

## Pathole And Manhole Detecting System Using Radar And Wireless Communication

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### Abstract

Urban flooding significantly reduces road visibility and often conceals surface irregularities such as potholes, open manholes, speed breakers, and debris. These hidden hazards pose serious risks to vehicles and riders, frequently resulting in accidents, vehicle damage, and unsafe driving conditions. To mitigate this problem, this study proposes a compact wireless road-irregularity detection system based on a radar-inspired sensing concept. The system integrates an ESP32 microcontroller with an SR-04T waterproof ultrasonic sensor to perform continuous real-time monitoring of the road surface beneath a moving vehicle. The ultrasonic sensor periodically transmits acoustic pulses toward the ground and calculates the distance by measuring the time-of-flight of the reflected signal. Variations from the normal ground clearance indicate the presence of surface anomalies such as depressions (potholes or uncovered manholes), elevated regions (speed breakers), or submerged obstacles during flood conditions. These distance fluctuations are processed by the ESP32 using threshold-based classification algorithms to identify the type of irregularity. When a hazardous condition is detected, the system can provide timely alerts to the rider or transmit data wirelessly for monitoring and analysis. The proposed design offers a low-cost, compact, and scalable solution that can be easily integrated into two-wheelers and automobiles operating in flood-prone urban environments. By enabling early detection of concealed road hazards, the system enhances rider awareness, reduces potential vehicle damage, and contributes to improved road safety.

**Keywords:** Road hazard detection, Pothole identification, Manhole detection, Speed breaker detection, Ultrasonic sensing, Real-time road monitoring, ESP32, Flood-affected roads.

### Introduction

Transportation infrastructure is an essential component of modern urban development, as it enables the safe and efficient movement of people and goods. However, many road networks across the world are increasingly affected by structural deterioration due to factors such as heavy traffic loads, aging pavement structures, poor drainage systems, and changing environmental conditions. These factors often lead to the formation of road surface defects including potholes, damaged pavements, and displaced or uncovered manholes. Such irregularities significantly reduce ride comfort and may lead to severe accidents, vehicle damage, and traffic congestion if they are not detected and repaired at an early stage. Conventional road inspection techniques mainly rely on manual surveys, visual inspection by maintenance personnel, or periodic road monitoring using specialized vehicles. Although these approaches have been used for decades, they suffer from several limitations. Manual inspections are time-consuming, labor-intensive, and often incapable of covering large road networks in a short period. Furthermore, these methods generally lack the

capability to provide real-time information about newly formed road defects. As urban areas continue to expand and traffic density increases, there is a growing demand for automated and intelligent systems that can monitor road conditions continuously and detect surface anomalies efficiently. Road surface defects such as potholes and irregular manholes are typically formed due to the combined effects of repeated vehicle loading, temperature fluctuations, water infiltration, and inadequate construction practices. When these defects remain unnoticed for long periods, they gradually expand in size and depth, leading to more severe structural damage to the pavement. Early detection and timely maintenance are therefore crucial for improving road safety and reducing long-term repair costs. Recent advancements in sensing technologies, embedded systems, and wireless communication have enabled the development of smart monitoring solutions capable of detecting road defects automatically. Radar-based sensing technologies have gained significant attention in recent years due to their ability to operate reliably under various environmental conditions. Unlike optical or camera-based systems that depend heavily

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on lighting conditions, radar sensors can function effectively in low visibility environments such as rain, fog, or nighttime scenarios. By transmitting electromagnetic waves toward the road surface and analyzing the reflected signals, radar-based systems can detect variations in surface profile and identify abnormalities such as potholes, depressions, or displaced manholes. The ability of radar sensors to provide accurate distance and depth measurements makes them particularly useful for road condition monitoring applications. Wireless communication technologies further enhance the effectiveness of such sensing systems by enabling real-time data transmission to centralized monitoring platforms. By incorporating wireless protocols such as cellular communication, Internet of Things (IoT) frameworks, or dedicated short-range communication networks, detected road anomalies can be instantly reported to traffic management centers or maintenance authorities. This allows rapid response and efficient resource allocation for road repair activities. Additionally, wireless connectivity supports large-scale deployment of sensing devices, allowing multiple monitoring units to operate collaboratively across extensive road networks. The integration of sensing technologies with wireless communication forms the foundation of an intelligent road defect detection system. Such systems can be mounted on vehicles or roadside infrastructure to collect continuous information about road surface conditions without interrupting normal traffic flow. The collected data can be processed using data analysis techniques to determine the location and severity of detected defects. Furthermore, integrating the system with geographic information systems (GIS) and cloud-based platforms enables authorities to maintain updated digital maps of road conditions. This information can support long-term infrastructure planning, improve maintenance strategies, and contribute to safer and more efficient transportation systems within smart city environments.

