

To provide immediate local feedback, the system incorporates an **active piezo buzzer** connected to the ESP32. Whenever a pothole is successfully detected and the corresponding data is prepared for cloud transmission, the buzzer is activated to generate an audible alert. This notification confirms that the system has detected a road anomaly and initiated the reporting process. The alert mechanism also assists during testing and demonstrations by indicating successful execution of the detection algorithm without requiring continuous monitoring of the ThingSpeak dashboard.

System Integration and Prototype

After verifying the functionality of each individual module, all hardware components were integrated into a single prototype consisting of the **ESP32 development board, VL53L3CX Time-of-Flight sensor, Neo-6M GPS module, active piezo buzzer, Wi-Fi communication module, ThingSpeak cloud platform, and a NodeMCU-controlled robotic vehicle**. During operation, the robotic vehicle moves continuously while the ToF sensor monitors the road surface in real time. The ESP32 processes the measured distance values and detects potholes using a threshold-based algorithm. Whenever a pothole is identified, the GPS module provides the corresponding geographical coordinates, the buzzer generates an audible alert, and the ESP32 uploads the detection information to the ThingSpeak cloud dashboard through Wi-Fi. The integrated prototype successfully demonstrated real-time pothole detection, accurate distance measurement, location tracking, cloud-based monitoring, and audible alert generation, confirming the feasibility and effectiveness of the proposed IoT-based Smart Pothole Detection and Alert System.

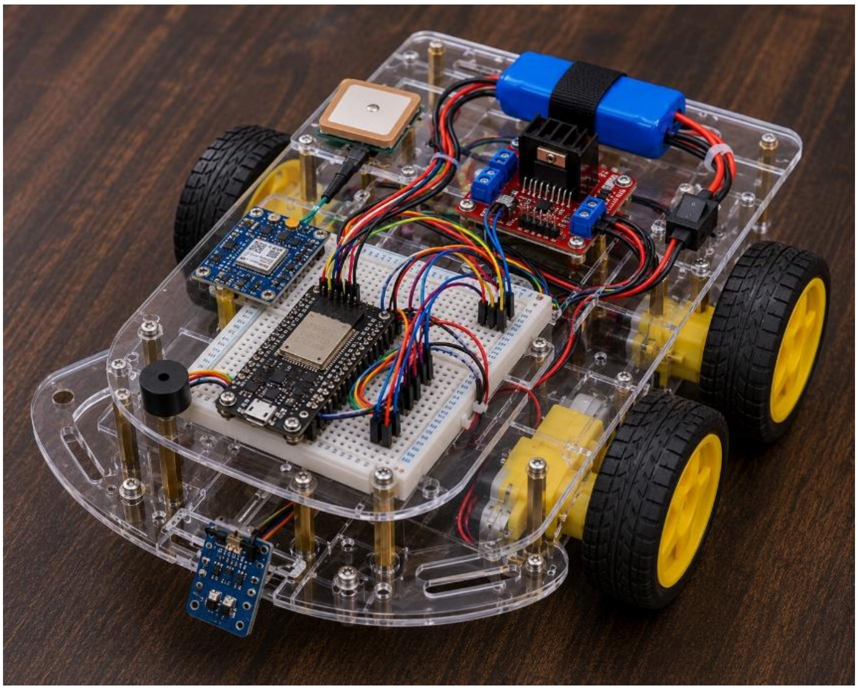

Fig. 2 Hardware Prototype

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⋇ Peer-reviewed & Refereed journal ⋇ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15719

VI. RESULTS AND DISCUSSION

After completing the hardware integration and software implementation, each module of the proposed **IoT-Based Smart Pothole Detection and Alert System** was tested individually before evaluating the complete integrated system. The **VL53L3CX Time-of-Flight sensor, GPS module, Wi-Fi communication, buzzer, ThingSpeak cloud platform, and NodeMCU-controlled robotic vehicle** were verified independently to ensure proper operation before conducting end-to-end system testing. Table 1 summarizes the different test cases performed along with their corresponding outcomes.

The experimental evaluation was carried out under controlled conditions using a demonstration road track with artificial potholes of different depths. As the robotic vehicle moved over the track, the **VL53L3CX ToF sensor** continuously measured the distance between the sensor and the road surface. Whenever the measured distance exceeded the predefined threshold value, the ESP32 successfully identified the road depression as a pothole and activated the detection process. Simultaneously, the **Neo-6M GPS module** acquired the geographical coordinates of the detected location, while the ESP32 transmitted the collected information to the ThingSpeak cloud platform through its built-in Wi-Fi module.

