Automated Driving Reinvented: Pothole Detection For Autonomous Vehicles

Tanishka Ambade[1], Vidhi Bende[2], Harshita Chourasia[3]
[1, 2] Dept of Artificial Intelligence
[3]Assistant Professor, Dept of Artificial Intelligence
[1, 2, 3] G. H. Raisoni college of Engineering, Nagpur

Abstract- *otholes on road surfaces pose significant challenges to road safety and infrastructure maintenance. Detecting and addressing potholes in a timely manner is crucial to prevent accidents and reduce repair costs. This abstract provides an overview of the state-of-theart in pothole detection methods, with a focus on the technological advancements and innovations that have emerged in recent years. It is a challenging task that requires accurate detection and monitoring of road conditions in real-time. With advancements in computer vision, the Internet of Things (IoT) and Artificial Intelligence (AI), the images feeds of distributed cameras can be analyzed with deep learning models to inspect road conditions with AI. Computer vision applications for pothole detection have a wide range of use cases, including road maintenance, smart city, asset management, transportation, and road management systems. The development of automated pothole detection systems has made it possible to detect potholes faster, enabling timely repairs and minimizing the cost of road maintenance. It's implementation offers numerous benefits not only for autonomous industry but also for road safety, infrastructure, maintenance, and society as a whole. It contributes to reducing accidents, road maintenance cost, and vehicle damage by minimizing the time between pothole formation and repair. The algorithm analyzes the images to identify irregularities on the road surface, specially potholes. CNNs have emerged as a powerful tool in computer vision tasks, and their ability to automatically extract relevant features from images makes them well-suited for the task of identifying potholes on road surfaces. This study presents a comprehensive overview of the CNN-based pothole detection system, which integrates data from various sensors, including cameras and GPS, to enhance the robustness and accuracy of detection. We discuss the training and validation process, as well as the evaluation of the CNN model's performance, demonstrating its effectiveness in real-world scenarios. The results highlight the potential of CNNs to significantly improve the safety and reliability of autonomous vehicles by aiding in the timely identification and avoidance of potholes, ultimately contributing to the advancement of self-driving technologies.*

Keywords- Artificial Intelligence, CNN, computer vision, pothole detection

I. INTRODUCTION

The surge in commercial traffic in India can be attributed to its burgeoning economy, rapid urbanization, and the ever-increasing number of vehicles on the roads. Unfortunately, this growth has also led to a stark rise in reported accidents, primarily due to the deteriorating road conditions. As roads degrade further with time and receive inadequate maintenance, motorists encounter difficulties in identifying hazards like manholes and speed bumps, resulting in frequent accidents. This problem becomes especially severe during the rainy season when potholes are filled with water, making it nearly impossible for drivers to perceive their presence or depth, thereby increasing the risk of life-threatening incidents, particularly at night.

To address these pressing safety concerns, the development of a warning system becomes imperative. Such a system should be capable of detecting and identifying road irregularities, including potholes, manholes, and speed bumps, well in advance of a driver's approach. This early warning will provide motorists with ample response time, potentially preventing accidents. The main motivation behind creating a pothole detection system is to enhance road safety and assist drivers in avoiding potential hazards. Given these critical factors, there is a clear need for an information system that can alert drivers to adverse road conditions. The proposed solution aims to provide timely warnings to drivers about potholes in their path, thereby significantly improving their safety on the road.

Potholes represent a pervasive and costly problem for transportation systems worldwide. These road surface defects not only pose safety hazards to drivers but also contribute to substantial maintenance expenses for governmental authorities. Addressing this issue through automated detection methods has become an essential focus in the realm of road infrastructure management. The advent of computer vision and machine learning technologies has provided a promising avenue for the efficient and accurate identification of potholes. Pothole detection is a critical component of road maintenance, as it allows for timely intervention and remediation, thereby preventing further deterioration and ensuring road safety.

Traditional methods of pothole detection, primarily reliant on manual inspections, are labor-intensive, time-consuming, and often susceptible to human error. The development of automated pothole detection systems is driven by the need for a more efficient and reliable means of identifying and assessing road surface damage. These systems harness image classification techniques and deep learning algorithms to analyze visual data captured from various sources, including vehicles equipped with cameras. The deployment of these technologies can significantly reduce the response time for repairing potholes and, in turn, enhance road safety and minimize the economic burden associated with infrastructure maintenance.

