

# ML Based Road Surface Assessment & Adaptive Route Suggestion System Using Unmanned Aerial Vehicles And IOT Sensing

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**ABSTRACT:** Road Surface Degradation including potholes and cracks causes accidents and make travelling uncomfortable. Manual inspections remain inefficient, costly, and inadequate for expansive networks. This project presents a drone-based road surface monitoring system that uses machine learning to detect potholes, cracks, and other surface defects efficiently. A drone equipped with a high-resolution camera captures continuous video of road segments, and the recorded frames are processed using a YOLO-based deep learning model to automatically identify damaged areas. Each detected defect is geo-tagged using GPS data and stored in a structured dataset for further analysis. Based on the severity and frequency of the identified damages, road segments are classified into different condition levels. A web-based application then analyzes this information to suggest safer and smoother travel routes between selected locations.

**Key words:** Road monitoring, Drone inspection, Pothole detection, Raspberry Pi, YOLOv8, GPS tracking.

## I. INTRODUCTION

### A) Background

Road infrastructure constitutes a foundation for transportation, and societal connectivity, facilitating daily commutes and economic activities worldwide (Ibragimov et al., 2024). However, continuous exposure to heavy vehicular loads, adverse weather conditions including heavy rainfall and extreme heat and insufficient maintenance precipitates surface degradation, manifesting as potholes, cracks, uneven pavements. Such defects not only inflict vehicle damage and induce traffic congestion but also elevate accident risks, prolong travel durations, and increase travel time and reduce comfort for passengers. Conventional road condition assessments predominantly rely on manual inspections (Jayaseeli et al., 2015) where workers visit roads and check damages by observation. This method requires a lot of time, manpower, and money. It is also difficult to monitor large areas frequently, especially in remote or rural locations. Sometimes, road damages are noticed only after accidents occur, which makes the situation more serious.

It offers an integrated drone-assisted road surface assessment that combines UAV (Unmanned Aerial Vehicle) imagery with an YOLO (You Look Only Once) based defect detection and adaptive route Suggestion. Drones are deployed to systematically capture geo-referenced road images, ensuring wide-area coverage with minimal manual intervention varying lighting and environmental conditions. The collected data is Pre-processed using ML (Machine Learning) Models to detect potholes, cracks, and surface deformities. The detected defects are mapped to generate detailed road condition, which are further integrated with routing algorithm to recommend safer and smoother travel paths. This end-to-end framework not only improves detection accuracy and computational efficiency but also supports proactive maintenance planning and intelligent transportation management.

### B) Literature Review

[1] Recent advancements in road condition monitoring have shifted from manual inspection techniques toward automated and vision-based systems. Traditional survey methods are time-consuming, expensive, and often inconsistent due to human subjectivity. To overcome these limitations, researchers have introduced deep learning frameworks capable of automatically assessing pavement conditions from high-resolution images. For example, an end-to-end deep learning approach for automated Pavement Condition Index (PCI) estimation was proposed in [2], demonstrating improved scalability and assessment consistency compared to manual evaluation methods. To enhance classification reliability under real-world conditions, multi-sensor integration techniques have been explored. A deep learning-based pavement inspection system integrating camera and IMU data for risk classification was presented in [3], improving robustness in dynamic environments. Earlier foundational research surveyed sensor- and GPS-based monitoring frameworks for road condition evaluation, establishing the groundwork for modern intelligent road monitoring systems [4]. Furthermore, RGB-D sensing combined with heterogeneous data fusion has been utilized for pothole

detection to improve detection accuracy and spatial understanding. With the rapid advancement of object detection algorithms; YOLO-based models have gained significant attention for real-time road defect detection. A comparative study evaluating different YOLO architectures for UAV-based road damage detection highlighted the balance between computational efficiency and detection performance [5]. Recent architectural enhancements to YOLOv8, such as improved backbone structures and lightweight model designs, were introduced to achieve faster inference speeds while maintaining high detection accuracy [6].

