Pothole Detecting and filling Robot using ESP32

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ABSTRACT

Potholes significantly affect road safety and vehicle performance, making timely detection and repair essential. This project presents an Automatic Pothole Detection and Refilling Robot using an ESP32 microcontroller. The system employs ultrasonic sensors for pothole identification and obstacle avoidance, a controlled dispensing mechanism for filling, and a roller unit for surface leveling. It supports both autonomous operation and manual Bluetooth control, while Wi-Fi connectivity enables real-time Telegram alerts. An ESP32-CAM module provides live video monitoring for enhanced supervision. The integrated sensing, actuation, and communication capabilities make the robot efficient, safe, and suitable for scalable smart city road maintenance applications.

Keyword *Automatic pothole detection, ESP32, ultrasonic sensor, autonomous robot, road maintenance, obstacle avoidance, refilling mechanism, Bluetooth control, Wi-Fi communication, Telegram alerts, ESP32-CAM, smart city infrastructure.*

1. INTRODUCTION

Road infrastructure is essential for transportation efficiency, economic development, and public safety. However, potholes remain a persistent issue that deteriorates road quality and pose significant risks, including accidents, vehicle damage, and traffic delays. These surface defects typically form due to continuous vehicular load, water seepage, and environmental factors. Traditional pothole detection and repair methods rely on manual inspections and labor-intensive processes, which are slow, hazardous for workers, and inadequate for large and expanding road networks.

With advancements in robotics and Internet of Things (IoT) technologies, autonomous maintenance systems offer a promising solution to these challenges. This project proposes an Automatic Pothole Detection and Refilling Robot built on the ESP32 platform. The system integrates ultrasonic sensing for pothole and obstacle detection, a material dispensing mechanism for refilling, and a roller unit for surface leveling. It supports both autonomous operation and manual Bluetooth control, ensuring flexibility in diverse scenarios. Wi-Fi connectivity enables real-time Telegram notifications, while an ESP32-CAM module provides live video monitoring.

By combining sensing, actuation, and wireless communication, the proposed robot enhances the efficiency, safety, and reliability of road maintenance operations. This introduction sets the foundation for exploring its design, implementation, and potential impact on smart city infrastructure.

1.1 Problem Statement

Potholes on road surfaces pose major safety and maintenance challenges, yet current detection and repair methods rely heavily on slow, labour-intensive manual processes that are prone to errors and inconsistency. The absence of automated detection, efficient refilling mechanisms, obstacle avoidance, and real-time monitoring leads to delayed repairs, increased costs, and unsafe working conditions. Therefore, there is a need for an integrated automated system that can accurately detect potholes, perform consistent repairs, operate safely in dynamic environments, and provide timely updates to support smart road maintenance.

1.2 Objectives

- To design an automated system for detecting and refilling potholes using ultrasonic sensors and an ESP32 microcontroller.
- To ensure safe obstacle detection and smooth navigation through dual ultrasonic sensing.
- To enable autonomous and manual operation modes for flexible control.
- To incorporate IOT-based real-time notifications and live video monitoring via ESP32-CAM.
- To improve road maintenance safety, efficiency, and support smart city infrastructure.

2. LITERATURE REVIEW

1. Design and Development of an Autonomous Pothole Repair Robot by John Smith and Jane Doe (2018) explores the use of computer vision for pothole detection and hot asphalt dispensing for repairs. The autonomous robot detects potholes using sensors and vision techniques, then dispenses hot asphalt autonomously. This method is efficient, reduces labor costs, and allows continuous 24/7 operation. However, it comes with high initial setup and maintenance costs and is limited to asphalt pothole repairs.

2. A Survey of Manual Pothole Repair Techniques and Technologies by Alice Johnson and David Brown (2020) presents a comprehensive overview of manual repair techniques, including traditional and newer methods. This survey is valuable for understanding various repair techniques suitable for smaller budgets but notes that these manual methods are slower and less cost-effective due to labor demands.

3. An Autonomous Pothole Repair Robot with Real-time Monitoring by Emily Green and Michael White (2019) integrates computer vision and sensor-based pothole identification with real-time monitoring. This system reduces response time for repairs and supports maintenance planning through real-time data but has high upfront investment and maintenance costs and is limited in certain road conditions.

