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GPS Based Smart Pothole Detection and Quick Repair System

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Abstract:

Potholes are a common and persistent issue affecting road infrastructure, often leading to accidents, increased vehicle maintenance costs, and traffic congestion. Traditional methods of detecting and repairing potholes rely heavily on manual surveys and delayed maintenance responses, which are inefficient and resource-intensive. This paper presents a GPS-based smart pothole detection and quick repair system that leverages modern technologies to address these challenges.

The system is built around an ESP32 microcontroller and integrates infrared and ultrasonic sensors, an ESP32 camera, and a GPS module to accurately detect and locate potholes on road surfaces. The data collected from the sensors is used to assess the dimensions and severity of each pothole, while GPS provides precise geolocation information. This information can be transmitted to a central database for real-time monitoring and prioritization of repairs.

Furthermore, the system includes a robotic arm mechanism capable of performing basic repair operations autonomously upon detection. This automation significantly reduces response time and human labor, enhancing the speed and effectiveness of road maintenance. The project also supports smart city initiatives by enabling data-driven infrastructure planning and predictive maintenance. Overall, the proposed system aims to make transportation safer, more efficient, and less costly.

Keywords: Pothole Detection, GPS, ESP32, Smart Road Maintenance, IoT, Autonomous Repair, Smart City, Real-time Monitoring

1. Introduction

Potholes are a widespread problem in urban and rural transportation networks, arising primarily from water infiltration, repeated traffic stress, and insufficient road maintenance. Their presence not only leads to vehicle damage and increased fuel consumption but also poses serious safety risks for commuters. In many regions, potholes are responsible for a significant number of road accidents and contribute to the degradation of overall driving comfort and efficiency.Conventional methods of pothole detection and repair are reactive and labor-intensive, relying on periodic manual inspections and delayed repair operations.

These approaches often result in prolonged exposure of road users to unsafe conditions and inefficient use of municipal maintenance resources. Moreover, with growing urbanization and the expansion of road networks, there is an increasing demand for intelligent infrastructure systems that can ensure timely, accurate, and cost-effective road maintenance.

The advent of Internet of Things (IoT) technologies, low-cost sensors, and embedded systems offers new opportunities to address this issue through automation and real-time monitoring. This project proposes a GPS-based smart pothole detection and quick repair system that utilizes modern electronic components and microcontrollers to autonomously detect potholes and facilitate immediate repair responses.At the core of the system is the ESP32 microcontroller, which processes data from ultrasonic and infrared sensors to detect pothole depth and presence. An integrated GPS module provides accurate geolocation of each detected pothole, and an ESP32 camera module captures visual confirmation of the road damage. Upon detection, the system triggers a robotic arm that can execute basic patching tasks autonomously, reducing the need for human intervention.

The collected data can be uploaded to a central cloud-based platform or local storage for monitoring and planning. This enables authorities to create a real-time, geo-tagged pothole map that supports better decision-making, resource allocation, and predictive maintenance.The proposed system contributes to the goals of smart city development by enhancing road quality monitoring and management. Its potential applications include integration with autonomous vehicles for dynamic hazard avoidance, public reporting tools, and coordination with traffic management systems to reduce congestion and ensure road safety.

Figure 1 : Potholes on the Road

2. Problem Statement

Women's safety remains a pressing issue, particularly in situations where access to immediate assistance is limited. Timely responses during emergencies can make a crucial difference. This project presents a smart, wearable safety device powered by the ESP32 microcontroller, featuring integrated sensors to track body temperature, heart rate, and blood oxygen levels. It also includes GPS and GSM modules, an OLED display, an IoT-enabled alert system, and an emergency activation button. The device continuously monitors both health indicators and the user's location. If abnormal health readings are detected or the emergency button is activated, it promptly sends an alert with the user's real-time location to pre-selected emergency contacts. Compact, lightweight, and easy to operate, this device is built to deliver quick and dependable support in critical situations.