#### Literature Survey

Several research studies have explored the use of sensing technologies and intelligent systems for detecting road surface defects such as potholes and damaged manholes. Researchers have investigated different sensing approaches including radar-based detection, ground penetrating radar, mobile sensing techniques, and IoT-enabled monitoring platforms to improve the efficiency and accuracy of road condition monitoring. Patole *et al.* conducted an extensive study on the application of automotive millimeter-wave radar systems for road surface monitoring. Their research focused on the use of Frequency Modulated Continuous Wave (FMCW) radar to generate range profiles of road surfaces. By analyzing variations in the reflected radar signals, the system is able to identify sudden changes in

surface depth that correspond to potholes or other irregularities. The authors emphasized that radar-based sensing offers reliable performance even in challenging environmental conditions such as poor lighting, rain, or fog. This capability makes radar technology a promising solution for continuous road condition monitoring in real-world driving environments. Another important study was conducted by Al-Qadi and Lahouar, who investigated the use of Ground Penetrating Radar (GPR) for detecting subsurface defects within pavement structures. The GPR system operates by transmitting electromagnetic waves into the road surface and analyzing the reflected signals from underground structures or material boundaries. Their research demonstrated that GPR technology can effectively detect hidden infrastructure elements such as buried manholes, voids, and structural weaknesses beneath asphalt layers. The findings of this study highlighted the importance of radar-based technologies in supporting preventive road maintenance and infrastructure assessment. Research by Wesam Moneer Rasheed, Raed Abdulla, and Low Yee San focused on the recognition and monitoring of manholes within urban environments. The authors emphasized that missing or damaged manholes pose significant risks to road users and represent a serious safety concern in modern cities. Their study proposed a detection system capable of identifying manhole locations and monitoring their conditions. The system integrates Internet of Things (IoT) technology to update the detected information on an online platform. This data can then be integrated with navigation applications such as Waze or Google Maps to provide warnings to drivers and assist city authorities in monitoring road infrastructure more effectively. Another related study by Aniket Kulkarni, Nitish Mhalgi, Sagar Gurnani, and Dr. Nupur Giri investigated the use of mobile sensing techniques for pothole detection. Their system utilizes sensors available in smartphones to detect abnormal vibrations caused by potholes while a vehicle is in motion. The collected data is then used to identify possible pothole locations. One of the primary advantages of this approach is its low implementation cost, as it relies on widely available mobile devices without requiring specialized hardware. However, the study also identified certain limitations, including the lack of a centralized database for storing and analyzing collected data. In addition, the accuracy of location detection depends heavily on GPS signals, which may sometimes produce inaccurate results. These limitations highlight the need for more reliable and integrated detection systems capable of providing accurate real-time information for large-scale road monitoring.

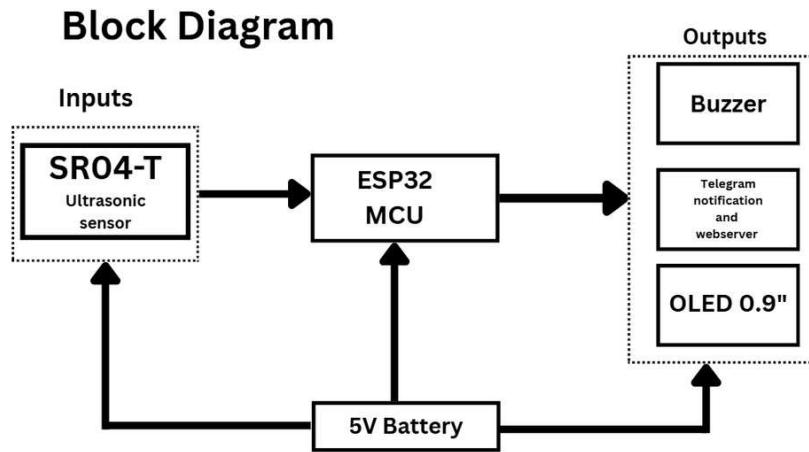
**Block Diagram and System Methodology**