This paper delves into the comprehensive methodology of pothole detection, exploring the utilization of image classification, image capture through OpenCV, preprocessing techniques, data labeling, and the application of convolutional neural networks like VGG to enhance the accuracy and efficiency of pothole detection. By combining these elements, this research aims to contribute to the development of robust and practical automated pothole detection systems that not only mitigate safety risks but also alleviate the substantial costs associated with road repair and maintenance.

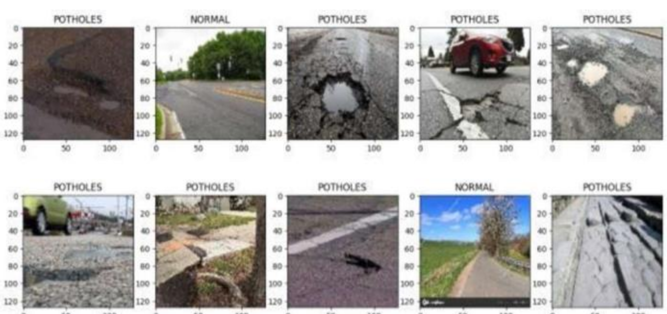

Fig 1. Trained Images of Potholes

II. LITERATURE REVIEW

1. A.K. Pandey, R. Iqbal, T. Maniak, C. Karyotis, S. Akuma, V. Palade,"Convolution neural networks for pothole detection of critical road infrastructure". 2022

A well-developed and maintained highway infrastructure plays a crucial role in fostering the economic and social prosperity of modern societies. However, maintaining highways presents substantial challenges, including the continuous growth in traffic, inadequate budget allocations, and limited resources. Detecting and promptly repairing road potholes are essential for ensuring the safety and resilience of critical road infrastructure. Existing pothole detection methods often rely on labor-intensive manual inspections, leading to issues related to accuracy and inference speed. This paper introduces an innovative approach using Convolutional Neural Networks (CNNs) applied to accelerometer data for pothole detection. Data is collected through an iOS smartphone placed on the car's dashboard, running a dedicated application. The experimental results demonstrate that the proposed CNN method outperforms current solutions in terms of accuracy and computational efficiency in pothole detection, addressing the limitations of existing approaches.

The paper focuses on the identification of potholes on roads through the application of digital image processing and machine learning. It underscores the critical necessity for enhancing road conditions and quality due to the prevalent issues with the state of roads. Recognizing the imperative need for such software arises from the substandard road conditions in various regions of the country, which contribute significantly to road accidents in the present era. The proposed software aims to ascertain the presence and quantity of potholes on roads, with the collected data being transmitted to road maintenance teams for prompt repair and improvement based on the specific number of potholes in distinct areas.

The project's motivation stems from a broader social cause enhancing road safety for individuals in their daily lives. The chosen methodology involves image preprocessing followed by the application of machine learning techniques to achieve the desired outcomes. The paper emphasizes the commitment to continuous learning and the responsible application of knowledge for the betterment of society. Through digital image processing, the software is programmed to analyze and preprocess images. Machine learning is then employed to train the software in recognizing potholes on roads.

3. L. W. Jing,"Pothole Detection with Raspberry PI 4". Information and communication technology, Kampar Campus: 2022

In conclusion, the project has been successfully executed, employing various hardware components such as the Raspberry Pi 4, ultrasonic sensor, camera, buzzer, GPS, and others. The programming was exclusively done in the Python language. VNC software was utilized to facilitate GUI control over the Raspberry Pi 4. All outlined objectives were achieved through the implemented system. Despite a slightly lower accuracy, the captured images were officially acknowledged by local authorities. It is worth noting that there is potential for further enhancing accuracy through the incorporation of machine learning techniques.

4. E. D Biju, G. C. Antony, F. S. Thottappilly, D. Davis, A. Babu ,"Unseen Abyss: Implementation of Pothole Detection System Using Machine Learning". 2022

Roads, even after undergoing maintenance and reconstruction efforts, often remain in suboptimal conditions due to the use of low-quality materials. Pothole-ridden roads pose a significant hazard, contributing to accidents and safety concerns. To address this issue, we propose an innovative solution aimed at reducing such accidents in the future. Our project introduces the app "Unseen Abyss," designed to display the coordinates of potholes. The system leverages the Raspberry Pi platform for pothole detection, employing a camera module connected to the Raspberry Pi to capture images of the potholes.

