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Machine and Deep Learning Algorithms for Automatic Pothole Detection in Internet of Things: A Comprehensive Review

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***Abstract*—Potholes are a type of obstructions on road that can damage vehicles, impair drivers' safety and also lead to traffic accidents. However, it is necessary to design an effective automated pothole detecting system to help the authorities in the timely maintenance and repair of roadways. So, in this survey, various image processing and object detection algorithms are discussed to automate pothole detection. Additionally, Machine Learning (ML), Deep Learning (DL) and Hybrid models are recommended for pothole detection to address the problems in real-time environments. Furthermore, DL algorithms are used to analyze complex image data and identify potholes by learning distinctive visual features. Then, ML algorithms are used to create the best possible model with the maximum prediction accuracy of pothole incidence. Then, in order to enhance the overall performance of road pothole identification, hybrid models were used to integrate two or more algorithms.**

Keywords—automatic pothole detection, deep learning, hybrid models, internet of things, machine learning.

I. Introduction

An efficient construction of roads is a must for every nation to provide countrywide transportation services. The infrastructure of roads makes it possible to link people and move goods, which improves business prospects, employment possibilities, economic development, and the nation's healthcare system [1]. On the other hand, potholes should be fixed as soon as possible to reduce their role under unfavourable events. So, the growth of an effective autonomous pothole identification system in real-world circumstances is necessary due to the many damages caused by potholes [2, 3]. Numerous techniques for detecting potholes have been developed recently [4], including hardware sensors, real-time image processing, and simulations. These techniques, however, are ineffective in real-world situations and adverse weather, such as foggy days or nighttime with poor visibility. Therefore, drivers' safety is improved with the suggestion of pothole detection system for sharing the pothole data [5]. Therefore, an automated pothole identification and localization system based on thermal image analysis is covered in this survey using ML and DL algorithms. Thermal imaging is a useful technique for early fault condition identification that works well in a variety of weather situations, including fog and darkness. This supports the early and expeditious road repair, which lowers risks and drastically, the number of fatal and seriously injured traffic accidents [6]. Additionally, the IoT is used to identify surface imperfections on roadways in real-time using ML, DL, and hybrid models based on pothole detection systems.

II. Literature Survey

Ahmed [7] suggested Effective DL Convolution Neural Networks (CNNs) to identify potholes in real-time sufficient accuracy. To extract low-level data, image processing object detectors relied on manually created representations. To find potholes in a single frame, various prior image processing research projects have been conducted. Consequently, the suggested framework was used for the k-mean clustering approach for automatically predict and select the optimal anchor boxes for that databases throughout training. However, the suggested model was failed to predict the potholes due to the variation of size.

Using DL, Chu et al. [8] presented a Decision Support System (DSS) for an independent road data's for the development of smart cities. In this model, the images were collected from the roads, and analyzed by using the Global Positioning System (GPS). It coordinated with the image and was sent to the decision layer to identify any potholes in the road. By analyzing the process, this model performed better and required less computing power than the other models. However, the suggested method's time and computational costs and time were higher due to the vast parameters.

A CNN model was developed by Ozoglu and Gökgöz [9] using training and testing procedures carried out in identical environmental settings. A mobile application for iOS was created to collect and send data on road vibrations by using a smartphone's integrated three-axis accelerometer and gyroscope. Pixel-based graphics were created from analogue road data, and many CNN models with varying layer configurations were created. As a result, the suggested

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framework was used for the identification of road surfaces, especially in case of vibration-based data evaluation in time series. However, CNN was not identify and analyze various road problems, including speed bumps to classify the potholes effectively.

Aljohan [10] proposed a CNN and an improved ML model using a heuristic method to detect potholes. The suggested approach employed an improved random forest model for pothole identification and a shallow CNN for feature extraction. The recommended method initially extracted feature sets from input images using the shallow convolutional layer. Next, the traits deemed significant were removed using the particle swarm optimizer. Lastly, to find potholes, a random forest and a particle swarm optimizer were coupled.

Ruseruka et al. [11] developed a DL model that was trained using the You Only Look Once (YOLO) technique to identify and quantify potholes. The suggested process included four stages: obtaining datasets, preparing data, training the model, and testing the computer-vision detection model. Images were needed for testing and training the learnt model in data gathering as it was based on computer vision. A range of pothole images was collected from the online resources to train and test the algorithm. Nevertheless, YOLO required the manual evaluation of the road to control the scale system, which was leads to errors.