**Working Principle**

The proposed detection system operates by measuring the distance between the sensor mounted on a vehicle and the road surface beneath it. A waterproof ultrasonic sensor (SR-04T) is used to emit high-frequency sound waves toward the road surface. When these waves encounter an object or the road surface, they are reflected back to the sensor. The time taken for the transmitted signal to return to the receiver is measured and used to calculate the distance between the sensor and the road. During normal road conditions, the distance measured by the sensor remains relatively constant because the surface is even. However, when the vehicle passes over a pothole, damaged road section, or uncovered manhole, the distance changes

abruptly. These variations are detected by the ultrasonic sensor and transmitted to the ESP32 microcontroller for analysis. The ESP32 processes the received data and compares it with predefined threshold values to determine whether the detected variation corresponds to a pothole or manhole. If a road defect is identified, the system immediately generates an alert through a buzzer and displays the warning message on the OLED screen. Additionally, the ESP32 can transmit the detected information through wireless communication such as Wi-Fi or Bluetooth to external devices or monitoring platforms. This enables real-time reporting of road conditions and helps authorities or drivers take appropriate action to avoid potential hazards.

**Block Diagram Description**



**Block Diagram of Pothe and Manhole Detection System Using Radar and Wireless Communication**

The block diagram of the proposed system represents the functional relationship between different hardware components involved in road anomaly detection. The entire system is powered by a portable battery supply that provides the required voltage for all electronic components. This allows the system to operate independently when mounted on a vehicle. The ultrasonic sensor acts as the input device responsible for detecting road surface variations. It continuously measures the distance between the sensor and the ground by emitting ultrasonic pulses and receiving the reflected signals. The measured data is then transmitted to the ESP32 microcontroller. The ESP32 microcontroller serves as the main processing unit of the system. It receives the distance data from the ultrasonic sensor and performs calculations to determine whether the road surface is normal or contains irregularities. Based on the analysis results, the microcontroller controls output devices such as the buzzer and OLED display. The OLED display provides visual feedback to the user by displaying real-time information about road conditions and sensor measurements. Messages

such as “Normal Road,” “Pothole Detected,” or “Manhole Detected” are displayed depending on the system status. The buzzer acts as an audible alert mechanism that warns the driver or nearby users when a road defect is detected. The wireless communication capability of the ESP32 allows the system to transmit detection data to remote monitoring devices. This feature enables integration with mobile applications, cloud servers, or centralized monitoring systems used by municipal authorities. Through this communication channel, road defects can be recorded and analyzed for maintenance planning.

**Methodology**

The methodology of the proposed system involves several stages including system initialization, distance measurement, data processing, defect detection, and alert generation. Initially, the system is powered using a battery source, after which the ESP32 initializes all connected peripherals such as the ultrasonic sensor, OLED display, buzzer, and wireless communication interface. Once initialization is complete, the ultrasonic sensor

begins transmitting ultrasonic pulses toward the road surface. The reflected signals are captured by the sensor, and the time difference between transmission and reception is calculated. This time-of-flight measurement is used to determine the distance between the sensor and the road surface. The ESP32 continuously receives these distance values and analyzes them using predefined threshold parameters. Under normal conditions, the measured distance remains stable within a certain range. If the measured value increases beyond the threshold, it indicates the presence of a depression or gap in the road surface such as a pothole or open manhole. When such a condition is detected, the system activates the buzzer to provide an audible alert and updates the OLED display with a warning message. At the same time, the ESP32 can transmit the detection data wirelessly to a mobile device or monitoring system. This enables real-time information sharing and allows authorities to identify hazardous locations quickly.

The detection process continues continuously as the vehicle moves along the road. This ensures that multiple road defects can be identified over a large area, improving safety and supporting efficient road maintenance operations.

