A Research of Pavement Potholes Detection Based on Three-Dimensional Projection Transformation

He Youquan
Information Science & Engineering Department
Chongqing Jiaotong University
Chongqing, China
hhh_1234567890@163.com

Wang Jian, Qiu Hanxing, ZhangWei, Xie Jianfang
Information Science & Engineering Department
Chongqing Jiaotong University
Chongqing, China
240482903@qq.com

***Abstract*—In order to detect the three-dimensional cross-section of pavement pothole more effectively, this paper proposes a method which employs optical imaging principle of three-dimensional projection transformation to obtain pictorial information of pothole's cross-section in pothole detection. Multiple digital image processing technologies, including: image preprocessing, binarization, thinning, three-dimensional reconstruction, error analysis and compensation are conducted in the series of image analysis and processing. Experimental results indicate that the method is markedly superior to traditional methods in many aspects. For its simple detection principle, low cost and high efficiency, the method suggests great practical and promoting value.**

Keywords-Three-dimensional projection transformation; pavement fault detection; digital image processing

I. INTRODUCTION

With the rapid development of economy, China's mileages of highway is increasing rapidly, which makes road maintenance more and more important. Now, how to detect effectively the real-time condition of pavement and raise the level of road maintenance become the most urgent issue and challenge[1].

Currently, there are some common pavement fault detection methods, like manual measurement, vehicle vibration sensors, laser technology, image and video detection. Although manual measurement is direct viewing with high accuracy, its low efficiency make it not suitable for large-scale and long range detection; The Vehicle vibration the sensor requires simple device and costs low, but its accuracy is poor, which makes it can only general reflect the non flatness of road; As for laser detection technology[2], it uses multiple high-performance laser sensors for road conditions acquisition, which makes it with high accuracy for data collection, but it's not quite fit to short-range detection, since large amount of data collection requires advanced hardware which cost too much. Concerning advantages and disadvantages of the methods mentioned above, this paper uses three-dimensional(3-D) projection transformation to acquire three-dimensional image of road cross-section. Then analyzes and processes the stereo imaging using digital image processing technology. After transformation between object side and image side coordinate system, it finally remodeling the three-dimensional cross-section of real potholes. Additionally, to get accurate width and depth of pothole, here we take binocular stereovision for error correction[3].

II. SYSTEM ARCHITECTURE AND RELATED PRINCIPLE

As shown in Figure 1: the system uses a LED linear light as an auxiliary light and makes it ray on road surface vertically. Then, it uses two CCD sensors, one at left and right another, to access pavement image.

Especially, their central axis should be set in 30 to 60 degree angle, not parallel with the light.

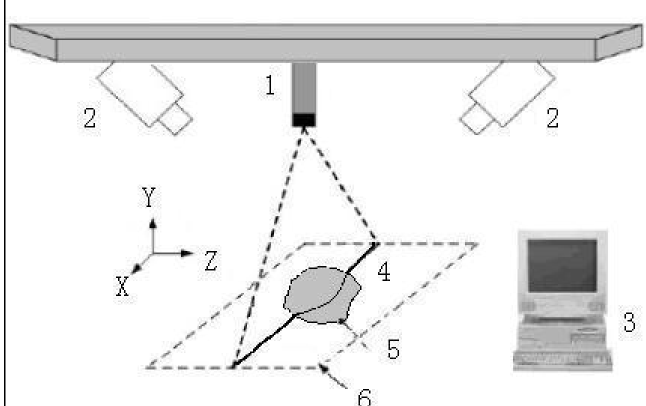

Figure 1. System architecture.

As we all know, LED line light could only form a very narrow light band when it rays on road surface. So, as shown in Figure 2, if we take no consideration of camera distortion, the imaging light from any angle should be a straight line when the road surface has no damage defects. But, if pit damage exists, luminous band's shape will change at the defect. That is to say, every point of light band would in different depth in the pothole. According to the principle of 3-D projection transformation, these different depth points would imaging a deformation slit of light, just like the luminous band shown in Figure 3. Therefore, we can calculate the actual coordinate value of each point through transformation between object side and image side coordinate system, and finally reconstruct the real cross-section accurately.

Figure 2. LED light band on smooth-riding surface.

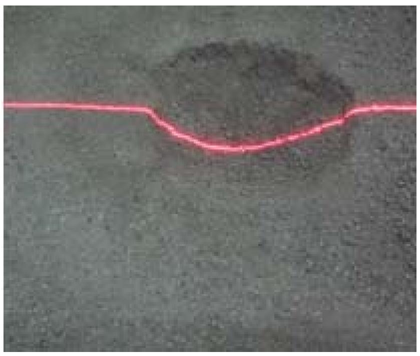

Figure 3. LED light band in pothole.