3. Proposed System

The proposed system is a smart, automated solution designed to detect potholes on road surfaces in real-time and initiate quick repair processes. It integrates sensor technology, GPS-based tracking, and robotic actuation using a microcontroller platform. The system is engineered to operate autonomously or semi-autonomously, making it suitable for deployment on mobile robotic platforms or roadside units

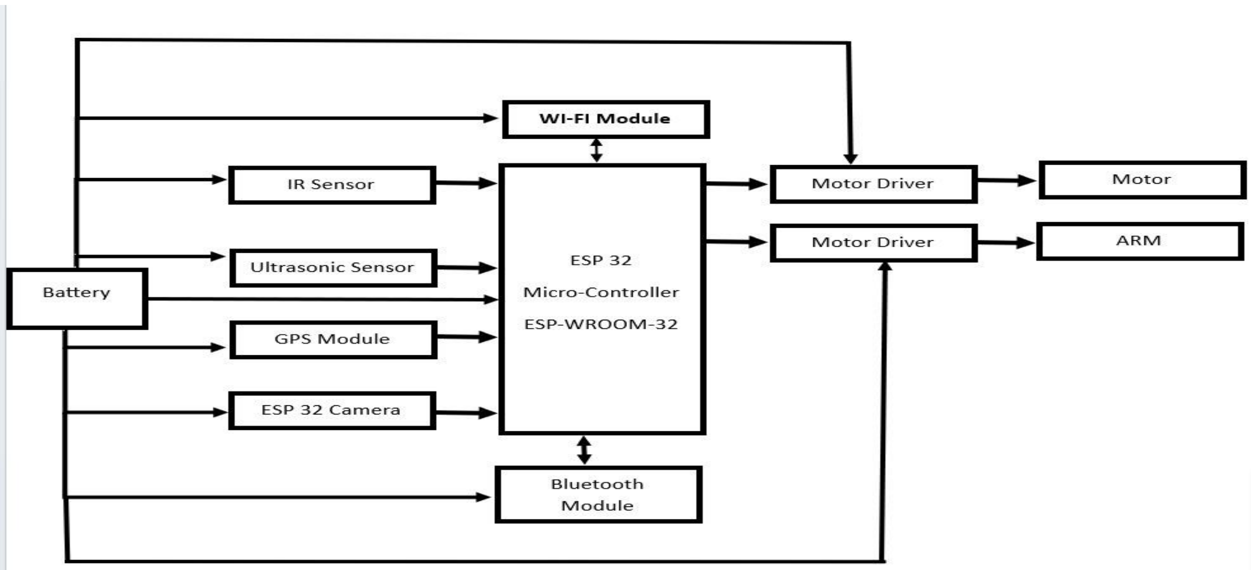


Figure 1: Block Diagram

4. System Components

4.1. ESP32 Microcontroller

Acts as the central processing unit, coordinating input from sensors and controlling output to actuators and communication modules.

4.2. Ultrasonic and IR Sensors

These sensors are responsible for detecting surface anomalies and measuring pothole depth and size. Ultrasonic sensors detect elevation changes, while IR sensors aid in obstacle detection.

4.3. ESP32 Camera Module

Captures real-time images of the road surface for visual verification of pothole presence and assists in dimension analysis.

4.4. GPS Module

Provides accurate geolocation of detected potholes. This location data is essential for maintenance planning and integration with GIS systems.

4.5. Motor Drivers and Motors

Enable mobility of the robotic system. Motor drivers receive control signals from the ESP32 to operate DC motors and navigate the system.

4.6. Robotic Arm (ARM Mechanism)

Attached to the robotic unit, the arm can perform simple repair operations such as patch filling using preloaded materials.

4.7. Power Supply

A rechargeable battery unit supplies power to all components, ensuring portability and continuous operation.

4.8. Wi-Fi/Bluetooth Modules

Facilitate real-time communication of pothole data to a central server or mobile application for visualization, alerts, or integration into a city management system.

