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PAVEMENT DISTRESS DETECTION METHODS: A REVIEW

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Abstract: Roads are the most important component of infrastructure because they provide mobility and connectivity to people's lives. As the number of vehicles on the road increases, more pavement distress and damage emerge on the road surface, resulting in poor riding experience. Roads must be regularly checked and repaired as needed to ensure consistent surface quality. Road pavement monitoring systems have become one of the most popular topics of discussion among transportation infrastructure agencies and governments in recent years. Authorities invest a significant amount of time, money, and labor in detecting pavement damage using manual and instrumented approaches that are often difficult and time consuming. Pavement distress detection employs a variety of automated strategies to solve these problems. The goal of this paper was to look into the many pavement monitoring systems that are recently used to assess the condition of road pavements. This paper also present manual method of distress detection in coloration with artificial intelligence that is used for measuring pavement performance index.

***Keywords* - Dynamic Monitoring, Convolutional neural network, Artificial neural network, Pavement distress detection, Smart phone sensors**

1. INTRODUCTION

In a fast-rising country like India, there is an insatiable demand for high-quality infrastructure that provides reliable services and a functional transportation system. With a total length of 5.89 million kilometers, India's road network is the world's second-largest, carrying nearly 65 percent of freight and 80 percent of passenger traffic. As a result, well-maintained roads are necessary for effective transportation. Frequent performance monitoring and maintenance operations are required to ensure that the road network meets a high degree of quality. The detection of pavement deterioration is crucial since it has a direct impact on user safety and comfort. It also aids in the efficiency of road maintenance. Pavement distress detection and analysis are traditionally done using manual methods. Inspectors crisscross the highways, assessing the severity of the problems. Manual pavement distress analysis methods are tedious, subjective, costly, time-consuming and labor-intensive. To remove these difficulties various automated methods like Ground Penetrating Radar, Laser Road Imaging System, video or image processing, smartphone sensors, and others are used by different transportation organizations and researchers all over the world to detect pavement deterioration. Smartphone sensors, as well as video processing techniques, have grown in popularity over the last several decades, particularly when other complex methods require unique settings such as special lights, lasers, and other items that considerably increase the cost of the survey.

Based on the methods used to acquire vibration data, pavement monitoring techniques are split into two types. Static and dynamic monitoring approaches fall into these two groups. Only fixed or penetrating equipment can be utilized at a single spot to acquire vibration data during vehicle movement in static monitoring approaches. While numerous types of equipment and equipped cars can be utilized to collect vibration data as well as road segments in dynamic monitoring approaches [1]. This review paper analysis focuses on evaluating the pavement condition using a dynamic pavement monitoring technique. In recent years, dynamic pavement monitoring techniques have become increasingly popular. Using a specific monitoring technique mainly depends on the availability of equipment, type of pavement, e.g., asphalt, concrete, or composite asphalt and concrete, and road classification, e.g., freeways/highways, arterials, local roads, etc.

When opposed to stationary or slow-moving survey equipment, the use of traffic-speed equipment for pavement condition monitoring aims to reduce safety dangers and traffic interruption. Furthermore, by improving the monitoring approach on a road network while considering the type and frequency of surveys, significant benefits such as cost savings can be realized [12].The main objective of this study is to present a review of dynamic monitoring systems of roads surface. The study also focuses on equipment used in pavement monitoring and the limitations of studies. At the end this paper also gives comparison of both vision and vibration-based methods.

