



A PORTABLE NON-CONTACT ROAD TEXTURE DETECTION METHOD BASED ON PHOTOGRAMMETRY

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KeyWords

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ABSTRACT

The anti-skid performance of highway pavement is not only related to driving comfort, but also directly affects the safety of high-speed driving. Road anti-skid performance is directly related to pavement texture topography. Collection and analysis of pavement texture data can effectively predict road anti-skid performance. At present, conventional manual Sand Patch Test (SPT) method has low measurement efficiency and uncontrollable texture information loss. The non-contact road texture detection equipment based on the principle of laser triangulation has been gradually applied in the field of road detection in recent years due to its advantages of fast reading and high precision. Unfortunately, most of these equipment are expensive to acquire and maintain. Hence, this paper proposes a road texture detection method based on photogrammetric three-dimensional reconstruction technology. The method uses a conventional camera device to take photos of the detection area, and the 3D model is reconstructed through the open source algorithm Openmvg. Finally, the mathematical modeling software based on Matlab is used for calculation and analysis. Compared with laser triangulation modeling and handheld 3D imaging modeling methods, the results show that among the three non-contact detection methods, laser triangulation detection has the highest detection accuracy. The photogrammetric detection method is better than the handheld 3D imaging, and the correlation coefficient between the Mean Texture Depth (MTD) value based on photogrammetric detection and the manual Sand Patch Test method reaches 0.9083, which can effectively predict the anti-skid performance of the road surface.

1. INTRODUCTION

According to a report from the Ministry of Transport of The Peoples Republic of China, "During the 14th Five-Year Plan period, China's expressway development will gradually shift from a period of large-scale concentrated construction to a period of network optimization and improvement that is significantly slower and more focused" [1]. At present, highway traffic accidents occur frequently. The main reason is the insufficient anti-skid performance of asphalt pavement [2]. The good surface texture of the pavement ensures the comfort and safety of driving. Therefore, in road construction and Detection of pavement surface texture during the entire life cycle of operation and maintenance is of great significance to evaluate pavement skid resistance.

At present, pavement texture measurement within China and abroad mainly includes contact and non-contact measurement [3]. Contact measurement is usually manual measurement, which is cumbersome and inefficient. This method usually includes manual Sand Patch Test method and pendulum friction. Through Coefficient method and continuous trailer friction coefficient tester method, parameters such as MTD (Mean Texture Depth) and friction coefficient can be obtained to reflect the road texture. However, the experiment is affected by human subjective factors and is inefficient during the test. It has a certain impact on traffic flow and driving safety. In addition, contact measurement cannot obtain macro- and meso-texture digital information, and cannot provide detailed data for subsequent macro- and meso-uniformity spectrum analysis [4, 5].

Based on the shortcomings of the above contact methods, a large number of domestic and foreign scholars have devoted themselves to non-contact measurement methods. Non-contact measurement mainly includes industrial Computer Tomography (CT) scanning, laser triangulation, handheld 3D scanning measurement, among others, and close-range photogrammetry. [6, 7] Among them, the first three methods need expensive testing equipment. Close-range photogrammetry is favored by researchers for its cheap and efficient testing characteristics. Photogrammetry 3D reconstruction technology can provide accurate 3D models for buildings, roads, bridges, et cetera. It provides an important reference basis for the design, construction, and maintenance of objects in rivers, lakes and other environments [8]. It is an image-based 3D reconstruction technology that takes photos from multiple perspectives and uses computer vision technology to reconstruct multiple objects. Three-dimensional reconstruction is performed on the photos from different viewing angles to obtain a 3D model of the object [9].

Therefore, this article combines the current research progress of photogrammetric 3D reconstruction and proposes a photogrammetric based road texture reconstruction and model processing method based on the open source OpenMVG algorithm, in order to provide a methodological basis for intelligent road texture detection.

2. EXPERIMENTAL DATA ACQUISITION

2.1 Test site selection

In order to highlight and compare the test effects of three non-contact 3D reconstruction instruments for pavement texture, this experiment selected a variety of test pavement as test sites. Compared with cement pavement, asphalt pavements have more pits on the surface and are rougher. These pits in asphalt pavement maybe filled with water, gravel and other debris. In order to verify the accuracy of the three test methods compared with the manual sand laying method, and at the same time take into account individual variability, we selected different road sections, different road construction years, and different degrees of aging. The road surface was used as a test site, and three common and typical road surfaces were selected, as shown in Fig. 1 below. There are 10 test sites each for permeable sidewalks, cement pavements, and asphalt pavements.