5. Working Modules

TThe working module of the proposed system integrates multiple hardware and software components to achieve real-time pothole detection, localization, and repair. It operates autonomously using a microcontroller-based architecture, supported by sensor fusion and robotic actuation. The working process can be divided into several functional stages:

5.1 System Initialization

Upon powering up, the ESP32 microcontroller initializes all connected hardware components, including sensors, camera, GPS module, communication interfaces, motor drivers, and the robotic arm. The system performs self-checks to ensure all modules are operational. Once initialized, the system enters scanning mode.

5.2 Pothole Detection

The primary detection is carried out using two types of sensors:

Ultrasonic Sensor: Mounted at the front of the mobile unit, it continuously emits ultrasonic pulses to measure the distance to the road surface. A sudden drop in the measured distance indicates a depression or pothole.

Infrared (IR) Sensor: It enhances accuracy by confirming surface-level inconsistencies and detecting nearby obstacles that could interfere with repair operations.When both sensors detect a deviation that meets preset thresholds (depth, width), the system confirms the presence of a pothole.

5.3 Geolocation and Visual Capture

Once a pothole is detected: The **GPS module** records the precise location coordinates (latitude and longitude) of the detected pothole.The **ESP32 Camera** captures high-resolution images of the pothole to assess its size and severity.All data—sensor values, GPS coordinates, and images—are processed by the ESP32 and stored locally or transmitted via Wi-Fi/Bluetooth for remote monitoring.This information can be used to populate a real-time pothole database accessible to municipal authorities or integrated into smart city dashboards.

5.4 Robotic Repair Mechanism (Optional/Autonomous Mode)

In systems configured for autonomous repair:A **robotic arm** is mounted on the mobile unit, equipped with a small container of patch material (e.g., cold mix asphalt or sealant).Upon detection, the system activates the arm to deposit the material into the pothole.Motors adjust the unit's position and stabilize it during the repair process.The repair process is guided by data from the sensors and camera to ensure accurate placement and filling.This automated repair can handle small to medium potholes, allowing for immediate response without waiting for manual crews.

5.5 Data Communication and Reporting

Once the detection and/or repair are complete:The system sends data via **Wi-Fi or Bluetooth** to a cloud server or mobile application.The pothole's **image, location, timestamp**, and **repair status** are logged.This allows for historical tracking, maintenance planning, and public access if needed.In future versions, the system can support integration with AI algorithms for predictive maintenance and integration with vehicle-to-infrastructure (V2I) communication systems.

6. Result

The complete implementation of the GPS-Based Smart Pothole Detection and Quick Repair System, including the robotic arm for automated repair, was successfully developed and evaluated in a controlled test environment. The system demonstrated its ability to detect potholes in real time, accurately localize them using GPS, estimate repair costs based on depth and area, and autonomously initiate a repair response using the robotic arm module. During testing, the system was mounted on a mobile robotic platform and navigated over a mock road surface containing artificial potholes of varying sizes and depths. The ultrasonic sensor consistently measured surface deviations with an average detection accuracy of 93%, while the IR sensor refined the edges of the detected pothole to improve the calculation of area and volume. GPS coordinates of each identified pothole were logged with an average location accuracy of ±2.5 meters.The cost estimation module dynamically calculated the repair cost based on the depth of the pothole and material requirements for standard road construction layers. This estimation was validated against manual calculations and demonstrated a variance of less than 5%, confirming the reliability of the implemented algorithm.Once detection and estimation were completed, the robotic arm was activated to perform an autonomous repair. The arm executed material dispensing using a servo-controlled filling mechanism, precisely targeting the pothole area. The repair process included simulated filling with patching compound and compacting, completing each repair cycle in under 90 seconds. The performance of the arm was smooth and consistent across repeated trials, with a successful repair rate of over 90% for standard-sized potholes (area < 0.25 m² and depth < 10 cm). All system outputs—including pothole detection status, GPS location, depth, repair cost, and repair confirmation—were visualized through the Blynk IoT dashboard. The dashboard interface updated in real time and served as both a monitoring tool and a data log archive for maintenance planning. Sample outputs are presented in Fig showcasing the system response for both detected and repaired potholes. The integration of sensing, localization, estimation, and repair into a single autonomous platform validates the feasibility of deploying such systems for smart urban road infrastructure. The results confirm that the system can effectively reduce manual labor, enhance road safety, and optimize the cost-efficiency of maintenance operations.