#### Hardware Description

##### Li-ion Battery with TP4056 Module

A rechargeable lithium-ion battery is used as the primary power source for the proposed system. The battery provides the required electrical energy for the ESP32 microcontroller, ultrasonic sensor, OLED display, and other peripheral components. In portable electronic systems, lithium-ion batteries are commonly used due to their high energy density, lightweight structure, and long operational life. In this project, the widely used 18650 lithium-ion battery is employed. The name “18650” represents the battery dimensions, where the diameter is approximately 18 mm and the length is about 65 mm. The 18650 battery typically operates at a nominal voltage of around 3.7 V, with a fully charged voltage of approximately 4.2 V and a discharge cutoff voltage near 2.5 V. Depending on the manufacturer and battery type, the storage capacity generally ranges between 2000 mAh and 3500 mAh, allowing the system to operate for extended periods without frequent recharging. To ensure safe and efficient charging of the battery, a TP4056 charging module is integrated into the power supply circuit. The TP4056 module is designed specifically for charging single-cell lithium-ion or lithium-polymer batteries. It uses a constant current and constant voltage charging method, which helps maintain battery health and prevents damage caused by improper charging conditions. The module accepts a 5 V input supply, usually provided through a micro-USB or USB

Type-C connector. The charging process occurs in two stages. During the initial stage, the module supplies a constant current to quickly raise the battery voltage. Once the battery approaches its maximum voltage level, the charging mode shifts to constant voltage, gradually reducing the current to prevent overcharging. When the charging current falls below a certain threshold, the charging process automatically stops. Many TP4056 modules also include additional protection circuits that safeguard the battery from overcharging, over-discharging, short circuits, and excessive current flow. These protection mechanisms improve system safety and extend the overall lifespan of the battery.

##### TP4056 Charging Module

The TP4056 charging module is a compact integrated circuit designed for charging single-cell lithium-ion batteries in portable electronic devices. It is widely used in embedded systems, IoT projects, and battery-powered electronics due to its simplicity, reliability, and low cost. The module operates with an input voltage range of approximately 4.5 V to 5.5 V, which can be supplied from USB ports, adapters, or other regulated power sources.

One of the key features of the TP4056 module is its constant current/constant voltage (CC/CV) charging algorithm, which ensures safe and efficient battery charging. During the constant current stage, the module delivers a stable current to the battery, allowing rapid charging while maintaining safe temperature levels. As the battery voltage approaches its maximum limit of approximately 4.2 V, the charging controller gradually reduces the current to maintain a stable voltage across the battery terminals. The module typically includes indicator LEDs that display the charging status. For example, one LED indicates that charging is in progress, while another LED signals that the battery has reached full charge. Some versions of the module incorporate additional protection circuits such as the DW01A protection IC and FS8205A MOSFET, which prevent battery damage caused by excessive voltage, current, or short circuits. Because of these safety features, the TP4056 module is highly suitable for battery-powered monitoring systems such as the proposed road defect detection device.

##### OLED Display

An OLED (Organic Light Emitting Diode) display is used in the proposed system to provide visual feedback to the user. OLED technology differs from conventional LCD displays because it does not require a backlight. Instead, each pixel emits its own light when an electrical current passes through organic materials within the display structure. This feature results in higher contrast ratios, improved viewing angles, faster response times, and reduced power consumption. The OLED display used in this project is a compact 0.96-inch module with a

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resolution of  $128 \times 64$  pixels. These displays are commonly used in embedded systems because they are lightweight, energy efficient, and capable of displaying both text and graphical information. The module typically communicates with the ESP32 microcontroller through the I2C communication protocol, requiring only two signal lines for data exchange along with power and ground connections. In the proposed pothole detection system, the OLED display serves as a real-time user interface. It displays information such as the measured distance from the ultrasonic sensor and the status of road conditions. For example, when the road surface is normal, the display indicates a safe condition, whereas warning messages are shown when a pothole or open manhole is detected. This visual feedback allows users to quickly understand the current system status without needing additional external devices.