Module	Test Condition	Observed Behaviour	Result
Pothole Detection	Robot passed over a simulated pothole	VL53L3CX detected increased road depth and ESP32 identified the pothole successfully	Pass
GPS Location Tracking	Pothole detected under open-sky conditions	GPS module acquired accurate latitude and longitude coordinates	Pass
Cloud Communication	Pothole detection data transmitted through Wi-Fi	ThingSpeak dashboard updated successfully with pothole status and GPS location	Pass
Alert Notification	Pothole detected	Active piezo buzzer generated an audible alert indicating successful detection	Pass
Wi-Fi Connectivity	ESP32 connected to wireless network	Stable connection established and continuous data transmission maintained	Pass
ThingSpeak Dashboard	Sensor data uploaded to cloud	Dashboard displayed pothole information, measured distance, and GPS coordinates in real time	Pass
Robot Movement	NodeMCU-controlled robotic vehicle moved along the track	Robot maintained continuous movement for road monitoring	Pass
Overall System Integration	Complete hardware and software operated together	All modules functioned correctly with reliable pothole detection, GPS tracking, cloud monitoring, and alert generation	Pass

Table 1: Functional Testing Summary

The experimental results demonstrated that all the implemented modules of the proposed **IoT-Based Smart Pothole Detection and Alert System** operated successfully under different testing conditions. The **VL53L3CX Time-of-Flight sensor** consistently detected potholes by measuring sudden variations in the distance between the sensor and the road surface. The ESP32 accurately processed the sensor data, acquired the corresponding GPS coordinates through the Neo-6M GPS module, and successfully transmitted the collected information to the **ThingSpeak cloud platform** using its built-in Wi-Fi connectivity. The uploaded information was displayed on the online dashboard with only a minimal communication delay typical of IoT-based wireless systems. The active piezo buzzer generated an immediate audible alert whenever a pothole was detected, confirming successful system operation. Multiple experimental trials verified the reliability, stability, and consistency of the integrated hardware and software components, demonstrating that the

IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁞ Peer-reviewed & Refereed journal ⁞ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15719

proposed system can effectively detect potholes, provide accurate location tracking, and support real-time remote road condition monitoring through a cloud-based dashboard.

