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Pavement Monitoring: A Comparison of Smartphone and Accelerometer sensors

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Abstract

The increase in vehicular traffic volume on our roads intensifies the need for comfortable and safe riding. To satisfy the comfortable and safe riding needs, frequent inspections of pavement health statutes is needed. Sustainable pavement condition comes from accurate monitoring, accurate assessment, and routine maintenance actions. Monitoring the pavement condition is a technique used to obtain precise details about the level of damages, roughness, and smoothness of the road surface. A regular monitoring system can help transport agencies and governments determine the current and future pavement conditions. This study uses two monitoring devices, including a smartphone application and an accelerometer sensor, to collect pavement vibration data for a local road. In addition, a comparison between the devices is presented in terms of accuracy, efficiency, and best locations to be mounted. The results show that both methods provide accurate monitoring results with some considerations on the best mount locations.

1.Introduction

Nowadays, the need for an accurate pavement assessment system has become necessary for most transport agencies and governments to determine the health status of roads and pavement performance. A pavement assessment system is essential in selecting appropriate maintenance and treatment of pavement damages, and consequently, saving maintenance cost, time and efforts. However, a significant stage precedes the assessment stage, which is the monitoring or observation stage. In the monitoring stage, pavement surfaces need to be inspected and observed to collect all the information about the road condition. This information includes distresses type, distresses severity, the quantity of pavement distresses, and the overall condition data such as type of pavement, number of layers, history details, and age of pavement. An accurate monitoring technique is key to an effective pavement evaluation system and appropriate maintenance techniques. Figure 1 shows the sequence diagram of the pavement management system.

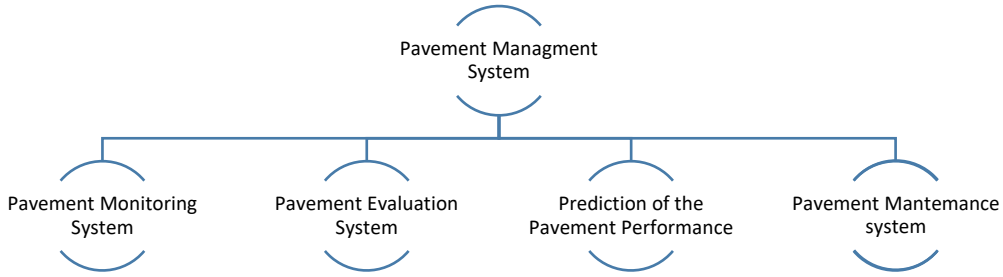

Figure 1: pavement management system branches.

Sustainable pavement condition comes from accurate monitoring, significant assessment, and frequent maintenance actions. To achieve a highly accurate monitoring system, advanced techniques and equipment can be used to collect the desired data. Therefore, many monitoring techniques are used worldwide to evaluate pavement conditions, such as vision-based, vibration-based, and visual inspection methods. At the same time, various monitoring devices are used to collect the observed condition data of the pavements, including smartphone applications, acceleration sensors, geophone sensors, profilometers, penetration sensors, and video cameras. The efficiency of using each type of device varies according to the size and type of the monitoring works. In addition, each device has advantages and disadvantages that differ from other devices.

Monitoring the pavement condition is a technique used to collect information about road surface damages, roughness, and smoothness. The accuracy of monitoring results mainly depends on several factors, including devices quality, weather condition, traffic condition, pavement age, and quality of the pavement material.

This study compares two monitoring devices, including a smartphone application and an accelerometer sensor, to collect the pavement vibration data and determine the more accurate mount location inside the vehicle that provides more consistent vibration signals. This paper is structured as follow; the literature review is presented in the next section. It is followed by the explanation of data in Section 3. After that, the results are presented and discussed in Section 4. While in Section 5, the conclusion and future research direction are presented.

2. Literature Review

Pavement monitoring has a significant role in the pavement management system. Hence, governments and transport agencies focus on finding the best monitoring technique that reflects the actual pavement conditions. Therefore, selecting accurate monitoring devices represent a challenge for many researchers to detect the type and severity of pavement distresses and the overall pavement condition performance (Douangphachanh & Oneyama 2014).