#### SR-04T Ultrasonic Sensor

The SR-04T ultrasonic sensor is the primary sensing component used in the system for detecting road surface variations. It is a waterproof ultrasonic distance sensor designed for applications where the sensing environment may involve moisture, dust, or outdoor conditions. Unlike the standard HC-SR04 ultrasonic module, the SR-04T uses a single waterproof transducer connected through a cable, making it suitable for harsh environmental conditions such as flooded or wet road surfaces. The operating principle of the SR-04T sensor is based on ultrasonic wave reflection. The sensor emits high-frequency sound waves, typically around 40 kHz, which travel through the air until they encounter a surface or obstacle. When the sound waves strike an object, they are reflected back toward the sensor. The module measures the time interval between transmitting the ultrasonic pulse and receiving the reflected echo signal. Using this measured time interval, the system calculates the distance between the sensor and the object using the principle of time-of-flight measurement. Since the ultrasonic wave travels from the sensor to the surface and back again, the calculated time is divided by two to determine the actual distance. By continuously measuring this distance, the system can identify changes in the road surface profile. Under normal road conditions, the measured distance remains consistent. However, when the vehicle passes over a pothole, open manhole, or other irregularity, the detected distance suddenly increases. This variation is captured by the ultrasonic sensor and transmitted to the ESP32 microcontroller for processing. Due to its measurement range, waterproof design, and reliable performance, the SR-04T sensor is well suited for road surface monitoring applications.

#### Software Implementation Embedded C

Embedded C is a specialized version of the C programming language designed for programming microcontrollers and embedded systems. The C language was originally developed by Dennis Ritchie at Bell Laboratories in the early 1970s, primarily for system programming and operating system development. Over time, it became one of the most widely used programming languages due to its efficiency, portability, and ability to interact directly with hardware components. In embedded applications, Embedded C provides developers with precise control over memory usage, processor registers, and input/output ports. This capability makes it particularly suitable for systems with limited computational resources. Embedded C programs can execute quickly and reliably, which is essential for real-time applications such as sensor monitoring and control systems. Another advantage of Embedded C is its portability across different microcontroller platforms. A well-structured C program can be adapted to various hardware architectures with minimal modifications. In the proposed pothole detection system, Embedded C is used to read sensor data, perform calculations, control output devices, and manage communication between system components.

#### Embedded C++

Embedded C++ extends the capabilities of Embedded C by incorporating object-oriented programming (OOP) concepts such as classes, objects, inheritance, and encapsulation. These features allow developers to design modular and reusable code structures, which is beneficial for complex embedded applications. Using Embedded C++ enables better organization of software components, improved code readability, and easier maintenance. In systems involving multiple sensors, communication modules, and display interfaces, object-oriented programming simplifies the management of hardware drivers and software modules. Modern microcontrollers such as the ESP32 support Embedded C++ programming through development platforms like the Arduino IDE and ESP-IDF. These platforms provide libraries and hardware abstraction layers that simplify communication with sensors, displays, and wireless modules. As a result, developers can focus more on system functionality rather than low-level hardware configuration. In this project, Embedded C++ is used to implement the control logic for the ultrasonic sensor, OLED display, and buzzer, while also managing wireless communication for transmitting road hazard alerts.

#### Software Flow and System Operation

The software implementation follows a structured execution sequence to ensure continuous monitoring of road conditions. When the system is powered on, the ESP32 microcontroller initializes all connected peripherals including the ultrasonic sensor, OLED