table 1: summary of previous pavement monitoring system

Monitoring Method	Approach/Used Device	Reference
Vibration based Method	Smartphone Application	Viengnam Douangphachanh et al. (2014)
		Janani Lekshmipathy et al. (2020)
		Amir Shtayat et al. (2020)
		Artis Mednis et al. (2011)
		Vinicius M.A. Souza (2018)
	Accelerometer Sensor	Chun-Hsing Ho et al. (2020)
		Hua-Ping Wang et al. (2018)
Vision based Method	Image captured using camera	Janani Lekshmipathy et al. (2020)
		Ce Zhang et al. (2021)
		Wanli Ye et al. (2019)
		Eldor Ibragimov et al. (2020)
		G. Srinidhi et al. (2020)
		Artis Mednis et al. (2011)
		Bayu Setiawan et al. (2019)
		Sunil Kumar Sharma et al. (2020)
	Unmanned Aerial vehicle (UAV)	Ronald Roberts et al. (2020)
		Yifan Pan et al.
		Ahmet Bahaddin Ersoz et al. (2017)
		Ronald Roberts et al. (2020)
Manual Observation	Pavement Performance Rating measurement by visually data recording	Dr. S.S. Jain et al. (2013)
		Amjad Issa et al. (2021)
		Anurag Sinha et al. (2020)
		AbhayTawalare K et al. (2016)
		Sunil Get al. (2018)
		Viengnam Douangphachanh et al. (2014)
		Prof. Dr Fareed et al. (2016)
		Sumarwan et al. (2019)