## II. METHODOLOGY

The proposed system integrates drone-based road monitoring, machine learning based defect detection, and adaptive route optimization through a web platform. Initially, drone equipped with a high-resolution camera is deployed to capture continuous road videos across multiple surveyed routes. The recorded video is processed frame-by-frame, and a YOLO-based object detection model is applied to automatically identify pavement defects such as potholes and cracks. Each detected defect is associated with its corresponding GPS coordinates to ensure precise geographical mapping. The detection results are structured and stored in an automatically generated Excel sheet containing details such as defect type, location, frequency, and temperature and severity level. Based on the intensity of detected defects, each road segment is assigned a road condition score and categorized into quality levels such as good, moderate, or poor.

This structured dataset forms the foundation for route decision-making. For adaptive route suggestion, React-based web application is developed. The user selects source and destination locations, and the system processes the uploaded Excel dataset to compute weighted road segments based on defect severity and distance. A routing algorithm determines the safest and most efficient path by minimizing exposure to highly damaged road segments. GPS integration and map visualization are incorporated to display routes dynamically. The overall system performance is evaluated using detection metrics such as Precision, Recall, and mean Average Precision along with comparative route safety analysis.

### A) COMPONENTS

#### ➤ Raspberry pi

The Raspberry Pi shown in Fig.1 is a compact, single-board computer designed to perform computing tasks similar to a conventional desktop system while consuming minimal power. It includes a processor, RAM, USB ports, HDMI output, networking support, and General-Purpose Input/Output (GPIO) pins on a single board. Due to its flexibility, portability, and compatibility with multiple operating systems, the Raspberry Pi is widely used in embedded systems, IoT applications, robotics, and real-time data processing systems. In the proposed drone-based road surface assessment system, the Raspberry Pi functions as the central processing and control unit. It receives video input from the camera module and processes the frames using a trained YOLO-based deep learning model to detect cracks and potholes. Simultaneously, it collects real-time geographic coordinates from the GPS

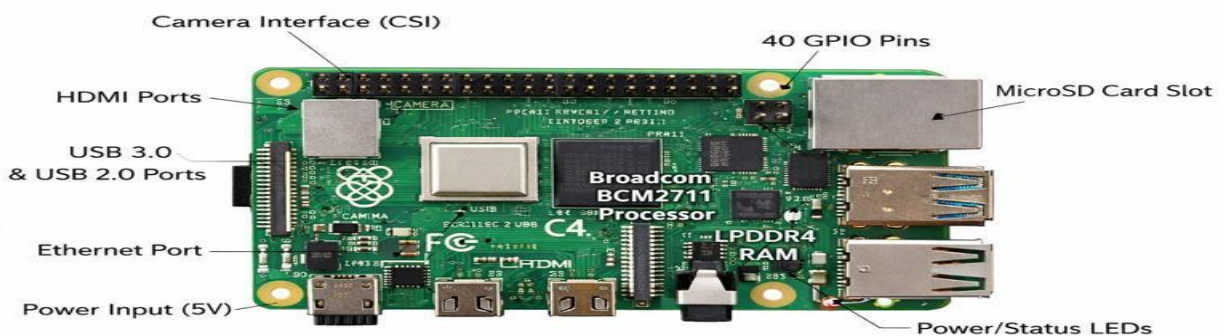


Fig.1 Raspberry Pi

module and associates them with detected defects for geo-tagging purposes. The Raspberry Pi also organizes the processed data into a structured Excel sheet containing defect type, location, and severity information. Additionally, it manages communication between hardware components and ensures smooth data flow to the web-based application.

### ➤ GPS Module

The Global Positioning System (GPS) module as shown in Fig.2 is a satellite-based navigation device used to determine precise geographic location coordinates. It operates by receiving signals from multiple Earth-orbiting satellites and calculating the receiver's position. A typical GPS module provides latitude, longitude, altitude, speed, and time information in real time. Widely used in navigation systems, vehicle tracking, unmanned aerial vehicles (UAVs), and geographic mapping applications due to their accuracy, reliability, and low power consumption. In the ML-based road surface assessment and adaptive route suggestion system, the GPS module plays a critical role in geo-tagging detected road defects. The module is interfaced with the Raspberry Pi, which continuously reads real-time latitude and longitude values. When the YOLO model detects a pothole or crack from drone-captured video frames, the system simultaneously records the corresponding GPS coordinates. These coordinates are stored in the generated Excel sheet along with defect type and severity. By associating each detected defect with its precise location, the GPS module ensures spatial accuracy and supports adaptive route generation for safer navigation.