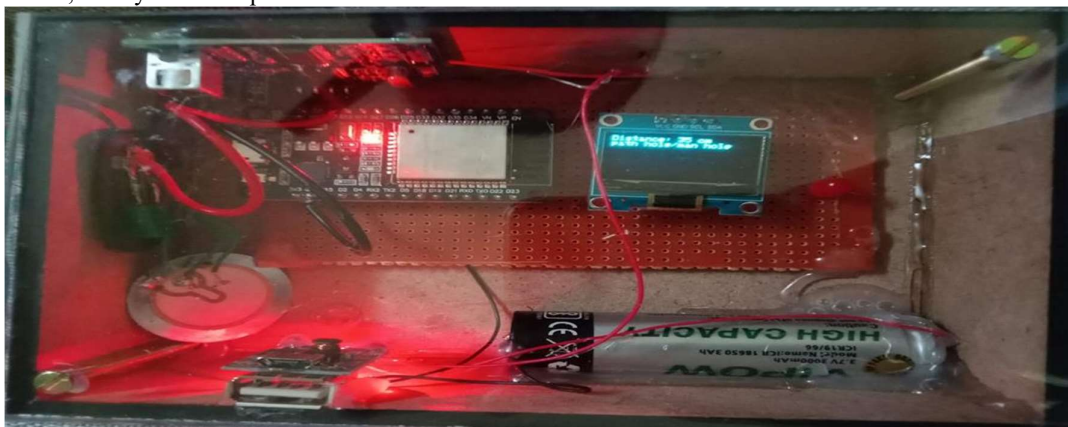
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display, buzzer, and wireless communication interface. The system also establishes a connection with the configured wireless network to enable remote communication. After initialization, the program enters a continuous loop where the ultrasonic sensor measures the distance between the vehicle-mounted sensor and the road surface. The measured distance value is displayed on the OLED screen, allowing users to monitor the sensor readings in real time. The software then evaluates the measured distance against predefined threshold values to determine the road condition. If the distance falls within the normal range, the system considers the road surface to be stable and no alert is generated. However, if the measured distance indicates a sudden increase beyond the normal threshold, the system interprets the condition as a

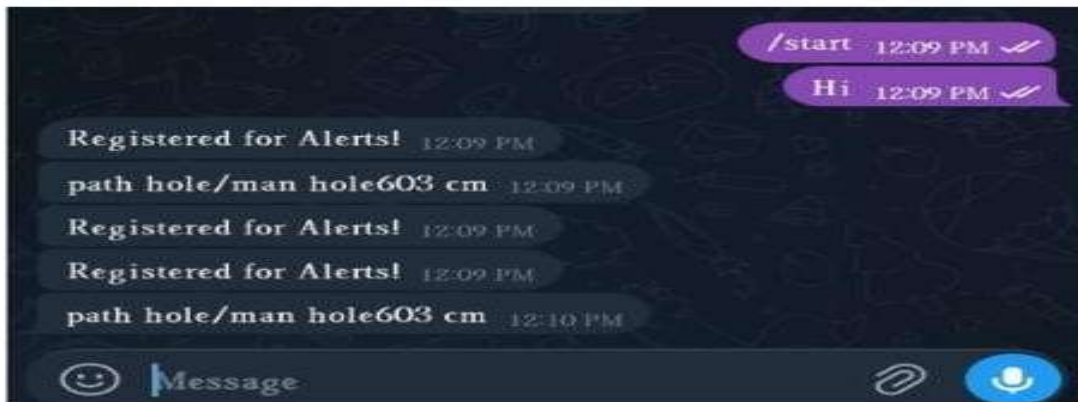
pothole or open manhole. Once a road defect is detected, the ESP32 activates the buzzer to produce an audible warning and displays a corresponding alert message on the OLED screen. At the same time, the system can transmit a notification through wireless communication to external monitoring platforms or mobile devices. After completing this detection cycle, the system continues monitoring the road surface by repeating the loop with minimal delay. This continuous monitoring approach ensures that road irregularities can be detected in real time as the vehicle moves, allowing immediate alerts and improved road safety.

**Results and Discussion**

**Results**



**Fig 1 Pathhole and Manhole Detection System using Radar**



**Fig 2 Pathhole and Manhole Detection System using Wireless communication**

The developed pothole and manhole detection system was tested to evaluate its ability to identify road surface irregularities under different conditions. The system was mounted on a test platform where the ultrasonic sensor continuously measured the distance between the sensor and the road surface. Experimental observations confirmed that the sensor could successfully detect variations in road height caused by potholes and manholes. During normal road conditions, the distance readings remained relatively stable and

within the predefined threshold range. When the sensor encountered a pothole or open manhole, a noticeable increase in the measured distance was observed. The ESP32 microcontroller processed these measurements and accurately classified them as road anomalies. Once detected, the system activated the buzzer and displayed alert messages on the OLED screen. In addition to local alerts, the system also demonstrated the capability to transmit detection data using wireless communication. This feature allows the detected road hazards to be shared

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with external devices or monitoring platforms for further analysis. The experimental results indicate that the proposed system can effectively detect road defects in real time, making it suitable for practical deployment in road monitoring applications.

