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Complex parts measurement system based on 3D depth vision

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ABSTRACT. *with the continuous promotion of the industrial upgrading of the manufacturing industry, the inspection efficiency requirements of the manufacturing industry for parts are becoming higher and higher. At present, the traditional measurement methods include gauge, caliper, profilometer, universal tool microscope, ray and other methods, but with the rapid development of industry, the traditional measurement methods can't meet the needs of efficient measurement of industrial production line. Vision based measurement technology has the advantages of non-contact, high precision and easy to realize automation. The monocular vision measurement system is simple in structure and easy to operate, and has gradually become an important measurement method in the field of high-precision measurement [1] of part size. But for the detection of complex parts, the conventional 2D vision image is to extract the features of the measured object from the gray image and measure it in the X-Y plane. The method based on the standard scale is difficult to accurately measure the size. Aiming at the problems faced in the current complex parts detection, through the research of image theory, camera calibration theory and visual dimension measurement technology, a 3D depth vision [2] measurement system for complex part size is designed, which combines depth information with 2D vision measurement technology. The experimental results show that the system can meet the requirements of stability, reliability, high precision and strong anti-interference ability in measuring the size of complex parts.*

KEYWORDS: *3D depth vision, complex parts, dimension measurement system*

1. Introduction

At present, there are already some RGBD depth camera products on the market, such as Microsoft Kinect and Intel RealSense. These products greatly promote the development and application of 3D depth vision technology. Due to the complex geometry and uneven size of complex parts, it is difficult to achieve by conventional measurement methods. Therefore, it is of great social benefit to master 3D depth vision measurement technology and develop 3D vision dimension measurement system for complex parts. The purpose of this paper is to apply the depth information and image processing algorithm of 3D depth camera to the visual dimension measurement of complex parts. According to the principle of camera pinhole imaging [3], the mapping principle of RGB camera and depth camera, and the calibration theory, the three-dimensional spatial coordinates of pixels in RGB image are obtained, and the point-to-point size measurement is realized through theoretical derivation. Combined with image preprocessing technology, edge detection technology [4], corner detection technology [5], using feature point extraction algorithm to optimize the measurement points. On this basis, a set of non-contact, high-precision and visual dimension measurement system of complex parts based on 3D depth vision is developed to promote the application and development of visual dimension measurement technology. Our main method: firstly, the principle of depth image imaging of RealSense d435 camera is analyzed, and the depth image depth value is obtained by converting the depth pixel and the actual size unit based on the depth map mapping and alignment color map method. Because the measuring points are in different planes during the measurement, the 3D coordinates of the point to be measured in the camera coordinate system are calculated according to the hole imaging model, projection transformation principle and depth information. Then, the camera distortion coefficient is obtained by using the calibration optimization algorithm, and the measured pixels are compensated and corrected. At the same time, the correct measurement points are extracted according to the feature map by combining the edge detection algorithm and Harris corner detection algorithm [6]. Finally, a complex part size measurement system based on 3D depth vision is developed. The system mainly includes hardware part and software part. As figure 1 hardware system: light source, RealSense d435 depth camera, computer, stage. As figure 2 software system: image processing module, size detection module, database module. The software system is integrated based on C + + object-oriented programming and QT platform.

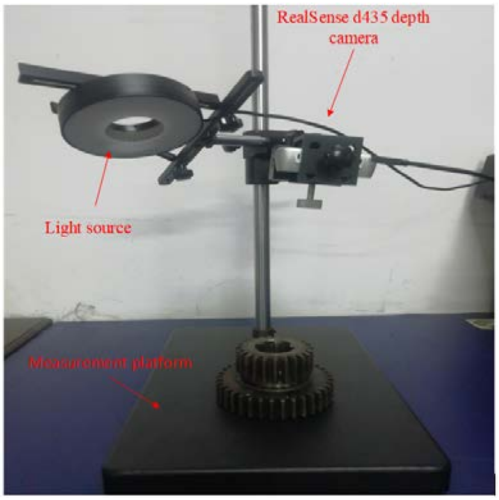

Figure. 1 Hardware system

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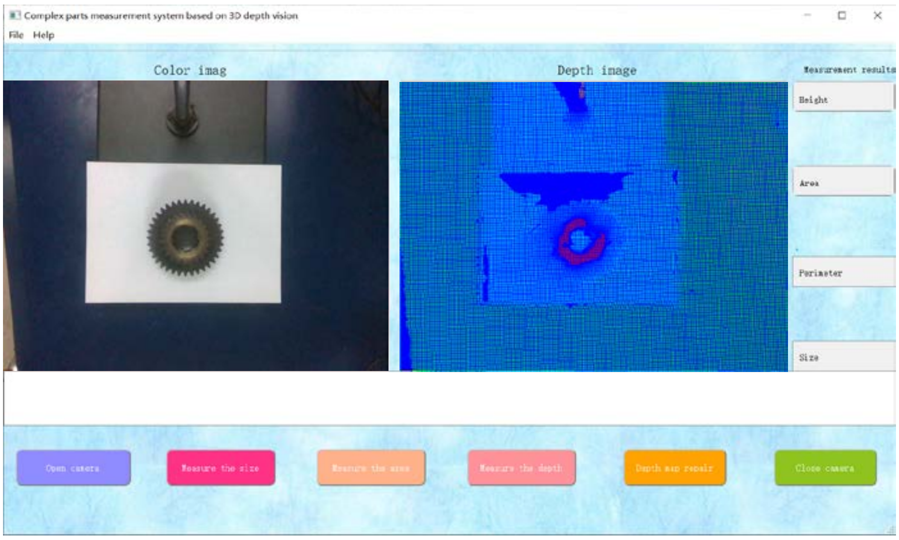

Figure. 2 Software system

2. Related work

The dimension measurement method based on 3D depth vision usually includes image binarization, morphology operation, edge detection and other image preprocessing operations; 3D dimension measurement mainly uses the depth value in Z direction combined with 2D vision plane measurement, calculates the three-dimensional coordinates of each measurement point through conversion and pixel proportion relationship, and realizes point-to-point measurement through 3D Euclidean distance formula.

