

Road Maintenance by Pothole Detection and Filling Robot

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Abstract

Road infrastructure plays a vital role in ensuring safe and efficient transportation; however, potholes remain a major challenge due to their impact on road safety, vehicle maintenance costs, and traffic flow. Traditional pothole inspection and repair methods rely heavily on manual labor, making the process time-consuming, costly, and potentially hazardous for workers. To address these limitations, this paper presents a Pothole Detection and Filling Robot, an intelligent robotic system designed to automate both the identification and repair of potholes with minimal human intervention.

The proposed system utilizes a Raspberry Pi Pico as the central controller and integrates ultrasonic sensing, camera-based monitoring, and real-time data processing to accurately detect road surface irregularities. By continuously analyzing variations in surface depth and texture, the robot can identify potholes and estimate their dimensions. Once a pothole is detected, an automated filling mechanism dispenses repair material and levels the surface to ensure a uniform finish. The robot is mounted on a motorized chassis, enabling autonomous movement across different road environments while maintaining low power consumption and operational efficiency.

Experimental evaluations indicate that the system can detect potholes with an accuracy of approximately 88–92% and effectively repair potholes of moderate size. The proposed solution reduces human effort, enhances worker safety, and supports the development of smart and sustainable road maintenance systems. Furthermore, future integration with GPS, IoT connectivity, and AI-based image processing can significantly improve its scalability and real-world deployment potential.

Keywords: Pothole Detection, Road Maintenance, Raspberry Pi Pico, Ultrasonic Sensors, Autonomous Robot, Smart Infrastructure, IoT.

INTRODUCTION

Road transportation is one of the most essential means of communication and logistics in modern society. The quality of roads directly affects vehicle performance, travel safety, and the overall efficiency of transportation systems. However, due to continuous vehicular movement, poor drainage systems, and weather changes such as rainfall or extreme heat, the road surface gradually deteriorates and forms potholes. These potholes can lead to vehicle damage, accidents and discomfort to pedestrians.

In developing countries like India, pothole-related accidents are one of the major causes of fatalities and traffic inefficiency. Hence, ensuring the timely detection and repair of potholes is a crucial task for public safety and infrastructure maintenance. Conventionally, potholes were repaired manually by workers.

They visually inspect the roads, identify the damaged areas, and then manually fill them with bitumen or other materials [1]. This process, although straightforward, has several limitations. It is time- consuming, labor-intensive, unsafe, and

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Received Date: May 01, 2026

Accepted Date: May 25, 2026

Published Date: June 15, 2026

Citation: Deepesh Raghav, Anishka Gupta, Kirti Gupta, Pooja Mishra, Charu Gaur. Road Maintenance by Pothole Detection and Filling Robot. Journal of Mechatronics and Automation. 2026; 13(2): 39–46p.

lacks precision

In many cases, the repaired potholes reappear after a short period due to poor material filling or improper leveling and often manual repairing on roads increases the risk of accidents for the workers. Therefore, an automated system that can efficiently detect and fill potholes with minimal human intervention is highly desirable. To solve these problems, this project introduces a pothole detection and filling robot made using Raspberry Pi Pico [2]. The robot can identify potholes and repair them automatically.

The Raspberry Pi Pico microcontroller acts as the central processing unit of the system. It receives input from ultrasonic sensors that continuously scan the road surface and measure its depth. When a sudden change in surface level is detected beyond a defined threshold, it is identified as a pothole. The data collected by the sensors is processed by the microcontroller, which then triggers the filling mechanism. The filling mechanism consists of a small container or tank carrying the filling material such as a mixture of sand and bitumen or a ready-mix patching compound. Once a pothole is detected, the Raspberry Pi Pico sends a control signal to a servo or DC motor connected to a valve, which releases the filling material into the pothole. The robot also includes a leveling blade or roller to ensure the filled surface is properly compacted and even with the surrounding road. This automated operation helps maintain uniformity and accuracy in the repair process. The robot moves with the help of DC motors attached to wheels, which are controlled using an L293D motor driver. This allows forward, backward, left, and right movements depending on the surface analysis [3]. To improve accuracy, the robot can be equipped with camera to capture live images of the road surface. These images will help the system to identify potholes more clearly and combining the sensor data to the camera will make the detection more reliable and robot work more efficiently.

