A Concise Review Of Pothole Detection Techniques

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***Abstract*—Potholes present a challenge for road infrastructure and public safety. It is crucial to detect and address these road defects to maintain efficient transportation systems. Our study offers a summary of approaches used for pothole detection highlighting advancements as well as the remaining challenges. The review encompasses sensing technologies, methods for processing data, and machine learning paradigms that are used to solve the issue of pothole detection. Additionally, it explores limitations and unresolved questions in this field such as the need for real-time detection reliability in weather conditions and the development of cost-scalable solutions. By providing a synopsis of the state-of-the-art research and recognizing areas for further investigation this review aims to be resourceful, for both research personnel and practitioners interested in pothole detection systems.**

Keywords—Pothole detection, Object detection, Image Processing, CNN, R-CNN, YOLOv1, YOLOv2, YOLOv3, YOLOv4, YOLOv5, YOLOv7.

I. Introduction

For as long as humans have migrated, roadways have proved to be one of the main forms of transportation. Over the decades, the transportation medium has evolved and so has the state of the roads. The development of a nation can be measured by the condition of its roads. In recent years, India has risen to be the second-largest roadway network. Nearly 90% of India's population and 65% of our country's freight transportation uses roadways. Poorly constructed roads riddled with potholes, faulty concrete speed breakers, and outdated drainage networks together are contributors to an increase in accidents and injuries throughout the country. Encountering potholes during one's journey is not only uncomfortable but also poses a safety hazard to both humans as well as the vehicle. According to a newspaper article of BMC's data, despite the concretization of roads, around 60,000 potholes have been recorded in Mumbai to date in 2023 which has significantly increased from 2022 having roughly 38,000 and in 2021 having 44,000 potholes.

The detection of instances of a particular class's semantic objects in digital photos and videos is the focus of the computer technology called object detection, which is associated with image processing and computer vision. Object detection models are trained using a training dataset to return the coordinates of the objects in an image that it has been trained to recognize. The system does so with varying levels of accuracy which we term as the confidence of the system. Over the years a significant evolution has been there has been a significant evolution in the models used for object detection. Traditional computer vision techniques that relied on handcrafted features were used earlier. During the 2010 decade, the use of R-CNN was the earliest known attempt to apply the concept of deep learning to object detection. Faster R-CNN was an improvement upon R-CNN.

The year 2015 brought with it the advantages of fast inference time by dividing the image into a grid and predicting bounding boxes and class probabilities directly, using YOLO. Joseph Redmon and Santosh Divvala introduced the popular object detection algorithm, You-only-look-once, which presents the key idea of viewing object detection as a single regression problem instead of breaking down the tasks of object detection into multiple steps.In other words, YOLO uses a single, comprehensive view of the image to concurrently predict bounding boxes and class probabilities.YOLO is used in various real-time cases.

Fig 1.1, as given below shows the generic flow of object detection and hence identifying potholes on the road.

II. Related Work

Maheshwari Kotha, et.al (2020) suggested a real-time pothole detection mobile application. The paper suggested

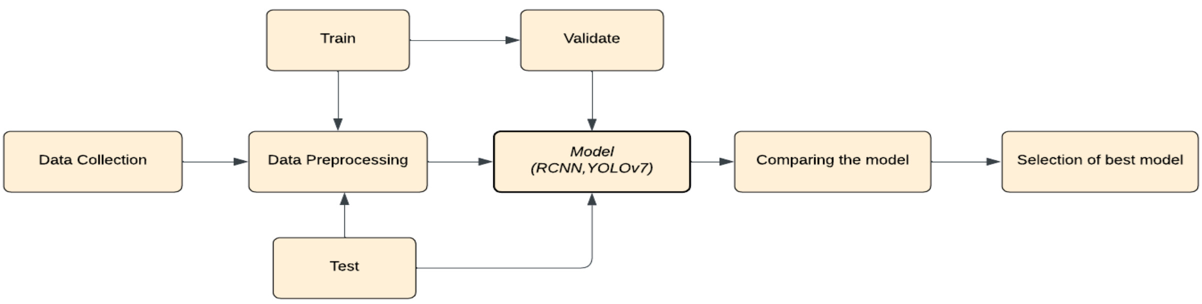

Fig 1 Generic Flowchart of Object detection

two techniques, accelerometer-based detection which had about a 55% accuracy rate in identifying potholes, and vision-based detection achieved nearly 60% accuracy. The application identifies potholes using both methods and is plotted on Google Maps, serving as a safety measure for various vehicle users. The model uses 400 image datasets where 150 images are real-time and 250 images are obtained from the Internet. [15]

