Influence of Unit Length on Pavement Roughness Evaluation Results Based on Driving Vibration Data

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Abstract. The method of evaluating pavement roughness with vibration acceleration data collected by smart phones is influenced by many factors, of which the length of pavement evaluation unit is an important one. In order to explore the influence of evaluation unit length on pavement roughness evaluation result with vibration data, this paper carried out a driving experiment, used the self-developed smart-phone APP acquisition running-vehicle vibration of data, used the multi-function checkout automobile detection of pavement smoothness, and established the relationship models of pavement roughness — vibration index and speed index when the evaluation unit length are 100 m, 500 m and 1000 m respectively. The results showed that when the unit length is 1000 m, the accuracy of the evaluation model is the highest, and the determination coefficient reaches 0.876. The verification experiment also proved that the evaluation model has good accuracy and stability. And also it was showed that the accuracy of the pavement roughness evaluation model increases with the increase of the length of the evaluation unit, which may be related to the matching error between the vibration data and the pavement roughness. How to improve the accuracy of the evaluation results about the short unit is the key content to be studied in the future.

Keywords. Road engineering, pavement roughness, evaluation unit length, automobile driving vibration, smart phone.

1. Introduction

Roughness is an important index of pavement performance, good pavement roughness could improve ride quality and comfort [1-3], reduce the impact between vehicle and pavement [4, 5]. Therefore, it is an important content of pavement management and maintenance to keep pavement evenness in good condition. According to the highway subgrade pavement field test procedures (JTG E60-2008) [6], The test methods of roughness in China mainly include the 3-meter straight rule, continuous flatness meter method, vehicle-mounted bump accumulator method and vehicle-mounted laser flatness meter method. At present, vehicle-mounted laser flatness meter has advantages in measuring accuracy, reliability and efficiency, so it is widely used in the test of pavement flatness.

With the development of the Internet & information technology and its application in the field of road traffic [7], the problem of pavement roughness on-line monitoring has become a focus of research of many scholars at home and abroad. Including our country, many countries have carried out the research of pavement roughness monitoring method with using smart phone and Internet. The core content about using smart phones to detect or monitor the roughness condition is to establish the relationship model between the pavement roughness and the driving vibration. 2014, the longitudinal section of the pavement by twice numerical integration of acceleration data was generated [8], which
used the acceleration data collected by a smart phone. The higher the collection frequency is, the better the quality of the generated longitudinal section of the road [9-11]. 2015, according to vibration data collecting in the course of driving with smart phones the relationship between vibration variance and pavement performance index (PSI) was fitted at the speed conditions of 64 km/h and 80 km/h respectively [12]. 2017, Yang [13] proposed a pavement roughness index based on the power spectral density (PSD) of driving vibration acceleration, and verified the correlation between the index and international roughness index (IRI) when the speed was 60 km/h. 2019, a pavement performance monitoring system [14] based on crowd-sourced temporal and spatial data was proposed. 2020, Wu [15] used the data of driving vibration acceleration collected by smart phones to test pavement roughness, so as to realize the intelligent evaluation of road surface driving quality index (RQI).

From the existing literature, using smart phones perception driving data of public participatory pavement roughness monitoring method has a certain possibility. Due to the influence of vehicle type, smart phone type and its fixed position in the vehicle, sampling frequency, and many other factors, a lot of problems should to be solved for using driving vibration data to monitoring pavement roughness, and one of them is the length of evaluating unit. According to different purpose there are different ways such as 10 m 100 m 1000 m. However, smart phone acquisition of vibration acceleration is a continuous acquisition mode, which needs to be matched with the pavement roughness acquisition unit to realize the intelligent evaluation of pavement roughness. Therefore, in the application how to determine the length of evaluating unit is a problem worth studying. Using the smart phone APP independently developed by the author and others, the vibration data in the process of driving was collected, and in this paper the relationship model between vibration data and pavement roughness were established, also the influence of evaluation unit length on model accuracy was discussed in this paper.

2. Experimental Methodology

2.1. Driving Test

In this study outdoor driving tests were conducted. Two sections of asphalt pavement, which called Chunbo Road and Feiyue Avenue located in Jinan of Shandong province, were selected. According to the on-site test of the road roughness index by the multi-function test vehicle, it can be known that the length of the two road sections were 2000 m (Chunbo Road) and 1100 m (Feiyue Avenue) respectively. For the convenience of analysis, the length of Feiyue Avenue was taken as 1000 m. Therefore, the total length of the experimental section in both driving directions was 6000 m, which could be divided into 6 units with a length of 1000 m, or 12 units with a length of 500 m, or 60 units with a length of 100 m.

Figure 1. The position of smart phone.