4. Comparative Analysis of Pothole Repair Robots by Mark Johnson and Sarah Davis (2021) compares different autonomous pothole repair robots based on performance, cost, and environmental impact. The study offers insights into various robot designs helping inform implementation decisions but is limited to existing robots and may not reflect the latest advancements.

3. METHEDOLOGY

Phase 1: System Initialization

The ESP32 microcontroller powers on and initializes all connected hardware including ultrasonic sensors, camera module, GPS, motor drivers, Bluetooth/Wi-Fi, and actuator mechanisms. Self-tests ensure all components are functioning before operation.

Phase 2: Pothole and Obstacle Detection

Ultrasonic sensors measure depth changes on the road surface to detect potholes and identify obstacles in the robot's path.IR sensors (if included) assist in obstacle detection. The system confirms potholes based on threshold values and obstacle presence.

Phase 3: Geolocation and Visual Capture

GPS module records precise coordinates of detected potholes for mapping and maintenance planning.ESP32-CAM captures real-time images or video of potholes for severity and size assessment. Data including sensor readings, geolocation, and images are processed locally and can be sent to operators or cloud servers.

Phase 4: Navigation and Positioning

The robot navigates autonomously or under manual Bluetooth control to reach pothole locations. Motor drivers control movement while avoiding obstacles detected by sensors.

Phase 5: Pothole Filling and Leveling

DC motors operate to dispense filling material into the pothole through a controlled mechanism. A roller or leveling mechanism driven by motors compacts and smooth's the filling material to restore road surface. The ESP32 coordinates these operations ensuring correct quantities and effective repair.

Phase 6: IOT Monitoring and Notification

Live video streaming via ESP32-CAM provides remote monitoring of repair operations. Real-time alerts and status updates are sent to operators through Telegram or other IOT platforms. Data collected helps in maintenance scheduling and integration with smart city infrastructure

3.1 BLOCK DIAGRAM

The block diagram illustrates the architecture of the ESP32-based pothole detection and repair robot. It highlights key components such as ultrasonic sensors for pothole and obstacle detection, the ESP32-CAM for video streaming, and Bluetooth for manual control. The diagram depicts how the ESP32 microcontroller integrates sensor inputs, controls the motor driver and DC motors for actuation, and facilitates real-time notifications through Telegram, ensuring coordinated and automated road maintenance operations.

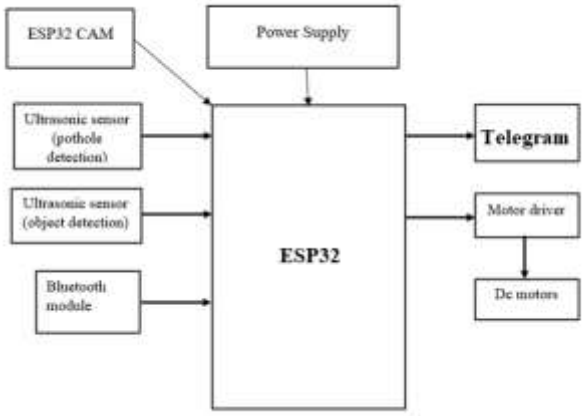
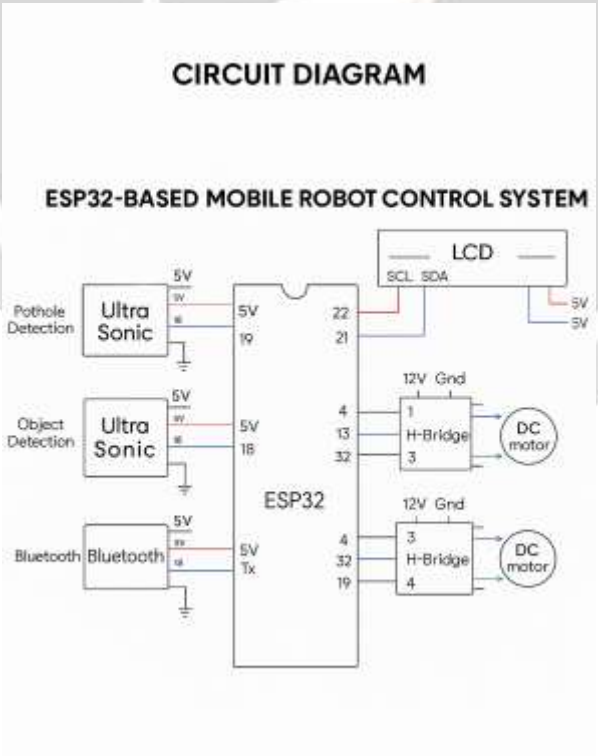