Aaquib Javed et.al.,(2021) presented a system for identifying potholes using a Region-Based Convolutional Neural Network. The study introduces a solution based on object detection, employing the R-CNN and SSD Mobile Net algorithms, and it is trained using a dataset from Bangladesh containing diverse pothole images. The outcomes reveal effective pothole identification with a peak confidence level of 93%.[8]

Kavitha R et.al., (2021) introduced a system that can be used by autonomous vehicles to detect potholes using YOLOv3 to train the CNN model. A newly created dataset consisting of classes of objects uses CNN and a max-pooling layer for prediction to improve accuracy in the detection of small targets.The experiment result shows the detection of all classes of objects with a high score and accurate detection of bounding boxes. The autonomous vehicle's ability to detect potholes on Indian roads enables it to go smoothly and avoid being struck by them. [12]

Oche Alexander Egaji et.al., (2021) proposed an Android application-based approach for pothole detection in terms of binary classification.A dataset of 30,808 was collected from Android phones.The research used a combination of the stratified K-fold cross-validation technique and holdout. With a comparable accuracy of 0.8889, the Random Forest and KNN demonstrated enhanced results using the test dataset After random search hyperparameter adjustment the Random Forest model’s accuracy is 0.9444. Further annotations will help the model categorize the potholes in more detail.[17]

Khaled R. Ahmed, (2021) has developed an efficient deep-learning CNN model for real-time, accurate pothole detection. Using a dataset accumulated from multiple sources as well as images from a smartphone video camera set up on the windshield of the vehicle. The experimental outcome indicates that Ys model should be used in real time situations, such as embedding in automobiles, as it has demonstrated a fast detection rate. Faster R-CNN with ResNet50 can be used for more complex hardware configurations when accuracy is top priority. MVGG16, which is smaller than both, can be utilized if the size of the Faster R-CNN model is an issue. [20]

Yongjin Zeng, et.al (2022) utilizes deep learning for identifying cracks in roads on collected road images, using the YOLOV5 model for training and detection. Five groups are identified from the gathered collection of road crack data: mesh cracks, potholes, repairs, and regular transverse and longitudinal cracks. A rectangular frame with a 4:3 aspect ratio is employed to capture the full image in order to extract the local features of road fractures.[16]

E Sai Tarun Kumar Reddy et.al.,(2022) used CNN and YOLO v7 Algorithm for detecting potholes. The dataset used in the algorithm consists of 289 images, which is separated into groups for training, testing, and validation. The proposed model used YOLO v7 and CNN for image classification. The model shows good accuracy and speed due to the use of the YOLO v7 algorithm. The latitude and longitude coordinates can be used to mark the potholes in the future.[3]

Madarapu Sathvik et.al.,(2022), suggested YOLOv7 pothole detection, a robust object detection model which provides an increase in accuracy without a corresponding rise in inference costs. The dataset of 289 images gives a confidence level of 0.5 mAP, recall of 0.95 and precision of 1.In comparison to other models used for pothole, YOLOv7 achieves an accuracy level of 2% higher compared to R-CNN, while concurrently exhibiting 509% faster inference time as well as an F1 score of 0.51. Locating individual potholes on the map using latitude and longitude coordinates as well as forming reports to find the most effective strategy to navigate them is a future advancement.[7]

Priyanka Gupta et.al., (2022) presented a novel method for detecting potholes in roads using deep learning techniques. The proposed model convolutional neural networks (CNNs), specifically the ResNet50 model, which employs transfer learning to fine-tune the model for the purpose of identifying potholes. The outcomes of the experiment show the model's effectiveness, achieving a high validation accuracy of 98%, outperforming previous pothole detection methods. [10]

Muhammad Haroon Asad, et.al (2022) suggested a real-time pothole identification system utilizing multiple deep learning methods. Two models, YOLO family and SSD-mobilenetv2, have been trained on the same dataset. Even though YOLOv5 achieved mAP@0.5 95% but failed to detect distant potholes and exhibited misclassification. Whereas, mAP@0.5 for YOLOv4 and Tiny-YOLOv4 were 85.48% and 80.04%, respectively with Tiny-YOLOv4 demonstrating faster inference times.[14]