Smartphone and accelerometer sensors can be used to monitor pavement conditions using the vibration-based method. Both devices can measure the vibrations of the vehicle body during movement over road segments. The vibrations of the vehicle chassis are an indicator of the road smoothness levels. Besides, the smoothness of the road surface represents the level of riding comfort for roadway users. In other words, the smoother road pavement means lower vehicle vibrations during riding.

Many studies implemented a smartphone application in monitoring the pavement condition. A smartphone was used as a sensor to collect pavement vibration data during vehicle movement (Shtayat et al. 2019; 2020a). Moreover, many researchers have agreed that the mount location

significantly impacts the vibration results and the overall monitoring outcomes (Shtayat et al. 2020b). There are significant factors such as the availability and cost of using a smartphone application as an attractive alternative device in pavement monitoring. Souza et al. (2018) developed a low-cost monitoring system named "Asfault" to monitor the pavement health status. They used a smartphone sensor fixed on the front dashboard of the vehicle to measure the vibration data representing the observed road surface condition. A hatchback car was used as a test vehicle to evaluate different urban roads in Brazil at a speed of around 80 km/hr. Also, Yeganeh et al. (2019) tried to validate the use of a smartphone application in detecting pavement anomalies. Their study focused on using assistant devices such as mobile phone cameras and GPS to confirm the location and quantity of pavement distress. The vibration data were collected from the arterial road in Iran at speeds of less than 50 km/hs. The smartphone was installed on the front dashboard, while the mobile camera was mounted on the front glass using a particular phone holder to record a video during movement. The results showed that the vibration data from the smartphone sensors were acceptable, and it was appropriate to be used as a monitoring device for pavement evaluation purposes. Du et al. (2020) proposed a model to measure the efficiency of smartphone sensor outputs in pavement distress detection using different variables such as travel speed, vehicle type, and distress type. They confirmed that vibration data from a smartphone were accurate to detect surface potholes and speed bumps.

On the other hand, an accelerometer sensor was used in previous studies to evaluate the pavement condition (Koch et al. 2013; Bajwa et al. 2020). An accelerometer sensor measures the vertical amplitude, which reflects the roughness and level of pavement damages. In another study, Chen et al. (2011) used two accelerometer sensors to evaluate the road pavement condition. They used a prob van as a test vehicle, and the speed test was about 80 km/hr. One sensor was fixed on the front dashboard, and the GPS sensor was fixed on the vehicle chassis above the left front wheel. Katicha et al. (2016) focused on evaluating the road pavement condition using an accelerometer sensor. They fixed the accelerometer inside a prob vehicle, and they measured the vibrations at a speed of 80 km/hr.

Most transport agencies and governments are still looking for cheap, available, accurate, and simple monitoring techniques to be used in pavement evaluation systems. According to the literature, limited numbers of studies have focused on using an accelerometer sensor in monitoring the pavement condition, unlike smartphones, which were widely applied in previous studies. In addition, limited studies have focused on the best positions/locations to mount the monitoring devices for accurate measurements. In this study, two monitoring devices, including a smartphone application and an accelerometer sensor, were used to collect pavement vibration data of a local road. Also, a comparison between the devices was presented in terms of accuracy, efficiency, and best locations of mounting the device.

3. Data

This section explains the site location and the installing process for the accelerometer sensor and the smartphone. In addition, the procedure of monitoring the pavement condition is presented in this section.

This study focused on monitoring the health status of a local road in Fitzroy, Melbourne, Australia. The local road named “Spring Street" is a two-way local road. According to the visual inspections, the road has many pavement defects that spread along the 150 meters length of the street. These degradations include cracking (alligator, longitudinal, transverse, and edge), ravelling, and patching. These defects cause less comfort riding, more maintenance costs

and more efforts to be fixed. In this study, the conditions such as tire condition, tire pressure, number of passengers during the data collection were considered in both collection methods. Figure 2 shows the site of the study. In this study, a calibration procedure was performed after moving on an ideal pavement to identify the range of noise from the vehicle chassis and engine.

