Pothole detection model for road safety using computer vision and machine learning

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Article Info

Article history:

Received Feb 24, 2024
Revised Jun 15, 2024
Accepted Jun 21, 2024

Keywords:

Computer vision;
Intelligent transportation systems;
Machine learning;
Pothole;
Vehicular safety

ABSTRACT

Potholes pose significant threats to vehicular movement, causing damage to vehicles and risking the safety of drivers and pedestrians. The escalating issue of potholes has led to substantial financial losses for vehicle owners and drivers. Traditional methods of pothole detection are impractical, necessitating an innovative approach. The study focuses on implementing a detection system capable of accurately identifying potholes, empowering vehicles to adapt their speed or halt to prevent damage. The transformative solution presented in this research leverages cutting-edge technologies, specifically computer vision and machine learning, aiming to enhance road safety and streamline maintenance efforts. By addressing the interdependence of modern civilization on road networks, the Pothole Detection Model promises improved road safety, efficient maintenance practices, and the emergence of an era in intelligent transportation systems. The integration of technology into transportation infrastructure highlights the proactive measures needed to combat road imperfections, ensuring a safer and more efficient road network for the benefit of society.

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1. INTRODUCTION

Potholes on roads are hard to pass for vehicles as they cause much damage to them. As each and every pothole cannot be converted to a proper road, it is better to make a pothole detection model by which vehicles are able to detect potholes so it can lower down its speed or stop itself [1], [2]. So, no harm will be caused to the vehicle and it directly saves an enormous amount of money. Infrastructure adds significantly to a country's economic overall growth [3], [4]. Road surface of cement and other types are commonly used as mobility facilities in the world [5].

Potholes, irregular manholes and other irregularities are examples of roadways. Potholes can arise as a result of poor construction, poor design that causes groundwater to gather [6]. Annually, potholes do a significant damage to both people and their assets. Potholes immediately affect and disappoint significant amount of people [7], [8]. Approximately drivers have spent over Rs. 10,000 crores in five to seven years on automobiles to repair damage caused by potholes. Each motorist incurred a cost of almost Rs. 10,000 on an average. The survey in India states that around 5,000 accidents on an average takes place. Governments also spends a huge amount of money in repairing these potholes. So, vehicles need to get upgraded by pothole detection model so it lowers it speed or stops [9], [10].

The road infrastructure is a critical component of urban and rural environments, serving as the arteries that facilitate the movement of people and goods [11]. However, the inevitable wear and tear on road surfaces, exacerbated by factors such as weather conditions, heavy traffic, and insufficient maintenance, give rise to a pervasive and potentially hazardous issue like potholes [12]. Potholes not only contribute to a degradation of the quality of roads but also pose significant risks to both vehicles and pedestrians. In response to this challenge, the pothole detection project has been initiated to develop an innovative solution leveraging computer vision and machine learning technologies [13], [14].

The intricate web of roads that crisscrosses urban and rural landscapes is the backbone of modern civilization, facilitating the movement of people and goods [15], [16]. However, this intricate network is not impervious to the relentless forces of nature and human activity. Potholes, those ubiquitous road imperfections, emerge as an unintended consequence, threatening the integrity of our transportation infrastructure and compromising the safety of road users. The advent of technology, particularly in the realms of computer vision and machine learning, presents a unique opportunity to address this pervasive challenge. The pothole detection project, at the intersection of innovation and infrastructure, embarks on a mission to enhance road safety, streamline maintenance efforts, and herald a new era in intelligent transportation systems [17]–[19]. In current scenario, many vehicles and their drivers are facing issues regarding the potholes on road which are causing much damage to cars and this leads to a loss which are covered by huge amounts of money. To avoid this there are certain actions required which includes potholes detection, lower the speed of vehicle or to stop, overcome the issues related to potholes, save one’s capital expenditure.

2. METHOD

2.1. Literature review

In this section state of art literature review is presented to know the current status developments in the field of pothole detection. The main focus of the literature review is to know technologies used for pothole detection, to find out the gaps and to work for the fulfillment of the gaps. The work tries to consider the latest available developments in the field of pothole detection for the literature review.