M. Vasudev Rao et al. (2022) propose an innovative method to tackle the problem of dimension estimation and pothole detection with cutting-edge deep learning techniques. Around 600 image dataset is used and covers images from various seasons, providing a diverse range of road conditions. The tiny YOLO model has 53 convolutional layers,is used to identify the potholes with their approximate dimensions present on the roadside. Because of its lightweight design, the suggested model can store videos for shorter periods of time and with less space.[9]

Au Yang Her et.al.,(2022) provided an enhanced YOLOv5 pothole detection system in real time for cars in Malaysia. The paper introduces a solution using computer vision technology installed in vehicles, employing YOLOv5, a Convolutional Neural Network-based deep learning model. The results demonstrate improved accuracy, with YOLOv5 models achieving mAP@0.5 scores of 80.8%, 82.2%, and 82.5% on various versions.[5]

Boris Bucko et.al.,(2022) demonstrated a pothole detection system based on computer vision in difficult circumstances. The dataset includes clear weather images labeled with a structured format and additional subsets for unfavorable circumstances, accumulating 1052 photos. The outcomes demonstrate how poorly Yolo v3-SPP functioned in wet, dusk, and nighttime conditions. In almost every difficult scenario, Yolo v3 was outperformed by Sparse R-CNN.[21]

Aketi Ajay, et.al(2022) proposes a method to detect potholes using a camera mounted on a vehicle, with the aid of image processing methodologies. The system aims to reduce manual effort and improve efficiency by promptly identifying and notifying authorities about potholes. Various image processing techniques such as edge detection and Hough transforms are employed for pothole detection. The proposed work extracted frames from a video and achieved an accuracy of 77% for more than 50 images of the dataset.[13]

Shrinjoy Sen et.al., (2023), Talk about the potential application of the YOLO algorithm. Initially the model used Yolov3 a 600-image short dataset clicked at 30 to 45 degrees of angles yielded a 70 percent accuracy rate in detecting potholes at a distance of approximately 10 meters from the vehicle traveling at 30 km/h. To improve accuracy, additional datasets are employed at 20 to 90 degree angles with respect to the ground which gives an accuracy of 85 to 90 percent. Potholes at 50 meters distance from a 60km/h driven vehicle are detected allowing the driver roughly four to five seconds to apply the brakes or reduce the speed of the vehicle.[1]

Rohan Chorada et.al.,(2023), propose a CNN-based Real-time pothole detection model using InceptionV3 CNN architecture which reached a high detection rate of 95.2% while reducing false positives. The accuracy achieved by the model is 80\%. One of the key features of the research paper is that the proposed method provides a more effective way to observe potholes by providing live video capturing which enables real-time monitoring and detection of potholes, thus helping in road safety.[2]

R. Sathya et.al.,(2023), proposes the use of YOLOv3 for detecting potholes which provides an improvement in mAP of 83.26 while a significant reduction in computing cost is observed. On comparing the performance measure of YOLOv3 to previous versions, the proposed model increases the precision of detecting small objects with an incredible processing speed of 45 fps. In order to help with road maintenance, the method can also be started using a GPS module that, after the dashboard module has located the pothole, generates the coordinates.[4]

Savita Chougule et.al (2023) used deep learning algorithms, specifically YOLOv3 and YOLOv5, to detect potholes from video images captured by a camera module. Images from Google Image Search and photos taken with an Android phone camera from roads with damage are included in the dataset. The central processor of the suggested system is a Raspberry Pi 4B, which processes the recorded video stream and executes the pothole detection algorithm. The YOLOv5 was found to be working more effectively than YOLOv3, in terms of precision, sensitivity, and average precision (AP) values of 0.763, 0.548, and 0.635, respectively.[11]

Tejas B S et.al.,(2023) presented a “Real Time Detection of Humps and Potholes”. A custom dataset of 150-200 images of urban roads are used in the proposed model. Raspberry Pi, Open CV are used for capturing images, saving them, TensorFlow is used for detection of potholes and humps from images stored. The model gives an accuracy of 90%.In future findings, with increased CPU and GPU capabilities, live feed from camera better processing can be achieved.[18]

Yang Zou et.al.,(2023) presented an improved YOLOv5-based lightweight pothole detection technique. The paper introduces a streamlined pothole detection model based on an improved YOLOv5s framework enhanced with attention mechanisms and innovative techniques. Through experiments conducted on a dataset that combines publicly available data and self-captured images, the enhanced YOLOv5s model achieves notable improvements, boasting a 90.7% accuracy and an 89.1% average accuracy.[6]