The driver used in this experiment was healthy and experienced. Under the condition of 10 Hz sampling frequency, the data of three-direction acceleration, GPS position, speed and so on were collected. A Honda CRV, which was an ordinary passenger vehicle in normal condition, was the vehicle used in the driving test. The Huawei Honor smart phone used in the experiment was fixed on the middle armrest of the CRV front seat, as shown in figure 1. The experimental speed was set at three speed levels, namely low speed (25-40 km/h), medium speed (40-60 km/h) and high speed (60-
80 km/h). Three times of driving data acquisition were conducted at each speed level. Before the experiment, turned on the data acquisition software installed on the smart phone and keep the data traffic on all the time. The vehicle could be started only after the GPS signal switching on and stable. Before entering the test road, the vehicle should has reached the speed required for this test and also should keep the speed stable within the corresponding speed level during the test, while avoiding the operation of emergency acceleration or deceleration or lane change.

2.2. Data Processing Method

The driving distance of the experimental vehicle was calculated according to the speed and acquisition frequency. By comparison, the error between the calculated driving distance and the actual driving distance was within 3%, which basically achieved the requirement of accuracy. The pavement roughness value was obtained from the multi-function test vehicle, and the roughness index was IRI, unit: m/km or mm/m. The length of the pavement roughness detection unit was 20 m, according to the purpose of this study, the IRI value of the section length of 100 m, 500 m and 1000 m could be calculated separately, as shown in figure 2, figure 3 and figure 4.

![Figure 2. The IRI of 1000 m detection unit.](image1)

![Figure 3. The IRI of 500 m detection unit.](image2)

![Figure 4. The IRI of 100 m detection unit.](image3)

In order to establish the relationship between IRI and driving acceleration data, the vibration index and the velocity index corresponding to the evaluation unit length of IRI should be calculated. Because the experimental road surface was not a standard wavy facility [16], and the experimental vehicles also did not travel evenly, the experimental vehicle also had a certain amount of instability before and after or left and right, in addition to the up and down vibration. This indicates that the flatness may not only affect the vertical vibration of the vehicle, but also lead to some transverse oscillation of the vehicle. Therefore, the composite value of vibration data in x, y and z collected by smart phone was adopted as the evaluation index of vibration acceleration. The specific calculation formulas are shown in equations (1) and (2), and the unit of acceleration is m/s².

\[
a_{vib,i} = \sqrt{(a_{vib,ix})^2 + (a_{vib,iy})^2 + (a_{vib,iz})^2}
\]

\[
\begin{align*}
    a_{vib,ix} & = a_{meas,ix} - a_{meas} \\
    a_{vib,iy} & = a_{meas,iy} - a_{meas} \\
    a_{vib,iz} & = a_{meas,iz} - a_{meas}
\end{align*}
\]

where: \(a_{vib,i}\) is the \(i\)-th synthesized data of driving vibration acceleration in the evaluation unit; \(a_{vib,ix}, a_{vib,iy}, a_{vib,iz}\) are the driving vibration acceleration data in x, y, and z directions in the \(i\)-th evaluation unit respectively; \(a_{meas,ix}, a_{meas,iy}, a_{meas,iz}\) are the \(i\)-th original acceleration data in x, y and z directions collected by the mobile phone in the evaluation unit; \(a_{meas}\) are respectively the average values of the original acceleration data in x, y and z directions in the detection unit.

The average of the resultant vibration acceleration results at each moment in the evaluation unit was taken as the driving vibration index \(a_{vib}\) of the evaluation unit, and the average of the speed data at
each moment in the evaluation unit was taken as the driving speed index $v$, with the unit of speed being km/h. Then the statistical method was used to establish the relationship model between the two indexes and IRI.

3. Result and Analysis
According to the original data and the processing methods in 2.2, the pavement roughness index $IRI$, the driving speed index $v$ and the driving vibration index $a_{vib}$ within each evaluation unit would be calculated respectively at the evaluation unit length is 100 m, 500 m and 1000 m. Firstly, correlation analysis was carried out on the influencing factors of driving vibration index, and the results were shown in table 1. From the perspective of correlation coefficient and significance, $a_{vib}$ has a linear correlation with $IRI$ and $v$, that is to say, the vibration index value was affected by both the pavement roughness and the driving speed. Therefore, driving speed is a key factor that must be considered when building the relationship model between driving vibration data and road roughness.

| Vibration indicator | Detection unit length(m) | Correlation results | Speed indicator: $v$ |
|---------------------|-------------------------|---------------------|---------------------|
|                     |                         | Roughness index: $IRI$ | Speed indicator: $v$ |
|                     |                         | Sample size: 540 | Sample size: 540 |
|                     |                         | Coefficient of association: 0.711 | Coefficient of association: 0.505 |
|                     |                         | Significance: $10^{-6}$ | Significance: $10^{-6}$ |
|                     |                         | Sample size: 108 | Sample size: 108 |
| $a_{vib}$           | 100                     | Coefficient of association: 0.773 | Coefficient of association: 0.605 |
|                     |                         | Significance: $10^{-6}$ | Significance: $10^{-6}$ |
|                     |                         | Sample size: 54 | Sample size: 54 |
|                     | 500                     | Coefficient of association: 0.781 | Coefficient of association: 0.616 |
|                     |                         | Significance: $10^{-6}$ | Significance: $10^{-6}$ |
|                     | 1000                    |                         |                      |

