PROJECT PROPOSAL

Project Title: Design and Implementation of a Pothole-Filling Robot Using Computer Vision

Supervisor:
Eng. Stephanie Masika

Team Members:

Shem Koech
Elisha Jilo
Disckson Mbogo

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CHAPTER ONE 1. Introduction

Potholes are a persistent problem that degrades road infrastructure and compromises vehicle safety. Traditional repair methods are labor-intensive, costly, and rely heavily on manual inspection. This project proposes an autonomous robotic system capable of detecting and filling potholes using computer vision and embedded systems.

The proposed system will incorporate a Raspberry Pi with a camera module running OpenCV to detect potholes based on surface anomalies. An Arduino-based control unit will manage both the movement and filler dispensing mechanism. This hybrid architecture leverages low-cost hardware to deliver practical and scalable automation for road maintenance.

2. **Objectives**

Design and construct an autonomous robotic vehicle.

Implement computer vision algorithms for pothole detection.

Interface the vision system with an Arduino microcontroller for actuation.

Develop a basic filler-dispensing mechanism responsive to vision feedback.

Evaluate the robot's performance in simulated road conditions.

3. **Background and Problem Statement**

In Kenya, road defects such as potholes are often left unaddressed due to the high cost and delayed response associated with traditional repair methods. While advanced road-scanning systems exist globally, they are financially out of reach for most municipalities.

This project aims to offer a scalable, low-cost solution by developing a mobile robot equipped with camera-based vision that can autonomously detect and fill potholes.

4. **Methodology**

Design Phase:

CAD modeling of the robot chassis and filler system
Component selection (Raspberry Pi, camera, Arduino, motors, filler system)

Computer Vision System:
Raspberry Pi with Pi Camera
Detection of potholes using shape and depth inference via OpenCV

Control System:

Arduino receives detection signals via serial communication
Servo-controlled filler mechanism triggered by pothole detection
Motor control using L298N driver for navigation

Testing Phase:

Field tests on surfaces with artificial potholes
Metrics logged: detection accuracy, fill time, and error rates

Tools and Technologies:

Raspberry Pi 4
Pi Camera Module
Arduino Uno
OpenCV (Python)
L298N Motor Driver
SolidWorks (for CAD modeling)
Arduino IDE and Python

5. **Expected Outcomes**

A functional prototype capable of detecting and filling potholes autonomously

Reliable computer vision algorithm for small-scale pothole identification

Integrated Arduino-controlled filler system

Performance validation under simulated conditions

A complete technical report and documentation

6. **Timeline**

Phase	Duration
Design & Planning	Week 1 – Week 2
Hardware Integration	Week 3 – Week 4
Vision System Development	Week 5 – Week 6
Testing & Calibration	Week 7
Final Report & Presentation	Week 8

7. **Resources and Budget**

Component	Cost (KES)
Raspberry Pi 4	7,000
Pi Camera Module	2,000
MicroSD & Accessories	1,000
Arduino Uno	800
DC Motors & Driver	1,200
Servo for Filler	500
Chassis & Wheels	1,500
Wires & Connectors	500
Total Estimate	14,500

8. **Conclusion**

This project aims to deliver a prototype pothole-filling robot by integrating computer vision and embedded systems. The outcome is expected to offer a cost-effective and scalable automation solution for road maintenance in resource-constrained environments.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter presents an overview of existing studies and technological advancements in the fields of pothole detection, autonomous road repair systems, and filler deployment mechanisms. It specifically focuses on their relevance and application within the context of road infrastructure maintenance in Kenya.

2.1 Pothole Detection Using Vision Systems

In Kenya, pothole detection and road maintenance are primarily manual and reactive, resulting in inefficiencies and delays. Vision-based technologies offer a more efficient and scalable approach. Previous studies, particularly from local institutions such as JKUAT and Kenyatta University, have explored using computer vision techniques like edge detection and image thresholding to identify surface anomalies that may indicate potholes. These methods rely on identifying discontinuities in surface contours and gradients. Research has demonstrated the effectiveness of shape-based classification in distinguishing potholes from other road surface irregularities, such as stains or shadows. The challenge, however, lies in adapting these techniques to Kenya's variable road conditions, such as uneven lighting and diverse surface textures. This project seeks to address these challenges by developing adaptive algorithms capable of overcoming these environmental variables.