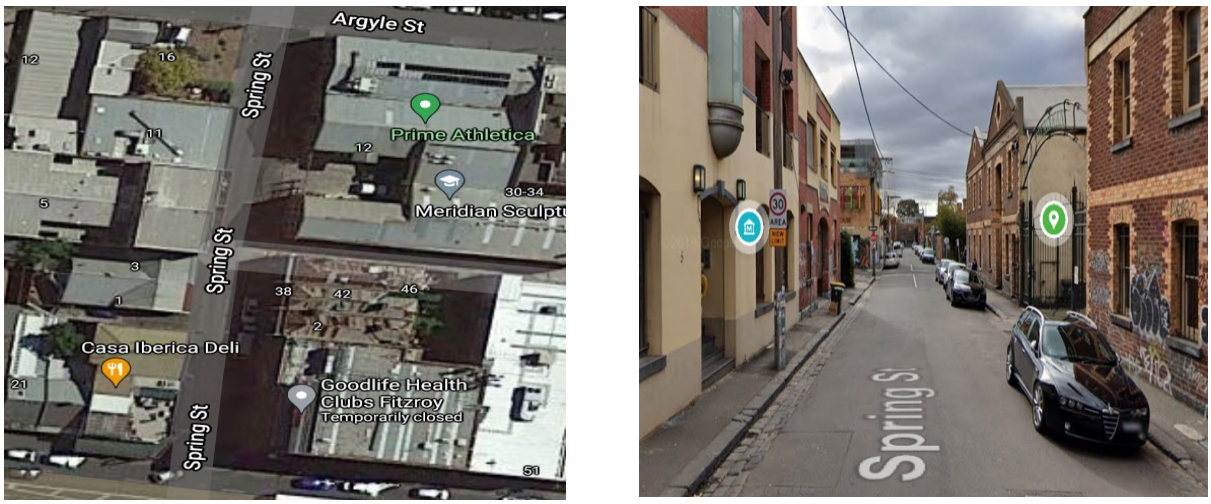

Figure 2: Site location of the study (google map).

3.1. Using a smartphone application in monitoring the pavement condition

A vibration-based method is a technique used by many researchers to indicate the actual condition of road pavement and selecting appropriate maintenance actions. As mentioned previously, a smartphone is widely used as a pavement monitoring tool for three primary purposes, including 1) measuring vibrations using specific applications and software, 2) recording a video to document the road condition, and 3) matching the locations of defects using a built-in GPS (Shtayat et al. 2020). In this study, an iPhone 8 device was mounted in two recommended positions inside a vehicle: the front dashboard and the back trunk of a sedan car model (Toyota Prius 2009). The smartphone device was placed on the front and back boards using double-sided tape in both positions. Besides, the vertical amplitude values were recorded at a15 km/hr speed, representing the vibrations from the pavement during vehicle movement. The vibrations were extracted in three axes x, y, and z. The 15 km/hr speed was selected according to the previous studies (Shtayat et al. 2019). More simple, at this low speed, the driver could move over the pavement without any impact from the ongoing traffic. Also, no deceleration, acceleration, or braking was recorded at low speeds. Figure 3 shows the vibrations measured using a smartphone from the front dashboard.