In this paper, the method of multiple linear fitting was adopted to obtain the relationship between pavement roughness and driving data indicators under different evaluating unit lengths, as shown in table 2. It can be seen that with increased of the unit length, the determination coefficient ($R^2$) of fitting relationship also increased. When the length of the evaluation unit was 1000 m, the $R^2$ reaches 0.876.

| Detection unit length(m) | The fitting relationship |
|--------------------------|--------------------------|
| 100                      | $IRI = 3.619a_{vib} - 0.043v + 2.141$ | $R^2 = 0.679$ |
| 500                      | $IRI = 4.535a_{vib} - 0.055v + 1.979$ | $R^2 = 0.852$ |
| 1000                     | $IRI = 4.741a_{vib} - 0.058v + 2.041$ | $R^2 = 0.876$ |

The data of driving vibration acceleration, speed data, GPS position information was collected continuously, so there was a certain error in the matching between the collected data and the pavement roughness data (as mentioned above), and the accurate correspondence could not be realized at present. In addition, the GPS data in this paper was civilian GPS, and the accuracy could not reach point-to-point correspondence. Third, the collected data needs to be uploaded to the server, so there is a certain lag time in this process. For the above reasons, the smaller the length of the evaluation unit is, the greater the matching error of the collected data and the flatness data will be. By increasing the length
of the evaluation unit, the matching error could be reduced. That is to say, the average of a larger range will reduce the error of single data.

The above analysis shows that increasing the length of the evaluation unit can improve the accuracy of the evaluation model, but if the length of the evaluation unit is too large, the evaluation model will lose its practical significance and cannot achieve the more accurate monitoring target of the pavement roughness. Therefore, determining the reasonable length of the evaluating unit is an important technical content to realize the intelligent monitoring of pavement roughness.

The relational model of evaluating unit with a length of 1000 m was experimentally verified in the following. Two asphalt pavement (Zhongwuqu Road and Longyin Road) were selected in Beijing, which had a length of 20 km and 11 km respectively. The multi-function test vehicle was used to detect the pavement roughness, and it was found that the previous road roughness value was larger and the road condition was worse, while the latter road roughness value was smaller and the road condition was better. The driving experiment was carried out according to the method in the above. The vibration acceleration, GPS position and time information were collected by smart phone APP and the driving data indexes were calculated according to the method in this paper. The calculated IRI value by using the relationship model with the evaluating unit length of 1000 m were compared with the measured IRI value coming from the multi-function test vehicle, as shown in figure 5 and figure 6. It can be seen that the change trend of the two was highly consistent. Summarized the data in figure 5 and figure 6, and the result was taken as figure 7. The data from the verification experiment also showed that the calculated results of the evaluation model obtained in this paper when the evaluating unit is 1000 m had a high correlation with the measured results of pavement roughness, and R square reached 0.8857, which was basically consistent with the accuracy of the fixed-point driving experiment ($R^2$=0.876), or even slightly higher, indicating that the evaluation method proposed in this paper had a good applicability.

![Figure 5](image_url) **Figure 5.** Comparison of calculated IRI value and detected value under complex road conditions (Zhongwuqu Road).

![Figure 6](image_url) **Figure 6.** Comparison of calculated IRI value and detected value under good road conditions (Longyin Road).

![Figure 7](image_url) **Figure 7.** The calculated IRI value and test value of the verify section.

4. Conclusions

Based on the purpose of intelligent evaluation of road roughness, this paper discusses the influence of the length of evaluation unit on the accuracy of evaluation, and the main conclusions are as follows:
(1) The driving vibration index was correlated with the smoothness index IRI and the speed \( v \). When using the driving vibration data to evaluate the road surface roughness, the dual influences of the road surface roughness and the driving speed should be considered. (2) The length of the evaluation unit had a great influence on the accuracy of the pavement roughness evaluation model based on driving vibration index and driving speed. Within the scope of the experiment in this paper, the greater the length of the evaluation unit is, the higher the accuracy will be. This may be more related to the spatio-temporal matching error between driving data and pavement roughness. (3) The verification experiment of ordinary asphalt pavement showed that the evaluation model proposed in this paper had good stability and maybe have a possibility of further application.

The study in this paper preliminarily proves the influence of evaluating unit length, but the mechanism of the influence needs to be explained by more extensive experiments. At the same time, how to improve the accuracy of evaluation results when the length of evaluation unit is small, so as to make the model more practical is also the content that should be studied in the future.

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