Development of the flatness detection system for cement concrete pavement construction phase

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Abstract. This article describes a pavement roughness detection system that can be used to test the flatness of the construction phase (before the concrete to harden) cement concrete pavement. The test system is based on optical triangulation principle, by the laser projector and a CCD image sensor camera composition, using a structured light technique for three-dimensional visual measurements. The system can plastic cement concrete pavement flatness detection directly help improve the flatness of the cement concrete pavement.

1. Introduction

Pavement roughness is an important index of construction quality and service level\cite{1}. The size of roughness is related to the safety, comfort and the impact strength on pavements and the service life. Uneven road surface will increase driving force, and make vehicles generate additional vibration, which will cause traffic bumps and affect the speed and safety of vehicles as well as the smoothness of driving and comfort of passengers. At the same time, vibration will apply impact force on the pavement, thereby enhancing the damage of pavements and car parts as well as tire wear and increasing fuel consumption. What's more, for dense waterway net regions, uneven roads will also accumulate and stagnate rainwater as well as accelerate the pavement damage from water. Therefore, in order to reduce the vibration impact force, improve the driving speed as well as improve the driving comfort and safety, pavements should keep smoothness to a certain extent.

At present, the pavement roughness detection is done after the road is open\cite{2}, that is, detection after cement concrete is hardened, and at this time the flatness has been finalized. If the flatness fails to meet the requirements, only polish or even rework measures can be taken\cite{3}, which not only increases construction cost, but also affects project progress and open time\cite{4}. Therefore, it is necessary to study the pavement roughness detection technology in the construction process (before cement concrete is hardened). With the advance of paver, the paved concrete is immediately detected for flatness. The detection uses non-contact scanning mode, making reciprocating motion about 10cm above the ground within the paving width, scanning and labeling the uneven places. Through the scan, find out in time the bumps or flat surface, then wear or trowel the labeled places and repair the defects in the construction so as to improve the flatness of concrete in the plastic stage, and ultimately improve the pavement roughness.\cite{5-7}

2. Structured light testing principle

The structured light 3D vision measurement is based on optical triangulation theory, in which the laser projector and CCD camera make up image sensor. The acquisition of the surface data in the flatness measurement system is achieved by several line structured light sensors. Line structured light 3D
vision measurement technology, the most commonly used in non-contact measurement technology, is based on the laser triangulation method. A line structured light measurement sensor is composed of a line structured light projector, an optical lens and an area-array CCD camera, as shown in Figure 1.

![Line structured light sensor schematic diagram.](image1)

**Figure 1.** Line structured light sensor schematic diagram.

### 3. Design of laser testing system structure

The overall structure of the system is shown in Figure 2. In the measurement system, the measurement coordinates of the system are set up by using two reference targets. The point laser in one of the reference targets is taken as the origin of the coordinate, its projection direction is X axis, and the connecting line between the two lasers is Y axis, and the vertical axis is Z axis. In the measurement process, the reference target is fixed, providing the measurement system with a unified measuring datum. In the measurement process, the mobile measuring bridge is moving along the road surface, and the 3D data of the surface of the whole pavement is obtained by the structured light sensor in the moving process.

![The overall structure of measurement system.](image2)

**Figure 2.** The overall structure of measurement system.

In the measurement system, the measurement coordinates of the system are set up by using two reference targets. The point laser in one of the reference targets is taken as the origin of the coordinate, its projection direction is X axis, and the connecting line between the two lasers is Y axis, and the vertical axis is Z axis. In the measurement process, the reference target is fixed, providing the measurement system with a unified measuring datum. In the measurement process, the mobile
measuring bridge is moving along the road surface, and the 3D data of the surface of the whole pavement is obtained by the structured light sensor in the moving process. The 3D data are the detected pavement against the coordinate of the Y axis and the Z axis of a single measurement position of the moving measuring bridge (Figure 3).

Figure 3. Schematic diagram of the test system.

Two laser range finders are installed on the mobile measuring bridge, and the moving distance of the mobile measuring bridge relative to the reference target is measured, and then the coordinate of the X axis of the surface data is determined. In the measurement process of the mobile measuring bridge, the height of the mobile bridge relative to the reference target, that is, the coordinates of the Z axis direction, will be changed because of the uneven pavement, thus affecting the accuracy of the measurement. In the measurement system, the laser is imaged with two datum line array CCD and cylindrical imaging prism, and the coordinates of the Z axis direction caused by uneven pavement roughness are compensated[8].

4. Global calibration technique for laser testing system

Several line structured light sensors are needed in the whole road roughness measurement system. In order to ensure the unity of the measurement data of the line structured light sensors, a global calibration of the whole measuring system is needed. A global calibration plate target is used in the whole process of the measurement system. The target is repeatedly and arbitrarily placed within the field of view of the camera to collect target image with feature points and light bar, using visual calibration technique to obtain the camera intrinsic matrix $A[f_x, f_y, c_x, c_y]$ and distortion coefficients $k_1, k_2, P_1, P_2$, and get the rotation matrix $R$ and translation matrix $t$ for every piece of target image. Using the third column $(R_3, R_6, R_9)$ of matrix $R$ as the normal vector, to determine the target plane equation with point $(T_1, T_2, T_3)$.