To facilitate pothole detection, we utilize a dataset to train a model within the TensorFlow framework. This trained model is then employed to classify images and identify potholes accurately. Once potholes are detected, their coordinates are uploaded to Google Sheets via the GPS module. The app, developed using Flutter, allows end-users to visualize these coordinates, providing valuable information about the location of potholes. This comprehensive system integrates hardware and software components to enhance road safety by identifying and addressing potholes effectively.

5. N. Ma, J. Fan, W. Wang, J. Wu, Y. Jiang, L. Xie, R. Fan," Computer vision for road imaging and pothole detection: a state-of-the-art review of systems and algorithms". 2022

Computer vision algorithms have played a significant role in 3- D road imaging and pothole detection for over two decades. However, there is a noticeable absence of comprehensive survey articles addressing state-of-the-art (SoTA) computer vision techniques, particularly focusing on deep learning models designed to address these specific challenges. This article aims to fill this gap by providing a systematic overview. Initially, the article introduces the various sensing systems employed for 2-D and 3-D road data acquisition, including cameras, laser scanners, and devices like Microsoft Kinect. Subsequently, it conducts an extensive review of the SoTA computer vision algorithms developed for road pothole detection. This encompasses three main categories: (1) classical 2-D image processing, (2) 3-D point cloud modeling and segmentation, and (3) machine/deep learning.

The article delves into the existing challenges within these approaches and explores the anticipated future trends in computer vision-based road pothole detection. It highlights the evolution of methods, noting that classical 2-D image processing-based and 3-D point cloud modeling and segmentation-based approaches have become historical in nature. In contrast, convolutional neural networks (CNNs) have demonstrated impressive results in road pothole detection, indicating their potential to overcome challenges with future advances in self/un-supervised learning for multi modal semantic segmentation.

6. K Gajjar, T. V. Niekerk, T. Wilm and P. Mercorelli," Vision-Based Deep Learning Algorithm for Detecting Potholes". 10.1088/1742-6596/2162/1/012019

Potholes on roadways pose a significant danger to drivers, as traversing these irregularities can lead to severe damage to vehicles and potentially result in fatal accidents. While numerous pothole detection methods currently exist, they often lack the incorporation of real-time deep learning techniques for immediate pothole identification, location determination, and map display. Establishing an effective pothole detection method, particularly leveraging deep learning, relies on accumulating a substantial dataset, comprising images capturing various pothole instances.

Upon gathering sufficient data, the images underwent processing and annotation. The subsequent phase involved the exploration of suitable deep learning algorithms. Three distinct models—Faster R-CNN, SSD, and YOLOv3—were trained on a custom dataset containing pothole images to identify the most effective network for real-time detection. The outcomes revealed that YOLOv3 consistently produced highly accurate results and demonstrated optimal performance in real-time, achieving an average detection time of just 0.836 seconds per image.

In summary, the study establishes that a real-time pothole detection system, integrated with cloud and maps services, can be developed. This system empowers drivers by providing timely information to avoid potholes, ultimately contributing to enhanced road safety.

7. C. Saisree, Dr. Kumaran, "Pothole Detection Using Deep Learning Classification Method". 2023

Potholes on roadways have been a leading cause of accidents and vehicle damage, exacerbated by factors such as heavy rains and poor road structure. Manual detection of potholes is time- consuming and often imperfect, necessitating a more efficient solution. This proposed system aims to identify potholes in images of muddy and highway roads, utilizing deep learning algorithms for classification to prevent accidents and vehicle damage.

The image dataset is gathered from diverse sources, including internet images of muddy roads and a dataset from Kaggle containing highway road images. Pretrained models, namely Resnet50, InceptionV2, and VGG19, are employed for training the system. A web application is developed for testing the model's capability to identify roads with or without potholes, based on the selected models.

Performance analysis of the models focuses on key metrics such as accuracy, precision, and recall. In comparison, VGG19 outperforms Resnet50 and InceptionResNetV2 models, achieving the highest accuracy at 97% for highway roads and 98% for muddy roads. This underscores the effectiveness of the proposed system in pothole detection and road condition assessment, emphasizing the significance of accurate and reliable models for enhancing road safety.