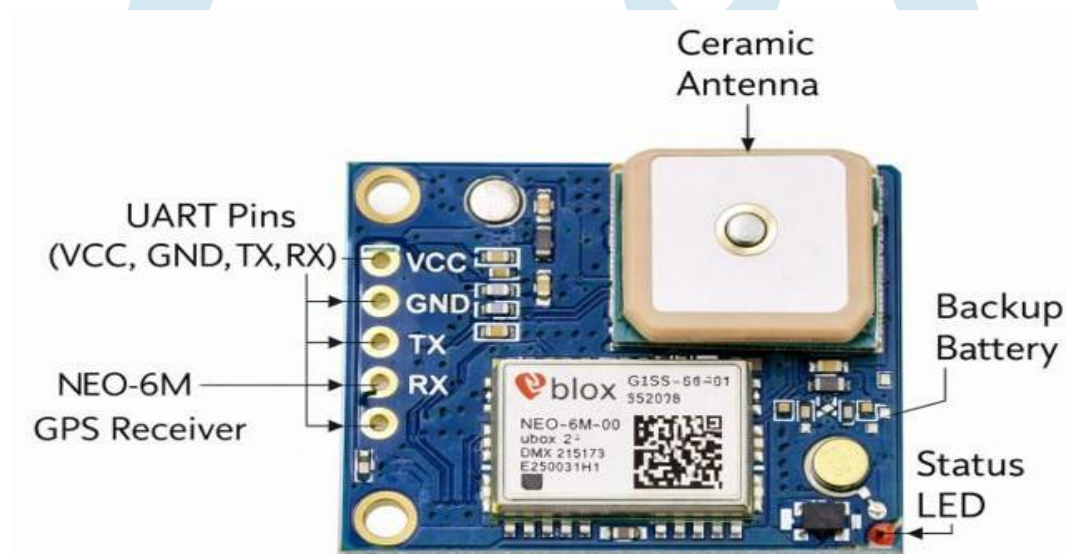


Fig.2 GPS Module

### ➤ Raspberry Pi Camera

The Raspberry Pi Camera is a small camera module designed to work with the Raspberry Pi computer. It is mainly used for capturing images and recording videos in different projects. The camera connects directly to the Raspberry Pi board through the CSI (Camera Serial Interface) port using a ribbon cable. It is lightweight, compact, and easy to install, which makes it suitable for many applications such as surveillance systems, robotics, drones, and computer vision projects. The Raspberry Pi Camera can capture high-quality images and videos, and it can also be used with programming languages like Python to process images using libraries such as OpenCV. Because of its small size, low power consumption, and good performance, the Raspberry Pi Camera is widely used in IoT and AI-based projects.



Fig.3 Raspberry Pi Camera

As the drone moves forward, the camera keeps recording the road condition, including visible defects such as potholes, cracks, and surface damages. The captured video feed is directly transmitted to the Raspberry Pi, where a pre-trained detection model processes each video frame. The system analyses the frames one by one to identify road defects, highlights the detected areas with bounding boxes, and keeps track of the number of issues found. This automated approach reduces the need for manual inspection. Additionally, the live video feed is streamed to a dashboard interface, allowing users to monitor road conditions in real time.

