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Evaluation of the Pavement Condition Performance Using Artificial Neural Network

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Abstract. Roads are considered the artery of countries that feed cities and regions and have great importance in achieving high levels of services for its users in facilitating their transportation and their goods from one place to another. Governments attach increasing importance to road conditions to achieve sustainability in the services provided to roadway users and thus increase users' satisfaction with government services. Perhaps one of the things that governments aim to monitor the road surface conditions. Where, Keeping the pavement in high-quality conditions can achieve the highest levels of comfort while driving, reducing vehicle maintenance costs, reducing traffic accidents, and thus increasing traffic safety. Monitoring the pavement condition is considered one of the significant applications to evaluate the pavement condition by determining the type and severity of defects on the pavement surfaces. In this study, a vibration-based method is used to measure the level of comfort riding a passenger car at a speed of 40 km/hr on local roads in Melbourne. The vibration signals are measured using an accelerometer sensor fixed on the front dashboard of a sedan car. The vibration signals then are smoothed and filtered to be used for the detection of the pavement defect locations according to the fluctuations in signals. Besides, the filtered vibration data was then divided into training and testing databases to develop an artificial neural network model named Long-Short-term memory LSTM. The LSTM is used to automatically detect and classify the quantity and quality of pavement defects according to the conducted vibration data.

Keywords. Pavement Monitoring, Prediction, Vibration data, Artificial Neural Network

1. Introduction

Roads are the lifeblood of countries. Where it represents the basic element of the infrastructure and provides absolute service to its users. The culture of caring and taking care of road conditions has become prevalent among governments and transport agents due to its great role in achieving economic growth and increasing the transportation of goods and people through them. Therefore, it has become imperative for countries to

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achieve the highest levels of service and comfort for road users in all their forms, including drivers, passengers, and pedestrians. Each element of the road users needs special studies and procedures to ensure a high level of satisfaction with the services provided. Perhaps one of the most important procedures to be followed is the application of monitoring systems for pavement conditions. And then a comprehensive evaluation of the level of pavement performance by determining the type and severity of defects on the road surfaces. Followed by determining the type and method of appropriate maintenance. Returning to the procedures for monitoring the pavement condition, the first and necessary step is to determine the efficiency of the pavement status and the level of damage, if any. Moreover, these procedures have the advantage of detecting the type, severity, and quantity of defects on road surfaces.

The pavement monitoring techniques are divided into two methods, including static and dynamic monitoring techniques. Static monitoring depends on the presence of auxiliary measuring tools such as penetrated sensors [1] and fixed cameras [2], which are installed in specific locations on the road shoulder in order to monitor the condition of the pavements within a specific period of time. In contrast, the dynamic monitoring system depends mainly on moving from one place to another on the road body to determine the quantity and quality of pavement defects spread on the road surfaces. Vibration-based methods are one of those techniques that were commonly used to evaluate road pavement conditions. These methods depend mainly on detecting the vibrations using smartphones [1][3] and accelerometer sensors [4] from the vehicle chassis during the movement over the road segments. These monitoring techniques focus mainly on analyzing the conducted vibration signals and identifying the fluctuations in signals which represent the higher to the high severity of pavement defects, while the low fluctuations indicate low pavement defect severities. The accelerometer sensor showed a significant contribution in monitoring the pavement condition performance [5]. The monitoring results are more accurate compared to the mobile phone application's results [6]. While the availability of the smartphone is much higher than the accelerometer, in addition to the significant difference in the cost price and simplicity of use [7]. The evaluation methods vary with the variety of the used tools. Except, for visual inspection, many tools are used to assess the pavement health status such as cameras, sensors, and equipped vehicles. Besides, there are significant techniques to identify the type and severity of pavement defects, including vibration-based methods, and prediction models [1]. Regarding the data collection tools, a camera was used and installed on a front vehicle chassis which is moving at a certain speed on a side road. The camera was used in order to determine the types and severity of defects. Also, Radopoulou et al. (2016) [8] used a modern type of camera in order to photograph roads at high speeds and record high-resolution snapshots of cracks and defects.