(a) Permeable concrete pavement



(b) asphalt pavement



(c) cement pavement

Fig. 1 Test site of three different pavement

2.2 Acquisition of 3D pavement surface model based on 3D laser texture instrument

In this research, LS-40 scanner was used to collect pavement surface texture data. The device is shown in Fig. 2. The LS-40 uses 3D laser triangulation imaging technology to collect and process 2D and 3D images while Fig. 3 shows the schematic diagram. The built-in motor stage moves a very fine laser beam on the target surface or object, while the high-resolution camera takes the laser beam picture from a certain angle, and finally forms a 3D model [10]. The LS-40 scans with a longitudinal and lateral resolution of 0.01 mm and 0.05 mm respectively, and a scanning range of 102mm×115mm. As a result, the device can obtain high-resolution 3D surface images to analyze macro- and micro-texture characteristics of the pavement.

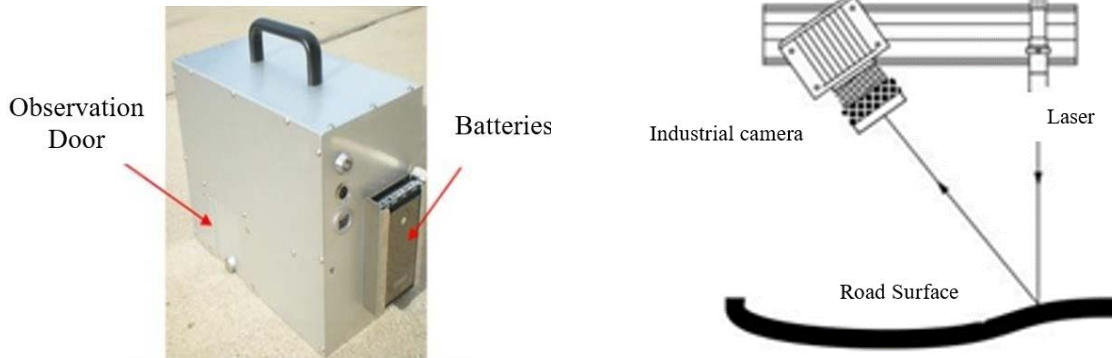


Fig. 2 LS-40 Laser 3D surface scanner Fig. 3 Direct laser triangulation principle diagram

The LS-40 computer operating software was used to scan the model. Due to the existence of pavement noise such as pavement material reflection, the ideal 3D model could be obtained by using the "filloutliers" function in Matlab software to remove the outlier points and then using the Gaussian filter function. Fig. 4 shows the 3D topography of two permeable concrete pavement.

(a) Pervious concrete pavement 1

(b) pervious concrete pavement 2

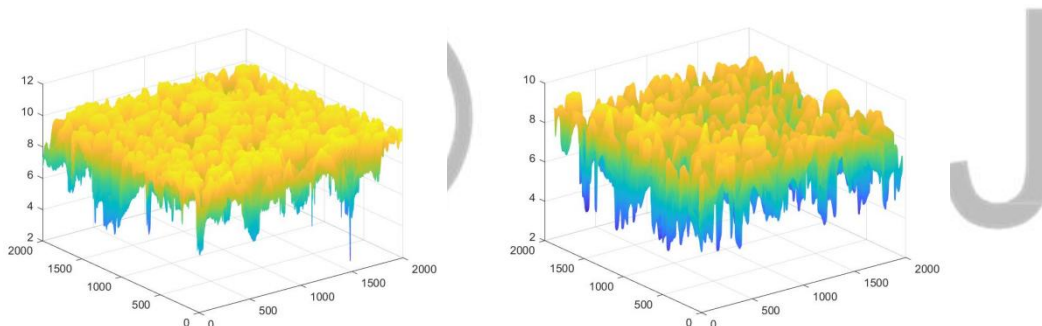


Fig. 4 Road model obtained by 3D laser texturing instrument

2.3 3D Road Model Acquisition Based On Handheld 3D Scanner

In this research, iReal 2S, a handheld scanner by SCANTECH was used. As shown in Figure 5, this color three-dimensional surface scanner can scan without sticking points and can obtain high-definition and delicate color textures.