III. CALIBRATION OF SIGNALIZED POINTS

To determine the relationship between object side and image side coordinates, we must first determine the physical location of test section. In the test section using standard techniques set several standard samples, and measure the side of its object coordinates. Then get the standard set points in the coordinate system as the image side coordinates, and find out the relationship between object side and image side coordinates. To improve accuracy, the most common orientation was binocular stereovision, which uses two cameras to locate the position.

A. Set the standard samples in the object side coordinates

Choose a square with all sides for 100mm, respectively, four vertices (corresponding to A, C, D, E)as the center of a circle, 12mm radius for the circle, then place B 30mm away from A on the AC edge as the center of a circle, 12mm radius for the circle to set landmarks. In the object plane, by E for origin, the right direction for the X axis, Y-axis is vertical upward direction, a Cartesian coordinates is established. Five sings point side coordinates are A (0,100), B (30,100), C (100,100), E (0,0), D (100,0), as shown below.

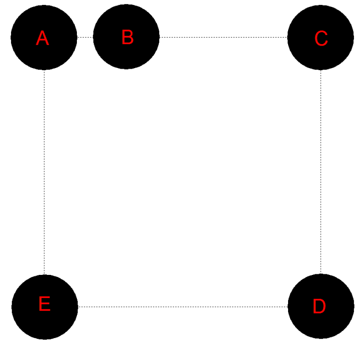

Figure 4. Landmarks under the object side coordinates.

B. image coordinates under the image side coordinate

The sample point photo getting from CCD sensors is shown in Figure 5.

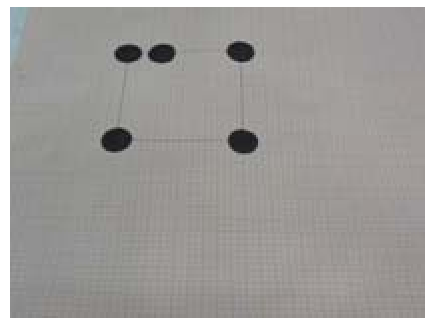

Figure 5. Sample point .

Before we get the sample point's image side coordinates, we should binarizate the image 5 first. The result is shown in Figure 6. After processing only black and white figures are left, white with a 0, and black with a 1. Due to the resolution of the images of 1024 * 768, figure 6 can be preserced as a 0-1 matrix with 1024-line and 768-list in a computer. Through the gravity method we can calculate the center of circle in the image side coordinates. The results of the five round circle coordinates are A(179.5,278.1), B(180.1, 382.1), C(175.1, 627.5), E(418.5, 305.8), D(417.9, 613.4). So far we get the image side coordinates of landmarks.

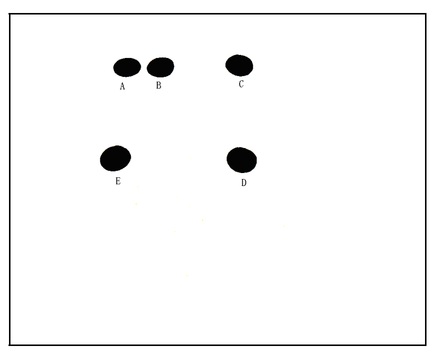

Figure 6. Sample point after binarizate.

C. Transform image side coordinates to object side coordinates

According to the center of the five circles in the object side and image side coordinates, use RAC two-step method combined with orthogonal least squares method to calculate the rotation matrix R and translation matrix T, thus we establish the camera and object plane relative position. Here R is the 3×3 rotation matrix. T is the 3×1 translation vector. R is the camera internal parameters. T is the object side relative to the orientation of the coordinate system, called the camera extrinsic parameters[4].

Without consideration of the factor of distortion and take lens model as an ideal imaging model, the object side and image side coordinate conversion formula 1[5] as follows:

$$\begin{cases} u = \dfrac{(r_1 x_0 + r_2 y_0 + t_x) f}{0.265(r_7 x_0 + r_8 y_0 + t_z)} + u_0 \\ v = \dfrac{(r_4 x_0 + r_5 y_0 + t_y) f}{0.265(r_7 x_0 + r_8 y_0 + t_z)} + v_0 \end{cases} \quad (1)$$

Through the formula 1, object side coordinates (x, y) and image side coordinates (u, v) can exactly corresponding . To improve the accuracy, we use two cameras maintained their relative position to capture the signs point and then get two photos. Orthogonal rotation matrix and translation matrix can be determined by each photo and the original image through the RAC two-step. Then we can get the relative position of the camera and landmarks.