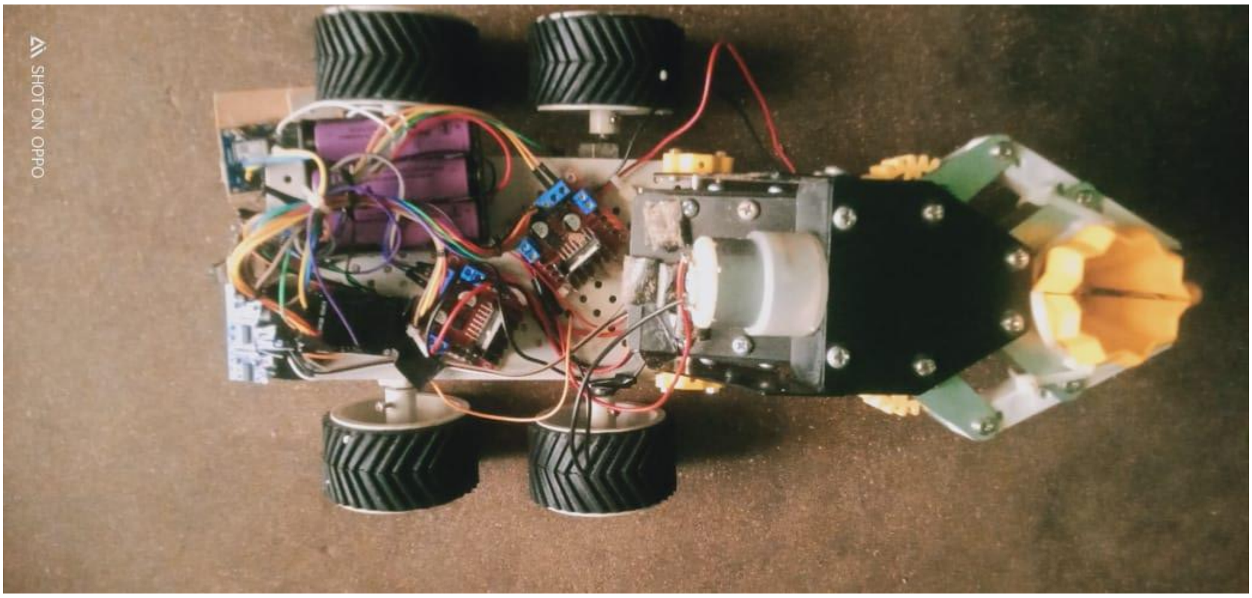


Figure 3: Sample photo of prototype of the model

