2018 International Conference on Sensing, Diagnostics, Prognostics, and Control

# 3D reconstruction of rotating objects based on line structured-light scanning

Jinhu Deng, Binqiang Chen, Xincheng Cao, Bin Yao
School of Aerospace Engineering
Xiamen University
Xiamen, China
cbq@xmu.edu.cn

Zhongqi Zhao, Jianxun Yu
Shaanxi Hanjiang Machine Tool Co., Ltd
Xi'an, China
zzqfxy@163.com

***Abstract*—In order to achieve the 3D reconstruction of objects, a rotation scanning method based on line structured-light is proposed. Firstly, the line laser is installed together with the camera's optical axis in a certain angle, the measured object is fixed on the rotating motion module, the camera is used to photograph the light stripe which is on the surface of the object under the different rotating phase, and the image processing and method extracting the center of light in a circular kernel is used. The light-spots are restored to the 3D point cloud according to the laser plane parameters and the camera's internal and external parameters calibrated before. According to the rotational phase recorded, 3D point cloud is reconstructed around the rotating shaft for 3D relative position. The paper designs a simple device for 3D reconstruction of sphere based on line structured-light scanning, and the accuracy of 3D point cloud recovery algorithm is tested.**

***Keywords—3D reconstruction; structured-light; circular kernel; grayscale barycenter method; image processing***

## I. INTRODUCTION

With the development of science and technology and manufacturing industry, the detection technology of computer vision is becoming more and more widely used in the field of industrial production because of its advantages of noncontact, high precision, fast speed and automation [1]. In the computer vision detection system, the method of monocular line structured-light has been widely used because of its flexible structure, convenient installation and low cost. A large amount of data can be obtained at one time through the camera to the contour modulated by the surface morphology of the measured object, and the efficiency is much higher than that of the point laser method [2]. As the single image after processing can only offer the 3D point cloud data of a certain outline of the object, to restore the 3D shape, it is necessary to rotate or displace the measured objects to obtain the image of the light stripe under different space positions [3].

In the monocular line structured-light vision system, the extraction of light center and the matching of 3D feature points are the key and difficult points. In order to solve these difficulties, the extraction method of light gravity in a circular kernel is adopted, and the 3D reconstruction of objects is completed by using the camera calibration principle.

## II. THE MEASURING PRINCIPLE

### A. Hardware Composing

The measurement system consists of two parts, namely, sensor module and rotation module. The sensor module consists of a CMOS camera and a semiconductor laser. The rotation module is mainly a rotary table.

As shown in Fig. 2, to ensure that the target object is exposed to the public field of view, the line laser is installed together with the camera's optical axis in a certain angle, then the object is photographed. At the same time, the rotating platform works to drive the target object to rotate. According to calibration of the structured-light plane, the light points obtained by the image processing are restored to the 3D point cloud. The concrete working process of the measurement system is shown in Fig. 1.

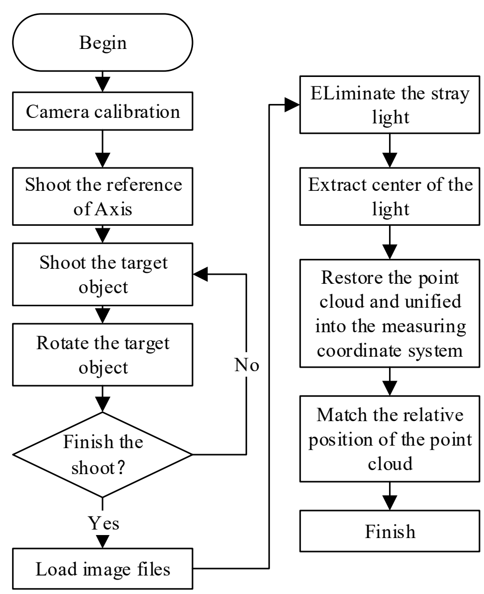


Fig. 1. Experimental process.

978-1-5386-6057-7/18/$31.00 ©2018 IEEE
DOI 10.1109/SDPC.2018.00053

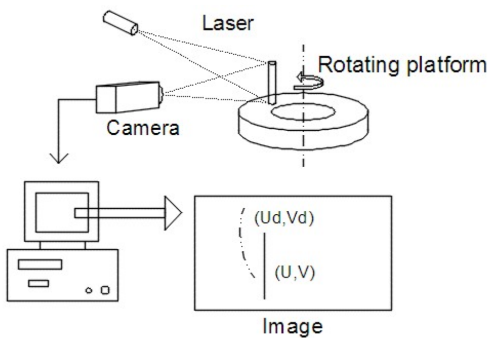


Fig. 2. Mathematical model of the system.