In order to achieve the most sustainable road conditions, emphasis should be placed on pavement management through the application and implementation of systems to predict the conditions and performance of pavement surfaces. It includes identifying and classifying pavement defects according to different input variables such as vibration data [9], laser scanner data [10], and images processing [11]. The prediction model provides clear information and details on the actual and future condition of pavement and the behavior of pavement defects. Artificial neural networks ANN [12] and machine learning ML [13] prediction models have significant contributions in the field of predicting pavement conditions and defects performance. Therefore, in this study, an artificial neural network model named LSTM was developed to predict the behavior of pavement defects. The model is a time-series prediction model that was built to accurately detect and classify the quantity and quality of pavement defects.

This paper is structured as follows. The following section provides a dataset and explains the road pavement monitoring methodology. The discussions are presented in Section 3, followed by Section 4, which summarizes the findings and conclusions.

2. Data

The section provides all the details on the site location of the study, setting up the monitoring devices, and data collection procedure. Analyzing and matching the conducted vibration signals with real pavement conditions are also given.

This study aimed to dynamically monitoring the pavement condition performance of a local road in Melbourne, Australia. The road name "Cecil" is a local road located at Fitzroy with a speed design of 40 km/hr. According to the visual inspection, the road has different distress types, including cracks and patches, see Figure 2. These degradations on the pavement surface cause less comfort riding, more deterioration in road life, and more maintenance costs for both vehicles and the road.

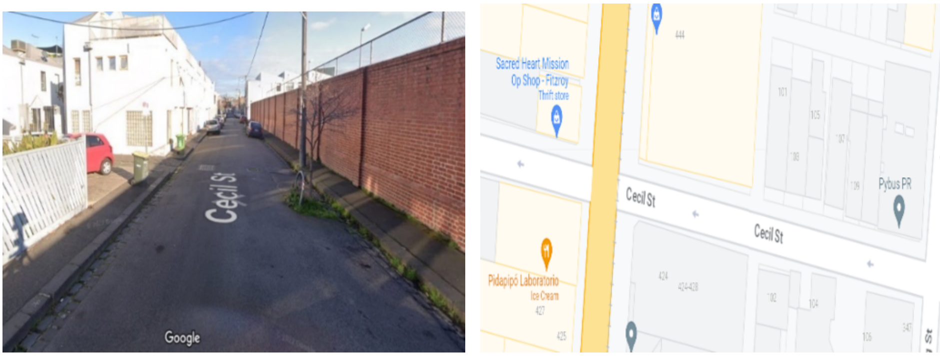

Figure 1. Site location of the study (Google Maps)

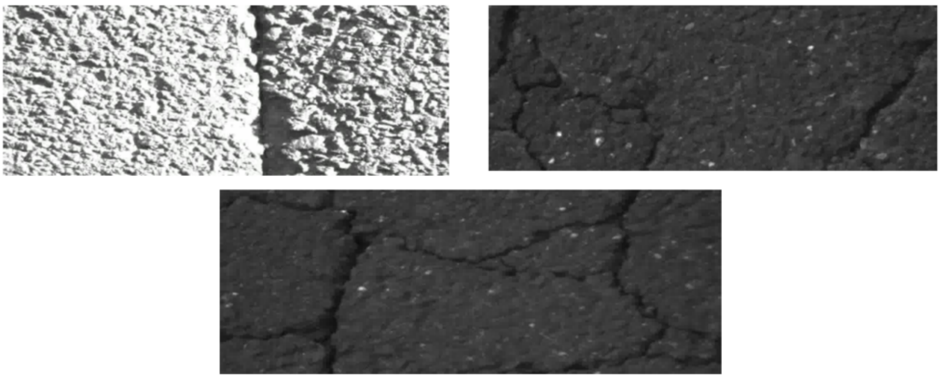

Figure 2. Captured defect images from the line scan camera

2.1. Data collection using an accelerometer sensor

A vibration-based method was used to indicate the actual pavement condition in order to find and select an appropriate maintenance process. Many researchers recommended using an accelerometer due to its accuracy, fast, and high sensitivity to detect a wide range of vibrations while driving at very low travel speeds [14]. In this research, an accelerometer sensor was utilized to measure the vibration of the vehicle chassis while driving at 40 km/h over the road segment length of 70 meters. The accelerometer sensor was installed at the front dashboard position of a Toyota Prius 2009 using double-sided tape. Also, LabVIEW NXG 2020 was used to store the measured vibration data from the sensor to the laptop. Figure 3 presents the conducted vibration signals (acceleration) from the selected local road. Besides, a line scan camera was also used to record a video while driving in order to record the pavement status and match the spot positions of pavement distresses with the conducted vibration signals.