Fig -1 Block Diagram

- Ultrasonic sensor (pothole detection) → ESP32 Microcontroller → Motor driver/DC motors (filling and leveling)
- Ultrasonic sensor (object detection) → ESP32 Microcontroller → Navigation control (collision avoidance)
- ESP32-CAM → ESP32 Microcontroller → Telegram/Bluetooth module (live monitoring and operator alerts)

3.2 CIRCUIT DIAGRAM



The circuit diagram illustrates the hardware architecture of an ESP32-based mobile robot control system designed for autonomous pothole detection, obstacle detection, and navigation. The system integrates two ultrasonic sensors—one dedicated to pothole detection and the other for obstacle avoidance—each interfaced with the ESP32 through designated GPIO pins for trigger and echo signal processing. A Bluetooth module is connected to the ESP32 for manual override and wireless control. The LCD display communicates via I2C (SCL and SDA) lines to provide real-time system feedback. Motor actuation is achieved using two H-Bridge driver modules, each powered by a 12-V supply and controlled by the ESP32 through PWM-enabled pins, enabling bidirectional control of the DC motors. Proper grounding and regulated 5-V supply lines are distributed across all components to ensure stable operation. This modular and efficient circuit layout supports real-time sensing, processing, communication, and locomotion, enabling the robot to autonomously detect potholes and navigate safely in dynamic environments.

3.1 WORKING PRINCIPLE

In automatic mode, the robot advances using DC motors while an ultrasonic sensor constantly scans the road ahead to detect depth variations that indicate potholes. When a potential pothole is identified, the system confirms it by comparing sensor readings to preset thresholds. Simultaneously, a second ultrasonic sensor monitors for obstacles. If any obstructions are found, the robot pauses to prevent collisions and resumes only when the path is clear.

Once a pothole is detected, the robot halts at the correct position. A DC motor-controlled dispensing unit activates, releasing filling material such as sand, tar, or gravel into the pothole. Following the filling phase, another motor powers a roller mechanism to compact and level the repair material, restoring the road surface. Throughout this process, the ESP32-CAM streams live video for real-time operator monitoring. The ESP32 also sends Telegram notifications updating the status, such as detecting a pothole, initiating the filling, or successfully completing the repair.

For challenging environments where automation may not be feasible, manual mode permits operators to control the robot and all mechanisms via Bluetooth commands. After each repair, the robot resumes forward movement and continues scanning for additional potholes until the filling material is depleted or the designated area is covered, thus automating and streamlining routine road maintenance operations.

