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Groove Depth Detection Method Base on the Line Laser Vision Measurement on Cement Concrete Pavement

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Groove Depth Detection Method Base on the Line Laser Vision Measurement on Cement Concrete Pavement

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Abstract. The groove depth has a decisive influence on the anti-sliding performance of cement concrete pavement, and it also plays an important role on the noise of cement concrete pavement. Aiming the shortcomings of traditional measurement methods of groove depth detection on the cement concrete pavement, a measurement method base on the structure light vision model was proposed. This method was realized by that the groove depth was obtained by 3D coordinate of the light strip according to the camera model and the structure light plane equation. A new algorithm based on double 2D plane target was proposed as the key step of this method.

1. Introduction

The groove on the cement concrete pavement is an important guarantee for the safety of it. The groove depth is the decisive element for the anti-sliding ability of the pavement. In addition, the groove depth has a great influence on traffic noise[1]. During the use of cement concrete pavement, the groove depth is continuously degraded due to the tire wear and the repeated freezing-thawing of the road surface[2]. Therefore, it is of practical significance to evaluate the anti-skid ability of the road by detecting the groove depth in the service life of the road, and it also provides a technical means for the study of noise reduction of the cement concrete pavement. At present, there were three types of methods for evaluating the anti-sliding ability of cement concrete pavements[3], the first type is fixed-point type, such as pendulum type friction instrument; the second type is continuous type, such as the British SCRIM slip test instrument; the third type uses the structural depth to indirectly reflect the anti-sliding ability, such as sanding method and the laser cross-section method, which was described in this paper. Compared with the laser cross-section method, this method has high sampling density, low cost, simple structure and can reduce detection of vehicle vibration on the detection results.

2. Detection System Theory

In this paper, the line laser was used to project the light strip to the surface of the road to form feature points. The feature points were extracted by the image obtained by CCD camera, and the three-dimensional information of the feature points was obtained according to the principle of triangulation, and then the groove depth was calculated. The system structure was shown in figure 1. After the line structure light called line laser was projected onto the road surface, due to the existence of the groove, the light strip was modulated by the groove of the road surface into two intermittent light bars. The distance between the two strips was determined by the groove depth. The position of the light bar on the road surface, and the geometric relationship between the groove depth and the CCD image of the light bar conformed to the principle of triangulation. And the image coordinates of



the light bar were obtained by digital image technology. The image coordinates of the light strip were obtained by digital image technology, and then three-dimensional coordinates of the road light strip were obtained by the camera model and plane equation with the light strip, and finally the groove depth was gained.

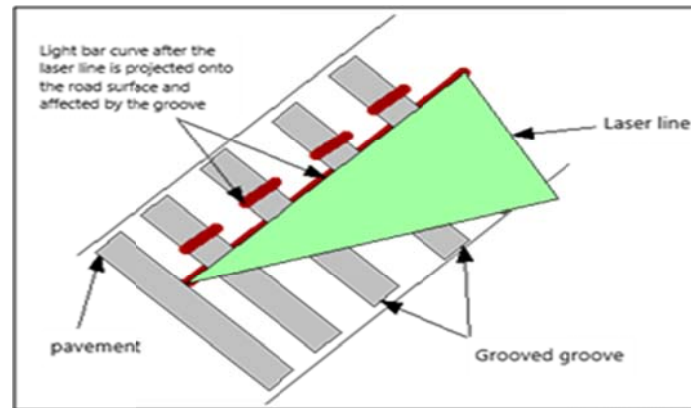


Figure 1. Structure light vision groove depth detection model

3. Camera Model

The position information of the structure light strip captured by the camera to form an image on the CCD sensor, and the spatial location relationship of the strip to the image was the camera model.