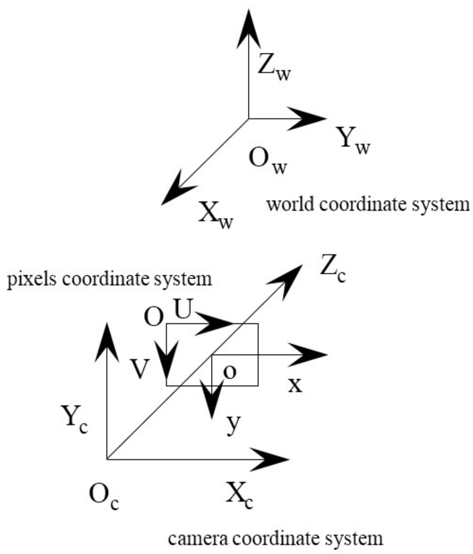


Fig. 3. Coordinate system.

### B. The Set Up of Coordinate System

Pinhole imaging is the most primitive method of imaging. Because of too little light intake, modern cameras use convex lenses to assist the spotlight, but they can still be equivalent to a pinhole camera model [4]. As shown in Fig. 3, $O_w - X_w Y_w Z_w$ is the world coordinate system, $O_c - X_c Y_c Z_c$ is the camera coordinate system, and $o - xy$ is the image coordinate system, $O - UV$ is the image pixel coordinate system. The 3D coordinates of the space point can be calculated by the pixel coordinates of the light-spots, the parameters of the light plane and the transformation relation matrix R and T of the world coordinate system and the camera coordinate system.

## III. Key Algorithm

The measured objects are placed in the common field of vision intersecting the optical axis of the camera and the light plane. The laser is projected onto the surface of the target object and is photographed to obtain the image of the line stripe.

### A. Preprocessing for The Line Stripe in Image

The intersected region in the image is only the line stripe. When the brightness of laser is much larger than the ambient light, the exposure time is adjusted, then most region of the image will become pure and dark. The remaining stray light usually comes from the scattering of the laser itself in the smooth concave object. At this time, we cannot shoot the two-state images of switch laser, and then eliminate the interference of stray light by subtracting [5].

At this time, a mean filter is performed on the image, where the $7\times7$ window tested is much better [6], and then the two value of the image (Fig. 4(a)) is formed according to a certain threshold. Islands bright block are formed, and the maximum bright block of the area is generally the region of interest. The binary image is processed by selecting the eight connected domain algorithm. The connected domains are numbered to find the largest area which will be saved (as shown in Fig. 4(b)). After processing, only the interested region of binary image is left, and the brightness value of the region is 1, which is called mask image.

(a) Binary image (b) Region of mask

Fig. 4. Regions of interest.

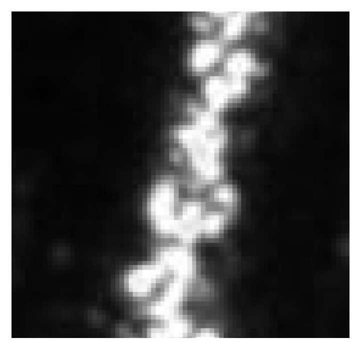

Fig. 5. The quality of the light band is affected.

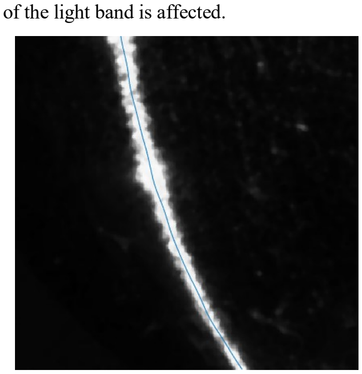

Fig. 6. Light stripes center extraction.

### B. The Modified Method of Light Stripe Center Extraction

When the surface of the target object is relatively regular, and the evenness is poor, it is easy to influence the diffuse reflection of the stripe, making the luminance of the ribbon uneven, such as the solitary island phenomenon of Fig. 5.