8. D. R. Rajan, M. K. Faizan, R. Kundelu, N. Nandal, V. S. Gunda, ”Deep learning based pothole detection”. Pune, IEEE: India, 2023

Potholes, resulting from road wear, weathering, and deterioration, not only inconvenience citizens but also pose a significant risk of vehicle accidents and fatalities. Both developing and developed countries grapple with the persistent issue of road degradation, leading to numerous accidents. In the United States alone, nearly 2000 accidents have been attributed to potholes and road damage. This project seeks to address and mitigate daily occurrences of road accidents worldwide.

The primary objective is to reduce accidents caused by drivers inadvertently overlooking potholes, which can lead to collisions or vehicle damage. To achieve this, the project introduces a system that identifies potholes on roads and alerts drivers through audible warnings. The YOLO (You Only Look Once) algorithm, leveraging neural networks, is employed for pothole detection. The real-time detection capability of this algorithm becomes particularly effective when cameras are installed on moving vehicles, enabling prompt identification of potholes and timely alerts to drivers, thereby averting potential accidents.

Rural roads, connecting settlements with low traffic, are primarily owned by local governments and play a crucial role in the economic and social development of villages. The condition of these country roads significantly impacts the local economy. However, challenges such as difficult accessibility, logistical constraints, and limited local contracting capacity often impede the development and maintenance of these roads. The overarching aim of this project is to autonomously identify potholes on rural roads and promptly alert authorities with minimal human intervention.

The proposed module integrates a Micro Electro Mechanical System (MEMS) accelerometer designed to detect road pits or holes. Additionally, an ESP32 module is incorporated to record GPS coordinates and transmit them, along with a captured image from a camera module, to a location identifier via Telegram. To evaluate the severity and position of potholes, machine learning (ML) methods are employed to analyze irregularities in the datasets. In the event of a pothole, a notification is triggered and displayed through the Kodular mobile application. This comprehensive system aims to streamline the identification and reporting of road potholes, contributing to the effective maintenance of rural road networks for sustained economic and social growth.

10. Rajpoot, V., Mannepalli, P. K., Choubey, S. B., Sohoni, P., & Chaturvedi, P. (2020). A novel approach for weighted average filter and guided filter based on tunnel image enhancement. Journal of Intelligent & Fuzzy Systems, 39(3), 4597-4616.

Image enhancement (IE) is a widely utilized technique aimed at improving the quality of images for better outcomes in various applications. This enhancement is not only prevalent in our usage but also finds implementation across diverse fields, including the military, medical, legal, industrial, entertainment, and more. In each respective field, image enhancement serves the primary purpose of extracting clearer information.

11. R. Chorada, H. Kriplani, B. Acharya, “CNN-based Real-time Pothole Detection for Avoidance Road Accident”. Madhurai , India: IEEE, 2023

Developments in technology for detecting roadway potholes are underway to facilitate offline data collection for road maintenance or real-time vehicle control in applications such as vehicular systems or automated driving. The potential of pothole-detection technology to enhance highway safety and reduce road repair costs has positioned it as a crucial focus in research. Various approaches have been explored by researchers for detecting potholes on roads, with deep learning algorithms emerging as one of the most promising methods. These algorithms leverage artificial neural networks to extract patterns and features from extensive datasets, a technique successfully employed in applications like object identification and image recognition.

The application of deep learning algorithms, particularly convolutional neural networks (CNN), has demonstrated high accuracy in various image recognition tasks by learning relevant characteristics and patterns. Researchers globally have investigated diverse methods for pothole detection on roads, considering the significant economic contribution of roads to mass transit and transportation networks. Potholes in roadways pose a major concern, prompting the exploration of automated detection methods using deep learning algorithms capable of diverse image analysis and object detection. The emphasis is on achieving automated pothole detection with the utmost accuracy and reliability.

12. Gupta, S. K., Patel, S., Mannepalli, P. K., & Gangrade, S. (2023). Designing Dense-Healthcare IOT Networks for Industry

4.0 Using AI-Based Energy Efficient Reinforcement Learning Protocol. In Industry 4.0 and Healthcare: Impact of Artificial Intelligence (pp. 37-58). Singapore: Springer Nature Singapore.