The world coordinate system consisted of " $X_w=[X_w, Y_w, Z_w]^T$ ". It was assumed that (u, v) was the image coordinate in pixels. The relationship between the coordinates of the "P" point represented by the world coordinate system and the image coordinates (u, v) of the imaging point "P" was the following formula[4].

$$s[u, v, 1]^T = M_1 M_2 X_w = M X_w \quad (1)$$

$$M_1 = \begin{bmatrix} a_x & 0 & u_0 & 0 \\ 0 & a_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad M_2 = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} \quad X_w = \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

Where "s" was the scale factor. M1 was only related to the internal structure of the camera, called the camera internal reference, determined by " a_x, a_y, u_0, v_0 ". M2 described the position of the camera, called the camera external parameter, determined by R, t. M was called the basic matrix of the camera and was determined at the camera calibration. (u_0, v_0) was the coordinates of the lens center projected in the (u, v) coordinate system. " a_x, a_y " were internal parameters related to the physical size and focal length of the camera. "R" was the rotation matrix of the camera in the world coordinate system. "t" was the translation matrix of the camera in the world coordinate system.

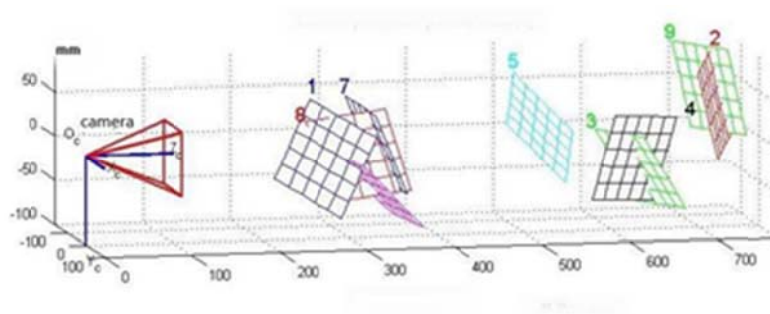
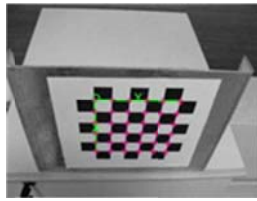


Figure 2. Relative position of the target

**Figure 3.** Target**Figure 4.** Views for calibration

The process of finding internal and external parameters was called camera calibration. In this paper, the camera calibration method based on plane checkpoints proposed by Zhang^[5] was used, in which planar square points with known coordinates called the target consisting of calibration points were used to solve the internal and external parameters of the camera from multiple viewing angles, and get the camera tangential distortion parameters for distortion correction. Calibration plate and camera position were shown in figure 2.

The 2D target board consisted of black and white squares of known size, printed by a laser printer. The intersection of two black squares was the calibration point, which can be automatically captured by the computer because of obvious geometric features. Camera position and angle were also very important, as shown in figure 2 and figure 3, the calibration shared 9 views, the black and white squares occupied most of the space of the image in four views closer to the camera. The other five views were farther from the camera, generally located near the working distance of the visual inspection system.

4. Structure Light Model and Calibration

The three-dimensional coordinates of the light bar can not be found by formula (1), and the equation of the plane with light bar must be added. It can be assumed that the structural light plane equation was formula (2):

$$AX_w + BY_w + CZ_w + D = 0 \quad (2)$$

The coefficients A, B, C and D were determined by the structure light plane calibration, and the structured light models were constructed by equations (1) and (2).

In structure light vision measurement, there were two types of calibration methods for system parameters. The first method was to calibrate the internal and external parameters of the camera. Then, a spot or a light bar on the stereo target were projected by the light beam or light plane of the laser to determine the spatial three-dimensional coordinates of the feature point. Finally, the optical plane equation of the laser was calibrated by the spatial three-dimensional coordinates of more than three feature points. Another method was to treat the camera and the laser as a whole, and the spatial three-dimensional coordinates and image coordinates of more than four feature points were directly used to obtain the transformation matrix between space coordinates and image coordinates as a parameter of the structure light vision system. In the second method, since the spatial three-dimensional coordinates of the feature points formed by the projected laser beam were difficult to obtain, such methods were less applied. The basic matrix M in the structure light model can be obtained by camera calibration in Chapter 2. Therefore, the calibration of the structure light vision system was mainly for the calibration of the structure light plane.

The optical plane calibration required at least three non-collinear three-dimensional coordinates of spatial points, so it was very difficult to obtain high-precision three-dimensional coordinates of the spatial points in the road laboratory. Therefore, two 2D checkerboard targets introduced in Section 2 was given to construct the coordinates of the three-dimensional space points required for the calibration of the structure light and light plane in this paper.