### III. IMPLEMENTATION

#### A) Block Diagram

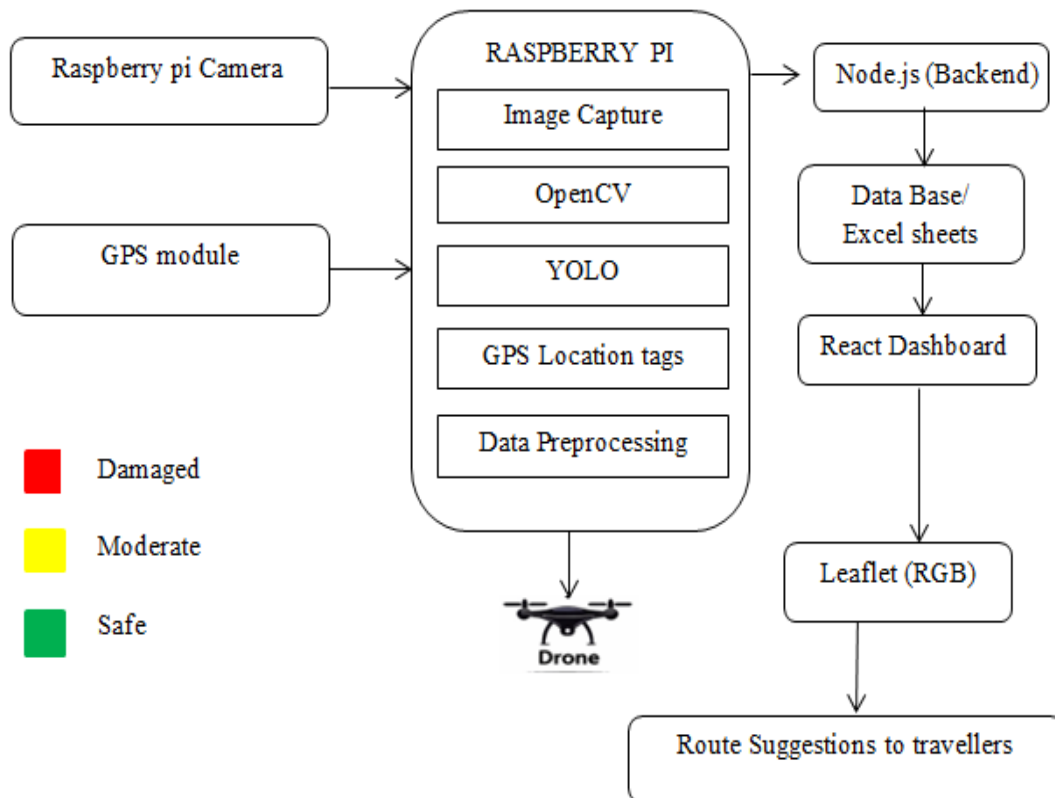
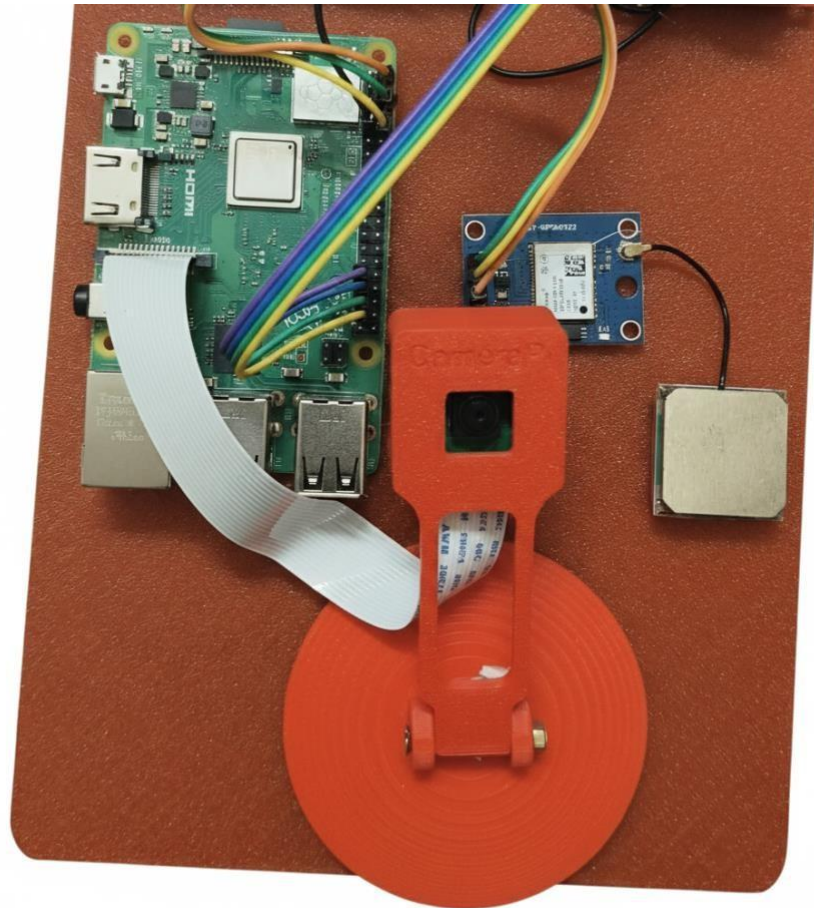