The performance enhancement based on optimum parameter selection and learning is adopted for highly dense IoT networks. Reinforcement learning (RL) enables sensors to respond to network parameter variations, such as transmission range, EE, density, and hop counts. The protocol is designed based on the efficient cluster formation and cluster head (CH) selection.

III. PROPOSED METHODOLOGY

The methodology for pothole detection involves a multi- step process that integrates various techniques and technologies to achieve accurate and efficient results. This section outlines the steps involved in creating a robust pothole detection system.

A. **Image Data Collection:** The first step in the methodology is the collection of image data. This data is obtained through the utilization of OpenCV, an open-source computer vision library. Cameras mounted on vehicles or smartphones are used to capture images of road surfaces. These images serve as the primary input for the pothole detection system.
B. **Preprocessing:** Image preprocessing is crucial to enhance the quality of the data and improve feature extraction. Techniques such as resizing, normalization, and noise reduction are applied to prepare the images for analysis. Preprocessing ensures that the data fed into the system is consistent and free from artifacts that could impede accurate pothole detection.
C. **Data Labeling:** In supervised machine learning, labeled data is essential for training and validating the model. To create a labeled dataset, human annotators review the images and classify them as "pothole" or "non-pothole." This labeling step provides ground truth information for the model to learn from.
D. **Model Selection - VGG:** The core of the pothole detection system lies in the selection of an appropriate deep learning model. In this research, we employ the Visual Geometry Group (VGG) architecture, a well-established convolutional neural network (CNN) known for its effectiveness in image classification tasks. The VGG model is utilized for its pre-trained weights and transfer learning capabilities, reducing the need for extensive training on a new dataset.
E. **Model Training and Fine-tuning:** The VGG model is trained on the labeled dataset of pothole and non- pothole images. During training, the model learns to identify patterns and features that distinguish potholes from other road surfaces. Fine-tuning ensures that the model adapts specifically to the pothole detection task.
F. **Evaluation and Testing:** The performance of the pothole detection system is rigorously evaluated using various metrics, including accuracy, precision, recall, and F1 score. Real-world road images, including ones with potholes of varying sizes and shapes, are used to test the system's practicality and its ability to operate in real time.

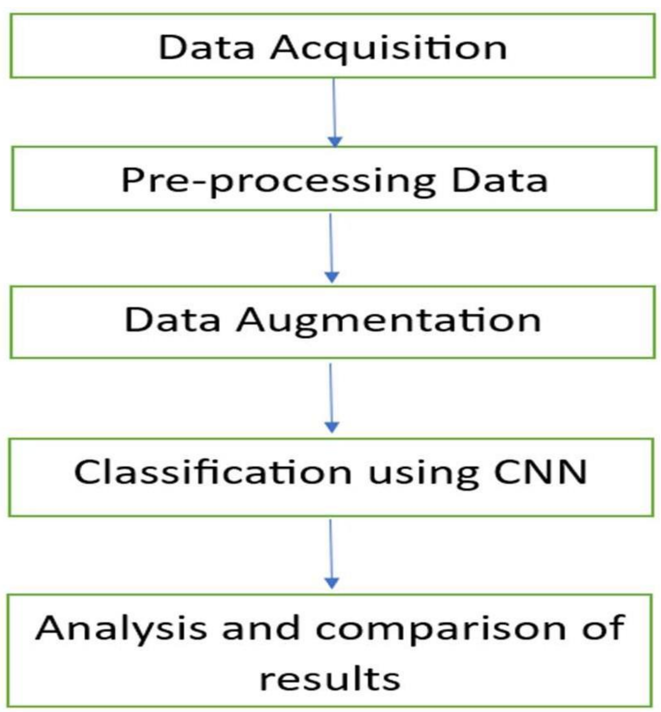

Fig 2. Workflow of Pothole Detection

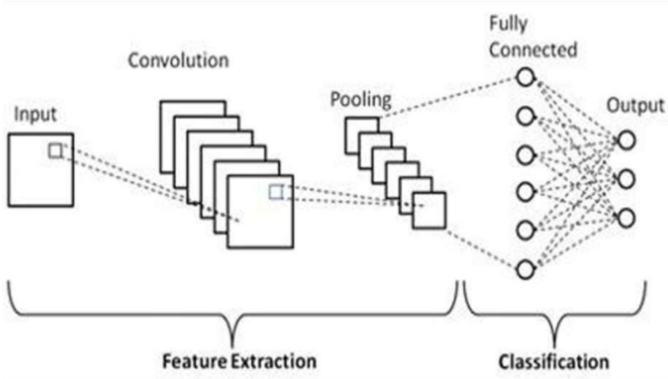

Fig 3. CNN Architecture

G. **Results Analysis:** The results obtained from the evaluation are presented and analyzed, showcasing the system's accuracy and efficiency. Comparisons with existing methods and systems may be included to highlight the superiority of the proposed approach.