As shown in figure 5, a three-dimensional feature point calibration system consisted of two non-co-planar checkerboard grid targets A and B. The piece of light emitted by the line laser was projected on the target A to form a light strip LA. Similarly, a light strip LB was formed on the target B. A1, A2, A3, and A4 were four points on LA; B1, B2, B3, and B4 were four points on LB. These 8

points can be used to regress the light plane. How to calculate the three-dimensional coordinates of these 8 control points was the key to the calibration of the light plane.

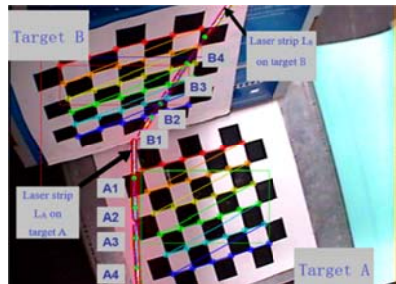


Figure 5. Structure light plane calibration system consisting of two planar targets

First the strip image was extracted in figure 5. The brighter strip image belonged to the part close to the white value in the gray image, but the checkerboard targets paper in figure 5 also has white, so it was recommended to use the region-based image segmentation method. The segmentation effect was shown in figure 6. According to the segmentation effect, the light bar was thicker and needed to be refined by methods such as corrosion, expansion, Hilditch, Deutch, mode refinement and morphological refinement, respectively. And then the Hough transform detection was performed on the refined image separately. It was found that the simple expansion and corrosion did not fit the light bar curve very well. After Hilditch, Deutch, pattern refinement and morphological refinement to use the Hough transform detect the angle of the light bar, it was found that the results of the four algorithms were not very different, and the fitting results were basically similar. Considering the complexity of the algorithm, morphological refinement was used to perform Hough transform. The image obtained by this method was shown in the figure 7 and figure 8.



Figure 6. Binarized target strip



Figure 7. Strip refinement

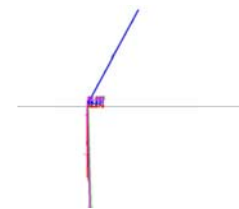


Figure 8. Strip Hough transform

Since the structure light strip control points (A1~A4 and B1~B4) were on the respective target planes., it was assumed that the first calibration point in the upper left corner of the target was the origin of the world coordinate system, and the three-dimensional coordinates and image coordinates of the control point satisfied the formula (3).

$$s \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} a_x & 0 & u_0 & 0 \\ 0 & a_y & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ 0 \\ 1 \end{bmatrix} \quad (3)$$

From the above formula, X_w , Y_w and “s” can be solved. It was assumed that the first calibration point of the upper left corner of the A target was the entire system origin, and the coordinate transformation formula of the four control points on the B target was the formula (4).

$$\begin{bmatrix} X_{wA} \\ Y_{wA} \\ Z_{wA} \end{bmatrix} = \mathbf{R}_A^{-1} \left(\mathbf{R}_B \begin{bmatrix} X_{wB} \\ Y_{wB} \\ 0 \end{bmatrix} + \mathbf{T}_B - \mathbf{T}_A \right) \quad (4)$$

In the formula, it was assumed that the first calibration point of the upper left corner of the B target is the origin of the world coordinate system, X_{wB} and Y_{wB} were the coordinates of the control points (B1 to B4) on the curve LB. X_{wA} , Y_{wA} and Z_{wA} were the coordinates of the control points B1 to B4, if the first calibration point of the upper left corner of the A target was the origin of the world coordinate system. R_A and T_A were the rotation matrix and translation matrix of the A target plane and the camera's optical center. R_B and T_B were the same. R_A , T_A , R_B and T_B were respectively calibrated by targets A and B by using the camera calibration method based on plane checkpoint proposed by Zhang Zhengyou[5].

Finally the three-dimensional coordinates of the control points of the structured light strips on the two targets A and B were available obtained to determine the optical plane equation, and then the parameter calibration of the structure light vision system was completed. The calibration of the internal and external parameters of the structure light system was performed using the calibration method described above, and the results were listed in Tab.1. The image coordinates, three-dimensional coordinates and calibration results of the light plane control points were listed in Tab.2.

