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STREET SURFACE ANOMALY SENSING SYSTEM

[1]Shivaram A M, [2]Sanjay Narayan Hangari, [3]Bharath Kumar A H, [4]B C Sevanthi, [5]Sneha R

[1]Professor, [2]Student, [3]Student, [4]Student, [5]Student
[1]Information Science And Engineering,
[1]Sai Vidya Institute Of Technology, Bengaluru, India

Abstract : Maintaining and ensuring the safety of roads is crucial for efficient transportation. Potholes present a major hazard to drivers and pedestrians alike, causing accidents and escalating maintenance expenses. This initiative introduces a cutting-edge approach to pothole detection and depth measurement. It combines the capabilities of the “Single shot multibox Detector”, (SSD), the Deep Learning Algorithm for instantaneous pothole spotting with ultrasonic sensors for precise depth assessment.

The proposed System is designed to notify drivers of the existence of potholes on the road, enabling them to take necessary precautions. When a pothole has been identified within the range of the vehicle's tires, the system issues a caution to the driver, prompting them to reduce speed or opt for an alternate route.

The core of this framework employs the SSD, Deep Learning Algorithm using the Region of Interest (ROI) technique, renowned for its effectiveness in object detection. This allows the framework to detect and locate potholes in Photos or Video frames taken by onboard cameras in real-time. This ensures immediate action can be taken when potholes are detected.

Besides identifying potholes, the system integrates ultrasonic sensors set up on the vehicle. These Sensors, are essential in identifying the depth of the identified potholes. By emitting ultrasonic waves towards the road surface and measuring the time taken for their return, the system can accurately calculate the depth of the pothole.

By merging advanced deep learning technology with sensor-based measurements, this project offers a holistic solution for effective pothole management, aiming to enhance road safety and reduce maintenance costs.

Keywords: **Potholes, Pothole depth, Deep learning, SSD algorithm, Ultrasonic sensor**

I. INTRODUCTION

Roads are essential components of contemporary transportation networks, acting as vital links that connect societies and support economic growth. Nonetheless, the quality of road infrastructure is frequently compromised by the existence of potholes. These road imperfections not only pose risks to the safety of motorists and pedestrians but also lead to escalating maintenance expenses. Potholes, resulting from factors like meteorological conditions and heavy vehicle traffic, persistently challenge road maintenance efforts. Unidentified potholes and surface defects can cause significant damage to vehicles, particularly to tires, and in extreme cases, result in severe accidents and fatalities. In today's bustling urban environments with continuous vehicular movement, prompt detection and effective management of road defects are crucial.

According to recent government data, potholes were a contributing factor in over 4,400 accidents in 2022, highlighting the severity of the issue. Addressing this challenge requires a sustainable solution that provides live data regarding road conditions to the public. Our innovative approach leverages camera technology and “Ultrasonic Sensors” to offer a swift, accurate, and cost-effective solution. The proposed system employs the SSD algorithm to identify potholes within the range of a vehicle's tires and utilizes ultrasonic waves to measure their depth. Subsequently, it alerts drivers or users regarding the state of a Road surface, enabling them to take necessary precautions.

Our project incorporates The Single shot multibox detector, (SSD) deep learning algorithm, well-known for its capability in real-time object detection, to detect and locate potholes in Photos or Video footage captured by onboard cameras. This facilitates prompt and precise detection, allowing for immediate action to address potential road hazards. Additionally, the system integrates strategically positioned ultrasonic sensors on a Vehicle to ascertain the depth of the identified potholes.

By merging advanced deep learning methodologies with sensor technology, our project aims to deliver a holistic and proactive approach to pothole management within transportation infrastructure. The ultimate objective is to enhance road safety, minimize accidents, and optimize the utilization of resources in road maintenance activities.

Incorporating a user-friendly interface, our system will enable road users to access real-time updates about road conditions, allowing them to make informed decisions while driving. This transparency and accessibility will not just enhance safety but also foster greater trust and engagement among the community towards maintaining road integrity.