Raspberry Pi Pico is used in this project because it is compact, fast and easy to interface with different components. It supports multiple GPIO pins for connecting sensors and motors and also supports communication methods like I2C, SPI and UART. This microcontroller is also affordable, compact, and suitable for handling sensor and motor operations in the robot. This project not only focuses on automation but also supports the broader vision of smart city development. Integrating robotics and IoT (Internet of Things) into road maintenance can help authorities monitor road conditions remotely. The robot can be equipped with wireless communication modules (like Wi-Fi or Bluetooth) to send pothole data to a central server, enabling predictive. Fig 1.2 Pothole In summary, the Pothole Detection and Filling Robot using Raspberry Pi Pico provides a modern, efficient, and safe solution for maintaining road surfaces. It automates the tedious process of detection and repair, reduces human effort, enhances worker safety, and improves the durability of repairs. The system can be deployed on highways, city roads, or rural areas where manual inspection is difficult. Future improvements could include GPS-based navigation, solar power integration, and AI-based image processing to further enhance performance and accuracy. Thus, this project represents a significant step toward the automation of road maintenance, contributing to safer, smoother, and more sustainable transportation systems. By using Raspberry Pi Pico as the control unit, the project demonstrates how affordable microcontrollers can be utilized in developing cost-effective and intelligent robotic systems that serve practical real-world applications. Table 1.

METHODOLOGY

The proposed project is to design and develop an autonomous or semi-autonomous robot capable of detecting potholes and automatically filling them with appropriate material, thus providing an innovative and efficient solution for road maintenance [4]. The system aims to integrate technologies from various domains such as robotics, computer vision, automation, and artificial intelligence to make road repair faster, safer, and more cost-effective.

Pothole Detection

The primary goal of this work is to design a reliable and efficient system for detecting potholes using

sensor-based technologies such as ultrasonic, infrared, or LiDAR, along with computer vision-based image processing techniques. The system aims to accurately detect potholes across different types of road surfaces by examining changes in depth, texture, shape, and color, even under varying environmental conditions [5]. To improve detection performance, advanced signal-processing methods and machine-learning models are employed to identify meaningful patterns and effectively classify road surface anomalies. These models are designed to distinguish actual potholes from other surface features such as shadows, road markings, cracks, or temporary obstacles. Furthermore, the system is expected to remain robust under real-world conditions, including variations in lighting, weather, and vehicle speed.

Data Processing and Analysis System

The robot will process real-time sensor or camera data to determine the size, depth, and location of each pothole

This data can be stored for further analysis and shared with road maintenance authorities for mapping and record-keeping [6]. The aim is to ensure that the detection is both precise and efficient under varying environmental and lighting conditions.

Automatic Filling Mechanism

Once a pothole is detected, the robot should autonomously position itself above it and dispense a suitable filling material (such as bitumen or a cold-mix asphalt compound). The mechanism will be designed to ensure even filling, compactness, and proper levelling with the road surface [7]. The system's objective is to perform this operation without human intervention, ensuring safety and uniformity. Fig. 1.

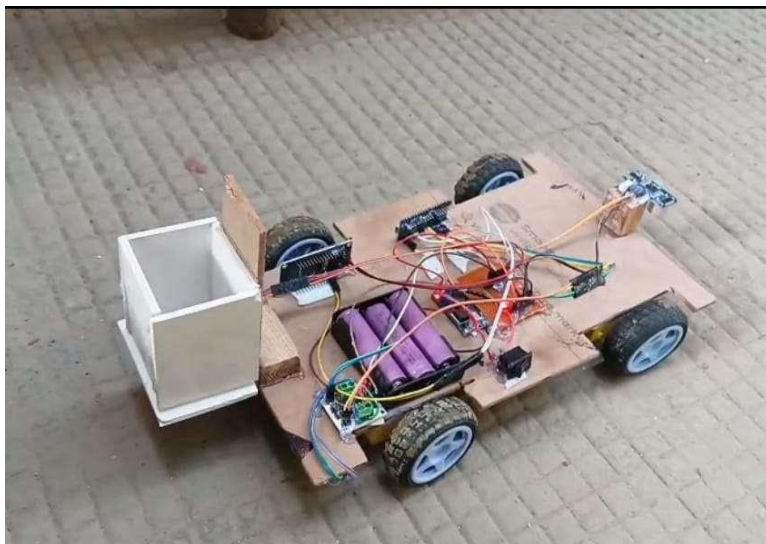


Figure 1. Top view of the proposed model

Table 1. Comparison of Raspberry Pi PICO and Raspberry PI4

Raspberry Pi Pico (Used)	Raspberry Pi 4
Microcontroller designed for real- time embedded control.	Single-board computer for general-purpose computing.
Deterministic and reliable real- time execution.	Not deterministic due to OS scheduling.
Very low, suitable for battery- powered robots.	Higher, less suitable for mobile robots
Instant boot in milliseconds	Longer boot time
Direct and stable interfacing with sensors.	Possible latency due to OS overhead