Table 1. Calibration results of internal and external parameters of structure light vision system

target	External parameter of camera						Internal parameter of camera					
	r_1	r_2	r_3	t_1	t_2	t_3	a_x	a_y	u_0	v_0	k_1	k_2
A	0.906	-0.184	-0.381									
	-0.266	0.453	-0.851	-122.77	-45.277	280.578						
	0.329	0.872	0.362									
	0.911	0.261	-0.319				858.7	939.65	434.53	258.66	-0.5229	0.3298
B	-0.245	0.965	0.089	-96.418	31.713	418.906						
	0.331	-0.003	0.944									

Table 2. Results of the structure light vision system

control point of light bar	Image coordination		Three-dimensional coordinates (z=0 plane coincides with A target, the first calibration point of the upper left corner is origin)			Calibration coordinates of structure light vision system		
	u	v	x	y	z	x	y	z
A1	259	224	22.9	-43.2	0.0	24.4	-44.5	12.2
A2	290	174	43.8	-62.0	0.0	46.0	-63.9	12.3
A3	321	124	65.4	-81.4	0.0	68.4	-83.9	12.4
A4	352	74	87.7	-101.4	0.0	91.5	-104.7	12.5
B1	226	365	0.0	18.5	109.9	-0.3	18.2	108.5
B2	227	391	0.0	35.5	150.3	-0.4	34.9	147.8
B3	231	470	0.1	105.3	316.4	-0.1	104.9	315.1
B4	233	522	0.2	178.5	490.6	-0.5	176.5	484.4

The formula of structure light plane was as follow: $z = 2.136x + 2.377y + 65.873$

The z-axis coordinates of each point of the A target after the structure light vision system calibration should be zero or close to zero. Because the paper used the A target plane as the $z=0$ plane, it was obvious that the z coordinates of the points selected by the light strip on the a target were all zero. But in Tab.2, they closed to "12". Analysis of the reason found that before and after converging light sources into a straight line by the line laser, the light was divergent and there would be a declination. The Z coordinate of the A target was not zero due to the algorithm used had a certain error. Considering that the error table only calculated the relative value of the coordinates on the strip, so it has little effect on the faulting of slab ends Detection.

5. Groove Depth Calculation Method

In the case of groove detection, obtained structured light image was preprocessed, binarized and refined to get the image coordinates of the center line of the strip. And then the three-dimensional world coordinates of any point on the strip can be obtained according to the image coordinates and formulas (1) and (2). The calibration, the $Z_w=0$ plane coincided with the road surface, so the coordinates of the Z_w axis represented the elevation of pavement structure at the light bar. The Z_w axis coordinate sequence was drawn independently for a curve similar to *l* in figure 9. Finally, the highest points Z_A , Z_B and the lowest points Z_C and Z_D of the two walls of the groove were respectively calculated to obtain the height difference h_1 and h_2 of the two walls, and the groove depth was the average values of h_1 and h_2 .

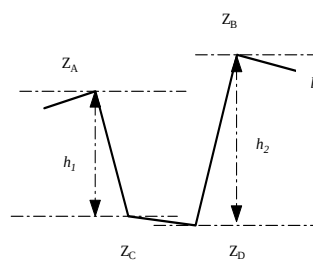


Figure 9. Schematic diagram of groove depth detection method

6. Conclusion

A groove depth detection method based on structure light vision was proposed. The method first obtained a strip image of the line structure light modulated by the cement concrete pavement. Then the principle of structured light vision and image processing technology was used to obtain the three-dimensional coordinates of the refined light strip were obtained. Finally, the groove depth was given by these coordinates.

Optical plane calibration in structure light vision systems was the key technology for system. A method for calibrating a light plane using two non-co-planar grid targets was proposed. In the method first extracted image of the light bar on the two targets by binarization, refinement and Hough transform provided two straight lines. Then the three-dimensional coordinates of any point on two straight lines were obtained from the spatial position relation of two targets, and finally the light plane was obtained by regressing no less than 3 non-collinear points on two straight lines.

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8. References

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