The image processing of the light bars in each target image is processed to obtain the coordinates of each point $(u'i, v'i)$. Distortion equation is used to process these coordinates and the theoretical imaging position $(ui,vi)$ of the light bars is obtained. The coordinates $(xci, yci, zci)$ of the camera coordinate system of the light bar point in each image are obtained, and are processed for PCA fitting plane.

In the measurement system, the measurement coordinates of the system are set up by using two reference targets. The point laser in one of the reference targets is taken as the origin of the coordinate, its projection direction is X axis, and the connecting line between the two lasers is Y axis, and the vertical axis is Z axis. In the measurement process, the reference target is fixed, providing the measurement system with a unified measuring datum. In the measurement process, the mobile measuring bridge is moving along the road surface, and the 3D data of the surface of the whole
pavement is obtained by the structured light sensor in the moving process. The 3D data are the detected pavement against the coordinate of the Y axis and the Z axis of a single measurement position of the moving measuring bridge. Two laser range finders are installed on the mobile measuring bridge, and the moving distance of the mobile measuring bridge relative to the reference target is measured, and then the coordinate of the X axis of the surface data is determined.

Through the mobile measurement bridge, the computer collects the information and carries on the fusion calculation to the collected data, so as to detect the plastic cement concrete pavement roughness. The plastic cement concrete pavement flatness detection system can include: CCD camera laser range finder, line structured light sensor, CCD camera, and point laser sensor.

5. Flatness testing process
To begin with, in the measurement system, the measurement coordinates of the system are set up by using two reference targets. The point laser in one of the reference targets is taken as the origin of the coordinate, its projection direction is X axis, and the connecting line between the two lasers is Y axis, and the vertical axis is Z axis. In the measurement process, the reference target is fixed, providing the measurement system with a unified measuring datum.

Next, in the measurement process, the mobile measuring bridge is moving along the road surface, and the 3D data of the surface of the whole pavement is obtained by the structured light sensor in the moving process. The 3D data are the detected pavement against the coordinate of the Y axis and the Z axis of a single measurement position of the moving measuring bridge.

Thirdly, the laser range finder measures the moving distance of the mobile measuring bridge relative to the reference target, and then the coordinate of the X axis of the surface data is determined. In the measurement process of the mobile measuring bridge, the height of the mobile bridge relative to the reference target, that is, the coordinates of the Z axis direction, will be changed because of the uneven pavement, thus affecting the accuracy of the measurement. In the measurement system, the laser is imaged with two datum line array CCD and cylindrical imaging prism, and the coordinates of the Z axis direction caused by uneven pavement roughness are compensated.

Then, the 3D coordinates of the pavement surface at the current measurement position are obtained by the line structured light sensor.

Finally, after computer data processing and integration, the whole pavement roughness change is obtained.

6. Test cases
In order to test the roughness of cement concrete pavement before hardening and calibrate the effectiveness of the test system, the project team carried out roughness detection in the field of sliding mode paving. See Figure 4.
In this experiment, the change of the roughness of the concrete before hardening is investigated, and the data at 1 hour, 2 hours, 3 hours, 4 hours, and 5 hours after the concrete paving are collected respectively. See Figure 5. Among them, the horizontal axis represents the concrete position, and the vertical axis represents the concrete deformation.

**Figure 5.** Change diagram of concrete flatness at different times.
From the data, it is found that the different parts of the concrete undergo plastic deformation in the hardening process to some extent, reaching 0.5-1mm in some individual points. It can be seen that the pavement roughness in this stage has made a difference, and the concrete or paver parameters can be adjusted based on these data, or artificial repair and other measures are taken to deal with the unqualified position in roughness[9].

7. Conclusions
The testing system is a kind of technology for 3D visual measurement based on the optical triangulation theory, by the image sensor composed of laser projector and CCD camera, and through line structured light. The system can be directly used to detect the flatness of the plastic cement concrete pavement (before cement concrete is hardening), to evaluate the surface roughness of cement concrete in the construction process, so as to improve the smoothness of cement concrete pavement.

References
[1] Ministry of Transport of the People’s Republic of China. JTG D40-2011 Specifications for Design of Highway Cement Concrete Pavement [S]. Beijing: China Communications Press, 2011
[2] Ministry of Transport of the People’s Republic of China. JTG/T F30-2014 Technical Guidelines for Construction of Highway Cement Concrete Pavements [S]. Beijing: China Communications Press, 2014
[3] Portland Cement Concrete Base and Pavement. GCM Section 502
[4] Zhang Guizhong, Chang Hong 2002 Detection method for high grade highway pavement roughness China Science and Technology Information 25(2) 21-23
[5] SPangler E.B, W.J.Kelly 1996 GMR Road Profilometer-A Method for Measuring Road Profile Highway Research Record 121 27-54
[6] Zhou Xiaoqing, Sun Lijun, Yan Li 2005 Development and trend of pavement roughness evaluation Journal of Highway and Transportation Research and Development 22(10) 18-22
[7] Liu Wanyu, Zhang Lei, Xie Kai 2007 Analysis of pavement roughness detection technology and its development status Industrial Measurement 17(1) 9-12
[8] Yang Shimin, Fu Xiangru 2010 Engineering Machinery Ground Mechanics and Operation Theory[M]. Beijing: China Communications Press 1 172-173
[9] Ling Ziliang 2008 Measures to improve the smoothness of cement concrete pavement [J] Construction Technology 5 38-41