II. LITERATURE REVIEW

Over the recent years, been a growing interest in leveraging advanced technologies, particularly computer vision and sensor systems, to detect potholes in real-time. Potholes Detection is a Very crucial subject that worth to pay attention for, and Comprehensive research has been conducted out. studying the same subject to identify them automatic with numerous advanced techniques.[1] proposed intelligent pavement pothole detection system by modifying the single stage CNN architecture-RetinaNet to detect potholes and perform metrological studies using 3D vision and also establishes an engineering solution to compute the depth of the potholes by developing a novel depth estimation algorithm. [2] used Convolutional neural networks, often known as CNNs. YOLOv7 was Used to annotate and train a pothole image dataset for this research, and the findings were analysed in term of recall, accuracy. The model was validated by examining a broad spectrum of photographs relating to potholes. The limitation is that they cannot find the depth of the pothole.

The authors of this study proposed [3] have utilized an image processing, machine learning and sensor based approach. The proposed method involves the use of the cameras and sensors to collect data on road conditions, analyse the data and identify areas with humps or potholes. [4] proposed an IoT based potholes and humps detection system that can integrated with the vehicle. They employ an ultrasonic sensor to locate potholes and speed bumps on the road and measure the depth and height of each, accordingly.[5] proposed a sensor-based pothole detection system using ultrasonic sensors. When the sensor detects the existence of road craters, it notifies the driver by sending an alert via mobile application which has to be integrated with detection system and the information can be stored in a server to intimate the government about road repairs and maintenance.

In their study, the authors [6] proposed a pothole detection system using automotive radar by estimating and contrasting the pothole radar cross-section (RCS) with the backscatter from a flat road. They estimate the two-dimensional RCS of potholes from the scattered electric field simulated using “Finite difference time domain” techniques. [7] used object detection algorithm. The researchers produced a 200 images dataset on Indian roads and trained using YOLOv4 and results were evaluated based on recall, precision and mAP. The model was verified using various approaches set of images and videos based on potholes. The limitation is that they cannot find the depth of the pothole.[8] Researchers employed deep learning frameworks to identify potholes. They generated a dataset of 1087 images containing over 2000 potholes and trained it using YOLOv4. The system could spot potholes from distances of until a hundred meters. This approach can assist in notifying government bodies about road potholes, enhance driver safety by detecting potholes well in advance, and boost the capabilities of autonomous vehicles to guarantee safe journeys for passengers in upcoming years.

The authors of the study proposed [9] have utilized Disparity Transformation and Otsu’s thresholding technique to identify the existence of potholes. Initially, a dense disparity map is modified to more effectively differentiate between damaged and intact road sections. For improved efficiency in disparity transformation, golden section search and dynamic programming are employed to calculate the transformation parameters. Subsequently, Otsu’s thresholding method is applied to isolate potential intact road sections from the altered disparity map. The disparities within these isolated sections are depicted by a quadratic surface through least squares fitting. Lastly, the point clouds corresponding to the identified potholes are derived from the reconstructed 3D road surface.

In their study, the authors [10] used deep learning methods to examine road photo archives in order to pinpoint any damage. The researchers produced a 665 images dataset and 8,000 potholes are available in the whole dataset approximately. The researchers used YOLO family algorithms to detect the potholes. The limitation is that they cannot find the depth of the pothole. [11] used sensor-based System to detect the potholes. The Ultrasonic Sensor is used to estimate the depth as a base for determining the pothole and there after its location is sent to mail.

III. ARCHITECTURE

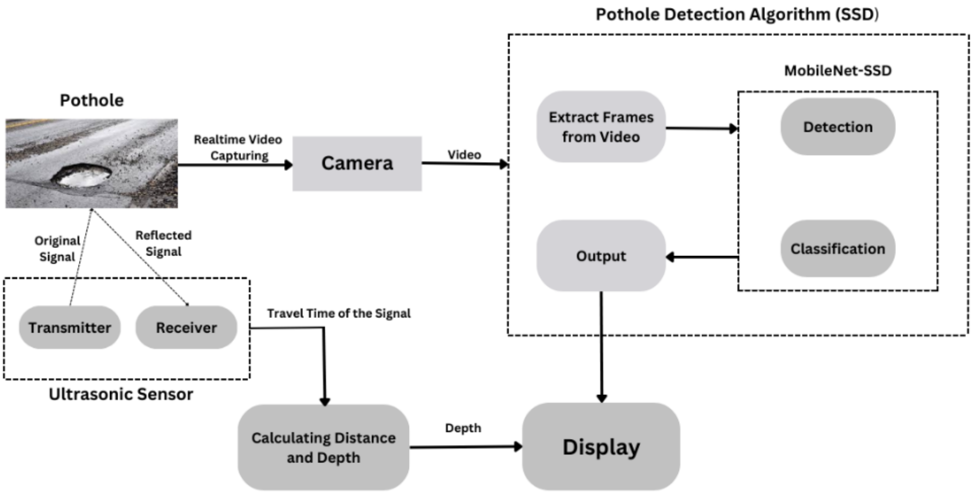
In this research endeavor, the suggested system is developed with a dual-component architecture, integrating cutting-edge technologies to ensure road safety and efficient maintenance. Below is a simplified overview of the system's architecture:

1. **The Real-Time Pothole Detection Module**:
   - This module employs the advanced Single shot multibox Detector, (SSD) algorithm, renowned for its capability in instantaneous object recognition.
   - Cameras set up on the vehicle capture images and video frames of the roadway texture while the Vehicles is in motion.
   - The SSD algorithm analyses the visual information in real-time, identifying and pinpointing potholes within the proximity of the vehicle's tires.
   - Instant alerts are generated and conveyed to the driver or system user regarding the detected potholes, enabling timely and appropriate responses.

2. **Pothole Depth Measurement Module**:

   - This module incorporates ultrasonic sensors strategically positioned on the vehicle's underside.
   - The sensors emit ultrasonic waves directed towards the roadway texture to assess the depth of the identified potholes.

- By measuring the time taken for the ultrasonic Wave to return after hitting the roadway texture, the system calculates the exact depth of the potholes.



System architecture

Camera: In our proposed system design, a Wi-Fi-enabled camera serves as a key component of the Real-Time Pothole Detection Module. This camera is strategically set up on the vehicle to capture high-resolution images and video clips of the roadway texture as the vehicle moves along. With its ability to produce clear and detailed visuals, the camera facilitates precise detection and analysis of potholes on the road. This camera is Equipped with Wi-Fi connectivity, the camera can instantly transmit the captured images and video footage to the central processing unit for immediate evaluation. Within the system framework, the Wi-Fi camera collaborates seamlessly with the Single shot multibox detector, (SSD) algorithm. Together, they process the visual data to detect and accurately locate potholes, contributing to the system's effectiveness in real-time pothole identification and alert generation for enhanced road safety.

SSD Algorithm: The Single shot multibox detector, (SSD) algorithm is a broadly acknowledged and efficient deep learning technique specifically crafted for Real-time Object identification tasks. Known for its speed and precision, SSD has become a preferred choice in various applications requiring instantaneous object recognition.

In the proposed system, the Single shot detector, (SSD) utilizes MobileNet as its foundational architecture, enabling swift and efficient object detection. MobileNet SSD is a specialized Object Detection model capable of determining the bounding box coordinates and recognizing the object class within the provided image.

Within the framework of our proposed pothole detection system, the SSD algorithm is a key component of the Real-Time Pothole Detection Module. This algorithm excels in quickly and accurately identifying objects within images and video frames. In our system setup, the Wi-Fi camera captures detailed images and video sequences of the Road surface. These visual information are then analyzed in real-time by the SSD algorithm to detect and locate potholes with high accuracy. By harnessing the capabilities of the SSD algorithm, our system is able to effectively identify and pinpoint potholes on the road.

Ultrasonic Sensor: An ultrasonic sensor is a device that utilizes ultrasonic frequencies beyond human auditory range to gauge distances to objects or identify obstacles. Operating on the principle of emitting ultrasonic waves and measuring the duration it takes for these waves to reflect back from an object, ultrasonic sensors can measure the distance to the object. Such a sensor usually comprises a transmitter that sends out the ultrasonic waves and a Receiver that picks up the waves upon their return from an object. Within the framework of the Suggested pothole detection System, “Ultrasonic Sensors” are carefully placed on the Vehicle to gauge the depth of identified potholes. These sensors send out ultrasonic waves to the Road surface and calculate the duration it take for the waves to rebound upon encountering the potholes. This information is essential for precisely assessing the depth of the potholes.

IV. METHODOLOGY

The methodology employed in the proposed pothole detection and measurement System, is a two-pronged approach that combines visual object detection using a camera and the Single shot multibox detector, (SSD) algorithm, along with depth measurement using ultrasonic sensors.