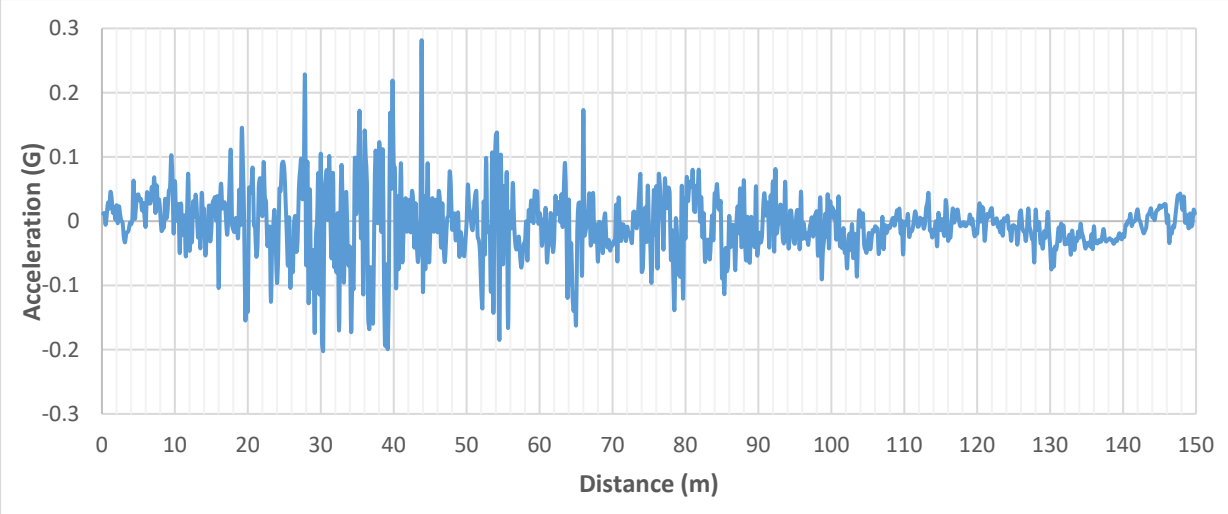

Figure 3: The measured vibration data using smartphone application from the front dashboard.

According to Figure 3, the results showed significant fluctuations in vibration data along the road segment. These fluctuations indicated that the vehicle's movement over the road surface was not smooth due to different pavement distresses and damages. After 100 meters, the acceleration data showed more consistency with small peak values due to the better pavement conditions. This figure presented the vibration data from the front dashboard. While the vibrations from the two positions were consistent in shapes and values, there was a few incompatible signal peaks due to several factors, such as the distance of the smartphone to the vehicle centre axis and the orientation axes of the smartphone (Janani et al. 2020). As mentioned previously, the smartphone's position is a significant factor in collecting consistent and accurate vibration signals.

3.2. Using an accelerometer sensor in monitoring the pavement condition

In this study, a triaxial accelerometer sensor model PCB 356B18 was also used to collect vibration data using a 15 km/hr speed during the vehicle movement. Three positions were selected to install the sensor, including the dashboard, rear trunk, and the top roof of a Toyota Prius 2009, which was the same vehicle that was used during smartphone measurements. The vibrations were extracted in three axes x, y, and z. Figure 4 shows the vertical vibration data collected from the accelerometer sensor.

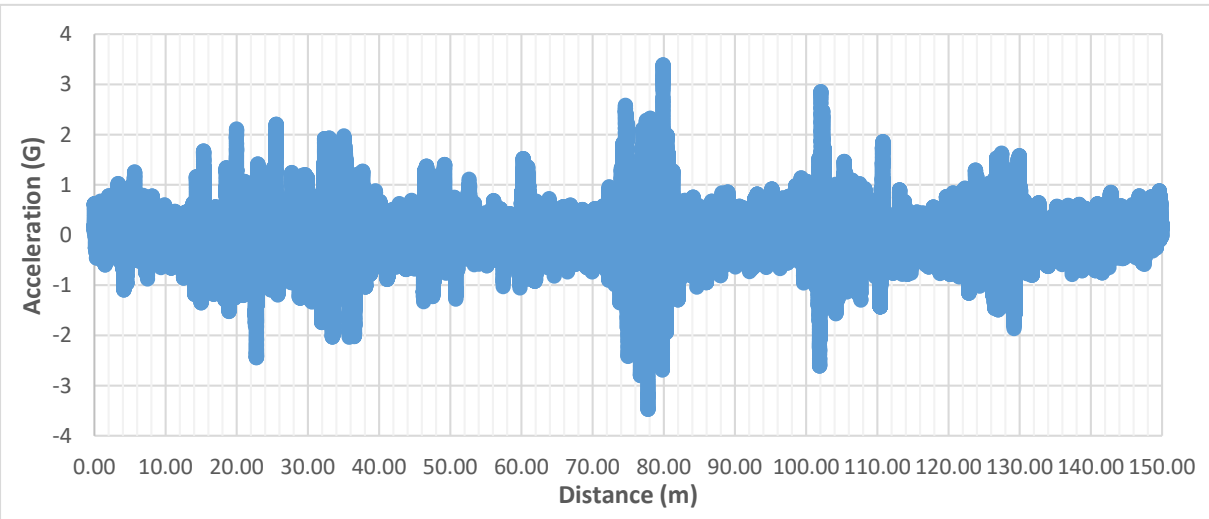

Figure 4: The measured vibration data using an accelerometer sensor from the front dashboard.

