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Laser-based measuring method for mean joint faulting value of concrete pavement

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ABSTRACT

To realize the critical assessment of concrete joint faulting, a laser-based 3D detection system (Laser-based Joint Faulting Meter, LJFM) was designed and a calculation method was proposed. The 3D information of joint faulting was obtained based on laser triangulation method. Automatic threshold determination method and mean joint faulting value calculation method were proposed based on the double peak characteristic of joint faulting 3D height histogram. To verify the precision and accuracy of the LJFM, indoor and field experiments were designed and conducted. Repeated experiments of simulated joint faulting in indoor experiment show that measurement results of the LJFM has lower coefficients of variation, better reproducibility and higher stability than that of the Level. In indoor and field experiments of different joint faulting, the coefficient of determination between the LJFM and the Level are 0.944 and 0.958 separately while the correlation coefficients between them are 0.9761and 0.979 (both significant at $p < 0.05$ level), respectively, indicating the good repeatability of the LJFM and the high correlation of the two methods. Experimental results indicate that measuring mean joint faulting value using LJFM has high stability and accuracy.

1. Introduction

With higher strength, better stability, longer service life and lower maintenance cost compared with other kinds of roads, concrete pavement has achieved rapid development. However, due to series of technical problems in the process of design, construction, maintenance, long-term wear, and impact of traffic loading [1,2] as well as erosion and destruction of natural factor [3], different kinds of concrete pavement distresses arise regularly which decreases the usability performance and service quality of the road obviously. Joint faulting [4] is an important influence factor for road service life and damage assessment of detection section [5]. Therefore, the study of mean faulting value detection method for cement concrete pavement has significant importance.

Many research institutions have carried out related study. Methods used currently can be divided into two groups: manual and automatic detection method. Manual detection method includes the Georgia electronic fault meter [6], mechanical dislocation meter and AASHTO method [7]. With slow speed, obvious interference on traffic and limitation of sampling point data [8], manual detection cannot get accurate joint faulting value. So it cannot help to grade and evaluate the damage degree of road.

Automatic detection methods are studied as well. In 2000, The United States LTPP (The Long-Term Pavement Performance) revealed the close link between average joint faulting value and IRI [9]; in 2011, Yang et al. studied the recognition of cement concrete pavement joint and calculation of its width and height [10]. But the method they proposed only meets the precision requirement in laboratory under ideal conditions without considering joint faulting on actual pavement. In 2011, location of joint and calculation of joint faulting value using binocular camera was realized by Ying et al. [11]. But the mathematical basis of this method determined that it cannot eliminate the influence of inconsistency and diversity of cement concrete pavement, as well as other natural environment factors. What's worse, great distortion of joint faulting value will appear when the cement panel deforms or leans. In 2011, the relationship between local pavement roughness and joint faulting value was studied [12,13]. However, it requires primarily

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research data of pavement which cannot be guaranteed and filtering methods it adopted may lead to the ignorance of joint faulting. In 2012, a feed-forward, multilayered, reverse conduction neural network model to research the prediction of joint faulting value was developed [14]. But widely distributed and large amounts of early detection data was needed to establish prediction model which is almost impossible. So this method is difficult to achieve in practice although it has some value in theory.

With the rapid development of laser technology, a number of states have adopted inertial high speed profiler to collect the profile data [15]. Tsai et al. assessed a method to collect faulting effectively using 3D continuous profile data which was originally designed for detecting pavement cracks. He also proposed that a signal-processing algorithm can be developed to calculate the faulting automatically [8]. Wang proposed a heuristic algorithm to distinguish joints from identified spikes which may include grooves and cracks as well as joints. Joint value was obtained in compliance with the revised AASHO R36-04 which means that specific algorithm to calculate joint value automatically wasn't developed yet [2].

From the analysis above, methods that can realize automatic detection of joint faulting value of cement concrete pavement accurately doesn't exist yet. So it is necessary to study automatic detection of joint faulting value with high accuracy and good practical performance. Laser-base Joint Faulting Meter (LJFM) was accomplished in this paper which realized the 3D detection of joint faulting value.

2. Joint faulting 3D data preparation

2.1. 3D data acquisition

The LJFM comprises of linear laser source, CCD camera, encoder, industrial computer, uninterruptable power supply, and the vehicle that carries all the equipment. The beam mode of the laser used in the system is line-focused laser. The laser line width is adjustable and can reach up to 1 mm. The fan angle is 60°and the laser wavelength is 808 nm.