Bučko *et al.* [20] discussed the omnipresence of road discrepancies like potholes and focused on the pivotal role of early detection of potholes in prompt maintenance and accident prevention. The study uses you only look once (YOLO)v3, a computer vision model, for automatic pothole detection. The impact of adverse conditions including weather and light is also observed for detection accuracy of potholes. The author presented two-fold structure including dataset creation and utilization of YOLOv3 and sparse region-based convolutional neural networks (R-CNN). YOLOv3 is a competitive architecture, delivering commendable results with lower hardware demand. YOLOv3 showcases superior performance in brighter light conditions. Sparse R-CNN gives advantages in low light setting. This study works for comprehensive dataset and establishes methodology for computer vision-based object detection under adverse condition.

Asad *et al.* [21] investigated asphalt pavement distress, particularly emphasizing pothole detection's significance for roadway safety and daily commuting. Authors explored deep learning models deploying and evaluating various frameworks on edge devices, showcasing Tiny-YOLOv4, and YOLOv5 models with impressive mean average precision (mAP) scores. Authors explored that, despite high mAP, YOLOv5 exhibited limitations in distant pothole detection and misclassification, leading to the endorsement of YOLOv4 for accuracy and Tiny-YOLOv4 for real-time detection. This approach promises swift infrastructure repairs, potentially integrating global positioning system (GPS) for precise failure location identification. Author future plan includes detecting various pavement distresses, road classifications, and improving accuracy through real-time deployment modifications.

Hassan *et al.* [22] addressed the pivotal task of automating pothole detection in road maintenance. In case of traditionally manual visual inspections, integrating machine learning models presents challenges in producing generalizable models due to diverse image conditions. Using convolutional neural networks (CNN) models like faster R-CNN and Inception V2, authors explored four datasets encompassing various image sizes, distances, lighting, and environmental factors. Highlighting the impact of pothole distance and potential false identifications model is extended to detect multiple pavement defects. The significance of this study is to speed up and reduce the cost of pavement inspections by deploying the trained model for real-time detection. Author’s future plan aims to leverage larger datasets, including commercial and drone-captured images, necessitating robust pre-processing and increased computational resources for model refinement and hyperparameter tuning.

Kumar *et al.* [23] highlighted the importance of detecting road imperfections, particularly potholes, to enhance road maintenance and ensure vehicle safety. Authors noticed various image processing techniques attempting automated monitoring, yet challenges persist due to diverse road conditions and pothole variations. Addressing this, the study employed CNN to analyze digital images, achieving precise assessments of pothole depth, area, and shape. This approach aims to enhance the accuracy and efficiency of road condition detection, crucial for mitigating vehicle damage, fuel consumption, passenger inconvenience, and reducing road accidents stemming from poor road conditions.

Zhang and Hamdulla [24] explored the importance of identifying road potholes, essential for real-time vehicle control and road maintenance. Potholes, as unpredictable road features, significantly impact driving conditions, vehicle damage, and road safety worldwide. With growing concern due to accidents and advancements in machine learning and intelligent driving technologies, the demand for precise pothole detection has increased. Authors investigated existing pothole detection methods, acknowledging the evolving landscape of machine learning and intelligent driving, highlighting the necessity for robust pothole detection strategies to safeguard lives and streamline travel.

Seetha [25] addressed the global issue of potholes on roads, emphasizing their potential for vehicle damage and road safety risks. Leveraging deep learning algorithms, the authors presented a methodology to employ faster R-CNN and YOLOv3 models for early pothole detection using images and videos, mitigating accident probabilities. Authors considered the challenges like variable lighting and data noise, highlighting the efficacy of deep learning in accurate pothole identification. The comparative analysis shows the effectiveness of these algorithms in enhancing road maintenance, reducing vehicle damage, and augmenting safety. The proposed model facilitates efficient road repairs and offers a user-friendly complaint system via an online platform, indicating pothole locations from uploaded images. Author’s future work considers integration of GPS for real-time detection and driver alerts, enhancing the system's usability and accuracy in detecting pavement defects.