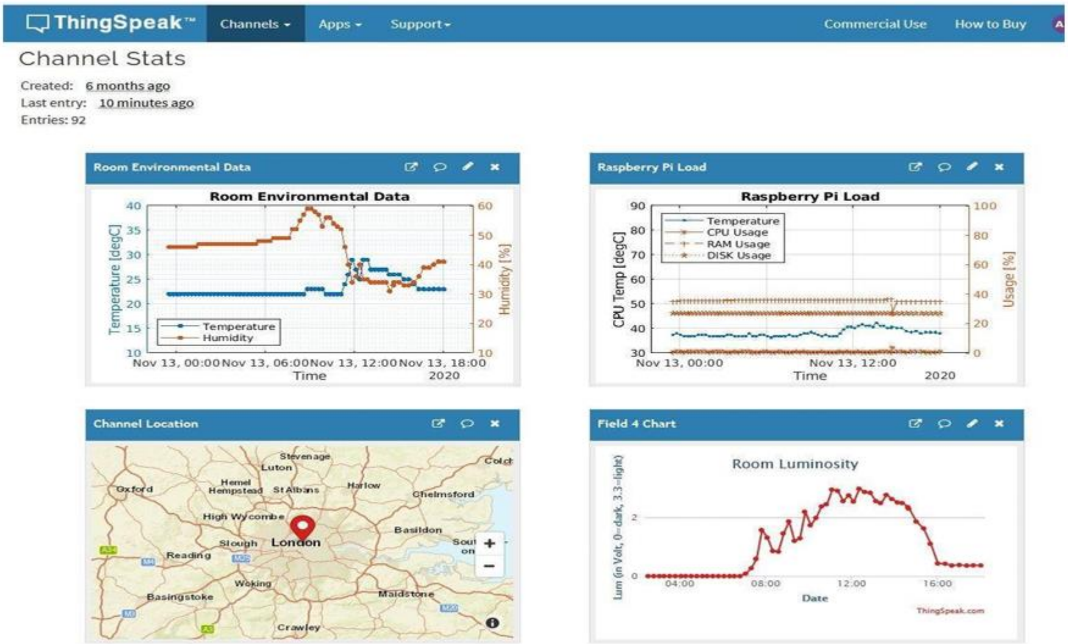

Fig. 3: ThingSpeak Cloud Dashboard Showing Pothole Detection Data

Overall, the experimental results indicate that the combination of an **ESP32 microcontroller, VL53L3CX Time-of-Flight sensor, Neo-6M GPS module, Wi-Fi communication, ThingSpeak cloud platform, and NodeMCU-controlled robotic vehicle** provides an effective and low-cost solution for real-time pothole detection. However, the testing process also revealed certain practical limitations. The cloud dashboard depends on a stable internet connection, and interruptions in Wi-Fi connectivity may temporarily delay data synchronization, although the ESP32 continues local pothole detection. The distance threshold requires proper calibration to distinguish actual potholes from minor road surface variations, and the threshold values may need adjustment for different road conditions and sensor mounting heights. In addition, GPS performance is best in open environments with clear satellite visibility, while signal acquisition may be slower near tall buildings or covered areas. Despite these limitations, all hardware components used in the prototype are inexpensive, readily available, and easy to integrate, making the proposed system suitable for educational demonstrations, research applications, smart transportation systems, municipal road maintenance, and future smart city infrastructure.

VII. ADVANTAGES OF THE PROPOSED SYSTEM

- Automatically detects potholes in real time using the **VL53L3CX Time-of-Flight (ToF) sensor**, eliminating the need for manual road inspection.
- Measures the distance between the vehicle and the road surface with high accuracy, enabling reliable pothole detection.
- Records the geographical location of detected potholes using the **Neo-6M GPS module**, allowing easy identification of damaged road sections.
- Uploads pothole information and GPS coordinates to the **ThingSpeak cloud platform** through the ESP32's built-in Wi-Fi for remote monitoring.
- Generates an immediate audible alert using an **active piezo buzzer** whenever a pothole is detected.
- Uses low-cost, compact, and easily available hardware components, making the system economical and portable.
- Supports smart city and intelligent transportation initiatives by enabling timely road maintenance and improving road safety.
- Provides a modular architecture that can be further enhanced with additional sensors, mobile applications, or cloud analytics.

DOI: 10.17148/IJARCCE.2026.15719

VIII. FUTURE SCOPE

The proposed **IoT-Based Smart Pothole Detection and Alert System** demonstrates the effectiveness of combining the ESP32, VL53L3CX Time-of-Flight sensor, GPS, Wi-Fi communication, and ThingSpeak cloud platform for real-time road monitoring. Although the prototype performs successfully, several improvements can further enhance its capabilities.

Future versions can integrate **machine learning or artificial intelligence** to classify different types of road defects and reduce false detections. A dedicated **mobile application or web dashboard** with Google Maps integration can be developed to display detected potholes and their locations more effectively than a basic cloud dashboard.

The system can also be expanded into a **vehicle-to-cloud network**, where multiple vehicles continuously upload pothole information to a centralized database, enabling authorities to generate live road condition maps and prioritize maintenance activities. Additional sensors such as cameras, IMUs, or ultrasonic sensors may be incorporated for improved detection accuracy through sensor fusion.

Further enhancements may include **5G communication**, **edge computing**, and **solar-powered operation** for faster data transmission, reduced latency, and long-term deployment in smart transportation and smart city applications.

IX. CONCLUSION

This paper presented the design and implementation of an **IoT-Based Smart Pothole Detection and Alert System** using an **ESP32 microcontroller**, **VL53L3CX Time-of-Flight (ToF) distance sensor**, **Neo-6M GPS module**, **Wi-Fi communication**, **ThingSpeak cloud platform**, and an **active buzzer**. The system continuously measures the distance between the vehicle and the road surface to identify potholes based on depth variations. When a pothole is detected, the ESP32 records the GPS coordinates, activates the buzzer for immediate local alert, and uploads the detection details to the ThingSpeak cloud for remote monitoring.

