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Road Guard: AI-Powered Road Damage Detection and Reporting System

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Abstract

Potholes are a major problem on Indian roads, creating serious risks for drivers and potentially damaging vehicles. Unfortunately, identifying and reporting these hazards often still depends on outdated methods like manual inspections or public complaints. These traditional practices are not only slow and labor-intensive, but they're also vulnerable to human error, which can lead to inconsistent responses. This is especially problematic in busy urban areas where timely maintenance is essential. To address this issue, we propose Road Guard, an innovative AI-powered solution for automatic road damage detection and reporting. Using advanced computer vision techniques and the YOLO v4 model, Road Guard can quickly identify potholes in real-time. It employs a high-definition camera combined with AMD Kria 260 hardware and GPS for accurate location tagging. Once a pothole is detected, the information is uploaded to a cloud server and made available through a user-friendly mobile app for both citizens and road maintenance teams. By minimizing reliance on human efforts, Road Guard provides a smart, efficient alternative to traditional inspection methods. This not only ensures quicker repairs but also enhances road safety for everyone on the road.

Keywords: *Pothole Detection, Road Safety, YOLO v4, Computer Vision, Real-Time Monitoring, GPS, IoT*

1. Introduction

Roads play a pivotal role in any nation, serving as vital pathways that facilitate transportation and foster economic and social connections between cities and towns. Unfortunately, these essential routes can deteriorate over time due to weather, heavy usage, and a lack of maintenance. One of the most common and dangerous outcomes of this wear and tear is the formation of potholes. What might seem like a minor inconvenience at first can quickly escalate into serious safety hazards, especially for those riding two-wheelers. In India, with its dense traffic and busy roads, potholes have become a frustrating reality for daily commuters. Historically, the responsibility for spotting and reporting these road issues has fallen to citizens and municipal workers. This usually involves a tedious process of filing complaints via helplines, mobile apps, or manual inspections by road authorities. While this method has been the norm for years, it is often slow and heavily dependent on human intervention. Response times can lag, and the potential for human error adds an element of unreliability to the system. By the time a pothole is inspected and repaired, many vehicles may have already sustained damage, or accidents could have taken place. However, recent advancements in artificial intelligence and computer vision have opened up intriguing new possibilities for automating the detection of road issues. Object detection models can now effectively identify potholes and other forms of road damage by analyzing real-time images. When paired with GPS technology and cloud connectivity, we can automatically detect, locate, and report road damage without requiring human intervention. Our project, Road Guard, embodies this innovative approach. We have developed a camera-equipped embedded system powered by the YOLOv4 object detection model and the AMD Kria 260 Kit. This system captures live images of roads, detects potholes, and sends this information, along with precise location data—to a central server. Consequently, this information is displayed on a mobile app, keeping both commuters and road maintenance authorities updated in real time. This process eliminates the delays and inconsistencies

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associated with manual reporting, leading to quicker repairs and improved road safety. Several recent studies have explored similar uses of AI for pothole detection. For example, Nikhila Boosam et al. (2024) compared the YOLOv4 and YOLOv5 models and achieved 95% accuracy, demonstrating that YOLOv5 offers superior precision and recall. However, their model was tested only on images and didn't assess real-time video under varying lighting and weather conditions. Rupsha Debnath et al. (2022) implemented a real-time YOLO-based system using vehicle-mounted cameras, but their research lacked detailed performance metrics and did not compare it with models like Faster R-CNN or SSD. Zakwan Syukri Mohd Shah & Mohd Norzali Haji Mohd (2024) introduced a Raspberry Pi-powered system with YOLOv5 for portable use, yet it struggled with limited accuracy (76%) and poor performance in low-light conditions. Aditya Prakash Devrukhkar et al. (2022) combined YOLO and Faster R-CNN to automate pothole detection and reporting, but their real-world testing was limited, and they provided no detailed accuracy metrics. Keval Doshi & Yasin Yilmaz (2020) proposed an ensemble approach involving YOLOv4 and other deep learning models, which improved reliability but required high computational resources, making real-time deployment on edge devices challenging. These studies underscore both the potential and the challenges of using AI for monitoring road surfaces. Building on this foundation, Road Guard aims to provide a low-cost, real-time, and location-aware solution that can be effectively integrated into smart city infrastructure. [1-2]

2. Objective of the Project

We are developing a smart system for real-time pothole identification and location on city and rural roads using high-definition imaging, AI (YOLO v4), and GPS on a compact platform. This will enhance road monitoring, streamline automated reporting, and improve repair efficiency and commuter safety via a centralized cloud platform. [3]

3. Methodology

The Road Guard system is an innovative solution that's designed to address the issues and delays often associated with traditional pothole detection and reporting. It consists of two main components: a vehicle-mounted device that accurately detects potholes in real time and a cloud-connected mobile application that keeps both everyday users and government agencies informed about road conditions. [4-5]

- **Vehicle-Mounted Device:** This device is installed in user vehicles and features:
- **AMD Kria Board:** This powerful hardware runs the YOLO v4 object detection algorithm specifically to identify potholes.
- HD Camera: It constantly captures images of the road surface to monitor for potholes.
- **GPS Module:** This component ensures that each detected pothole is accurately tagged with its location.
- **Buzzer:** An instant alert system that notifies the driver when a pothole is ahead.