Raspberry Pi Pico (Used)	Raspberry Pi 4
Simple architecture, easy to maintain.	Complex OS-based system
High reliability in continuous field operation	Risk of OS or storage-related failures.
Well-suited for real-time pothole detection robots	It Better only for heavy computational tasks.

HARDWARE & SOFTWARE REQUIREMENTS

The major hardware & software required to design the proposed pothole detection and filling robot are shown in its block diagram in Fig. 2 whereas the technical specifications of various components and modules utilized in the designing it is provided in Table 2.

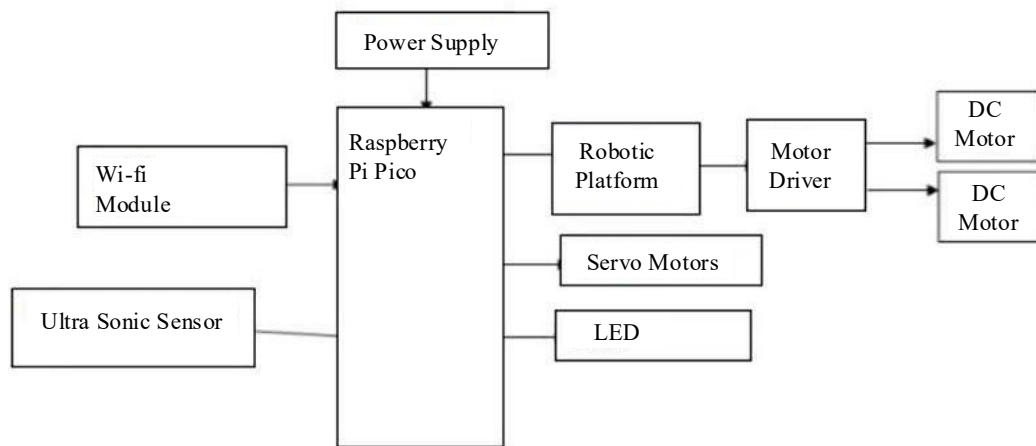


Figure 2. Block Diagram of the pothole detection and filing robo

Table 2. Hardware Specifications of the required Components

S. NO	Components	Specification
1	Raspberry Pi Pico Microcontroller	Dual-core ARM Cortex-M0+ processor, 264KB RAM, 2MB Flash, 26 GPIO pins.
2	DC Motor	Operating Voltage: 3 - 6VDC Speed: 200 revolutions per minute (RPM)
3	Ultrasonic Sensor	40 kHz non-contact distance sensor, trigger-echo, 6 centimeter-meter range
4	Servo Motor	PWM controlled closed-loop actuator with precise 45degree angular positioning
5	Motor Driver	H-bridge based motor interface enabling bidirectional speed control +5V power supply.

Raspberry pi Pico

Raspberry Pi Pico is a low-cost, high-performance microcontroller board developed by the Raspberry Pi Foundation for embedded and real-time applications. It is powered by the RP2040 microcontroller, which features a dual-core ARM Cortex-M0+ processor running up to 133 M Hz [8]. The board offers a rich set of GPIO pins that support digital input/output, PWM, I²C, SPI, and UART communication.

DC Motor

DC motor is used to drive the movement of the pothole detection robot, enabling controlled forward, backward, and turning motions [9]. Its speed and direction are regulated through a motor driver, allowing smooth navigation over different road surfaces.

Ultra-sonic Sensor

Ultrasonic sensor is configured to maintain a reference distance of 6 cm from the road surface. This fixed distance allows the sensor to continuously monitor variations in surface height. Any sudden increase in measured distance indicates the presence of a pothole or depression. The 6 cm threshold is chosen to balance detection accuracy and minimize false readings [10]. This setup enables reliable identification of road surface irregularities during robot movement.