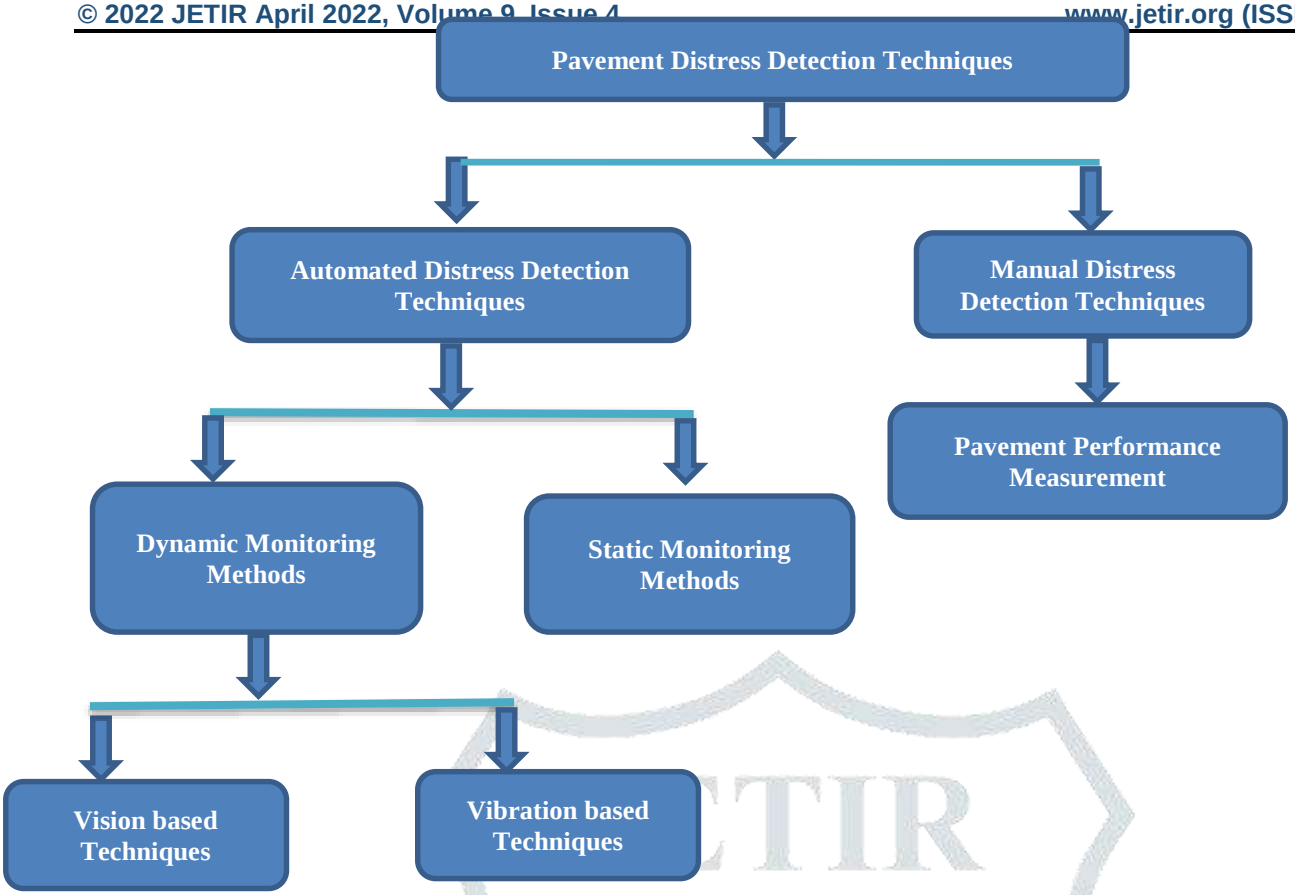

figure 1. flowchart of various pavement distress detection method

1.1 Distress Types:

According to IRC 82-2015(Code of practice for maintenance of Bituminous Road Surface) Distress types on bituminous road surface are consider as below:

table 2: types of distress on bituminous road surface

Cracks	Deformation	Disintegration	Surface Defects
Hair-line Cracks	Rutting	Potholes	Fatty surface
Alligator Cracks	Corrugations	Loss of aggregates	Smooth surface
Edge Cracking	Shoving	Ravelling	Streaking
Longitudinal Cracks		Stripping	Hungry Surface
Reflection Cracks		Edge breaking	
Shrinkage Cracks			

2. VIBRATION BASED METHOD

In this method of distress detection, vibration data of the road surface is collected. Vibration data should be collected using accelerometer sensor or can be taken directly through smartphone application. In all three directions, the accelerometer sensor measures gravity acceleration (x, y, and z). The z-axis depicts vertical wheel motion caused by a pothole or change in slope, the x-axis depicts vehicle acceleration and braking, and the y-axis depicts vehicle turning left or right. [5]

Almost every smartphone on the market today has a number of helpful sensors built in. The sensors were created to make the user interface and applications on smartphone more convenient and appealing. Furthermore, these sensors have the potential to be useful in a variety of other sectors. Because many similar sensors are currently in use in many sophisticated road roughness profilers, using smartphone sensors to determine road roughness condition has a lot of potential [11]. Bayu Setiawan et al. (2019) have created a database application that can track the status of a road on a regular basis and will eventually help associated authorities to plan and manage roads properly and sustainably.

figure 2 instrument set-up for data collection [1]

figure 3 accelerometer sensor [5]

Vibration-based automated methods of pavement distress detection were used by Janani Lekshmipathy et al. (2020) to detect distress. They discovered four different sorts of distress: potholes, patches, bumps, and cracks. Vibration data is gathered using an accelerometer and a gyroscope in the vibration-based method. The Artificial Neural Network (ANN) technique was used to analyse the data. They used manual surveying to validate the aforesaid strategy. The vibration-based method for detecting potholes, patches, and bumps has an accuracy of 80%. The findings demonstrate that vibration-based analysis is adequate for routine monitoring.

The vibration-based road pavement distress detection technique was implemented by Amir Shtayat et al. (2020). They used an e-bike and a car provided with Application for measuring vibration data and smartphone camera video recordings to collect road surface vibration data. The pavement vibration data is obtained using the "sensor log" smartphone application. Their research also looks at riding each car at different speeds, such as 5, 10, 15, and 20 km/h, as well as different vibration data gathering iterations. Comparative analysis is used to determine the best speed and number of iterations for obtaining the most accurate vibration data. In addition, a field inspection is conducted to determine the Current Serviceability Rating (PSR). The findings show that the test cars' travel speeds and the location where the vibration monitoring instrument is installed have an impact on the pavement vibration data. In order to acquire correct vibration data, the number of monitoring iterations is also important. The accuracy of the pavement vibration data obtained from the smartphone app in both test vehicles is adequate. Furthermore, PSR values are associated with pavement vibration monitoring techniques employing smartphone applications, indicating that this technique is accurate and suited for future road pavement monitoring projects. It also gives a precise indicator of the state and performance of the pavement.