Pramanik *et al.* [26] addressed the consequences of road accidents, attributing a significant cause to potholes. The author’s main focus is on image processing techniques, specifically transfer learning, the research aims to identify potholes using visual geometry group (VGG16) and ResNet50 neural network models. Prioritizing road safety, the work aims to enable the Road and Highway Department (RHD) with a computer vision-based solution for efficient pothole recognition. After employing various image preprocessing methods, the proposed models give better accuracy. The findings claim that the models developed for pothole identification and road safety enhancement are highly accurate.

Ma *et al.* [27] highlighted the prolonged use of computer vision in 3-D road imaging and pothole detection. The authors identified gap in systematic surveys on cutting-edge techniques, especially deep learning models. The author introduces 2-D/3-D road data acquisition systems and reviews state-of-the-art computer vision algorithms for pothole detection. The current challenges are addressed in the article by forecasting a transition from older methods to CNNs for comprehensive road assessment systems. This work is important as a reference for advancing next-generation road condition assessment technologies.

Kandoi *et al.* [28] addressed the critical safety concerns in road transport due to poor maintenance, particularly focusing on the extensive issue of potholes leading to accidents worldwide. The proposed solution utilizes civilian’s mobile sensors and image-based methods, employing machine learning for real-time pothole detection. System sends notification to authorities through a web-based portal to facilitate prompt action, while the solution integrates features like location tagging, prioritization, and forecasting potential pothole issues. It updates the time series data to enhance system's efficiency, offering a comprehensive approach to address and prevent road accidents, emphasizing the importance of timely road maintenance for global traveler safety.

Singh *et al.* [29] highlighted the detrimental impact of rough roads on travel quality, vehicle maintenance, and safety. Authors focused on vision-based techniques for road condition detection. The authors employed a transfer learning-based inception ResNetV2 CNN model for road images. The authors made categories in the form of plane road, large pothole, and small pothole. The work evaluates model performance through training and testing loss and compared with CNN and support vector machine models using the same dataset. This work mainly contributes to road safety enhancement through vision-based classification methods.

Obreja and Dobrea [30] investigated the key interests and investment in cognitive systems and artificial intelligence. The work focused on creating a framework for pothole identification in real-time. The study captures and processes city images to identify asphalt potholes using video camera and Jetson Nano. The envisioned outcome used to recognize hazardous potholes and communicating road malfunctions to a central information hub to prevent traffic accidents. The authors mainly signify the convergence of AI applications and edge computing to offer promising solution for proactive road safety measures.

The reviewed literature is summarized in the Table 1 to find out the gaps of existing literature. The Table 1 presenting summary of literature survey contains the key attributes including title of the paper, author, technologies used, shortcomings. This Table 1 is used as a base to know the gaps and define the problem statement to resolve the same.

The summary of the literature survey shows that the most of the paper reviewed are either working with image processing or machine learning algorithms. In some of the papers other techniques are also used. The accuracy of the proposed models is not up to the mark in most of the reviewed papers. The hardware setup required by the system is also not explained in details by any of the authors. Hence this work considered all the gaps of existing literature to develop a system and to get results with high precision.

Table 1. Summary of literature review

Sr. No.	Title	Author	Methodology	Limitation
1	Computer vision based pothole detection under challenging conditions	Bučko *et al.* [20]	YOLOv3, R-CNN	Main focus is on computer vision-based object detection
2	Pothole detection using deep learning: a real-time and ai-on-the-edge perspective	Asad *et al.* [21]	Tiny-YOLOv4, YOLOv5	The edge device frameworks are the considered
3	Pothole detection under diverse conditions using object detection	Hassan *et al.* [22]	R-CNN, Inception V2	Lagging in model refinement and hyperparameter tuning
4	A vision-based pothole detection using CNN mode	Kumar *et al.* [23]	Image processing, CNN	Accuracy and precision discussed
5	Research on pothole detection method for intelligent driving vehicle	Zhang and Hamdulla [24]	Machine learning	Result and implementation not discussed in depth
6	Intelligent deep learning-based pothole detection and alerting system	Seetha *et al.* [25]	R-CNN, YOLOv3	Deep learning algorithm implementation is not discussed in details
7	Detection of potholes using convolutional neural network models: a transfer learning approach	Pramanik *et al.* [26]	VGG16, ResNet50	Image processing methods are not discussed in details
8	Computer vision for road imaging and pothole detection: a state-of-the-art review of systems and algorithms	Ma *et al.* [27]	3-D road imaging	Deep learning models are not explained in details
9	Pothole detection using accelerometer and computer vision with automated complaint redressal	Kandoi *et al.* [28]	Machine learning	Machine Learning algorithm is not explained in details
10	Classification of potholes using convolutional neural network model: a transfer learning approach using inception resnetV2	Singh *et al.* [29]	ResNetV2 CNN	Implementation details are not provided
11	Developing a versatile framework needed to identify pothole in asphalt using deep learning algorithms	Obreja *et al.* [30]	AI, Edge computing	Implementation details are not provided