As drivers navigate the roads, the hardware monitors conditions in real-time. When a pothole is detected, the system immediately alerts the driver with a buzzer, logs the GPS location, and captures an image of the pothole. All of this information is then sent to the ThingSpeak cloud server. This proactive detection helps reduce accidents and minimize vehicle damage caused by unnoticed potholes.

3.1. Mobile Application

For those who don't have the vehicle-mounted device, a mobile app serves as an alternative way to receive alerts. This app: [6]

- Synchronizes continuously with the ThingSpeak cloud.
- Notifies users through sound and visual alerts when they are approaching known pothole locations.

This ensures that all road users can benefit from the pothole alert system, even without the physical hardware. [7]

3.2. Government Monitoring and Action

One of the standout features of the Road Guard system is the accessible mobile application for government authorities. Through this interface:

- Real-time pothole data is displayed on maps.
- Authorities can see exact GPS locations, timestamps, and image evidence related to potholes. [8]

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This organized data allows for quick actionable insights, making it easier for road departments to plan maintenance and repair efforts. It streamlines the repair process by reducing the need for manual inspections or reliance on citizen reports. Consequently, this enables more rapid responses, better prioritization of tasks, and more effective resource allocation. [7-9]

3.3. Overall Data Flow

Here's how the system works:

- **Detection:** The prototype scans the road, detects a pothole, alerts the driver, and uploads data to the cloud.
- **Broadcast:** The ThingSpeak server stores and syncs this data.
- **Access:** General users receive alerts through the app.Authorities have access to organized, real-time pothole data for timely action.

By blending edge AI, IoT, and cloud technologies, Road Guard creates a real-time, scalable, and inclusive system that enhances road safety and improves infrastructure management. Efficient communication and centralized monitoring are at its core, benefiting everyone on the road.gh efficient communication and centralized monitoring. (Figure 1) [10-13]

4. Results & Discussions

Real-world testing and deployment of the Road Guard system were completed successfully. Without human assistance, the technology detects potholes in real time and functions independently. For accurate pothole location mapping, it combines GPS tracking, an AMD Kria 260 hardware accelerator, a YOLOv4 object identification model, and a high-definition camera. Data, including the position of the pothole, is instantly uploaded to the ThingSpeak cloud upon detection. This information is available through a smartphone application that notifies users via audio notifications in real time when a pothole is approaching on their route. This feature guarantees safer travel by assisting commuters in avoiding possible damage. When a pothole is spotted, the system instantly informs the driver with a buzzer for users who have placed the actual Road Guard prototype in their cars. In addition to enabling users without the gear to still receive warnings through the app, this guarantees a proactive safety measure for those who are driving. The device is also intended to help road maintenance authorities and government representatives. They can get real-time pothole reports using the smartphone application, which facilitates speedier reactions and more effective road repairs. Officials can enhance overall infrastructure upkeep and prioritise important repairs by using real-time insights into road conditions. (Figure 2,3,4,5,6)

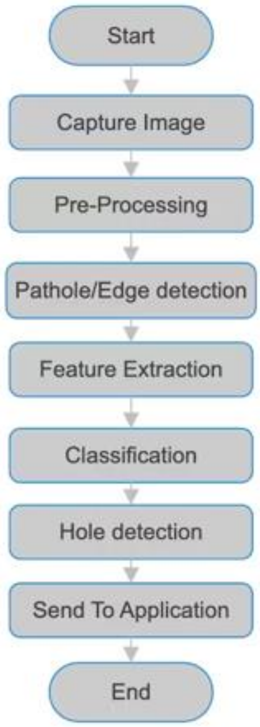

Figure 1 **Flowchart of the Road Guard Pothole Detection Process**

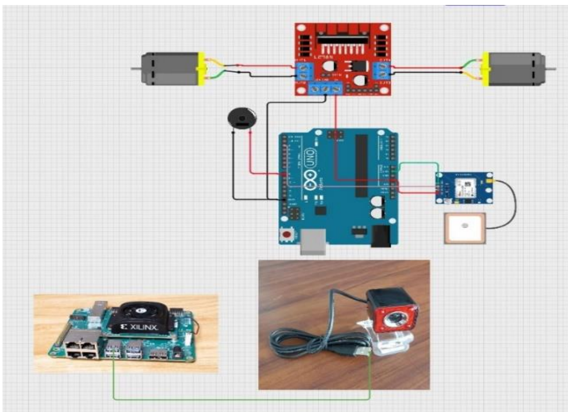

Figure 3 **Block Diagrams of Road Guard Prototype**

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Figure 4 Front View and Placement of the Vehicle-Mounted Deployment Setup