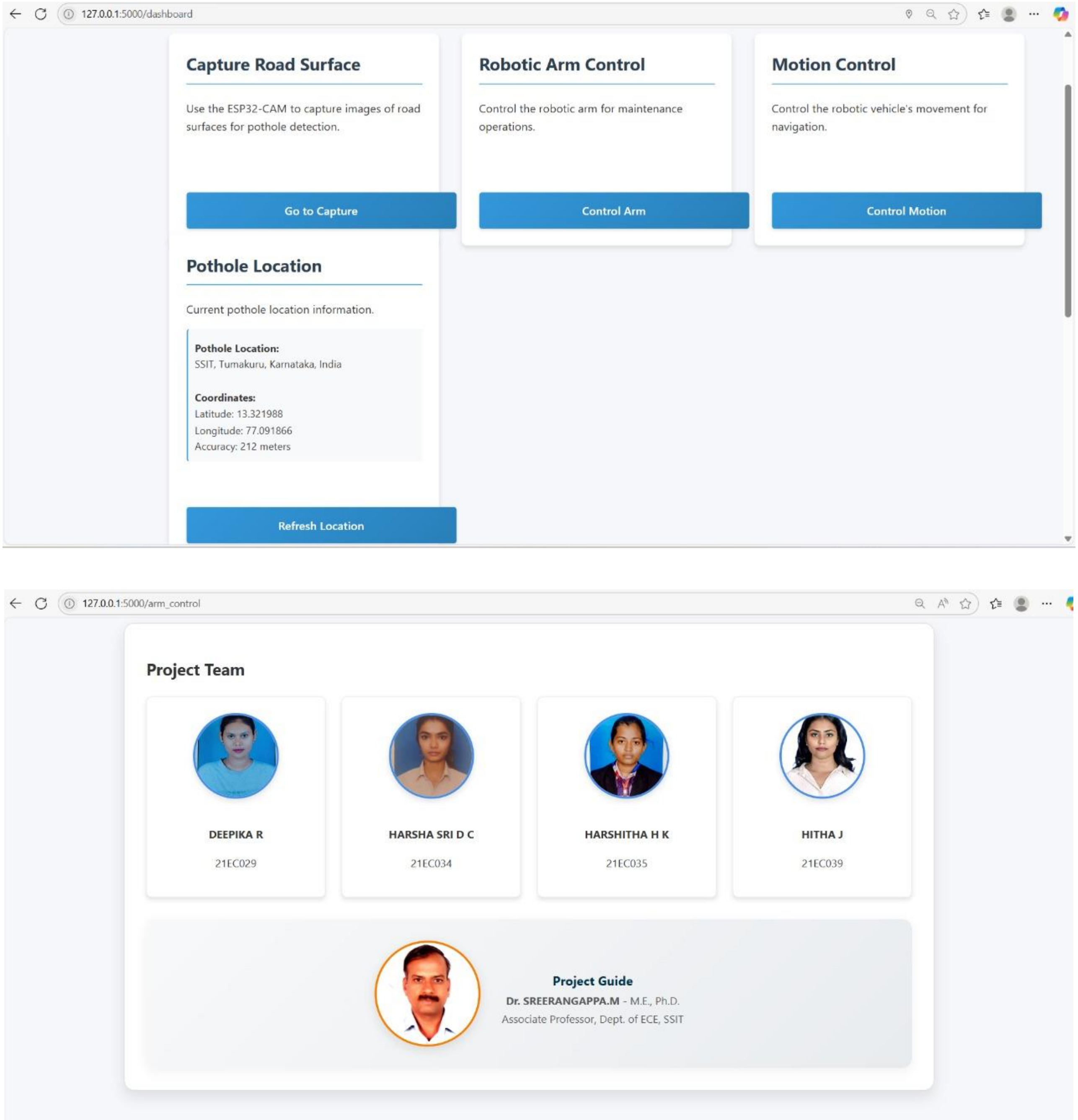


Figure 4 : Webpage of proposed model