1. **Visual Pothole Detection using Camera and SSD Algorithm**:
   - **Camera Placement**: A high-resolution camera is strategically mounted at the front of the vehicle, near the car's logo. This positioning ensures optimal coverage and clear imaging of the street surface ahead.
   - **Image Capture and Processing**: As the vehicle moves, the camera captures continuous images and video frames of the street surface. These visual data are subsequently processed in real-time using the SSD algorithm.
   - **Object Detection**: The SSD algorithm analyses the captured visual data to detect and identify potholes on the road. It excels in instantaneous object recognition within images and video frames, Allowing it to swiftly pinpoint potholes within the proximity of the vehicle's tires.

- **Alert Generation**: Upon detecting a pothole, the system generates instant alerts to alert the driver or system user, enabling timely and appropriate responses to ensure road safety.

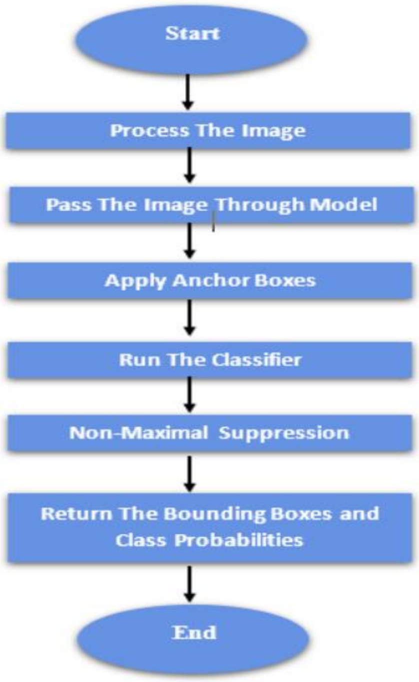
2. **Depth Measurement using Ultrasonic Sensors**:
   - **Sensor Placement**: Two "Ultrasonic Sensors" are set upped near the headlights of the Vehicle. This positioning is chosen to accurately measure the depth of the potholes that fall within the vehicle's tire range.
   - **Depth Measurement Process**: The "Ultrasonic Sensors" emit ultrasonic waves directed towards the road surface. Upon hitting a pothole, these waves return back to the sensors.
   - **Time-of-Flight Calculation**: By calculating the time taken for the ultrasonic waves to return after hitting the pothole, the system determines the Distance of the pothole accurately.
   - **Depth Data Integration**: The measured distance data from the "Ultrasonic sensors" are utilized to compute he depth of the pothole.

Object detection using SSD algorithm: Firstly, the input Images undergoes preprocessing to optimize it for the model's analysis. This preparation may include actions like resizing, normalization, and data augmentation to enhance the image quality and consistency. Subsequently, the preprocessed image is fed into the model, which generates feature maps that encapsulate a high-level abstract representation of the image content.

Once the image has been processed by the model, anchor boxes or default boxes are applied to the feature maps. These anchor boxes produce a series of potential bounding boxes, outlining the possible locations of objects within the image. A classifier then evaluates each enclosure rectangles to ascertain the object class it contains. To refine the detection results and eliminate redundant overlapping boxes, a technique called Non-Maximal Suppression is employed.

Ultimately, the algorithm outputs a refined set of enclosure rectangles, together with their corresponding category probabilities, providing a comprehensive understanding of the objects present in the Image.

A significant advantage of Single Shot Detectors (SSDs) lies in their speed and efficiency. Utilizing a unified network approach, SSDs are capable of real-time object detection, rendering them highly appropriate for applications like autonomous driving and surveillance systems. Furthermore, leveraging a pre-trained base network allows SSDs to capitalize on extensive labeled datasets commonly used in image classification tasks. This inherent capability enables SSDs to achieve impressive accuracy levels even when trained on smaller, more focused datasets.