3D pavement data is obtained automatically based on the laser pulse reflection principle and laser triangulation method. During data acquisition, the linear laser emits a laser onto the road to form a fringe contour which is captured by the CCD camera array, so as to acquire the height information of the road which is the data source used by the overall system. Its resolution is 0.5 mm both in the vertical and transverse direction. The 3D pavement data collected using LJFM is stored in computer in the form of dat files. Each dat file comprises of 1000 lines and 1536 columns which can be adjusted in the system and can represent an integrated joint faulting. The LJFM is stationary over a joint and one data file was obtained for that joint for now and further work will be done to make it a mobile method under the premise of maintaining its detection accuracy in future. The corresponding software was implemented as well.

2.2. De-noising the collected 3D data

There are some points with high values or zero values for several reasons. For example, exposed stones on the pavement will lead to random specular reflection or tiny crack where laser light cannot reach are likely to result in noise. These invalid data needs to be dealt with before calculating joint faulting value. After lots of tests, a combination of biphasic standard deviation filtering method with cascade morphological filtering algorithm was proposed by our research group [16]. It can eliminate the meaningless data and keep useful 3D data details meanwhile.

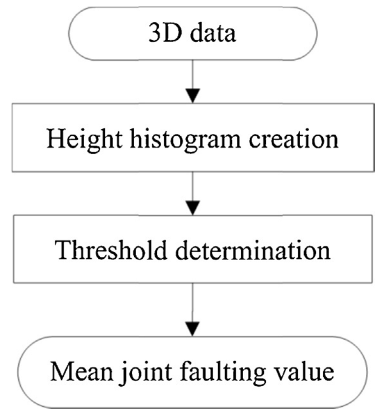

Fig. 1. Flow chart of mean joint faulting value calculation.

Filter the collected 3D data matrix $M_{m\times n}$. $M_{m\times n}$ is a matrix of m rows and n columns where M_{ij} is the data in i row, j column. The filtered matrix is denoted as $M'_{m\times n}$.

3. Mean joint faulting value calculation

Obvious height difference exists among the two slabs which make up the joint faulting, so 3D height data of road was regarded as grey value to create the double peak histogram of joint faulting. Calculation method of mean joint faulting value based on height histogram was proposed. The main flow chart is shown in Fig. 1.

3.1. Threshold determination

According to the height histogram, the next step is to determine its threshold. The specific steps are as follows:

(1) Get average value of the data Matrix $O_{m\times n}$, the minimum value and standard deviation of the data Matrix, denoted by avg, max, min, and sd, respectively.

$$\text{avg} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} O_{ij}}{m\times n} \tag{1}$$

$$\text{sd} = \sqrt{\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(O_{ij}-\text{avg}\right)^2}{m\times n-1}} \tag{2}$$

(2) On the abscissa, take avg as the demarcation point and find out the maximum ordinate $f_{(\text{value})}$, respectively, on the left and right sides. Denote their corresponding abscissa as val_1 and val_2.
(3) If the distance between two peaks is too close, it means that one of the valid peak is too low to be found and needs further search; Otherwise, let $\text{val}_{p1} = \text{val}_1$, $\text{val}_{p2} = \text{val}_2$ (if val_{p2} has been assigned a value, keep the original one) and jump to step 7.
(4) Compare $f_{(\text{val}_1)}$ and $f_{(\text{val}_2)}$. If $f_{(\text{val}_1)} > f_{(\text{val}_2)}$, then val_1 is a valid peak value and let $\text{val}_{P1} = \text{val}_1$ otherwise $\text{val}_{P1} = \text{val}_2$.
(5) Find out the median value of $f_{(\text{value})}$ and denote its corresponding abscissa as val_{mid};
(6) If $\text{val}_{\text{mid}} > \text{avg}$, it means the lower peak is on the left side(3D data of lower panel is fewer), otherwise, the lower peak is on the right side(3D data of higher panel is fewer). Adjust the demarcation point.
(7) Take the midpoint of the two peak position as the threshold which is expressed as:

$$\text{th} = \frac{\text{val}_{p1} + \text{val}_{p2}}{2} \tag{3}$$