III. TAXONOMY

Potholes on roadways are created by water seeping into the soil structure and the weight of continually moving vehicles. This potholes not only affects the vehicles but also the reason for causing road accidents. To automate pothole identification, this survey presents a variety of object recognition and image processing approaches. Additionally, ML, DL, and Hybrid models based on pothole detection systems are presented for exploiting the Internet of Things to identify surface imperfections on roadways in real-time. Additionally, Figure 1 depicts the pothole detection taxonomy.

A. Machine Learning Algorithms

ML techniques are used to generate an optimum model that has the maximum accuracy in identifying pothole occurrences. In this review, the ML algorithms are classified into three different classifier algorithms: Support vector machine (SVM), Random Forest (RF), and k-Nearest Neighbour (k-NN) for detecting potholes, as briefly discussed below.

1) Support Vector Machine: The Part of the supervised ML algorithm is called SVM. Regression and classification problems are analyzed by this algorithm [12] The SVM approach divides road surface images into square blocks before training and testing on feature vectors. The Gray-Level Co-occurrence Matrix (GLCM) and Discrete Cosine Transform (DCT) are used to build feature vectors from a histogram and two texture descriptors. Hence, SVM generates a binary image as output, where each image block is classified into "patch" and "no-patch". However, SVM performs worse when there is more noise in the data and there is an overlap between the target classes.

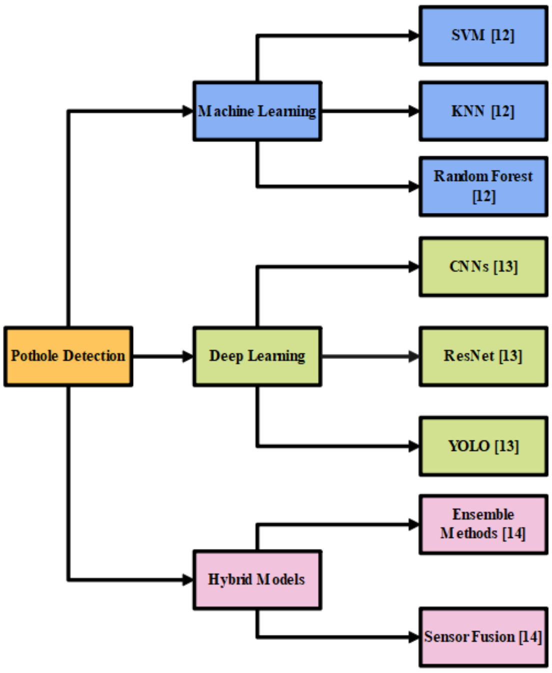

Fig. 1. Taxonomy for Pothole Detection

2) K- Nearest Neighbor: The non-parametric supervised ML algorithm KNN is a simple but effective tool for handling regression and classification issues [12]. Selecting the fixed value of K is the foremost process in this algorithm. To achieve better accuracy, one must choose an accurate K value through a process is known as parameter tuning. Then, the lowest *k* value of 1 or 2 lead to noisy results, and furthermore, a high value creates confusion at times, depending on the database. This is achieved by comparing attribute similarities with the labelled data. However, it faces difficulties in unbalanced and missing data.

3) Random Forest: Among the ensemble learning algorithms, RF identifies the class of new samples by combining a specific number of decision tree classifiers jointly [12]. It combines many decision tree predictors, each of which depends on the values of a randomly chosen random vector with an equal distribution on an individual basis. When utilizing large input variables and data, the suggested model decreased the model tendency to overfit. Because each tree is trained independently, it takes a lot of computing power to compile all of the predictions made by the trees.

B. Deep Learning Algorithms

The DL algorithms are recommended in this survey to predict the road whether or not the road is contained of pothole by collecting the images from online resources. In this review, the ML algorithms are classified into three classifier algorithms: Convolutional Neural Networks (CNNs), Residual Network (ResNet), and You Only Look Once (YOLO) to detect potholes briefly discussed.

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1) Convolutional Neural Networks: The CNNs are processed as a direct convolution operation on an image pixel to extract abstract data features. The CNN process is constant for all low-level features that involve edges, curves, straight lines, etc., until each of them becomes an independent complete feature map [13]. Then, these feature maps are combined to develop a convolutional layer in the initial layer which is used for the feature extraction process. The CNN is used to decrease the dimension of image data while obtaining relevant information. However, CNN needs a lot of data that has been labelled.

2) Residual Networks: The error rates rise as network depth grows, but however, there are situations where creating a deep network is necessary. ResNet effectively learns complex features from images, enhancing accuracy in identifying potholes by varying road conditions [13]. By pooling and convolving the characteristics of various scales and spaces, it substantially improves object identification performance by using the framework of global residual method. It addresses the issue that frequently occurs in big networks, while the depth of the network increases, and saturation and accuracy reduces. However, the Residual networks are complex, leading to overfitting and limited interpretability.