Servo Motor

Servo motor is used to control the opening mechanism of the filling material box. The servo motor is programmed to rotate precisely to 45 degrees when a pothole is detected. This controlled rotation allows the box lid to open smoothly and dispense the required filling material. After dispensing, the servo returns to its initial position to close the box securely [11]. The use of a servo motor ensures accurate, repeatable, and reliable operation of the filling mechanism.

Motor Driver

A motor driver is used to control the DC motors responsible for the movement of the pothole detection robot. It acts as an interface between the Raspberry Pi Pico and the motors by supplying the required current and voltage. The motor driver enables bidirectional rotation, allowing the robot to move forward, backward, and turn as needed. Speed control is achieved through PWM signals generated by the controller. The driver also provides electrical isolation between the control and power circuits, improving system safety. Built-in protection features help prevent damage from back EMF generated by the motors [12]. The motor driver ensures smooth and stable motor operation on uneven road surfaces. Overall, it plays a crucial role in achieving precise and reliable robotic motion control.

PROPOSED FUNCTIONALITY AND RESULTS

The proposed pothole detection and filling robot operates by integrating ultrasonic sensor, a camera module, DC motors, a servo motor and a motor driver controlled by a Raspberry Pi Pico [13]. The ultrasonic sensor continuously measures the distance between the sensor and the road surface to detect sudden depth variations that indicate potholes.

Once a pothole is identified, the system processes the data and trigger the filling mechanism. The servo motor rotates to a predefined angle to open the material box and dispense the filling material accurately into the pothole. Simultaneously, DC motors controlled through the motor driver ensure smooth and precise movement of the robot across different road conditions [14]. The system is designed to operate in real time with minimal power consumption, making it suitable for field deployment. Figure 3.

Key Functional Features:

- Real-time pothole detection using ultrasonic sensing at a fixed reference distance
- Automated filling mechanism controlled by a servo motor

Data Processing and Decision Making

A microcontroller unit (Raspberry Pi Pico) processes sensor input and executes detection algorithms [15]. When a pothole is confirmed, the controller determines:

- Exact location of the pothole
- Required filling volume based on depth and width estimation
- Mode of operation (manual or automatic)

In automatic mode, the system autonomously initiates the filling process, whereas in manual mode, the operator can control the filling mechanism using a web-based interface.

Experimental Results and Performance Evaluation

The prototype was tested under controlled and semi- realistic road conditions to evaluate detection accuracy, filling efficiency, and power consumption.