#### **Discussion**

The results obtained from the experimental testing demonstrate that the proposed pothole and manhole detection system provides an effective approach for monitoring road surface conditions. The use of ultrasonic sensing enables accurate detection of surface irregularities by measuring variations in the distance between the sensor and the road. Unlike visual inspection methods, this sensing approach is less dependent on lighting conditions and can function reliably in different environments. The integration of wireless communication further enhances the usefulness of the system by enabling real-time reporting of detected road defects. Maintenance authorities can receive immediate alerts about hazardous road conditions, allowing faster response and repair operations. This reduces the likelihood of accidents and minimizes damage to vehicles caused by poorly maintained roads. Although the system performs effectively in detecting road anomalies, certain limitations remain. For example, the detection accuracy may vary depending on sensor placement and vehicle speed. Environmental factors such as extreme weather conditions may also influence sensor performance. Future improvements such as integrating GPS for precise location tracking and applying machine learning algorithms for advanced classification could enhance the system's accuracy and reliability. Overall, the proposed system offers a cost-effective and scalable solution for improving road safety and supporting smart transportation infrastructure.

#### **Applications**

The proposed pothole and manhole detection system has several practical applications in modern transportation infrastructure and smart city development. One of the primary applications is in smart city infrastructure, where the system can be integrated with urban monitoring platforms to provide continuous updates about road conditions. By collecting real-time data on road defects, city authorities can improve infrastructure management and ensure safer transportation networks. Another important application is in highway and municipal road maintenance departments. The system can assist government agencies in identifying damaged road sections quickly and efficiently. Instead of relying solely on manual inspection, authorities can use automated monitoring systems to prioritize maintenance tasks and reduce operational costs associated with road surveys. The system can also contribute to the development of advanced driver

assistance systems (ADAS) in modern vehicles. By integrating the detection mechanism into smart vehicles, drivers can receive warnings when approaching potholes or open manholes, thereby improving passenger safety and preventing vehicle damage. In addition, the system can support traffic management systems by sharing real-time hazard information with traffic control centers. This information can help authorities reroute vehicles away from damaged roads and reduce congestion caused by unexpected road defects. Public transportation vehicles such as buses can also use this technology for continuous road monitoring. Since buses follow fixed routes daily, installing detection units on these vehicles would allow large road networks to be scanned regularly without additional monitoring vehicles. Furthermore, emergency service vehicles such as ambulances and fire trucks can benefit from the system by receiving alerts about road hazards along their routes. This can improve response times and ensure smoother transportation during emergency situations. The system can also be used in road construction and infrastructure audit projects. Contractors and engineers can use the detection mechanism to verify road surface quality after construction and ensure compliance with infrastructure standards.

#### **Conclusion**

The proposed pothole and manhole detection system using radar-inspired sensing and wireless communication presents an effective approach for improving road safety and infrastructure monitoring. By utilizing an ultrasonic sensing mechanism, the system can accurately detect road surface irregularities such as potholes and open manholes. The integration of the ESP32 microcontroller allows efficient processing of sensor data and enables wireless communication for real-time reporting of detected anomalies. One of the significant advantages of the system is its ability to operate continuously without requiring manual inspection. This automation reduces operational costs and enables faster identification of hazardous road conditions. The collected data can also assist authorities in planning maintenance activities and improving overall road infrastructure management. As a result, the proposed system contributes to safer transportation networks and supports the development of intelligent road monitoring solutions.

#### **Future Scope**

The future development of pothole and manhole detection systems is closely aligned with advancements in smart transportation and intelligent city infrastructure. In future implementations, advanced technologies such as machine learning and artificial intelligence can be incorporated to improve

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detection accuracy and predict road deterioration patterns. Predictive analytics could help authorities identify potential road damage before it becomes severe. Integration with GPS and cloud-based mapping platforms could enable real-time visualization of road conditions across entire cities. This would allow drivers to select safer routes and help emergency services avoid damaged road sections. Furthermore, connecting multiple sensing units through Internet of Things (IoT) networks could create a collaborative monitoring system where vehicles collectively contribute road condition data. Emerging communication technologies such as 5G networks may further enhance the system by enabling faster data transmission and improved connectivity. Additionally, more advanced sensing technologies and compact radar modules could improve detection precision and reliability.

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