The traditional grayscale barycenter extraction algorithm usually selects a strip of pixels in the radial direction of the light strip to gather the image coordinates of the light-stripes center, which will make the barycenter of light more sensitive to the surface quality [7]. In this paper, a extraction method of grayscale barycenter using circular kernel is proposed, so that the pixel selection area is no longer single, and has a certain effect on noise suppression. The method is to extract the skeleton of the mask image, and then remove the branch, and then get a skeleton line roughly passing the center of the light stripe. According to the skeleton line which is the motion track, the circular kernel slides on the original image. Then the location of grayscale barycenter is calculated by all the pixels in the kernel, and the extraction result of the center of the light stripe is obtained. As shown in Fig. 6.

### C. Transformation of Coordinate System

To set up the world coordinate system with calibration board as standard reference, the transformation equation from pixel coordinates to world coordinates can be established. The corresponding image on the image plane of the distorted coordinate $P_w(\mathrm{X}_w, \mathrm{Y}_w, 0)$ is actually $P_d(\mathrm{X}_d, \mathrm{Y}_d)$, while there is an offset from the undistorted coordinate $P_u(\mathrm{X}_u, \mathrm{Y}_u)$ due to lens radial distortion. In this regard, let $(\mathrm{U}, \mathrm{V})$ be the point's pixel coordinates in the computer image coordinate system. Thus, the relationship of above can be described in (1).

$$\begin{cases} X_d = (\mathrm{U} - \mathrm{U}_0) \cdot \mathrm{d}_x \cdot \mathrm{s}_x^{-1}, \\ Y_d = (\mathrm{V} - \mathrm{V}_0) \cdot \mathrm{d}_y, \\ r^2 = X_d^2 + Y_d^2, \\ f \dfrac{r_1 X_w + r_2 Y_w + t_x}{r_7 X_w + r_8 Y_w + t_z} = X_u = X_d (1 + \mathrm{k}_p \cdot \mathrm{r}^2), \\ f \dfrac{r_4 X_w + r_5 Y_w + t_y}{r_7 X_w + r_8 Y_w + t_z} = Y_u = Y_d (1 + \mathrm{k}_p \cdot \mathrm{r}^2), \end{cases} \tag{1}$$

Meanwhile, $d_x$ and $d_y$ are the center-to-center distances between pixels in the row and column directions, respectively. And $S_x$ is the uncertainty image factor. $(\mathrm{U}_0, \mathrm{V}_0)$ is the center pixel of the digital image. Furthermore, f is the focus of the lens. The calibration of these parameters is implemented using the method proposed in [4].

### D. 3D Point Cloud Reconstruction

The coordinates in the image can only determine the information on one line in the space, which cannot provide accurate space position, and the structure-light increases the depth information, thus completing the 3D point construction. Firstly, according to the coordinate transformation relation, the pixel coordinates are converted to the projection on the calibration board. According to the location of the original point of the camera coordinate system, the two points connection equation is obtained, and then it intersects with the light plane, that is, the actual space point coordinates of the light point.

After obtaining the coordinates of the space points, it is necessary to rotate the corresponding axes around the axis of rotation so that the relative positions can be restored.

### E. Search for The Equation of Space Rotation Axis

A circular bar is installed vertically on the rotating platform. Getting the parameters of more than two non-coplanar planes where axis locates, the equation of the rotation axis can be calculated. In order to obtain the parameters, using rotating platform, the camera can shoot the image of the circular bar in rotating 0 and 180 degrees, and then the camera is moved, and the other two-state images of the circular bar are also photographed.

After the circular bar turns over 180 degrees, the diagonal line of the selected two edges are the plane of the axis. According to the transformation relationship between the pixel coordinate system and the reference coordinate system, the axis is projected to the world coordinates on the calibration board, and then the origin of the camera coordinate is transformed to the position of the reference system. The parametric equation of the plane can be obtained by these points. Similarly, after changing the position of the camera, getting the parameters of another plane.

### F. Light Plane Calibration

The 2D calibration board is placed in the position that can intersect the light plane, and the calibration plate images are photographed in the laser state which is on or off, and then the calibration board is moved along the direction of the light plane to do the same operation.

Firstly, the light points of two calibration plate images with non-coplanar light stripes are extracted. Using the interior and exterior parameters of camera obtained from the calibration toolbox, the locations of light center are converted from the image coordinates to the coordinates of the world coordinate system, and the least square fitting is carried out for all the center points of the stripe, and the equation of the light plane is obtained [3].