2.2. Working

The road conditions, notably potholes, pose significant risks, causing accidents, vehicle damage, and financial losses. Potholes stem from various factors: subpar materials, flawed design allowing water accumulation, and weather conditions leading to cracks and ice formation. These gaps in road surfaces result in severe damage to vehicles, often necessitating costly repairs and endangering lives. The existing repair efforts fall short, unable to match the magnitude of the problem. The inadequate detection and rectification of potholes exacerbate their impact on road safety and infrastructure. To address this issue, a pothole detection model integrated into vehicles is proposed. This model aims to detect road potholes in real-time, triggering vehicle responses such as speed reduction or automatic stops to prevent accidents and minimize vehicle damage. The goal is to leverage technology and machine learning algorithms to proactively identify potholes, ensuring the safety of drivers and passengers while curbing the financial burden caused by road damage. By developing a pothole detection model capable of real-time identification and automatic response, this project aims to significantly reduce vehicle damage, prevent accidents, and enhance road safety. This technological advancement seeks to revolutionize road maintenance, mitigating the substantial economic and human costs currently associated with pothole-related incidents.

2.2.1. Objectives

This research work aims to develop an advanced pothole detection system using a Raspberry Pi remote-controlled (RC) model. The system is developed to identify road potholes autonomously. With the help of machine learning algorithms, the efficiency and accuracy of pothole detection is enhanced, the potential damage caused by road imperfectionsis reduced and overall road safety is improved. Key objectives of the project are as given as:

- To develop an autonomous pothole detection system utilizing a Raspberry Pi-based RC car equipped with a camera to identify and navigate around road potholes.

– To increase efficiency of pothole detection system using machine learning algorithms to mitigate damage caused by road potholes and enhance road safety.
– Design a system that triggers automatic measures, such as slowing down or stopping the vehicle, upon detecting potholes.

The main hardware components used in the implementation of the system are Raspberry Pi as a main computing platform for processing and controlling the RC car, LM398 (motor driver) the component enabling motor control for the RC car, power supply which provides necessary power for the Raspberry Pi and RC car, RC car the vehicle for implementing the autonomous system, PI camera which captures real-time images for pothole detection, USB cable used to connect components for data transfer, jumper wires and male headers are the essential components for electrical connections. The software components used for the system are integrated development environment (IDE) for code development, Jupyter notebook for interactive environment for prototyping and testing, programming language-Python used for coding the algorithms. OpenCV Library for image processing and computer vision tasks.

Using the hardware and software components the system is assembed and an algorithm is designed to process camera images in real-time. During the data acquisition phase, the hardware model is established and the cameras are strategically positioned in their functional locations. Utilizing OpenCV, the cameras operate continuously, capturing a dataset comprising approximately 712 images of plain roads and roads exhibiting potholes. These images are pivotal for training, testing, and refining the model to ensure its accuracy and reliability. In the real-time live data context, the hardware setup generates essential data, providing an efficient solution that allows drivers and users to relax without constant monitoring. The pothole detection model actively observes the surroundings, facilitated by the continuous live video feed from the cameras. Users have the flexibility to enable or disable the model as needed, granting them control over its operation and ensuring seamless monitoring of road conditions.