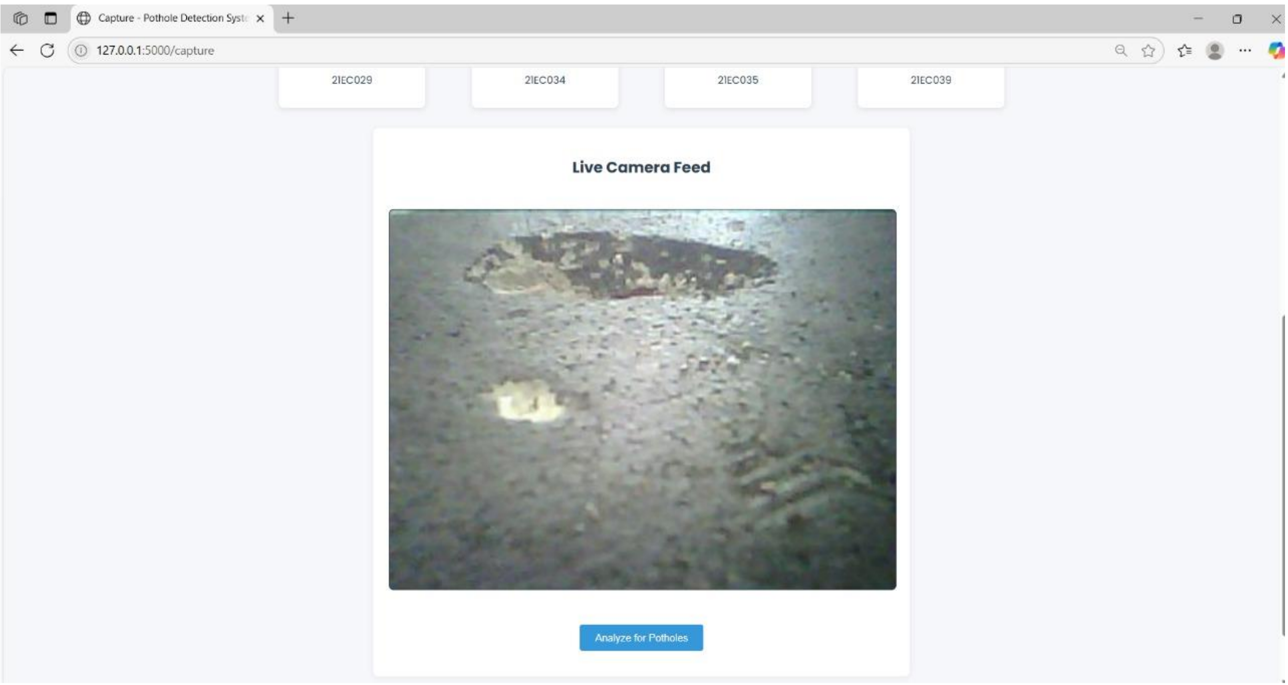
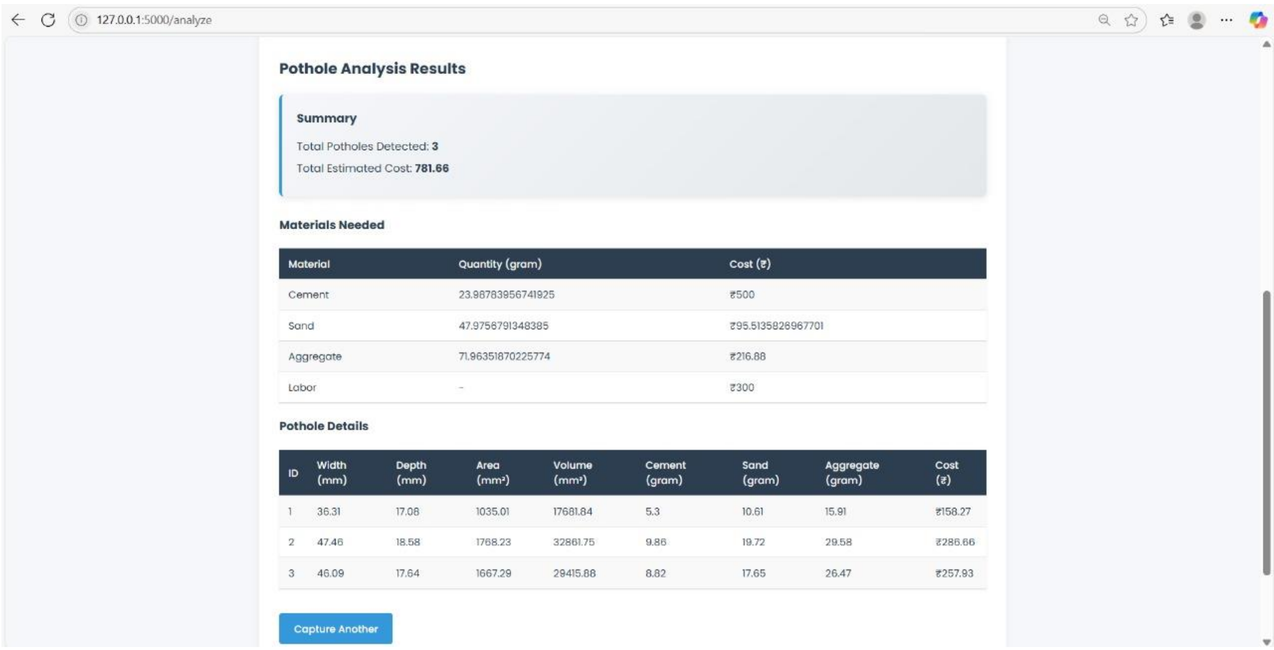