III. LITERATURE REVIEW

TABLE I. Comparative Analysis

PAPER CITED	METHOD	MERITS	CHALLENGES
15	Using vehicle Accelometer along it's z-axis	60% classification accuracy	Classification accuracy needs to be improved
8	R-CNN, SSD mobile net algorithm	93% confidence level	Failed in low quality images/videos
12	YOLOv3, Darknet 53, Rasberrypi 4, Tensorflow	Detects boundary boxes and potholes with highscore	Model needs to be trained to detect more objects.
17	Machine learning algorithms	RF Tree and KNN showed the accuracy of 89%. Accuracy after hyperparameter tuning is 94%	More samples are required.Further annotation is needed to categorize potholes.
20	YOLOv5, faster-RCNN, Deep Learning	Better mean precision and shorter inference time.	Developing a sustainable model to address extreme conditions in pothole detection.
10	ResNet50, ResNet	Accuracy of ResNet 50 is 98.05% and ResNet model is 97.08%.	The severity of the pothole needs to be detected with the region
14	YOLO family and SSD Mobilenettv	YOLOv4 with accuracy of 90% and 31.76 FPS	Detect road depressions, classify roads as per quality, and depth estimation of potholes
9	YOLO, Darknet-53	68% classification precision	Classification accuracy needs to be improved
13	Filtering technique, Edge detection, Morphological imaging	77% classification accuracy	Model needs to be trained and classification accuracy needs to be improved

16	YOLOv5 algorithm	Better detection results through YOLOv5 network under different networks	The computational efficiency can be optimized to reduce the processing time.
3	CNN and YOLO v7	High accuracy and speed due to YOLO v7	More training dataset needed
5	YOLO v5m, YOLO v5s, YOLO v5n	YOLO v5n performs better than other with 82.5% classification accuracy	Classification accuracy needs to be improved
19	Laser based methods	5.2% and 14.4% depth error in static and dynamic conditions respectively	The depth error in dynamic conditions needs to be decreased and classification accuracy needs to be improved
21	YOLO v3, Sparse R-CNN	Sparse R-CNN achieved better results than YOLO v3	The performance of selected models on different hardware configurations
7	YOLOv7, YOLOv4, YOLOv5	YOLOv7 has better accuracy and faster inference process than R-CNN.	Training model for different types of potholes
11	YOLOv3 and YOLOv5	YOLOv5 model outperforms the YOLOv3 model with accuracy of 97.22%	the model can be trained by hyper tunning the training parameter like Faster RCN
6	SimAM-C3 module, YOLO v5s, CARAFE	SimAM-C3 attached YOLO v5s model gives better accuracy than YOLO v5s.	The model doesn't classify different weather and pavement conditions
18	Rasberry Pi 3, Open CV,	90% classification accuracy	Single axis Gyroscopes needs to be used for increasing accuracy
1	YOLOv3,YOLOv4,CNN	Can alert the driver 5 seconds in advance when pothole is about 50 m from car	Mapping the potholes and alerting driver about next pothole in advance
2	InceptionV3 CNN,SGD,ConvNet	High detection rate of 95.2% and F1 score of 0.91	Dataset should be augmented to enhance accuracy and resilence of CNN
4	YOLO v3, YOLO v2, YOLO v1	The performance of YOLO v3 is better than the others	Integrating pothole detection system with smart transportation systems to enhance overall road safety.
22	Machine learning models	SVM, Random Forest Tree, and KNN provides best accuracies of 82%, 80% and 78%.	Additional annotation is required to develop a model that categorize potholes in details
23	CNN, Mask RCNN, YOLOv3	YOLO family is faster and consumes less time than CNN or R-CNN	Model needs to be trained with diverse dataset.
24	vision based, vibration method and 3D construction based methods	Model predicts shape of potholes and measure their volume using sterio vision technology	Improvements in pothole detection accuracy and real-time pothole detection is to be done
25	R-CNN, DAISS, HMS	Model accurately reflected the level of risk due to road surface damage	Limitations of using data from smartphone. Model doesn't take speed into consideration
26	Smartphone GPS sensors, K-means	65% accuracy classification	The positioning accuracy of smartphone GPS sensors was limited
27	CNN	Optimized pre-pooling CNN achieved recognition precision of 98.95%	Additional comparison with other existing models is missing
28	CNN	97.08% accuracy using pre-trained CNN model	Drawback of using thermal imaging as weather condition may change the accuracy and results

IV. Summarized Findings

From our analysis of the above-mentioned studies, we have outlined the following findings:

1. According to several authors, determining the accurate dimensions of the potholes and assessing their level of severity posed to be a significant challenge which was later overcome using Darknet CNN and Tiny YOLO on a diverse dataset.
2. Tracking and storing the coordinates of the potholes using a camera feed which can be plotted on a map is a promising advancement in this research field.
3. The limitations in accuracy can be resolved in the case of YOLOv5 by improving the classification of potholes to detect distant potholes.
4. Pothole detection using Random forest can be remarkably improved by hyperparameter tuning.
5. In future, the implementation of detailed datasets of various other conditions of roads other than potholes can help to detect humps and cracks as well.
6. The lack of a proper dataset proves to reduce the accuracy of the model which can be solved by using data augmentation.
7. Issues arising due to the usage of datasets with images of potholes under challenging conditions like low-intensity lights and different weather conditions can be conquered using computer-vision techniques.

V. RESULT

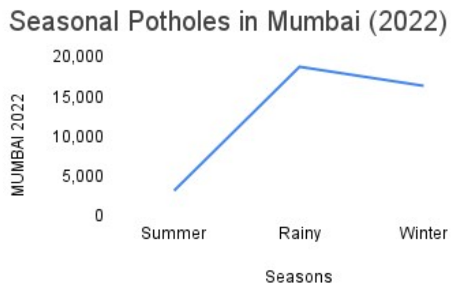

Fig 2 Seasonal Potholes in Mumbai (2022)

Fig 2, represents the variations in the number of potholes in 2022 in Mumbai city over the 3 seasons.The months are classified into 3 seasons February-May are the Summer months, June-September are the rainy season months and October-February are the Winter Season months.

We see a gradual increase in the number of potholes from the summer to the rainy season and a decrease from the rainy to the winter season.

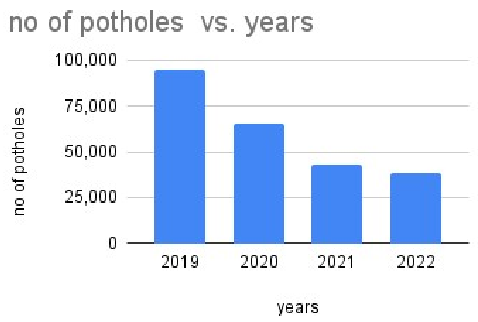

Fig 3 Year-by-year analysis of the number of potholes

Fig 3 shows a comparison of the number of occurrences of potholes in Mumbai over the years. The years considered are 2019-2022. The number of potholes over the years has significantly reduced due to the detection of potholes and timely road maintenance done by the Brihanmumbai Municipal Corporation(BMC).

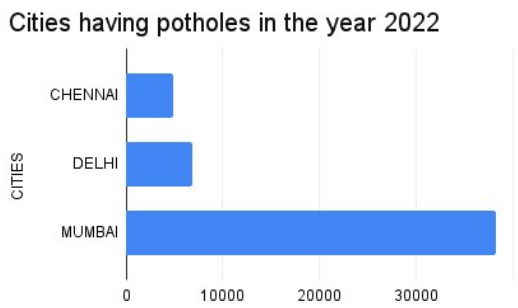

Fig 4 Occurrence of Potholes in the Metropolitan Cities in 2022

Fig 4, compares the number of potholes in the three metropolitan cities of India- Chennai, Delhi, and Mumbai.The cities have varying weather conditions which is why the number of potholes in the three cities vary.

VI. CONCLUSION

The automation of Pothole detection has proven to be a key automation in the development of our country and is expected to continue growing. The scientific community has made great strides in creating novel approaches to find potholes and enhance road infrastructure. The studies highlighted in this paper unveil the ongoing efforts to address the grave issue of pothole detection and their concerns with road safety using advanced technologies.

The above-mentioned papers have implemented a wide range of methodologies for object detection and image processing such as machine learning and deep learning algorithms, CNN and R-CNN architecture, InceptionV3, Darknet, and various versions of YOLO.The study depicts different models having different accuracies which depend on the parameters used in the training and testing dataset. Some of the key findings include real-time detection for timely alert systems, analyzing their depth, and increased classification accuracy by using YOLOv5. Researchers are exploring ways to integrate the aforementioned systems into vehicles to prevent and optimize road safety and infrastructure.

Together, these studies show how pothole detection could be greatly enhanced by sophisticated technology, with a particular emphasis on real-time capabilities and detection accuracy. As these technologies continue in their development and adaptation, the objective of mitigating accidents and improving the upkeep of road infrastructure remains attainable.

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