As shown in Figure 4, the results showed a significant swing in vibration signals at some spots along with the road. These fluctuations indicated that the road suffered from many types of pavement damage with various severities. Also, due to the sensitivity and sampling rate, the results showed that the vibrations conducted from the accelerometer sensor were higher and more varied than those measured by a smartphone. The primary reason for the increased variability was that the sensitivity of the accelerometer sensor was much higher than the smartphone.

4. Discussion

This study focused on comparing two monitoring devices, including a smartphone and accelerometer sensor. The overall results showed that each device has a significant contribution to accurately monitoring the pavement condition. The smartphone showed that the vibrations reflected most of the distresses and pavement conditions, and the road was well monitored. Meanwhile, the data conducted from the accelerometer sensor provided a highly accurate indication of pavement condition. This sensor could detect wide ranges of severities from very low to very high distress severities. Table 1 and Table 2 present monitoring data from the smartphone, accelerometer sensor, and visual inspection.

On the other hand, in Table 1, the sample data from the smartphone showed that the two positions provided accurate measurements in identifying the high severity pavement distresses along with the road. In addition, the data collected from the dashboard showed more consistency and less error in the locations and lengths of pavement defects.

Table 1. The measured pavement distresses using the smartphone application.

Distress type	Length in the field (m)	Location on the road (m)	Dashboard stations (m)	Error in length (m)	Error in locations (m)	Rear trunk stations (m)	Error in length (m)	Error in locations (m)
Patching	2.4	3.5	Not recorded	-	-	-	-	-
Edge cracking	2.2	7.3	Not recorded	-	-	-	-	-
Alligator cracking	1.3	15.3	15.67-17.17	0.2	0.37	16-17.67	0.37	0.7
Patching	1	18.8	19.33-20.5	0.17	0.53	19.17-19.67	0.5	0.37
Alligator cracking	1.4	16	Not recorded	-	-	-	-	-
Patching	1.6	28.4	27.66-29.33	0.07	0.74	27.83-29.17	0.26	0.57
Alligator cracking	5	29.5	29.33-34.33	0	0.17	30.33-35.33	0	0.83
Alligator cracking	1.1	32.5	Not recorded	-	-	-	-	-
Alligator cracking	1	43.9	44.33-45.5	0.17	0.43	43.83-44	0.83	0.07

As shown in Table 2, the sample data from the three positions (dashboard, rear trunk, and top roof of the vehicle) showed errors in the location and length of each distress type at the selected

positions. These errors appeared due to the fluctuations in the starting and ending points of measurements in the three fixed positions.

In addition, the errors from the dashboard were less than the other two positions because of two main factors, including the dashboard position was near to the vehicle centre and the wheel axles, which helped the accelerometer sensor to measure any inconsistent movement during riding. In addition, the dashboard position was away from any direct connection with the vehicle chassis, like the top roof position. While in the rear trunk, the most reason for the increased errors was the design of the sedan car. The rear trunk looks like a cantilever; thus, additional vibrations might affect the data. The overall monitoring results showed that the three positions satisfied high accurate measurement in identifying low, medium, and high severity of pavement distress.

Both devices provided acceptable accuracy levels of pavement monitoring. However, the lack of some smartphone data compared with the accelerometer sensor data was due to several factors. First, a smartphone application named "Sensor Log" was used to collect vibration data along with the road. The smartphone had a sampling rate of 50Hz, while the accelerometer sensor has a sampling rate of around 6000Hz. Therefore, the accelerometer's ability was much higher in detecting wide ranges of vibration data that represented the actual pavement condition.

Table 2. The measured pavement distresses using the accelerometer sensor.