Fig. 4 Block Diagram of R-CAD

The Block Diagram Shown in Fig.4 connecting the Raspberry Pi camera, GPS module, and DHT sensor to the Raspberry Pi mounted on the drone. While the drone flies over the road, the camera captures live video of the surface and sends it to the Raspberry Pi for processing. The GPS module provides real-time location coordinates, which are attached to each detected road defect. Trained YOLO model analyses the video frames to identify potholes and cracks, and the detected details such as location and time are stored in an Excel sheet or database. This data is sent to a Node.js backend and displayed on a React dashboard, where users can view road conditions and select the safest route between locations.

**B) Hardware****Fig.5 Hardware Setup**

The ML Based Road Surface assessment and adaptive route Suggestion System's Hardware Implementation shown in fig.5 is designed to perform real-time road monitoring using an integrated embedded platform. The central unit of the system is the Raspberry Pi, which functions as the main processing and control device. It is connected to a camera module through a ribbon cable for capturing road images and video during drone operation. The Raspberry Pi provides sufficient computational capability to run the trained object detection model and handle sensor data simultaneously.

A GPS module is interfaced with the Raspberry Pi to obtain accurate latitude and longitude coordinates. This allows each detected road defect to be geo-tagged with its exact location. Additionally, environmental sensors such as the DHT module can be connected to measure temperature and humidity, supporting environmental data collection. All components are powered through a portable power source, ensuring mobility during drone flight. The hardware components are securely mounted to maintain stability, proper wiring, and uninterrupted data transmission throughout the operation.

## VI. RESULTS

```
File Edit Shell Debug Options Window Help
Python 3.9.2 (default, Mar 20 2025, 02:07:39)
[GCC 10.2.1 20210110] on linux
Type "help", "copyright", "credits" or "license()" for more information.
>>>
===== RESTART: /home/pi/Desktop/pothole yolov8/gps.py =====
Robot moving | Pothole surveillance started
Pothole detected
Pothole detected
```