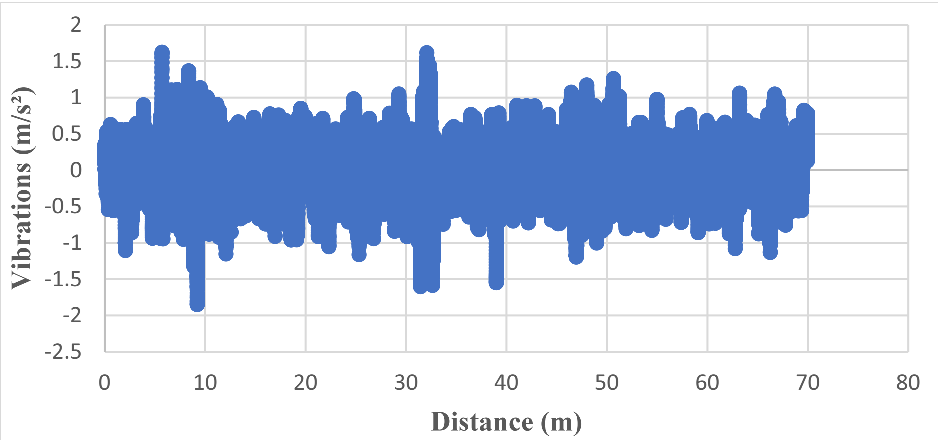

Figure 3. The conducted vibration signals using an accelerometer sensor

The above figure revealed fluctuation in signal values at different spot locations on the selected road. Fluctuations in the intensity and shape of the vibrations indicate that the traffic was not easy and comfortable because of many pavements' distress located at specific spots. The high peak values represented the high severity of pavement defects at 10 meters, 31 – 34 meters, and 38 meters. While medium pavement severity was located at 5 - 7 meters, 48 - 52 meters, and 64 – 68 meters. Besides, the signals showed less swinging in the peaks at some spots due to the better pavement heath. The locations, types, and severities of pavement defects were identified and matched manually with the conducted vibration signals using the recorded video which was captured using the line scan camera.

3. Discussion

The research focused on presenting a dynamic evaluation technique for local road conditions using a sensor installed on the dashboard of a private car. The study aimed to provide an accurate evaluation system for road pavement conditions. Also, an ANN model was developed to forecast pavement conditions in terms of detecting and classifying types and locations of pavement defects.

The monitoring results showed that the accelerometer sensor achieved the desired monitoring purposes in measuring consistent vibration data while the vehicle moving at a velocity of about 40 km/h over the selected road. The sensor has a significant impact on monitoring and evaluating the performance and behavior of road defects. The conducted vibration data represented the exact road surface condition with vary range of defect severities. Table 1 shows the measured road defects by the sensor.

Table 1. A sample of detecting locations and errors of the measured defects

Defect Name	Actual length (m)	Spot positions (m)	Measured stations (m)	Errors in the measured length (m)	Errors in the measured position (m)
Patches	2.4	3.5	3.35 - 5.67	0.08	0.15
Transverse cracks	2.2	7.3	7.49 - 8.14	1.55	0.19
Alligator cracks	3	12.5	12.55 - 15.36	0.19	0.05
Longitudinal cracks	1.4	16	16.78 - 18.55	0.37	0.78

According to Table 1, the sample data showed errors in the locations of the pavement defects. The main causes of these errors were the distance between the sensor and the camera, and the fluctuation in identifying the exact start point and end point of the road, therefore, a possible offset has been taken into consideration while matching the vibration data and recorded video. Selecting the dashboard as the main position to measure the vibration data was due to its close to the center of the vehicle, which helped the sensor to measure a wide range of vibrations during driving.