Fig. 5 Handheld scanner iReal 2S

The iReal 2S has advanced texture aligning and geometric feature aligning algorithms. It scans objects without continuous or irre-

gular textures or geometric features, iReal 2S combines texture/geometric/markers alignments with few markers to finish it. When encountering items with complex features, using hybrid aligning, only requires a few marking points to complete the scan. The detailed parameters of iReal 2S are shown in Table 1.

Table 1 Detailed parameters of iReal 2S handheld scanner

Model number	iReal 2S	
Type of Light Source	Blue Light	Infrared Light
Point Distance	0.2 ~ 3 mm	0.5 ~ 3 mm
Point Distance (single frame)	Up to 0.1mm	Up to 0.15mm
Alignment accuracy (For markers)	Up to 0.2 mm/m	Up to 0.25 mm/m

Object scanning can be carried out after the initial use of the equipment has been calibrated. The basic scanning process of this experiment is shown in Figure 6. Basically the process followed the following steps: (i) align the scanner with the site to be tested, and follow the software prompts to move the scanner to the appropriate height and angle. (ii) After the scanning is completed, the software processing step is entered. (iii) After point cloud processing, encapsulation, and saving operations, the three-dimensional model to be measured can be obtained for subsequent calculation and processing.

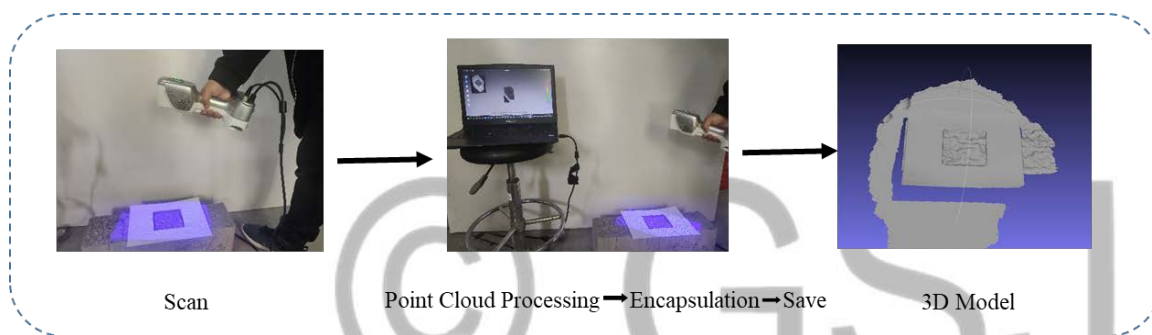


Fig. 6 Scanning flow chart

2.4 3D Pavement model acquisition based on close-range photogrammetry

Before establishing the 3D model of the road surface, it is necessary to complete the acquisition of 2D road surface photos. Close-range photogrammetry only needs to take multi-angle photos of the road surface to complete the 3D model reconstruction. When taking two-dimensional photos, about 15 photos should be taken in a circle around the shooting point, and 60% overlap between adjacent photos should be guaranteed to ensure better robustness of the model. In order to increase the local texture details of the 3D road model, after the overall photo is taken, local features such as surface pits should be taken at close-range to enrich the overall texture details of the model [11, 12]. The shooting equipment in this research was Xiaomi 11 smart phone, and the shooting parameters of the mobile phone are shown in Table 2

Table 2 Device parameters table

Categories	Parameters	
Phone camera parameters	Aperture value	F / 1.8
	Exposure time	1/601 second
	ISO speed	ISO-112
	Focus Distance	5mm
	Resolution	8000 ×6000

Multi-view 3D reconstruction refers to inferring the shape and structure of 3D objects through 2D images from multiple different views. This is often achieved through computer vision techniques such as stereo matching and triangulation. First, multiple images are calibrated to determine their relative positions. Then, the algorithm uses disparity information (that is, the difference in the position of the same object in the image from different viewing angles) to infer the depth information of the object in the three-dimensional space and the position of the shooting camera. The camera position estimation formula is shown in Equation 1. Finally, this information can be used to reconstruct the shape of the 3D object using 3D space modeling techniques such as triangulation.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & \alpha & u_x \\ 0 & f_y & v_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = K[R|t] \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (1)$$

Where: K -- camera internal parameter matrix;
[R|t] -- 3×4 matrix, called camera attitude;

After obtaining the two-dimensional photos of the road surface, the 3D reconstruction operation is carried out through the open source software OpenMvg, the operation steps are as follows: Based on Scale-invariant feature transform (SIFT), image feature descriptor extraction and matching, camera posture estimation, sparse point cloud reconstruction, dense point cloud reconstruction, point cloud grid modeling and road texture mapping are six steps. Its visualization process is shown in FIG. 7.