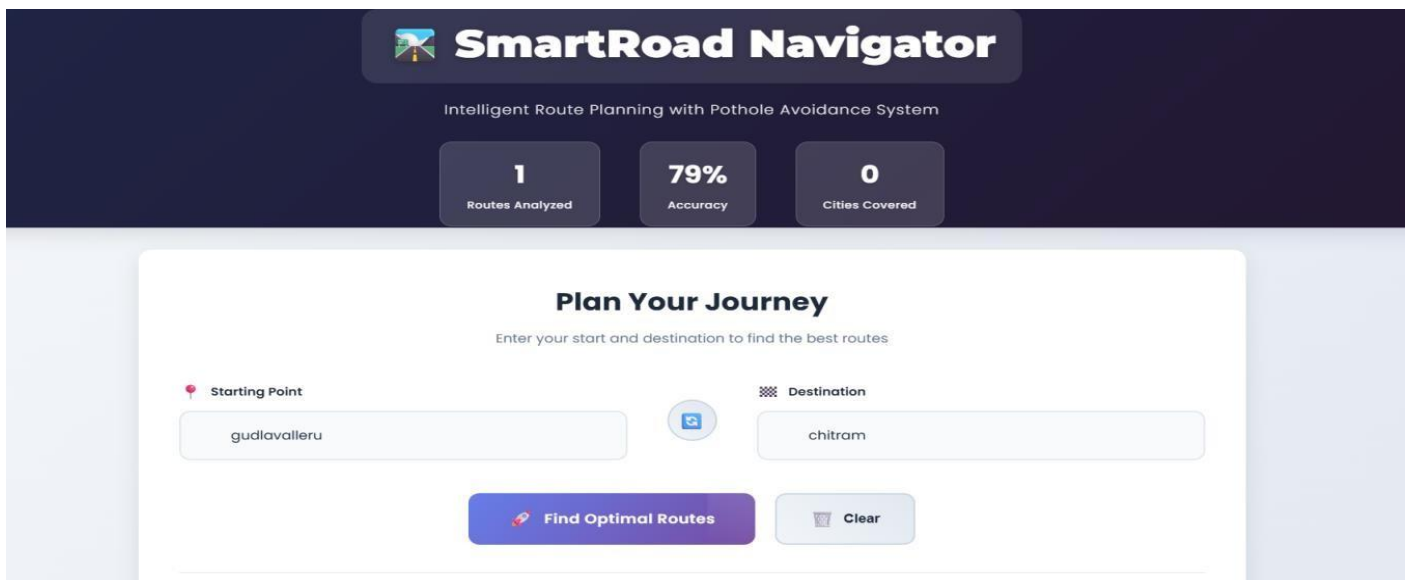


**Fig.6 Pothole Detected Using YOLO**

The results of the road surface monitoring system where potholes are clearly identified as shown in Fig. 6. The damaged portions of the road are marked with red boxes, and the pothole areas are shaded in purple to show the exact affected region. The display screen shows messages such as “Pothole detected,” which indicates that the system is successfully recognizing damaged spots on the road. More than one pothole is identified at the same time, showing that the system can continuously observe the road and detect multiple defects. This result confirms that the project can effectively find potholes and provide timely alerts during road monitoring and the corresponding excel sheet is generated as show in Fig. 7.

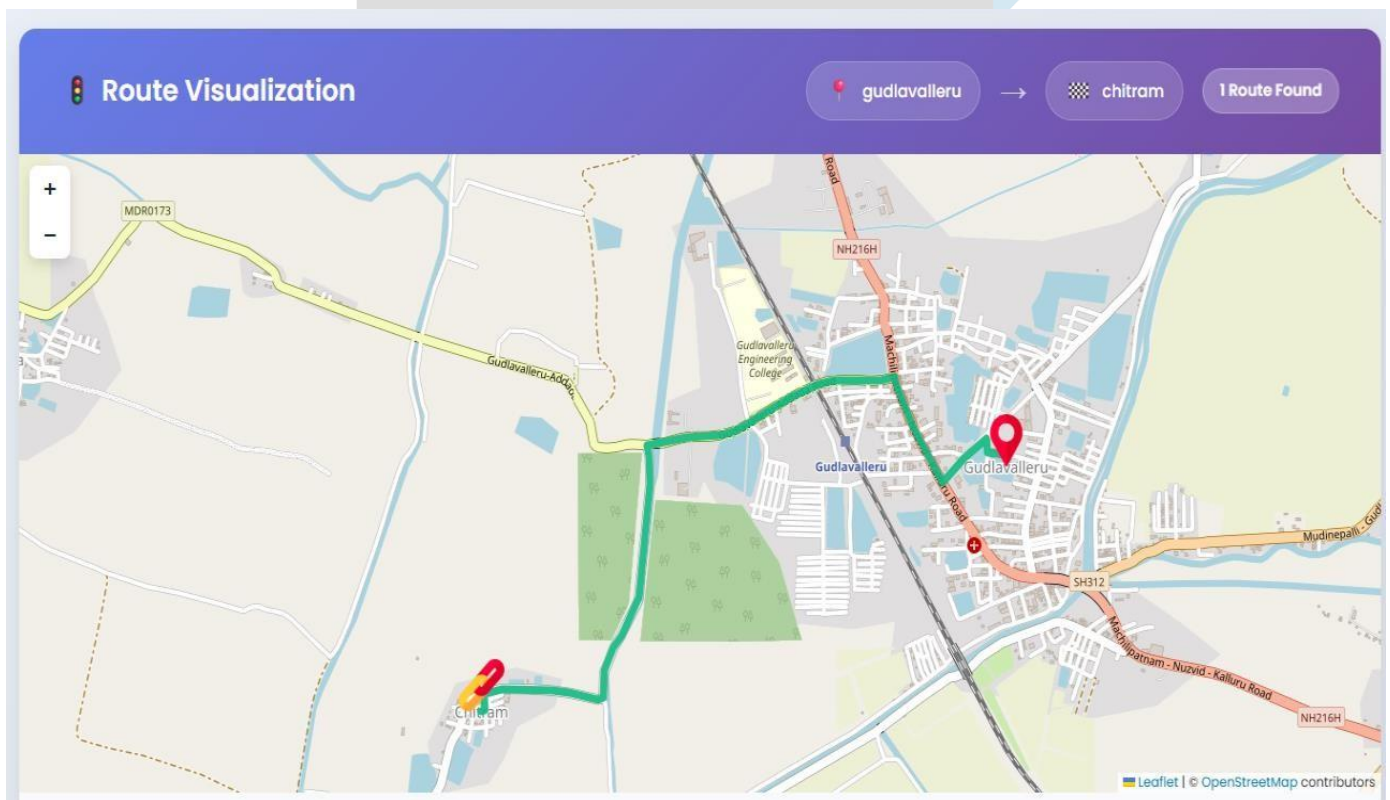
Timestamp	Lat (GPS)	Long (GPS)	Temp (°C)	Humidity (%)	Potholes (YOLO)	Severity
10:00:00	16.5012	81.0234	28.4	62	0	Low
10:00:05	16.5014	81.0237	28.4	62	0	Low
10:00:10	16.5016	81.024	28.5	61	0	Low
10:00:15	16.5018	81.0243	28.5	61	1	low
10:00:20	16.502	81.0246	28.6	60	0	Low
10:00:25	16.5022	81.0249	28.6	60	0	Low
10:00:30	16.5024	81.0252	28.7	59	0	Low
10:00:35	16.5026	81.0255	28.7	59	2	Low
10:00:40	16.5028	81.0258	28.8	58	6	high
10:00:45	16.503	81.0261	28.8	58	6	high
10:00:50	16.5032	81.0264	28.9	57	1	Low
10:00:55	16.5034	81.0267	28.9	57	0	Low
10:01:00	16.5036	81.027	29	56	0	Low
10:01:05	16.5038	81.0273	29	56	0	Low
10:01:10	16.504	81.0276	29.1	55	1	Low
10:01:15	16.5042	81.0279	29.1	55	0	Low
10:01:20	16.5044	81.0282	29.2	54	0	Low
10:01:25	16.5046	81.0285	29.2	54	0	Low
10:01:30	16.5048	81.0288	29.3	53	1	Low
10:01:35	16.505	81.0291	29.3	53	0	Low
10:01:40	16.5052	81.0294	29.4	52	0	Low
10:01:45	16.5054	81.0297	29.4	52	2	Low
10:01:50	16.5056	81.03	29.5	51	0	Low
10:01:55	16.5058	81.0303	29.5	51	0	Low
10:02:00	16.506	81.0306	29.6	50	1	Low
10:02:05	16.5062	81.0309	29.6	50	0	Low
10:02:10	16.5064	81.0312	29.7	49	0	Low
10:02:15	16.5066	81.0315	29.7	49	0	Low