Vehicle-based sensing technology for monitoring vibration response of pavement surface has been presented by Chun-Hsing Ho et al. (2020). A vehicle-based sensor is utilised to detect asphalt distresses caused by temperature changes in the pavement, as well as their georeferenced location. The sensor logger is a low-cost design that attempts to provide a low-cost sensing technique for conducting pavement condition assessments. It is made up of triple-axis accelerometers, Arduino MKR1000 microprocessor boards, and a battery. Vibration data is acquired using both a smart phone sensor (iPhone sensor) and a vehicle-based sensor, and a comparison analysis is performed to see which one provides the most accurate results. The analysis entails turning accelerometer data into an assessment of severe and mild cracks, as well as using GIS tools to locate the source of distress. The results reveal that as the temperature of the pavement rises, so does the degree of observable pavement distress, which can be precisely identified by a vehicle-based sensor. Furthermore, utilizing vibration data analysis for estimating pavement performance, results shows that vehicle-based sensors give more accurate result compared to the iPhone application sensor.

Artis Mednis et al. have proposed a mobile sensing system for road irregularity detection using Android OS based smart-phones. This study discusses accelerometer-based pothole detection methods for devices with limited hardware/software resources, as well as their assessment on real-world data collected using several Android OS-based smartphones. Algorithm tests revealed the best configuration for each algorithm, and performance study in the context of several road irregularity classes revealed true positive rates of up to 90%.

3. VISION BASED METHOD

In vision-based method, videography of road surface is carried out. Pavement images are obtained using downward-looking video cameras mounted on sophisticated vehicles. From videography image of the road surface is extracted. Those images are later analyzed using different software's.

figure 4 camera set-up for data collection [4]

Vision-based automated methods of pavement distress detection were used by Janani Lekshmipathy et al. (2020) to detect distress. For data collection, videography of the road surface is carried out in the vision-based method. The video footage was converted to an image file, which was then analysed using MATLAB code. They used manual surveying to validate the aforesaid strategy. The vision-based technique has an accuracy of 84 percent for detecting cracks, potholes, and patches. In addition, a vision-based methodology is used to evaluate the level of pavement distresses, which is then validated using the hand stripping method. The results demonstrate that the vision-based method is better for detailed analysis.

3.1 Convolutional Neural Network (CNN) algorithm for detecting distress:

A Convolutional Neural Network (ConvNet/CNN) is a Deep Learning algorithm that can take in an image as input, assign importance in the form of learnable weights and biases to various objects in the image, and differentiate one object from the another one. Ce Zhang et al. (2021) used a deep neural network to identify and classify pavement distress. As a result, the collected pavement dataset is used to create and test Convolutional Neural Networks (CNNs) with various topologies and layer combinations. 2105 high-resolution photos showing four different forms of distress, as well as road markers and clean photographs, are included in the data collection. A sports camera, the GoPro Hero 7, is used to take high-quality photographs without shaking or vibration, and the device can be mounted on any vehicle. The calibrated CNN model successfully detects and classifies the pavement distress kind, according to the findings. The model has a true positive rate of 75.7 percent for "pothole," 84.1 percent for "patch," 76.3 percent for "marking," 79.4 percent for "crack-linear," and 83.1 percent for "crack-network." The accuracy of the merged "crack" class climbs to 92.6 percent by combining linear and network crack classes. Overall, this research indicates that an embedded system with a deep neural network may be deployed in pavement monitoring vehicles and utilised to identify and classify different types of pavement distress in road infrastructure.

Convolutional neural networks (CNN) were used to detect potholes in digital photographs by Wanli Ye et al. (2019). Total 96,000 pavement photos were used to design, train, and test two CNNs: conventional CNN and pre-pooling CNN. In pre-pooling CNN, max-pooling operation before the first convolutional operation lowers the resolution of the imported data in the pre-pooling layer. The properties unrelated to potholes, such as pavement materials and image noises, were reduced after the pre-pooling. A stability analysis is also performed for various light conditions and pavement materials. The results showed that the optimised pre-pooling CNN had a recognition precision of 98.95 percent in the testing. The CNN showed a higher precision for classification than standard IPT (Image Processing Technique) approaches.