In order to enhance the vibration data and make them more consistent and emptier of any undesirable signals, data smoothing using a high-pass filtering technique was performed in order to enhance the vibration data from any noise [15]. The filtering or noise-canceling method was focused on soothing the vibration signals by removing the signals that represented the engine noise, and unexpected movements, including acceleration, deceleration, and braking.

After the application of noise-canceling using filtering techniques on the raw vibration data, the signals were then ready for building and developing prediction models. The study aims to identify the performance of road conditions by identifying and categorizing the degradations of pavement according to their types from the vibration signals. In this study, the LSTM was used to forecast the behavior of pavement defects. According to the vibration values (fluctuations), the proposed prediction model was divided into two main groups for testing and training, with a ratio of 30:70, respectively. The LSTM model was developed for multi-classification purposes not a binary. More clearly, the model can work with different types of pavement distresses at the same time. Moreover, four defect classes were taken into account in the ANN, including no distress, alligator cracks, transverse cracks, longitudinal cracks, and patches. All of the considered pavement defects were determined using the pre-processing steps. Table 2 shows LSTM results in the prediction of pavement degradation.

Table 2. The prediction of pavement defect performance using LSTM.

Features	LSTM Precision	LSTM Recall	LSTM f1-score
No distress	97%	96%	97%
Alligator cracks	80%	76%	78%
Transverse cracks	93%	88%	90%
Longitudinal crack	85%	85%	85%
Patches	87%	83%	85%
LSTM Accuracy			87%

Table 2 presents the LSTM efficiency in identifying and classifying different types of pavement anomalies from vibration data. Also, LSTM's results showed a significant performance in multi-detection and classification of different types of pavement defects including alligator cracks, transverse cracks, longitudinal cracks, and patches with an overall accuracy of about 87%. The LSTM metric values, including precision, f1-score, and recall also showed significant values in predicting the pavement defects. Besides, the performance of the LSTM in the detection and classification of the transverse crack was much higher compared to other defect types with about precision of 93%, recall of 88%, and f1-score of 90%. While the lowest prediction model metric values were found in detecting and classification the alligator cracks due to several factors, including large spot sizes, no specific boundaries, and in some cases, more than one type of defect can exist within the alligator cracks (compound two or more defect at the same spot). These factors may confuse determining the actual length, size, and beginning and end point of alligator cracks using vibration data [16].

4. Conclusions

In this research, a new technique of monitoring the pavement condition was performed depending on the vibration-based method. The vibration signals were measured and conducted using the accelerometer sensor. The selected test vehicle was then traveled on the selected local road sections at a travel speed of 40 km/h. Besides, a camera was used to record the road condition and surface anomalies in terms of quantity, type, and location to match them later with the obtained acceleration data. After that, the conducted signals were filtered to noise-canceling and smoothing the data. More clearly, removing the undesirable singles that may affect the accuracy of building and developing the prediction models such as the vehicle engine noise. The filtered acceleration data was then applied to develop the LSTM model. This model aimed to detect the number of pavement defects from the vibration data and classify the detected defects into types.

The results showed that the proposed dynamic monitoring method measured and evaluated the pavement condition accurately, after matching the data with the recorded video. More clearly, the vibration data represented different pavement defect severities from low to high. The camera was a significant assistant tool in detecting accurate locations and types of road surface degradation. In addition, the prediction results showed a significant contribution of the LSTM in the detection and classification of different pavement defects using the vibration data. The overall prediction accuracy was about 87%, which is significantly high, and indicates that the selected model was significant and appropriate for further prediction process. The study recommends using these evaluation devices to indicate the overall road pavement conditions in order to apply appropriate maintenance processes.

Moreover, different monitoring tools will be used to evaluate the overall and more defect types on road pavement in order to cover a wide range of distresses. Also, more investigations will be performed to identify the most significant prediction model that can accurately identify and classify the pavement defect types, severity, and locations.

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