3) You Only Look Once:. YOLO models are rebuilt to make them suitable for pothole detection tasks. The models are then validated and trained until the loss function reaches a steady-state line, indicating that the average loss has decreased. Every detected object in every image has to have a bounding box created around it in order to guarantee image quality.Then, it predicts potholes with higher accuracy when compared to other models with low computational costs. However, YOLO struggles to generalize objects in new or unusual aspect ratios as the model learns to predict bounding boxes from the data itself.

C. Hybrid Models

Hybrid models are used to combine two or more algorithms to improve the overall road pothole detection performance. In this review, the ML algorithms are classified into two different models, Ensemble methods and Sensor Fusion, to detect potholes was briefly discussed.

1) Ensemble models: By combining the output of many classification models, improved projected accuracy is attained by the machine learning approach known as ensemble learning [14]. It is feasible to alter the basic properties derived from natural images to make them more suitable for different medical imaging modalities since the ensemble classifiers achieves greater classification accuracy when compared to other classifiers. Nevertheless, the processing time for an ensemble classification system is slower than the other classifier.

2) Sensor Fusion: The data from various devices are fused and processed from this sensor to detect the road holes. It is the Integration of ultrasonic, accelerometer, and LiDAR sensors to gather precise data on road surfaces, enhancing situational awareness and enabling real-time analysis of environmental factors. The result of this fusion is a pothole detector, and these developments are transmitted to the cloud OneM2M platform, RSU, and other vehicles using a communication system. [14]. Hence, sensor fusion identifies road smoothness from obtained pitch orientation and road driving terrain gathered through categorical data from its sensors. However, it increases the complexity of the control system and increases the system costs. Furthermore, the comparative evaluation of the various methods for pothole detction is illustrated in Table 1.

IV. Comparative Analysis

TABLE I. Comparative Analysis of various models for pothole detection

Author	Method	Advantage	Disadvantage	Performance
Jordan et al. [15]	Created Pothole Detection, Classification and Logging (PDCL) model.	PDCL was utilized to increase the rate and prioritisation of pothole repair.	However, PDCL was generated by the radar and ineffective in the detection of potholes.	Accuracy
Dong-Hoe Heo et al. [16]	Presented a YOLO -V4 algorithms to detect and track potholes.	The suggested model used to generate input variables for modeling road deterioration processes for effective performances	However, the suggested model requires seamless pipeline for transferring the captured videos in the cloud infrastructure in real-time basis.	Accuracy, Precision, recall and F1-measure
Saksham et al. [17]	A novel technique of pothole localization utilizing thermal images utilizing deep neural networks based on bounding boxes	This model utilized in real time processing which require less storage.	The suggested method fails to perform effectively in real-world scenarios due to low visibility.	Accuracy
Maros Jakubec et al [18]	Presented Generative Adversarial Networks (GANs) to increase pothole detection across diverse weather and lighting conditions.	This method was used to predict potholes in low-resolution and high-resolution images.	It requires multiple encoders and decoders for each domain	Accuracy
Swain and Tripathy [19]	Presented VGG-16 pre-trained method to classify potholes effectively.	The suggested model used to segment the modified disparity map to analyze the regions that include roadways	Due to poor generalization the VGG-16 not properly trained.	Accuracy

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Wei [20]	Created to handle and examine the resultant data was the Spatio-Temporal Conv-Long Short-Term Memory Autoencoder (STCLA) framework.	The recommended model used for integrated learning models for safe and scalable methods for more straightforward navigation.	Further evaluations was required to improve the performance of the suggested model.	Accuracy

V. Problem Statements

- Due to the substantial processing overhead related to real-time pothole detection, it was a challenging task to evaluate large quantities of high-resolution images quickly.
- Large, predefined labelled datasets were challenging to obtain and maintain the training ML algorithms for improving the accuracy.
- High-quality annotations were required for precise labeling of pothole boundaries, being time-consuming and difficult to achieve.

VI. Conclusion

This survey recommended an accident prediction and mitigation system through hybrid, ML, and DL algorithms to improve road safety. Potholes on highways are mostly caused by water seeping into soil structures and the weight of constantly moving automobiles. This results in traffic accidents in addition to damaging the vehicles. DL algorithms are used to detect images and evaluate whether the roads are plain or full of potholes. Images are collected from internet sources. Then, using ML algorithms, the optimal model is developed that has the highest accuracy in predicting the occurrence of potholes. Then, utilizing hybrid models, two or more algorithms are integrated to improve the overall performance of road pothole recognition.

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