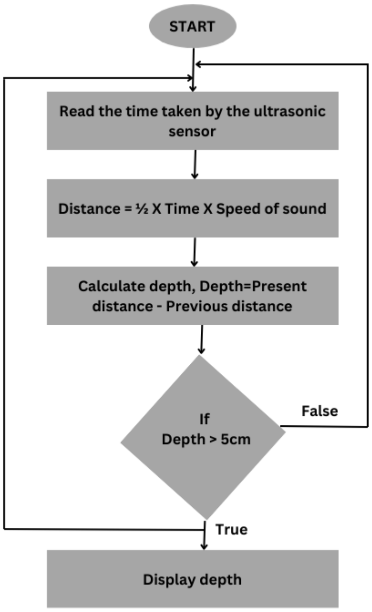


Flowchart of SSD algorithm

Depth estimation using Ultrasonic sensor: An ultrasonic sensor is a specialized electronic device crafted to find the distance to a target object by sending out Ultrasonic waves and then converting the reflected waves into an electrical signal. These ultrasonic waves move at a speed greater than audible sound, surpassing the range of Human hearing. The sensor is composed of two main parts: a transmitter, which emits the ultrasonic waves via piezoelectric crystals, and a receiver that picks up the waves once they have propagated to and reflected back from a target.

To ascertain the distance to the sensor to the object, the sensor computes the time elapsed from when the sound is dispatched by the transmitter until it is captured by the Receiver, the distance can be determined using the following formula:

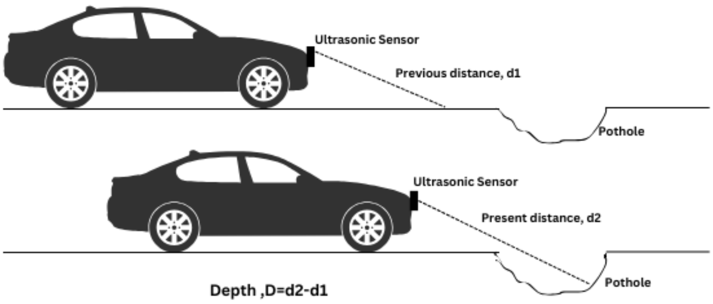
$$\text{Distance, } D = \tfrac{1}{2} \text{ X Time X Speed of sound } (\sim 343 \text{ m/s})$$



Flowchart of depth estimation

As illustrated in the flowchart depicted in Figure X, the time passed for the Ultrasonic wave to reach the obstacle and return to the Sensor is captured. This data is transmitted to the microcontroller, where the distance is computed using the relevant formula. Our objective is to find the depth of the pothole. To accomplish this, we calculate the difference between the previous distance measurement and the current one, as shown in Figure