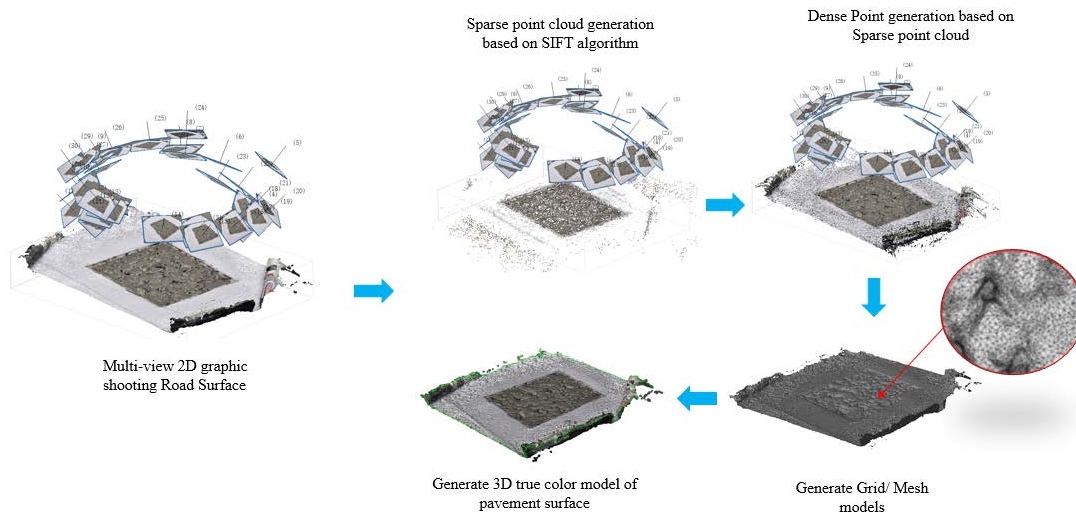


Fig. 7 3D reconstruction flow chart of road surface based on photogrammetry

3. 3D MODEL PROCESSING

After the completion of the 3D reconstruction of the surface texture topography of the test site, the 3D model processing software DesignX and MeshLab were used to further process the 3D model of the reverse-reconstructed surface texture. The main processing contents included: Adjusting the scale of the texture model, flattening the plane of the texture model, and correcting the hole filling[13]. The visualization flow chart is shown in Figure 8.

(1) Scale restoration: By comparing the distance between the marked points on the model in advance and the marked points on the 3D model, the actual scale factor of the 3D model was obtained. Then entered the scaling multiple in DesignX to complete the model scaling, and finally got the 3D model consistent with the actual road surface scale after the operation was completed.

(2) Model leveling: In the DesignX software, we found the horizontal plane on the model as a reference, as shown in Figure 8. In the 3D model, multiple points on the paper were used as reference points to establish a reference horizontal plane, and the reference plane was used to correct the world axis of the moving model to complete the coordinate axis leveling operation.

(3) Smoothing and model cutting: In the MeshLab software, the "Gaussian smoothing" function was used to reduce the noise of the model, and the outside impurity points of the model were deleted by switching the three-view display, and the three-dimensional model of the measured points was finally obtained for subsequent calculation.

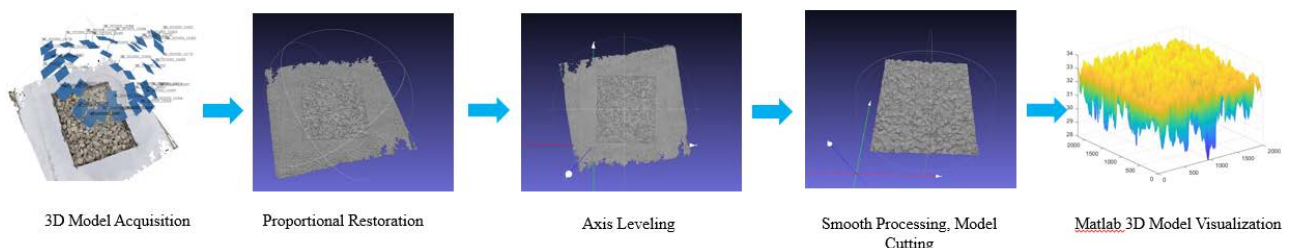


Fig. 8 3D model processing flow chart

4. CALCULATE COMPARATIVE ANALYSIS

The mean structural depth (MTD) is generally tested using the sand spreading method and is a widely used pavement anti-skid evaluation index in current specifications. It is defined as the ratio of the known test sand volume to the area covered by the paving. The calculation formula of the average structural depth value MTD value is:

$$V = \iint_D [F_0 - F(x, y)] dx dy \tag{2}$$

$$MTD = \frac{V}{A} \tag{3}$$

Where: F_0 -- the spatial plane covering the road surface;
 $F(x, y)$ --the area formed by the pavement elevation points;
 D --integration area;
 V --the volume enclosed between the road surface and plane F_0 , mm^3 ;
 A --is the area of area D , mm^2 .

In order to compare the non-contact measurement data with the sand spreading method, the sand spreading method was simulated in Matlab software as follows: by setting a highest plane Z (the green plane in FIG. 9 is the set plane Z) and the volume formed between the plane Z and the pavement texture is the volume V in equation (3). The area A is calculated by the "polyarea" function in Matlab, and the volume V and area A are substituted into formula (3) to finally solve the MTD value of the average construction depth.

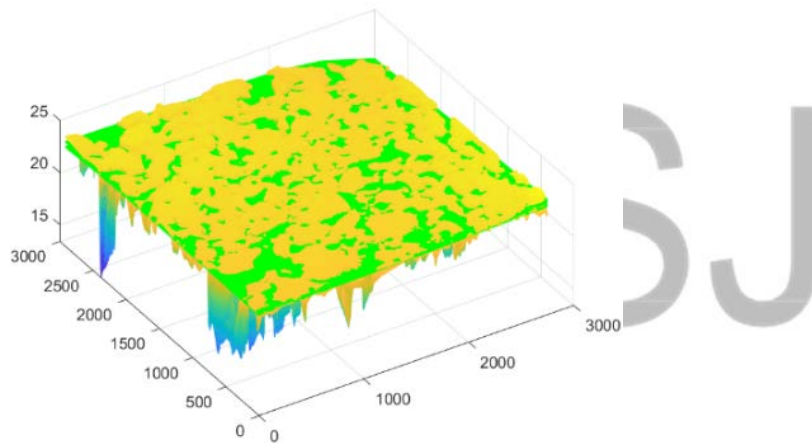


Fig. 9 3D simulation solution diagram

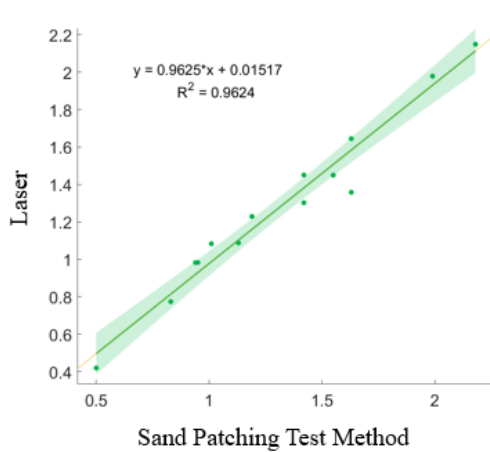
Through the above three methods, the three-dimensional modeling technology was applied to obtain the three-dimensional coordinate information of the road surface, the algorithm was written by MATLAB software to realize the three-dimensional space visualization of the road surface model, and the program was written by MATLAB to calculate MTD, and the MTD index of the macro structure depth of the road surface was extracted and calculated from the three-dimensional road surface model. The calculation results are shown in Table 3