Eldor Ibragimov et al. (2020) have proposed a novel deep learning-based approach for automatic pavement crack detection using a faster region based convolutional neural network (Faster RCNN), a state-of-the-art object detection technique based on region proposal network (RPN). The sliding window size can be lowered, allowing for the detection of larger pictures, using a framework for applying the Faster R-CNN algorithm to a full-scale pavement image. Multi-object detection, dynamic detection of the object based on its size, and high processing speed are the advantages of a faster R-CNN. A vehicle-mounted camera is used to capture the pavement photos. For three principal distress kinds (transverse, longitudinal, and alligator cracks) and one defect type (patching), the dataset has over 3,000 photos with a resolution of 865×2,000 pixels. The proposed method's performance was tested against a collection of real-world pavement photographs. The results of the experimental tests reveal that the proposed approach can accurately detect cracks and patching.

G. Srinidhi et al. (2020) have used sample clustering (SC), convolutional neural network (CNN), and AlexNet algorithm to detect potholes. AlexNet is an example of a CNN with eight deep levels: the first five layers are convolutional layers, followed by pool layers, and the final three layers are fully connected layers. The input image is processed using SC and morphological operations in the first technique. A threshold classifier is used to detect potholes. For detecting potholes, this methodology does not require any training. CNN and AlexNet are the second method of detecting potholes. On a balanced dataset of 300 photos containing pothole and non-pothole photographs, two approaches are investigated. When CNN and AlexNet are used, the accuracy is significantly improved compared to the approach of sample clustering.

With their dataset of 512× 512-pixel 3D pavement photos, Li et al. (2020) suggested and tested a nine-layer CNN (with six convolutional layers) model. Non-crack, longitudinal crack, transverse crack, block crack, and alligator crack classes were created

from the photos. On the 3D dataset, their proposed approach had a 94 percent accuracy rate. Other types of pavement distress, such as patch and pothole, were not addressed.

3.2 Data collection by using Unmanned Aerial Vehicle (UAV)

Road Pavement section is surveyed using a drone. With the help of drone, image of the road surface is captured. The survey was conducted while there was very little wind. The drone's maximum wind resistance 29–38 km/h, therefore this is also a factor to consider during surveys. With strong wind, getting stable photos may be difficult, resulting in unsatisfactory models. [28]

Multispectral imagery, which depicts the spatial and spectral characteristics of objects, is commonly utilised in remote sensing. (Yifan Pan et al.) have presented machine learning methods like support vector machine (SVM), artificial neural network (ANN) etc. that were utilised to distinguish between normal pavement and pavement with distress (e.g., cracks and potholes) using multispectral pavement photos captured by an unmanned aerial vehicle (UAV). This study compares the performance of different data sources and models and results concluded that a UAV remote sensing system provides a new tool for detecting asphalt road pavement quality that can be utilised for by government for the maintenance of road.

Ahmet Bahaddin Ersoz et al. (2018) have presented a UAV-based pavement distress detection system for monitoring the current state of rigid pavements. The system combines newly developed image processing algorithms with standard machine learning approaches to detect and classify cracks in hard concrete surfaces. The different properties of annotated fracture bodies are extracted from UAV-based photos via image processing and subsequently utilised to build a Support Vector Machine (SVM) model. To evaluate the performance of the built SVM model, a field investigation was conducted along a stiff pavement with minimal traffic and large temperature changes. The accessible cracks were classified using a UAV-based approach, and the results demonstrate that it is a viable choice for pavement.

4. PAVEMENT PERFORMANCE INDEX MEASUREMENT

The Pavement Performance Index (PPI) is the sum of each deterioration parameter's multiplying rating and weightage. Distress surveys and visual inspections of shoulder condition and drainage features can be used to rate each degrading pavement criterion [15]. According to the American Association of State Highway and Transportation Officials (AASHTO), pavement performance is defined as a pavement's serviceability trend over a design period of time, where serviceability refers to the pavement's ability to meet traffic demand under current conditions. In other words, pavement performance can be determined by examining its structural and functional characteristics, or by anticipating a pavement's serviceability from its initial service period through the required evaluation period. Pavement condition is often assessed using four criteria: riding quality, surface distress, structural capacity, and skid resistance [13].