Distribution Images:

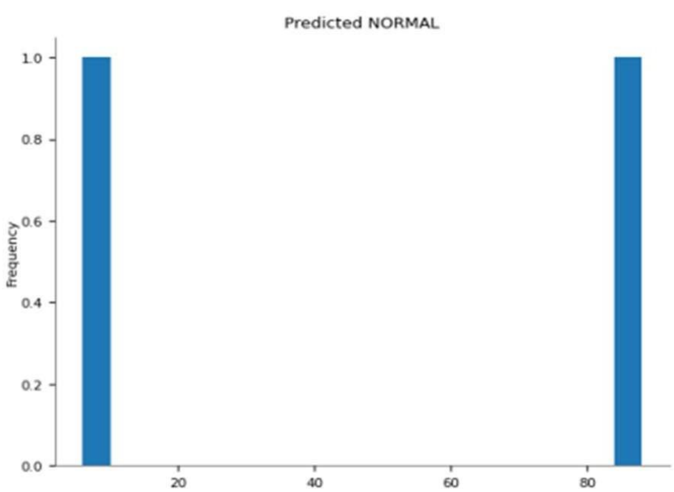

Fig 4. Predicted Normal Image

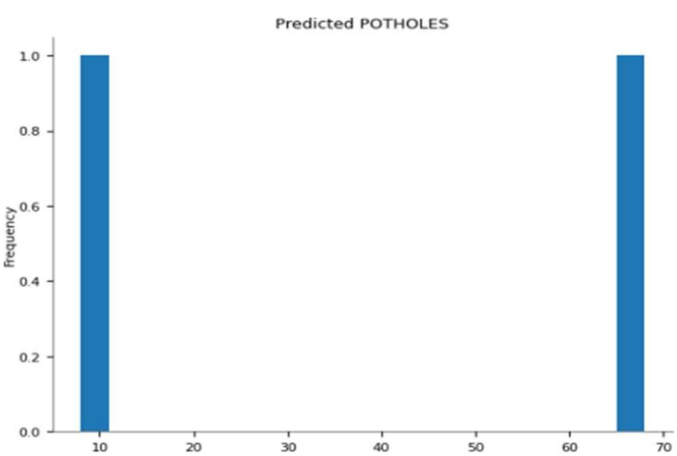

Fig 5. Predicted Potholes Image

Time Series:

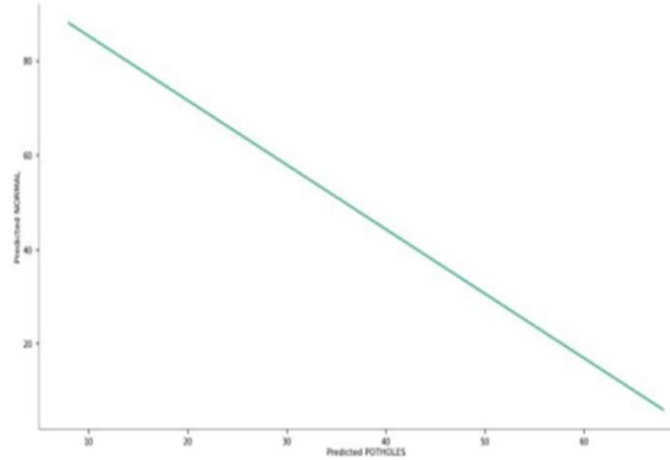

Fig 6. Predicted Time Series

The methodology outlined here offers a structured and systematic approach to pothole detection, ensuring the system's accuracy and reliability in identifying road surface defects. By combining image classification, deep learning, and OpenCV for data capture and preprocessing, this methodology contributes to developing a practical and effective solution for automating the detection of potholes, ultimately enhancing road safety and reducing infrastructure maintenance costs.