Distress type	Length in field (m)	Location on the road (m)	Dashboard stations (m)	Error in length (m)	Error in location (m)	Rear trunk stations (m)	Error in length (m)	Error in location (m)	Top roof stations (m)	Error in length (m)	Error in location (m)
Patching	2.4	3.5	3.35-5.67	0.08	0.15	4.18-6.51	0.07	0.68	3.75-6.32	0.17	0.25
Edge cracking	2.2	7.3	7.49-8.14	1.55	0.19	7.01-11.01	1.8	0.29	8.11-10.76	0.45	0.81
Alligator cracking	3	12.5	12.55-15.36	0.19	0.05	13.25-16.39	0.14	0.75	12.65-15.45	0.2	0.15
Alligator cracking	1.4	16	16.78-18.55	0.37	0.78	16.46-18.722	0.862	0.46	17.44-20.21	1.37	1.44
Patching	2	20.1	19.98-22.79	0.81	0.12	20.35-24.16	1.81	0.25	20.44-22.86	0.42	0.34
patching	1	26.4	25.96-27.75	0.79	0.44	25.65-26.83	0.18	0.75	25.83-27.7	0.87	0.57
Alligator cracking	3.1	29	29.64-31.96	0.78	0.64	28.46-32.15	0.59	0.54	28.93-31.73	0.3	0.07
Alligator cracking	1.1	32.5	33-34.77	0.67	0.5	33.05-35	0.85	0.55	44.38-46.72	1.24	1.08
Alligator cracking	1.4	43.3	44.08-46.81	1.33	0.78	42.98-44.77	0.39	0.32	59.11-60.66	0.15	1.11

When the vehicle move over the edge of patching, longitudinal cracking, or edge cracking, the ability of the smartphone application to detect the vibrations over these distresses is relatively lower compared with the accelerometer sensor due to low severities. For instance, at a distance of 7 meters, the recorded video showed an edge crack with a length of about 2.5 meters. The accelerator data showed that at 7 meters distance, there were slight fluctuations in vibration

peaks, which mean there was a type of distress. While, at 7 meters distance of smartphone data, the results showed normal fluctuations with nothing serious or any indication of distress.

Second, smartphones are general purpose mobile computing platforms and designed for other purposes than monitoring pavement; however, they are used widely in pavement monitoring with acceptably accurate results. Unlike the accelerometer sensor, which was designed for pavement monitoring and evaluation systems for highly accurate indications of pavement health. There are advantages and disadvantages of using the smartphone and accelerometer sensors to monitor the pavement condition, which is summarised in Table 3.

Table 3. The advantages and disadvantages of pavement monitoring devices.

Device type	Advantages	Disadvantages
Smartphone	simple, available, cheap, easy to use, acceptable accuracy, no codes needed	Not able to detect low distress severities, limited position to be mounted in, need more iterations to get an accurate measurement, and error rate varies according to the application used.
Accelerometer sensor	Accurate, multi-purpose used, reflect the actual condition of the pavement, and easy to mount	Expensive, complex, and need other assistant devices like a laptop.

5. Conclusion and recommendation

This study presented an overview of using two pavement monitoring techniques, including a smartphone and accelerometer sensors. Visual inspection was also performed to identify the location, type, severity, and dimension of each type of pavement distress. Besides, two different positions were selected to mount the smartphone inside a sedan car, including the front dashboard and back trunk. Meanwhile, three positions were chosen to install the accelerometer sensor, including the front dashboard, back trunk, and top roof of the vehicle.

The results showed that both the smartphone and the accelerometer have accurate monitoring and distress detection. Furthermore, the data showed an acceptable consistency range with an accurate rate in detecting high severity distresses regarding the smartphone. Also, the best location to mount the smartphone was on the front dashboard for more accurate data. The data collected from the accelerometer sensor showed more accuracy in detecting wide ranges of distress severities and types.

This study concludes that smartphones can be used as a monitoring device in the pavement monitoring system. Transport agencies and governments can use all road classifications and different test vehicles such as sedan cars, bicycles, and motorcycles to evaluate pavement conditions. Moreover, for more intense monitoring and advanced evaluation systems, accelerometer sensors are the best choice. Accelerometer sensors can also be used in different road types and limited test vehicles due to the need for assistant devices such as power sources and portable laptops.

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