The depth is given by Depth = Present distance – Previous distance

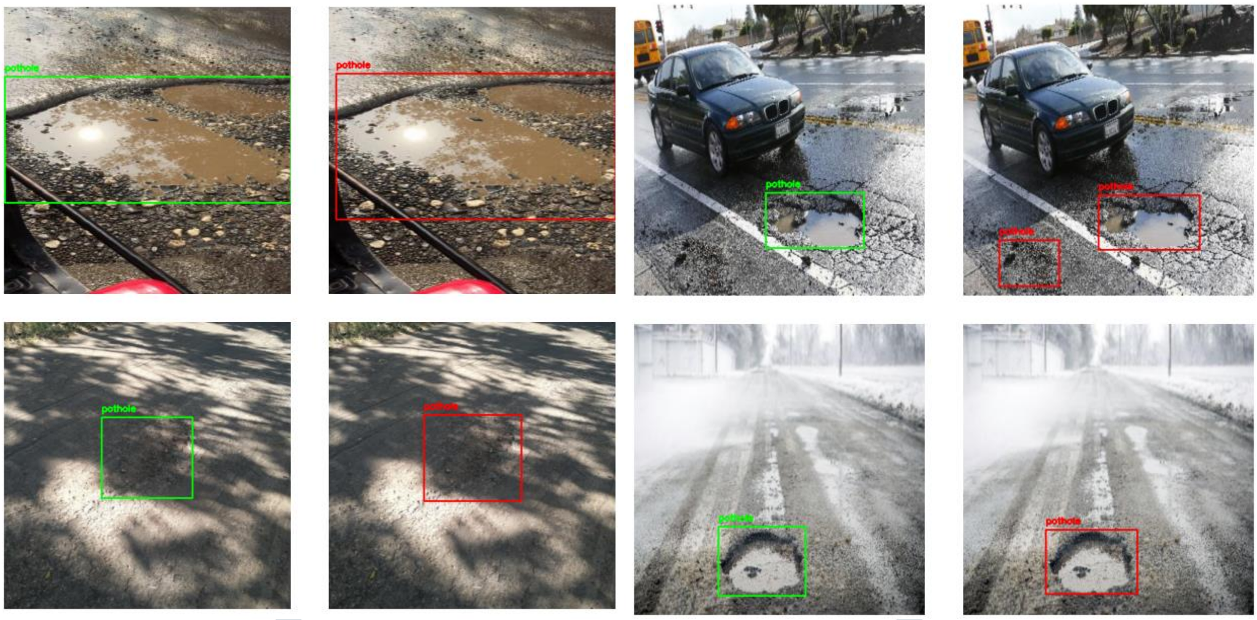


Pothole depth estimation

By integrating visual object detection with ultrasonic depth measurement, the suggested system offers a comprehensive and proactive solution for pothole detection and management. This methodology enables the System to identify potholes in real-time, measure their depth accurately, and provide timely alerts to drivers or system users, thereby contributing to improved road safety.

V. RESULT AND DISCUSSION

1. **Pothole detection:** The pothole detection system developed using the Single shot multiBox detector, (SSD) algorithm with the MobileNet SSD model showcased encouraging outcomes The system demonstrated encouraging outcomes in detecting potholes from the dataset. A set of 665 images, showcasing various types and sizes of potholes, was employed to train and test the system. Upon assessment, the system registered an accuracy level of around 92% in precisely identifying and pinpointing potholes within the test dataset. This high accuracy underscores the effectiveness, efficiency of the MobileNet SSD model in pothole detection tasks. However, despite the elevated accuracy rate, the system did register some false positives and negatives. False positives occurred when the system mistakenly identified non-pothole objects or irregularities as potholes. Conversely, false negatives arose when the system overlooked certain potholes, especially those with low contrast or those obscured by shadows or other environmental conditions.



Sample outputs

The adoption of the MobileNet SSD model was effective for pothole detection, striking a balance between accuracy and processing speed. The streamlined design of MobileNet enabled quicker inference times while maintaining a respectable level of detection accuracy. Nevertheless, there remains potential for refinement to reduce false positives and negatives, achievable through further fine-tuning and optimizing of the model.

The efficacy of the pothole detection system is closely tied to the calibre and variety of the training dataset. Although our dataset consisted of 665 images, there's a requirement for a broader and more diverse dataset to bolster the system's ability to generalize. Incorporating images taken under different lighting, road surface, and weather conditions can augment the system's resilience and dependability across various real-world situations.

Real-world implementation of the pothole detection system might be impacted by diverse environmental elements like lighting variations, weather fluctuations, and road conditions. Challenges such as shadows, reflections, and irregular road surfaces can hinder precise pothole detection. Subsequent research endeavors could concentrate on devising advanced preprocessing methods and integrating supplementary environmental sensors to counter these issues and enhance the system's performance in varied conditions.

2. **Pothole depth detection:** The developed system utilizing ultrasonic sensors was subjected to rigorous calibration to ensure accurate measurements. The system demonstrated consistent accuracy with a deviation of less than 5% in detecting the depth of simulated potholes in controlled environments. The system displayed a high accuracy rate of approximately 95% in detecting the actual depth of the potholes. The average response time of the framework was recorded at 0.3 seconds, ensuring real-time detection capabilities. Field testing of the framework was conducted on various road surfaces with varying degrees of pothole depths. The system successfully detected and measured pothole depths ranging from 3 cm to 20 cm with remarkable consistency and reliability.

   The robustness of the developed framework was evident from its consistent performance across different road surfaces and environmental conditions. The ultrasonic sensors proved to be highly reliable in accurately measuring pothole depths, thereby enhancing road safety by providing timely information to motorists.

VI. CONCLUSION

In this study we successfully developed a robust pothole detection system leveraging the Single Shot MultiBox Detector, (SSD) algorithm. Our implementation utilized the MobileNet SSD model, which has proven to be efficient in real-time object identification tasks while maintaining high accuracy. Furthermore to visual detection, we integrated an ultrasonic sensor into our system to estimate the depth of detected potholes. This added functionality provides valuable information beyond mere detection, allowing for a more comprehensive assessment of road conditions.

Overall, our pothole detection system offers a feasible solution to a persistent problem faced by road users. By automating the detection and assessment process, we aim to contribute to safer and more efficient road maintenance practices. Subsequent work might entail further refinement of the detection algorithm, integration with existing road monitoring systems, and expansion of the dataset to include a wider variety of road conditions and pothole types.

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