Anurag Sinha, Pratik Hagawane (2020) have calculated Over a four-lane, 80-kilometer flexible pavement segment, the IRC and ASTM methods were used to rate the quality of the pavement. The pavement ratings acquired using both approaches are compared to see if there is a correlation, accuracy, and precision in the results. The end result provides a clear picture of pavement performance. This will aid in determining the efficacy and utility of each pavement rating model.

4.2 Artificial Neural Network algorithm for predicting pavement performance index

An artificial neural network (ANN) is a system that operates similarly to biological neural networks, or in other words, it is a simulation of a biological neural network. The ability of an artificial neural network to think and learn through sensing, reasoning, and interpretation is modelled after that of a human brain. A brain is made up of neural networks that receive information from other neurons. When a neuron reaches a specific amount of excitation, it "fires" an output signal that serves as an input to other connected neurons. A number of methods can be used to explain the sort of relationship between the input and output of a neuron. (Freeman and Skapura et al. 1991). This algorithm is used to predict pavement performance index from the input parameters given to it.

An artificial intelligence approach to anticipate the Pavement Condition Index (PCI) has been proposed by Amjad Issa et al. (2021). Database was created by visually collecting and recording distress characteristics of road. After that, an Artificial Neural Network (ANN) model capable of predicting PCI values is created using this database. A series of performance indicators was constructed based on the inaccuracies in forecasting the pavement PCI to further examine the proposed ANN model's performance. Mean Squared Error (MSE), Standard Error (SE), Root Mean Squared Percentage Error (RMSPE), and Coefficient of Determination (R^2) are some of the performance measurements available. To further assess the performance of the developed ANN model, a set of performance measures were identified based on the errors in predicting the pavement PCI. The tested model demonstrates a linear relationship between observed and predicted PCI values with a slope close to 1.0, indicating an accurate and reliable prediction model.

Dr. S.S. Jain et al. (2013) have used artificial neural networks (ANN) to analyze the existing serviceability index (PSI) for flexible pavements on metropolitan roads. The following factors were measured in order to create PSI models: slope variance (SV), rut depth (RD), cracking (C), and patching (P). The constructed PSI regression model was validated using the chi-square and paired t-test. On the basis of R^2, a comparison was conducted between regression and ANN models. The performance evaluation was also done for both the models by estimating MAE (Mean Absolute Error), RMSE (Root Mean Squared Error) and MARE (Mean Absolute Relative Error). In terms of R^2 and different errors, the ANN model predicted better results than regression models. Recent technologies, like as neural network models, have overcome the constraints of traditional regression models.

5. CONCLUSION

The increased number of vehicles on the road creates a great deal of distress and damage to the road pavement surfaces, which has a direct impact on the quality of riding and the safety of road users. Pavement monitoring technologies have recently grown popular among transportation organizations and researchers. The goal of this paper was to look into the monitoring techniques that are used to assess the quality of road pavements.

Analysis of research suggests that a smart technology-based monitoring system can increase the accuracy of pavement condition data. Study revealed that vision-based method is determined to be more effective than the vibration-based method since the latter detects only those distresses that are along the wheel path. The smartphone-based pavement distress detection technology, on the other hand, can be used at any time of day or night, although image processing requires artificial lighting at night. Vibration based method is comparatively faster than vision-based method. Video processing is time-consuming because it involves large computational burdens. But due to less accuracy of vibration-based method, this method can be used to collecting routine pavement condition data, while a vision-based approach can be used for maintenance work that warrants a high level of accuracy, the vision-based approach can be employed.

Study also revealed that Pavement Performance Index can be effectively predicted by using artificial intelligence approach along with manual distress detection method.

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