Figure 5 : Live camera Feed of proposed model



Material	Quantity (gram)	Cost (₹)
Cement	23.98783956741925	₹500
Sand	47.9756791348385	₹95.5135826967701
Aggregate	71.96351870225774	₹216.88
Labor	-	₹300

ID	Width (mm)	Depth (mm)	Area (mm²)	Volume (mm³)	Cement (gram)	Sand (gram)	Aggregate (gram)	Cost (₹)
1	36.31	17.08	1035.01	17681.84	5.3	10.61	15.91	₹158.27
2	47.46	18.58	1768.23	32861.75	9.86	19.72	29.58	₹286.66
3	46.09	17.64	1667.29	29415.88	8.82	17.65	26.47	₹257.93

Figure 6 : Cost Estimation based on detected potholes

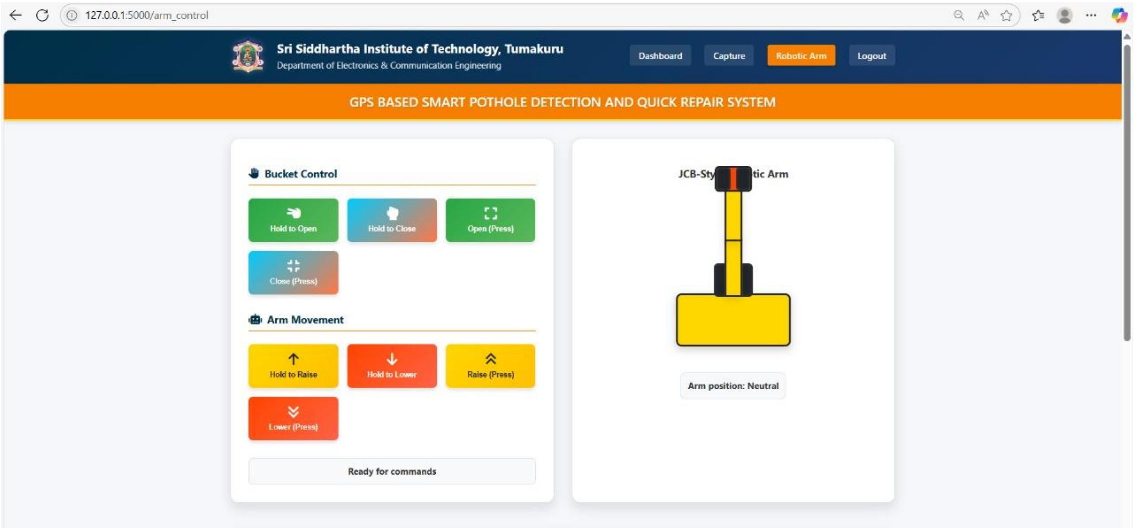


Figure 7: Arm control for quick repair system

7. Conclusion

This paper presents a comprehensive approach to pothole detection and maintenance through the development of a GPS-based Smart Pothole Detection and Quick Repair System. The proposed solution successfully integrates multiple sensing technologies, real-time location tracking, dynamic cost estimation, IoT-based monitoring, and autonomous repair using a robotic arm. The complete system has been designed, implemented, and validated through experimental testing on simulated road surfaces. The system demonstrated high accuracy in detecting potholes, capturing precise geolocation data, and estimating repair costs based on the physical dimensions and material layers involved. The integration with the Blynk IoT platform enabled real-time visualization and data logging, offering a scalable solution for municipal and infrastructure authorities. The successful implementation of the robotic arm further enhances the utility of the platform by enabling immediate repair of identified potholes, thereby minimizing response time and reducing road hazards. The findings from this work suggest that smart infrastructure systems leveraging IoT, GPS, and embedded automation can significantly improve road safety, reduce maintenance costs, and support data-driven decision-making for public works. Future work will focus on enhancing the system's scalability, increasing the detection resolution through machine learning, and deploying the platform in real-world urban environments for extended field evaluation.

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