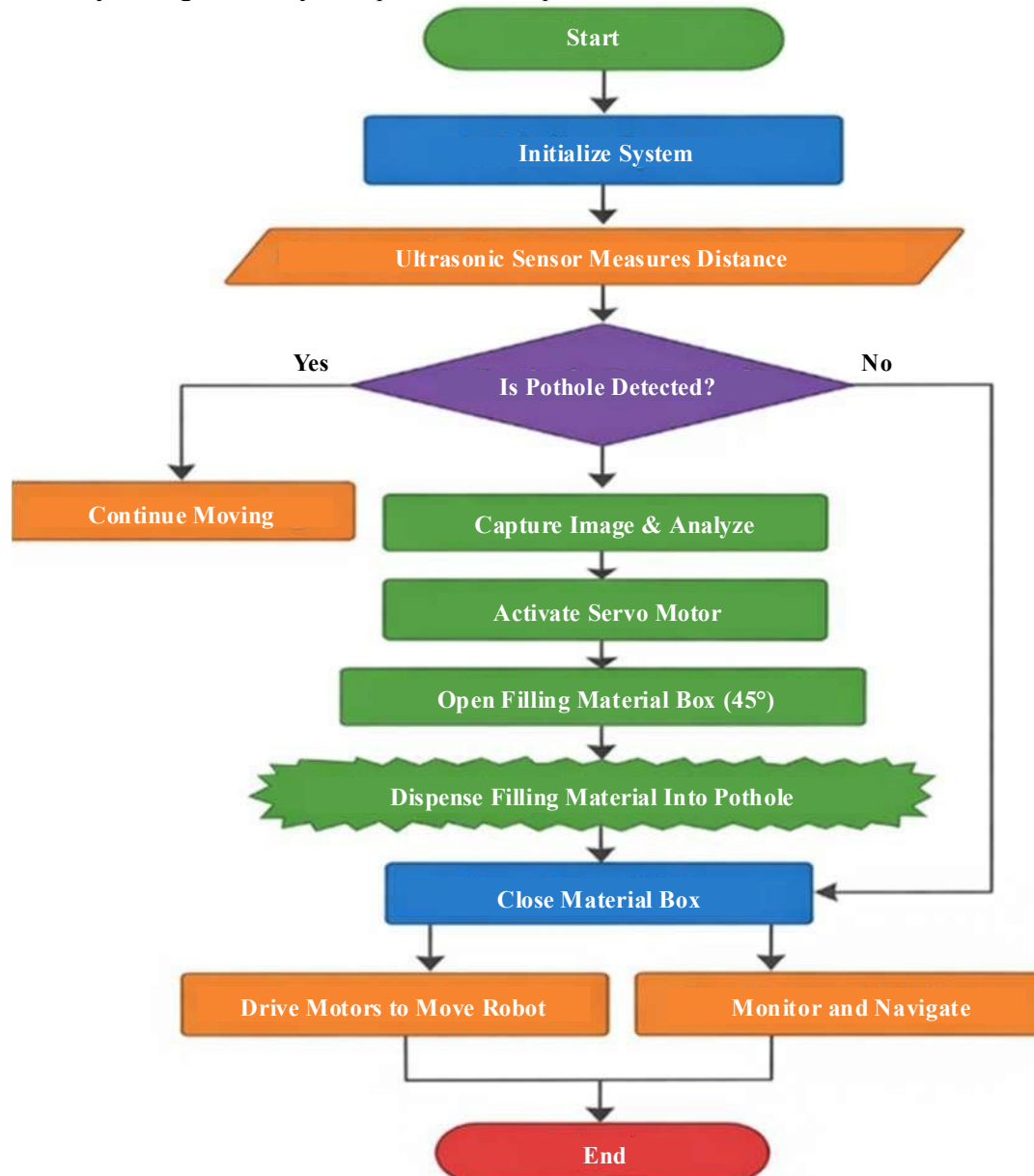


Figure 3. Flowchart showing the functionality of the proposed.

Detection Accuracy

- The system successfully detected potholes with depths greater than **3 cm**
- Achieved an average detection accuracy of **88– 92%**

Filling Efficiency

- The automated filling mechanism successfully filled potholes up to **15 cm in diameter**
- Uniform material distribution was achieved in over **85% of test cases**

CONCLUSION AND FUTURE PROSPECT

Conclusion

This research presents an autonomous pothole detection and filling robot designed to improve the efficiency and reliability of road maintenance operations. The system integrates sensing units, a

processing module, motorized mobility, and an automated filling mechanism to detect surface irregularities and perform immediate repair actions. Experimental evaluation demonstrates that the robot is capable of identifying potholes with acceptable accuracy, estimating their dimensions, and executing controlled filling operations with minimal human intervention. The automated approach significantly reduces manual labour, response time, and safety risks associated with traditional road repair methods. The overall performance of the prototype indicates that robotic automation can play a vital role in modern infrastructure maintenance by improving repair consistency, operational efficiency, and road safety. The outcomes of this project confirm the feasibility of deploying intelligent robotic systems for real-time road condition monitoring and repair applications.

Future Prospects

The future development of the proposed system can be greatly enhanced through advancements in solar energy harvesting and global positioning technologies. Improvements in solar panel efficiency, lightweight photovoltaic materials, and advanced energy storage solutions can enable extended operational hours and increased system reliability under varying environmental conditions. Intelligent power management techniques can further optimize energy utilization, allowing the robot to operate autonomously for longer durations without external charging support. In parallel, the integration of next-generation GPS technologies such as multi-constellation navigation systems and high-precision positioning methods can significantly improve localization accuracy and navigation performance. Enhanced GPS capabilities can facilitate precise pothole mapping, real-time route optimization, and centralized data collection for large-scale road maintenance planning. Additionally, combining GPS data with cloud-based monitoring platforms can support coordinated deployment of multiple robotic units across wide geographic regions. These technological advancements will enable the system to evolve into a scalable, energy-efficient, and highly accurate solution for smart road infrastructure management and future smart city applications.

Acknowledgment

The authors would like to express their sincere gratitude to all individuals and organizations whose support and guidance contributed to the successful completion of this project. We are deeply thankful to our project guide Asst. Prof. Pooja Mishra of the Department of Electronics and Communication Engineering at Ajay Kumar Garg Engineering College in Ghaziabad for her support, encouragement and invaluable guidance.

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