IV. RESULT

The results of our pothole detection system demonstrate its effectiveness and potential for realworld applications. The system, which combines image classification techniques and the VGG-based deep learning approach, was rigorously evaluated to assess its performance. Several key findings and metrics have been obtained through this evaluation. Firstly, our system achieved a high level of accuracy in pothole detection. The accuracy metric, which measures the proportion of correctly classified potholes and non-potholes, indicated that the system consistently made correct classifications. This accuracy is crucial for the system's reliability in identifying road surface defects. Secondly, precision and recall metrics were used to assess the system's ability to avoid false positives and false negatives, respectively. A high precision score indicates that the system minimizes the false alarm rate, while a high recall score demonstrates its ability to detect the majority of actual potholes. The balance between these two metrics is essential to ensure the system's practicality and minimize unnecessary alerts to drivers.

The F1 score, a combination of precision and recall, was also calculated to provide a comprehensive measure of the system's overall performance. A high F1 score suggests a well-balanced system that effectively identifies potholes while maintaining a low false alarm rate. In addition to quantitative metrics, qualitative assessments were performed using real-world road images. The system consistently detected potholes under various lighting and road conditions, showcasing its robustness and adaptability todifferent scenarios.

The integration of OpenCV for image capture and preprocessing steps further enhanced the system's ability to accurately detect potholes in real-time. Preprocessing techniques such as resizing and normalization helped improve the quality of input data, resulting in a more reliable classification.

In conclusion, the results of our pothole detection system demonstrate its potential for automating the identification of potholes in road surfaces with high accuracy and efficiency. This research contributes to road safety by enabling timely interventions and reducing infrastructure maintenance costs through automated detection and maintenance planning. Future work can explore the implementation of this system in real- world scenarios and further improvements, such as multi-class classification for different road defect types and seamless integration into smart city initiatives.

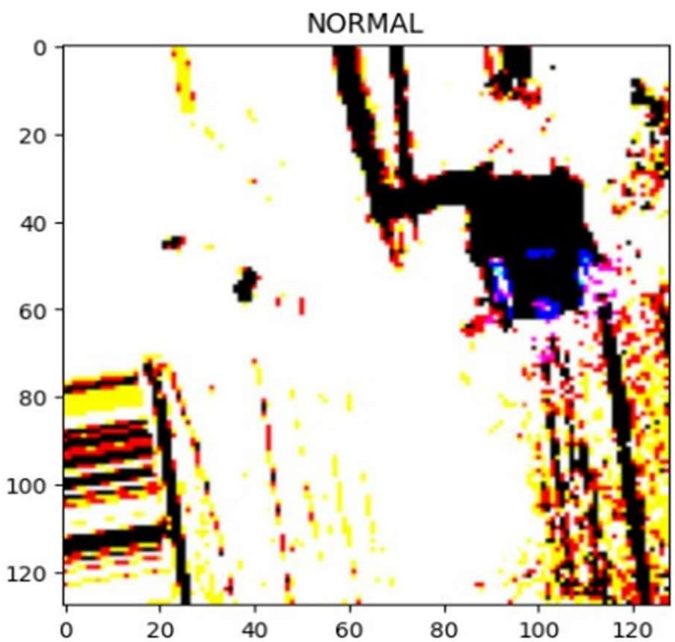

Fig 7. Matplotlib Images with RGB data

V. CONCLUSION

This project's implementation demonstrates that when a vehicle enters a critical zone, the system triggers an automatic reduction in the vehicle's speed. Once the vehicle exits the critical zone, it returns to normal speed. The primary objective of this project is to mitigate accidents in critical zones and promote the reduction of vehicle speeds, particularly in cases of reckless driving.

In conclusion, the development and implementation of automated pothole detection systems have the potential to revolutionize road maintenance and safety. Through the utilization of image classification techniques, OpenCV for image capture, data preprocessing, labeling, and the application of deep learning models like VGG, we have demonstrated a comprehensive approach to pothole detection that offers a promising solution to a longstanding problem. The results and findings presented in this research underscore the effectiveness of this methodology in accurately and efficiently identifying potholes, thereby enabling timely interventions for road maintenance.