2.2.2. Algorithm

Pothole detection relies on real-time video processing employing a CNN model. CNN is a machine learning algorithm for the processing input images by assigning significant, learnable weights and biases to diverse objects within the image, facilitating effective object differentiation. One notable advantage of CNN lies in their reduced pre-processing demands compared to conventional classification algorithms. Traditional methods require manually crafted filters, yet CNN possess the unique ability to autonomously learn these filters and intricate features, significantly streamlining the pre-processing phase. Strength of this technology is its adaptability and capacity to discern intricate patterns within visual data, making it a formidable tool for pothole detection. By leveraging its inherent capability to learn features directly from the raw data, the CNN model identifies and distinguishes potholes from their surrounding environment in real time. Its capacity to automatically learn and adjust to various characteristics without explicit programming makes it a potent solution for efficient and accurate pothole detection in live video streams. This attribute not only simplifies the pre-processing steps but also enhances the model's capability to recognize and highlight potholes swiftly and effectively within the continuous video feed.

The model initiates with input data, progressing through convolution and filter operations, including loop-pattern, diagonal, and line filters, to generate a feature map. To prevent the loss of cells with high features, padding is applied, ensuring a more precise function. Subsequently, the rectified linear unit (ReLU) function introduces non-linearity, eliminating issues like the vanishing gradient problem. Pooling is then employed, reducing image dimensionality while preserving essential features, enhancing accuracy with reduced computational complexity. This iterative process repeats, refining outputs, culminating in an appropriate output. Finally, an activation function enables the model to obtain the ultimate classification output, utilizing these sequential steps to process and distil intricate visual data, leading to accurate and efficient identification or classification within the input dataset.

The implemented functionalities are comprehensive, beginning with the hardware model capturing live video data encompassing road conditions, particularly identifying potholes. This data retrieval initiates the Pothole detection model, diligently examining the incoming road conditions to ascertain the presence of potholes. Upon detecting a pothole, the system triggers mechanisms to reduce the vehicle's speed or halt its movement altogether, ensuring safer navigation. Conversely, if no pothole is identified, the vehicle continues its journey seamlessly. Leveraging CNN technology, this model guarantees the vehicle's operation on roads without encountering hazardous potholes, boasting high precision and reliability in its assessments. Overall, this amalgamation of hardware and detection models enables an intelligent response to road conditions, ensuring vehicles navigate safely while actively averting potential pothole-related risks, underscoring the efficacy and accuracy of the implemented system.

3. RESULTS AND DISCUSSION

The implemented pothole detection system yielded commendable results, offering two significant functionalities: retrieving live video data from hardware and accurately identifying potential potholes on roads. The model's accuracy, a vital metric for autonomous vehicle operations on challenging terrains, proved robust, high overall accuracy rate of 92%. This metric highlights the model's proficiency in differentiating between road images with and without potholes. Moreover, precision and recall metrics underscored a balanced performance. The precision rate of 91% indicates a low false-positive rate, ensuring accurate identification of actual potholes, while the recall rate of 93% reflects the model's effectiveness in capturing a high proportion of existing potholes.

Furthermore, the system's real-time processing capabilities were a notable feature, allowing for instant pothole detection on video streams. This capability is critical for implementing proactive road maintenance measures, enabling timely interventions to mitigate potential damage and hazards caused by potholes. In essence, the developed pothole detection model, leveraging CNNs, demonstrated robustness and accuracy in identifying and localizing potholes within various road scenarios. These promising results indicate the potential of this system to contribute significantly to road safety, vehicle maintenance, and proactive infrastructure management.

4. CONCLUSION

The proposed system of pothole detection with live video capture from the hardware model, using CNN proved to be a reliable and precise method. This work offeres effective observation of potholes, presenting a significant advancement in perceiving road anomalies in real-time through live video feeds. The implementation of CNN for pothole detection signifies a significant stride, particularly in the realm of self-driving cars, especially in challenging conditions. This research contributes significantly to safer and more resilient urban infrastructure, paving the way for improved road safety and enhanced driving experiences. The future scope involves augmenting its capabilities by integrating additional models for pedestrian and obstacle detection, enhancing overall environmental visualization.

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