IV. STEREO RECONSTRUCTION OF REAL CROSS-SECTION

After calibration, which means relationship between object side and image side coordinate system has been fixed , we can process the image of light band with computer. Steps are as follows:

- Denoise the image and segment the light band.
- color invert, expand, shrink to extract the center of light band.
- Extract image coordinates of light band, coordinate transform and stereo reconstruct the cross-section transformation.

A. Image Denoising

Since CCD image collection was affected by equipment, environment and any other factors, digital images would have kinds of noise points. So we should denoise the image before further process, for the purpose of obtaining better results in subsequent image processing and analysis processes. This paper introduces neighborhood averaging to filter and remove mutation pixels. In order to facilitate extraction of light band, the image need to be segmented. Considering the particularity of LED light, which leading to significant different gray level between pothole and flat road, we employ Otsu thresholding segmentation algorithm[6,7]. Following Figure7 is the processing results when threshold value is set as 100:

Figure 7. Filtered light band after thresholding.

After denoising and threshold segmentation, the background area is removed, and a clearer light band is shown up for further information obtainment.

B. Color invert, expansion and contraction

In order to obtain precise three-dimensional data, we should calculate side-play amount of light band center, as center position affects measurement result greatly. Here we extract the light band center via shrink and expansion processing. And after color inverting and expansion, light band merge with its surrounding background from near to far. If two cracks are close enough, they would be joined together by means of expansion[8,9]. Several times process later, we successfully remove isolated noise points and reduce faultage and hollow space. Finally, the thinned light band image entirely changed to a curve in single pixel width, just as shown in figure 8:

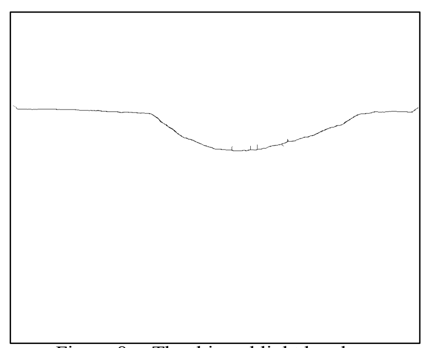

Figure 8. The thinned light band.

C. Extract image coordinates of light band, coordinate transform and stereo reconstruct the cross-section transformation

According to formula 1, we identified the corresponding relationship between object side and image side coordinate system. That's to say, we can work out the object side coordinates value of every image pixel when their image side coordinates value are given. The whole process is: input the thinned image into the processing system, obtain all the image side coordinates value about the light band, and then work out their corresponding object side coordinates value.

V. Experimental Results

In order to verify the accuracy of detection system, we compare the result of two methods, is shown in figure 9.

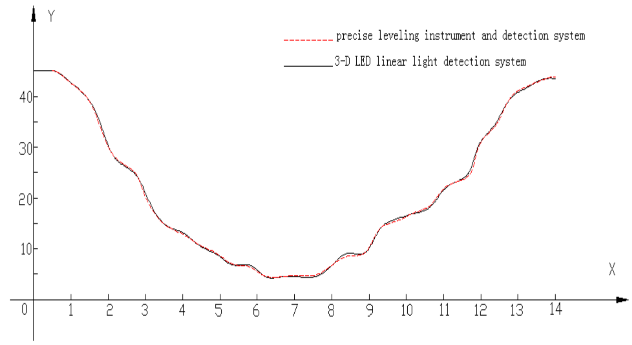

Figure 9. Reconstructed cross-section under precise leveling instrument and detection system.

As we can see from the graph, the maximum depth worked out by the system is 4.61288cm, only 2mm discrepancy with the measurement result of precise leveling instrument. It means that precision of out system is extremely satisfying. In order to reduce the error in the actual detecting process, following points should be paid more attention to: 1) choose CCD camera in high performance. the higher resolution power is, the smaller the deviation caused by subsequent processing . 2) Try best to avoid small-angle shooting to reduce camera's blind spot. 3) to improve the accuracy of camera calibration, employ at least 3 sets of calibrated images for camera calibration. 4) Choose appropriate image processing algorithms[10 ,11].

VI. Conclusion

This paper proposes a new method to detect potholes. Guiding by principle of binocular ranging, we can obtain 3-D image side coordinate system after obtaining binocular images. Then extract the deformed light band by a series of related image processing, and calculate the depth of real pit with appropriate coordinate transformation. Experiment result shows that this method has great anti-interference ability on illumination change and shadow image, and satisfies well the demand of accuracy in road damage detection. The method has great practical significance in road designing and maintenance. But the measuring result is affected by CCD camera, intensity of LED light and other environmental factors, so how to minimize their influence to improve the detection accuracy remains further study.

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