Table 3 Comparison of calculation results

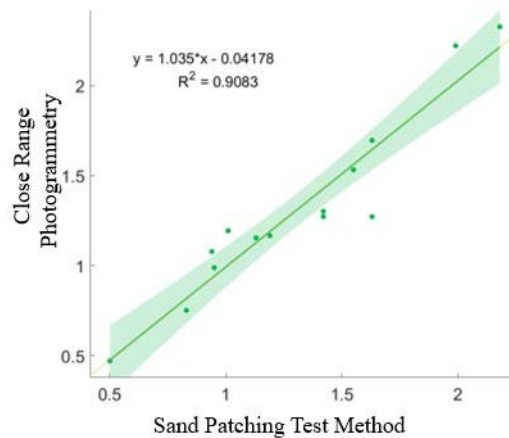
Base of sand Patching method	Laser triangulation Reconstruction		Photogrammetric Reconstruction		Scanner Reconstruction	
	Simulated calculated values	Relative error	Simulated calculated values	Relative error	Simulated calculated values	Relative error
0.50	0.41	16.81%	0.47	5.39%	53.94%	8.14%
0.83	0.77	7.11%	0.75	9.39%	62.80%	24.23%
0.94	0.98	4.87%	1.08	14.85%	108.50%	15.78%
0.95	0.98	3.86%	0.99	4.00%	71.03%	25.07%

1.01	1.08	7.36%	1.19	17.99%	117.13%	16.06%
1.13	1.09	3.44%	1.15	2.40%	113.16%	0.36%
1.19	1.23	3.28%	1.16	2.16%	119.79%	0.63%
1.42	1.45	2.44%	1.30	8.28%	121.56%	14.32%
1.42	1.30	8.09%	1.27	10.47%	146.64%	3.29%
1.55	1.45	6.24%	1.53	1.51%	123.10%	20.56%
1.63	1.36	16.62%	1.69	3.72%	122.69%	24.74%
1.63	1.65	1.26%	1.27	22.06%	150.11%	7.81%
1.99	1.98	0.24%	2.21	11.14%	182.52%	8.25%
2.18	2.16	1.07%	2.32	6.37%	203.39%	6.63%

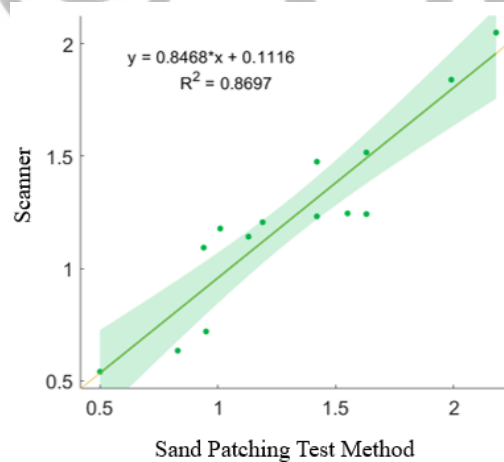
The sand patching test method and the test results of the other three methods were fitted and analyzed, and the analysis diagram is shown in Figure 10.



(a) Laser and Sand Patching test method



(b) close-range photogrammetry and sand Patching Test method



(c) Scanner and sand patching test method

Fig. 10 Comparison between three non-contact measurement methods and laying method

As can be seen from FIG. 11, compared with the measurement data of manual sand paving method, all three non-contact road texture measurement methods have a good correlation with the experimental results of sand paving method, and the correlation is greater than 0.75. Among them, the correlation between laser triangle three-dimensional modeling method and the three-dimensional road texture detection processing method based on photogrammetry proposed in this paper and the data of sand paving method is closer to 1. It shows that these two methods can be better used for intelligent pavement texture detection.

5. CONCLUSION

(1) Among the three non-contact road texture modeling methods, 3D laser texture instrument has the highest accuracy and can

be used for macro and micro texture extraction of roads, which is suitable for subsequent anti-slip and noise reduction analysis, followed by close-range photogrammetry, which is suitable for general macro texture analysis, and the worst effect is handheld 3D scanner, which is limited by its performance. Its three-dimensional model can obviously see the loss of microscopic texture details.

(2) In the comparison between the MTD values measured by the three non-contact methods and the on-site sand laying method, the correlation coefficients of the three-dimensional laser texture instrument test, the close-range photogrammetry test and the handheld scanner test compared with the manual sand laying method were 0.9624, 0.9083 and 0.8697, respectively, and the three methods had a good correlation with the sand laying method. Among them, the 3D laser method has the highest accuracy, and the close-range photogrammetry is superior to the hand-held 3D scanner.

(3) The road surface 3D model reconstruction method based on close-range photogrammetry proposed in this paper can be detected only by using common mobile phone camera functions. It is a cheap and reliable road surface texture detection method under the background that the road surface 3D texture detection equipment is imported and the price is high.

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