4. HARDWARE AND SOFTWARE REQUIREMENTS

4.1 HARDWARE REQUIREMENTS

- ESP32
- H-Bridge
- DC Motor
- Ultrasonic Sensor
- Bluetooth
- Power Supply

4.1 SOFTWARE REQUIREMENTS

- Arduino IDE
- Embedded C

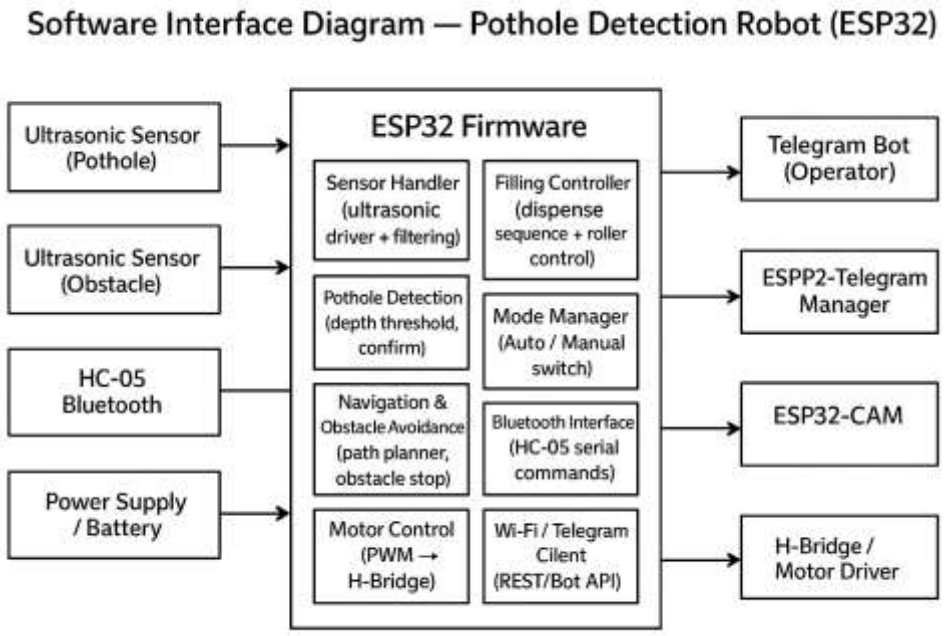
5. RESULTS

5.1 HARDWARE INTERFACE

Fig1: Pathole detection and filling Robot

The hardware architecture of the proposed system integrates a solar-powered energy module, a control unit, sensing elements, communication components, and electromechanical actuation. A photovoltaic panel serves as the primary energy source and charges a sealed rechargeable battery, which subsequently supplies regulated 5 V and 12 V outputs through a dedicated voltage regulator circuit. The microcontroller functions as the central processing unit and interfaces with peripheral modules, including dual L293D motor driver units, an ultrasonic ranging sensor, an alphanumeric LCD module, and a Bluetooth communication interface. The motor driver circuits receive control signals from the microcontroller to operate the left and right DC motors responsible for system mobility. The ultrasonic sensor (HC-SR04) is interfaced via digital Trigger and Echo pins to enable real-time distance measurement for obstacle or pothole detection. A 16×2 LCD display provides real-time visualization of operational parameters such as distance readings and system status. Wireless communication is facilitated through the HC-05 Bluetooth module using serial TX/RX interfacing for remote command transmission and status monitoring. Collectively, these hardware interfaces establish an integrated, solar-powered embedded platform capable of sensing, computation, actuation, communication, and user interaction.

5.2 SOFTWARE INTERFACE



The software architecture of the proposed pothole detection robot is implemented on the ESP32 platform and incorporates multiple functional modules for sensing, control, communication, and operator interaction. The firmware receives input from two ultrasonic sensors—one dedicated to pothole depth measurement and the other for obstacle detection—which are processed by a sensor-handling module that includes device drivers and signal-filtering routines. A pothole-detection module evaluates depth thresholds and confirms anomalies, while a navigation and obstacle-avoidance module performs basic path planning and stopping functions. Motor control is managed through PWM-based actuation signals issued to the H-bridge motor driver. A filling-controller module governs the material-dispensing mechanism and roller actuation. System operation is supervised by a mode-management unit that handles automatic and manual switching. For communication, the firmware integrates a Bluetooth-interface module to process HC-05 serial commands and a Wi-Fi/Telegram client that communicates with a remote operator via REST or Bot API services. External interfaces include the Telegram bot for operator control, ESP32-CAM for visual monitoring, and the motor driver for mobility actuation. Through this modular software design, the system achieves real-time sensing, autonomous navigation, remote control, and coordinated repair operations.

7. CONCLUSIONS

In conclusion, the Automatic Pothole Detection and Filling Robot showcases how automation, IoT integration, and smart control systems can transform conventional road maintenance into a faster, safer, and more efficient process. By combining real-time monitoring, automated detection, and self-repair mechanisms, this system not only reduces human effort but also enhances road safety and maintenance quality. Future developments like AI-based image detection and large-scale deployment can further expand its scope, making it a valuable step toward smart and sustainable urban infrastructure.

8. REFERENCES

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