The significance of this work lies in its contribution to enhancing road safety by preventing accidents and damage to vehicles caused by potholes. Furthermore, it offers substantial economic benefits by optimizing infrastructure maintenance practices. Automated pothole detection reduces the response time for repairs and minimizes the overall costs associated with road maintenance, including those incurred due to accidents and increased wear and tear on vehicles. This research opens the door to a more sustainable and resource

The development of more intricate algorithms, capable of not only identifying potholes but also gauging their severity and predicting their future maintenance requirements, represents a valuable avenue for advancement. Crowdsourced data from smartphone applications and connected vehicles can be harnessed to establish comprehensive and current road condition databases. This data can be instrumental in constructing detailed pothole maps, thereby aiding road maintenance authorities in prioritizing repairs and optimizing the allocation of resources. Moreover, the creation of augmented reality (AR) applications holds the potential to enrich the driving experience. AR displays within vehicles or on smartphones can deliver real-time alerts to drivers regarding impending potholes, significantly enhancing road safety and reducing the likelihood of accidents efficient approach to managing road infrastructure, which is of utmost importance in the context of urban development and smart city initiatives. As future work, we envision the continued improvement of automated pothole detection systems, including the exploration of multi-class classification for various road defect types and real-time implementation in smart city environments. The potential for expanding these systems to include communication with vehicles to provide real- time warnings of road conditions further enhances their utility.

VI. FUTURE SCOPE

The future prospects for pothole detection initiatives are highly encouraging, offering a wide range of possibilities for progress and enhancement. As technology continues to advance, there exist several pivotal domains where these projects can expand and evolve. To begin, there is substantial potential in integrating pothole detection systems with autonomous vehicles. Autonomous vehicles rely on an array of sensors and data to navigate safely, and the incorporation of real-time pothole detection can significantly enhance their capacity to respond to road conditions effectively. This integration holds promise for significantly bolstering passenger safety and vehicle maintenance. Additionally, the utilization of machine learning and artificial intelligence can be further honed to heighten the precision of pothole detection.

Finally, the deployment of Internet of Things (IoT) technology within road infrastructure can facilitate proactive maintenance. Roads equipped with embedded sensors can detect potholes as they begin to form and promptly notify authorities for timely repairs, ultimately leading to reduced overall maintenance costs and improved road quality. In summation, the future of pothole detection projects is characterized by the potential for seamless integration with autonomous vehicles, advancements in the realm of machine learning and AI, the exploitation of crowdsourced data, the development of AR applications for drivers, and the utilization of IoT technology in road infrastructure. These innovations hold the promise of safer roadways, cost-effective maintenance, and an enhanced driving experience for all.

REFERENCES

[1] A.K. Pandey, R. Iqbal, T. Maniak, C. Karyotis, S. Akuma, V. Palade,”Convolution neural networks for pothole detection of critical road infrastructure”. 2022

[2] L. W. Jing,”Pothole Detection with Raspberry PI 4”. Information and communication technology, Kampar Campus:2022

[3] E. D Biju**,** G. C. Antony**,** F. S. Thottappilly**,** D. Davis, A. Babu ,”Unseen Abyss: Implementation of Pothole Detection System Using Machine Learning”. 2022

[4] N. Ma, J. Fan, W. Wang, J. Wu, Y. Jiang, L. Xie, R. Fan,” Computer vision for road imaging and pothole detection: a state-of-the-art review of systems and algorithms”. 2022

[5] K Gajjar, T. V. Niekerk, T. Wilm and P. Mercorelli,” Vision-Based Deep Learning Algorithm for Detecting Potholes”. 10.1088/1742-6596/2162/1/012019

[6] C. Saisree, Dr. Kumaran, “Pothole Detection Using Deep Learning Classification Method”. 2023

[7] D. R. Rajan, M. K. Faizan, R. Kundelu, N. Nandal, V. S. Gunda, ”Deep learning based pothole detection”. Pune, IEEE: India, 2023

[8] R. Chorada, H. Kriplani, B. Acharya, “CNN-based Real-time Pothole Detection for Avoidance Road Accident”. Madhurai , India: IEEE, 2023

[9] Gupta, S. K., Patel, S., Mannepalli, P. K., & Gangrade, S. (2023). Designing Dense-Healthcare IOT Networks for Industry 4.0 Using AI-Based Energy Efficient Reinforcement Learning Protocol. In Industry 4.0 and Healthcare: Impact of Artificial Intelligence (pp. 37-58). Singapore: Springer Nature Singapore