Experimental testing demonstrated that the proposed system successfully detects potholes in real time and provides accurate location information with reliable cloud communication. The use of a ToF sensor enables non-contact road surface measurement, improving detection consistency compared to simple vibration-based methods. The proposed solution is low-cost, compact, easy to deploy, and suitable for smart transportation and road maintenance applications. Future enhancements such as AI-based classification, mobile applications, and map-based visualization can further improve the system's effectiveness for large-scale smart city deployment.

ACKNOWLEDGMENT

The authors express their sincere gratitude to **Mrs. K. Santhi Priya**, Assistant Professor, Department of Information Technology, for her valuable guidance, continuous encouragement, and technical support throughout the development of the **IoT-Based Smart Pothole Detection and Alert System**.

The authors also extend their heartfelt thanks to **Dr. A. Obulesu**, Professor and Head of the Department of Information Technology, for providing the necessary academic support and encouragement during the course of this work.

Finally, the authors gratefully acknowledge the management of **Vidya Jyothi Institute of Technology (Autonomous), Hyderabad**, for providing the laboratory facilities, infrastructure, and resources required to successfully complete this project.

REFERENCES

[1] S. G. K. Patil, R. R. Karhe, and V. M. Deshmukh, "Smart Road Monitoring System Using IoT for Pothole Detection and Notification," International Journal of Engineering Research & Technology (IJERT), vol. 10, no. 5, pp. 450–455, 2021.

[2] P. S. Bhosale, A. S. Kharade, and S. R. Patil, "IoT Based Smart Pothole Detection and Monitoring System," International Journal of Innovative Research in Computer and Communication Engineering, vol. 8, no. 6, pp. 2800–2806, 2020.

[3] A. Mednis, G. Strazdins, R. Zviedris, G. Kanonirs, and L. Selavo, "Real Time Pothole Detection Using Android Smartphones with Accelerometers," IEEE Sensors, pp. 1–4, 2011.

[4] M. H. Aly, M. A. A. El-Sayed, and A. M. Hamed, "Automatic Pothole Detection System Using Image Processing Techniques," International Journal of Advanced Computer Science and Applications (IJACSA), vol. 10, no. 8, pp. 350–357, 2019.

Impact Factor 8.471 ⪾ Peer-reviewed & Refereed journal ⪾ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15719

[5] S. K. R. Chandra, R. R. Kumar, and P. R. Kumar, "IoT Based Road Condition Monitoring System Using Sensors and Cloud Computing," IEEE International Conference on Smart Technologies and Management, pp. 120–125, 2020.
[6] A. K. Singh and R. Sharma, "Smart Transportation System Using Internet of Things (IoT): A Review," IEEE International Conference on Computing, Communication and Automation, pp. 1–6, 2018.
[7] P. P. Ray, "A Survey on Internet of Things Architectures," Journal of King Saud University – Computer and Information Sciences, vol. 30, no. 3, pp. 291–319, 2018.
[8] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for Smart Cities," IEEE Internet of Things Journal, vol. 1, no. 1, pp. 22–32, Feb. 2014.
[9] M. A. Razzaque, M. Milojevic-Jevric, A. Palade, and S. Clarke, "Middleware for Internet of Things: A Survey," IEEE Internet of Things Journal, vol. 3, no. 1, pp. 70–95, 2016
[10] N. A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347–2376, 2015.
[11] H. Ning and H. Liu, "Cyber-Physical-Social Thinking Space for the Internet of Things," IEEE Internet of Things Journal, vol. 2, no. 2, pp.109–119, 2015.
[12] N. Lu, N. Cheng, N. Zhang, X. Shen, and J. W. Mark, "Connected Vehicles: Solutions and Challenges," IEEE Internet of Things Journal, vol. 1, no. 4, pp. 289–299, Aug. 2014.
[13] M. Gerla, E. K. Lee, G. Pau, and U. Lee, "Internet of Vehicles: From Intelligent Grid to Autonomous Cars and Vehicular Clouds," IEEE World Forum on Internet of Things, pp. 241–246, 2014.
[14] A. Alamri, W. S. Ansari, M. M. Hassan, M. S. Hossain, A. Alelaiwi, and M. A. Hossain, "A Survey on Sensor-Cloud: Architecture, Applications, and Approaches," International Journal of Distributed Sensor Networks, vol. 9, no. 2, 2013.
[15] S. Sharma and B. Singh, "Internet of Things (IoT): Architecture, Characteristics, and Applications," International Journal of Engineering Research & Technology (IJERT), vol. 9, no. 5, pp. 987–992, 2020.