**Fig.7 Excel Sheet Generated**



**Fig.8 Web Application for Safe Route Suggestion**

The website developed using React to help travellers choose safer routes as shown in Fig. 8. The webpage is designed with a simple and clear interface where users can enter their starting point and destination. After entering the details, the system processes the information and suggests the best possible route by considering road conditions. The website layout is easy to understand, making it convenient for users to search and view route options quickly. It also displays basic information such as route analysis and accuracy, which helps users trust the system. This website acts as a user-friendly platform that connects the road monitoring system with travellers and helps them avoid damaged roads while planning their journey.



**Fig 9. Route Visualization using Leaflet**

Fig.9 Shows a map labelled “Route Visualization” that illustrates a travel path between two locations named Gudlavalлерu and Chitram. A green line on the map marks the suggested route connecting these places. Two location pins are shown: a red marker indicates the destination near Gudlavalлерu, and a red-yellow marker is placed at the starting point. The mapping software Leaflet is used to draw and display this route on the interactive map. The blue header at the top reports “1 Route Found”, meaning one path was identified for the journey.

## VII. CONCLUSION

In conclusion, we developed a system for assessing road surfaces using drones and machine learning, which can detect potholes, cracks, and other damages efficiently. Based on the assessment, the system suggests adaptive repair strategies to improve road safety and durability. By combining aerial imaging, data analysis, and smart decision-making, this approach provides a faster, more accurate, and cost-effective way to monitor and maintain roads. Overall, the project demonstrates how technology can make road maintenance smarter and more reliable.

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