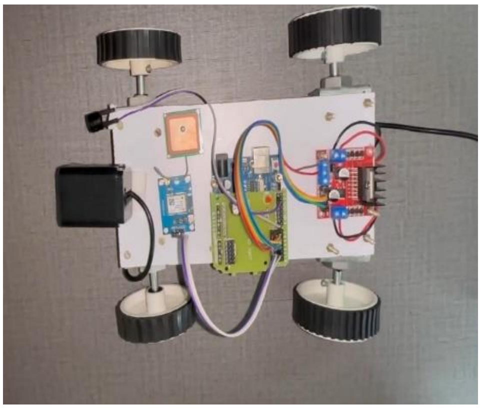

Figure 5 Demonstration of the Prototype Developed for Testing

The Road Guard system is a groundbreaking solution that automates pothole detection through advanced AI image processing and integration with the cloud. It sends real-time alerts to users via a mobile app, accompanied by an onboard buzzer, significantly improving road safety. Government officials can easily access data for quick road maintenance, which is crucial for enhancing our infrastructure. Plus, the system's scalability and adaptability make it a valuable tool for urban planning and traffic management. (Figure 6) [14-16]

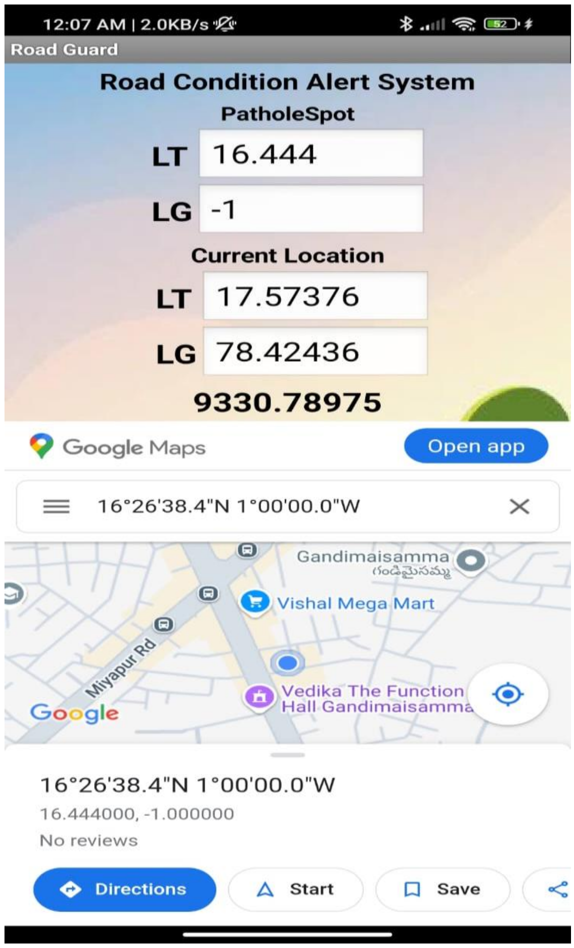

Figure 6 User Interface of the Road Guard Mobile Application Displaying Pothole Alerts and Location Data

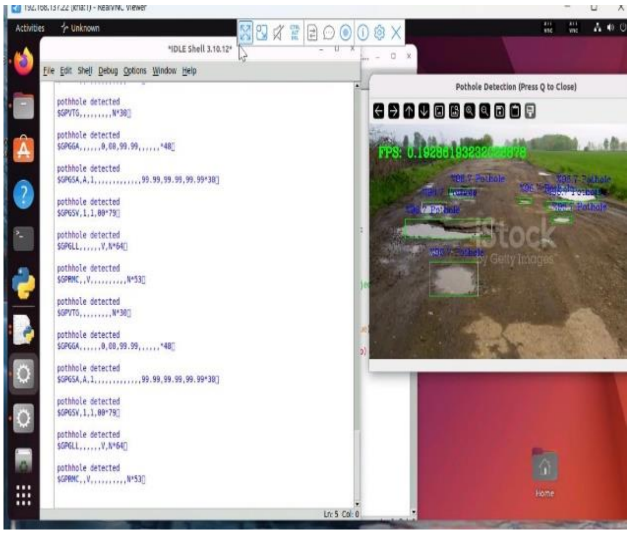

Figure 7 Real-Time Testing of Pothole Detection System on Computer Interface

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Conclusion

Road Guard is an exciting solution designed to tackle one of the longest-standing problems in our urban infrastructure: potholes. This innovative system is not only effective but also scalable and budget-friendly, making it easier for cities to enhance safety for commuters. With real-time alerts and cloud-based monitoring, it streamlines the process of identifying road damage. By incorporating automation and artificial intelligence, Road Guard improves the reliability of detecting issues on the road. This means civic authorities can quickly address road concerns without having to rely on manual inspections or waiting for the public to report them. It's a smart way to keep our roads safer for everyone. [17]

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