## IV. Design Experiment

The algorithms used in this paper are all tested by MATLAB. The camera model of the system sensor module is the Daheng MER-1810, using a 1/2.5 inch 18 million pixel CMOS photosensitive element, the image source size is 1.25 $\mu m$, and the laser type of 520nm green light semiconductor laser. The rotating module is a high precision manual six-axis platform. The calibration board is a checkerboard board with 1mm spacing. The system is constructed as shown in Fig. 1, and the object is shown in Fig. 7.

Fig. 7. Actual picture of the system.

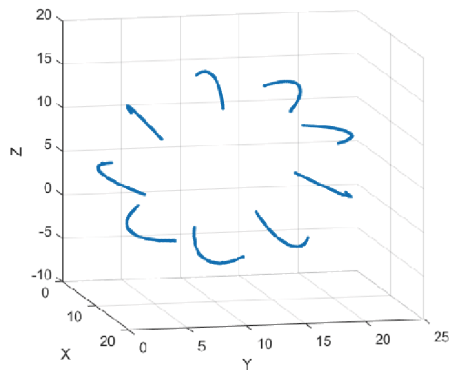


Fig. 8. Recovery relative position.

### A. Calibration of Camera

The calibration board is placed near the axis of rotation so that the camera can take the image clearly and continually change the azimuth of the calibration board. After taking enough images, the Camera Calibration Toolbox is used to calibrate the camera.

### B. Axis Image Acquisition

Firstly, the circular bar is installed on the rotary table and the camera position is adjusted so that the edge of the bar can be clearly imaging in the camera. After a picture is taken, the circular bar is rotated 180 degrees with the rotary table, and then an image is taken. After completing, the circular bar is removed and the calibration board is installed near the axis of rotation, and the image of calibration board is captured. Then the camera is rotated around the axis of rotation, and the image of calibration board is captured. The circular bar is remounted on the rotary table, and the circular bar image of 0 degree and 180 degree rotation is also captured like before.

### C. point cloud recovery and 3D reconstruction.

The restored 3D point cloud is rotated according to the recorded phase, and is displayed by scatter3 function in MATLAB, as shown in Fig. 8.

## V. Conclusion

A 3D reconstruction system is established in this paper. The scanning method of structured-light combined with object rotation is used to achieve 3D reconstruction and integrate 3D point cloud into the world coordinate system. The conclusions are as follows:

- We use the connected component method of image morphology to eliminate the influence of the reflected light caused by the concave object.
- Using the distortion model to correct the feature points, improve the accuracy of the measurement and reduce the influence of the camera itself on the measurement.
- The system uses the external reference calibration principle to calculate the location of the spatial axis, so that the laser does not need to coincide with the axis of rotation, which liberates the axis position.

The next step is to optimize the algorithm and hardware and improve the accuracy of the system.

## References


[1] Y. Ma, L. Hu, Z. Fang, S. Cao, “The development and application of computer vision detection technology.” J. Journal of University of Jinan(Science and Technology), vol. 18(3), pp. 222-227, 2004

[2] S. Ding, X. Zhang, Q. Yu, X. Yang, ”Overview of non-contact 3D reconstruction mearsurement methods,” J. Laser and Optoelectronics Progress, vol. 54 (7) , pp. 21-35, 2017.

[3] Y. Zhang, “The study of the rotary measuring instrument based on the optical cutting method,” D. Shandong University, 2016.

[4] G. Bradski, A. Kaebler, “Learning OpenCV,” M. pp. 407-409, 2009

[5] Q. Yu, X. Zhang, Y. Zhang, S. Wang, L. Qi, “Novel method for Structured-light plane calibration in 3D vision measurement,” J. Chinese Journal of Lasers, vol. 39, pp. 277-281, 2012.

[6] X. Zhang, X. Wang, F. Bai, C.Tian, X. Mei, “Improved gray centroid method for extracting the centre-line of light-stripe,” J. Laser and Infrared, vol. 46(5), pp. 622-626, 2016

[7] B. Liu, P. Wang, Z. Yong, C. Sun, “Measuring method for micro-diameter based on structured-light vision technology” J. Chinese Optics Letters, vol. 8, pp. 666-669, 2010.