2.2 Embedded Systems in Autonomous Road Robots

Embedded systems are a cornerstone of affordable robotics, especially for mobile applications like road maintenance. Local projects, including those by robotics groups at Nairobi-based startups and university workshops, have utilized Arduino microcontrollers due to their simplicity, affordability, and extensive local support. For more computationally intensive tasks, such as real-time image processing, the Raspberry Pi is widely used, offering an ideal balance between processing power and energy efficiency. The hybrid architecture—using the Raspberry Pi for vision processing and Arduino for motor control—has been successfully implemented in a variety of local robotics projects, ensuring reliability and ease of maintenance. This project will build upon this established architecture, aiming for an efficient and cost-effective solution for pothole detection and repair.

2.3 Navigation and Mobility in Local Road Conditions

Kenya's diverse terrain presents unique challenges for autonomous systems. Roads range from well-maintained tarmac to rough and unpaved surfaces. To address this, the mobility system of the robot must be robust enough to handle these variations. Previous academic projects have j most indoor and flat terrains. However, precision is essential when the robot needs to align perfectly with potholes. Research conducted by students at Dedan Kimathi University of Technology has explored the use of infrared sensors for distance measurement, improving robot alignment during navigation. Despite this, the complexity of these systems often increases, and therefore, this project will focus on utilizing vision-based feedback to guide the robot to accurate positioning over potholes, without requiring overly complex additional sensors.

2.4 Filler Mechanisms for Pothole Repair

While many research projects focus on pothole detection, few incorporate the next crucial step: the autonomous filling of the detected potholes. Current approaches in pothole filling systems are often limited to manual or semi-automated mechanisms, such as solenoid valves or simple hoppers. These methods have been shown to lack precision and reliability. Servo-actuated dispensers, as explored in previous studies, offer improved control over filler dispensing, with fewer mechanical components. This project aims to advance these systems by integrating the filler dispenser with the vision system to release filler only when a pothole is detected with sufficient certainty. By synchronizing the detection system with the filler mechanism, the project seeks to enhance both the accuracy and efficiency of the repair process.

2.5 Contextual Relevance and Scalability in Kenya

Kenya faces unique challenges in road maintenance due to financial constraints and limited access to advanced technology. High-tech road maintenance systems, such as those used in developed countries, are often financially unfeasible. In contrast, locally developed solutions that make use of affordable and widely available components have the potential to significantly improve the efficiency and effectiveness of road repair. Organizations such as Gearbox and SwahiliBox have demonstrated the power of frugal innovation in creating cost-effective solutions. This project aligns with this philosophy by leveraging locally available tools, such as the Raspberry Pi and Arduino, to develop an affordable and scalable solution for pothole repair that can be implemented in Kenya’s road maintenance programs.

2.6 Gaps in Existing Research

While significant work has been done in pothole detection and some in filler mechanisms, few studies have successfully integrated both aspects into a single autonomous system capable of fully detecting and repairing potholes in real-time. Most existing solutions focus either on detection or actuation, but not both. Furthermore, many of these projects are not suited for practical deployment, either due to their complexity or lack of detailed documentation. This project addresses these gaps by creating an autonomous pothole repair robot that integrates vision-based detection, accurate alignment, and real-time filler dispensing into one cohesive system.

Summary

The literature review highlights the gaps in existing research, especially in terms of fully integrated, affordable systems for pothole repair. While vision-based detection and filler deployment mechanisms are well-established individually, there is a clear need for a cost-effective, scalable solution tailored to the unique conditions of Kenyan roads. This project aims to bridge this gap by developing an autonomous robot capable of both detecting and filling potholes, offering a solution that is both practical and affordable for use in Kenya.