In the past few years, many scholars have carried out in-depth research on visual dimension measurement methods. An image measurement system for high precision measurement of part size is proposed by Ruoan X, et al [1]. The Sobel operator is used to extract the edge, which improves the measurement accuracy. In order to make the computer vision technology for comprehensive, reliable measurement of part size, and to ensure the accuracy and stability of the measurement data requirements. In Xiong X, et al [7] paper, CMOS camera, optical lens, parallel light source, such as the core hardware, build and develop a set of dimensional measurement system based on computer vision. Zuochang X et al [8] aiming to solve the online measurement problem exists in hot forging process of agricultural machinery components, a solution was explored base on the stereo vision of computer in this study. As a new technology to solve the measurement problem of the objects with irregular shape (such as multi-hole), machine vision provide a more effective way. Chen et al [9] build a measurement system of mechanical parts with multi-hole, the design and implementation of measurement system of mechanical

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parts with multi-hole based on machine vision will be discussed in this paper. In the actual three-dimensional measurement, most of the surfaces encountered are complex surfaces. By establishing the distortion model, Xiaoming Z, et al [10] proposed an improved planar flexible calibration algorithm. Feitin Z [11] proposed a new method of vehicle profile measurement based on laser point cloud 3D detection, which has higher detection efficiency than the traditional measurement method. Xiuliang P, et al. [12] used the 3D auxiliary measurement function of 3D multi-induction measuring instrument to complete the space dimension measurement.

3. Approach

3.1 Overview

Firstly, the depth image depth value is obtained by aligning the color map based on the depth map mapping. Then, the joint bilateral filtering algorithm is used to repair the depth map, and the 3D coordinates of the measured points are obtained based on the edge detection algorithm and Harris corner detection algorithm. Finally, the complex parts detection system is designed for verification in the experimental part.

3.2 Mapping alignment of depth map and color map

For RealSense D435 color camera and depth camera, camera parameters are automatically obtained by calibration algorithm, and the depth map of depth camera is aligned with color map mapping (as shown in Fig. 3, 4 and 5). The steps are as follows: according to formula (1), the pixel points of depth map ${P^d}_{u,v}$ in the original to depth coordinate system:

$$\dot{P}_{dc} = Z K_d^{-1} {P^d}_{u,v} \tag{1}$$

Where K_d^{-1} is the inverse of the internal parameter matrix of the depth camera. According to formula (2), the depth point $\dot{P}_{dc}$ in the depth space coordinate system is converted to the world coordinate system

$$P_w = T_{w2d}^{-1} \dot{P}_{dc} \tag{2}$$

Where T_{w2d}^{-1} is the inverse of the external parameter matrix of the depth camera, According to formula (3), the depth point P_w in the world coordinate system is converted to the color coordinate system:

$$\dot{P}_{cc} = T_{w2c} P_w \tag{3}$$

Where T_{w2c} is the external parameter matrix of the color camera. According to formula (4), the depth point P of the color coordinate system is mapped to the plane with Z = 1, which corresponds to the pixel point ${P^c}_{u,v}$ of the color image:

ISSN 2616-5775 Vol. 3, Issue 4: 21-30, DOI: 10.25236/AJCIS.030403

$$P^{c}{}_{u,v} = \mathrm{K}_c \left(\frac{\dot{\mathrm{P}}_{cc}}{Z}\right) \tag{4}$$

Where $\dot{\mathrm{P}}_{cc}/Z$ is normalized in the z-axis direction and K_c is the internal parameter matrix of color camera. In practice, formula (5) is obtained by combining formula (2) and (3), that is to obtain an Euclidean transformation matrix T_{d2c} from the depth camera coordinate system to the color camera coordinate system. The specific calculation is as follows, Where $\mathrm{T}_{d2c} = \mathrm{T}_{w2c}T_{w2d}^{-1}$:

$$\dot{\mathrm{P}}_{cc} = \mathrm{T}_{w2c}\mathrm{P}_w = \mathrm{T}_{w2c}T_{w2d}^{-1}\dot{\mathrm{P}}_{dc} \tag{5}$$

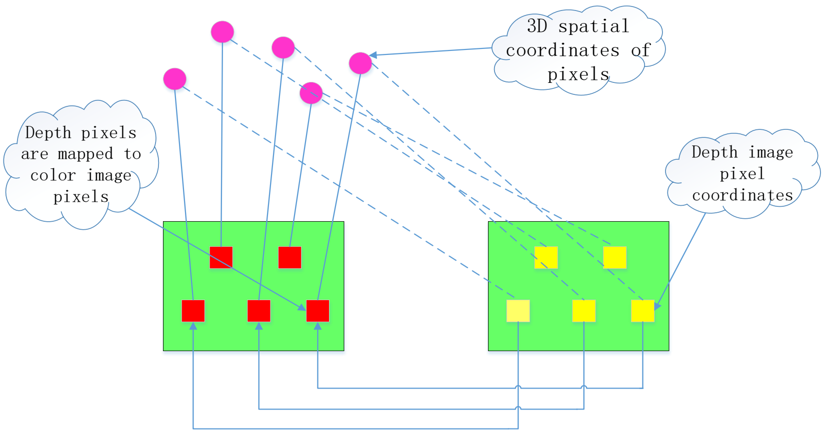

Figure. 3 Depth image and color image mapping alignment

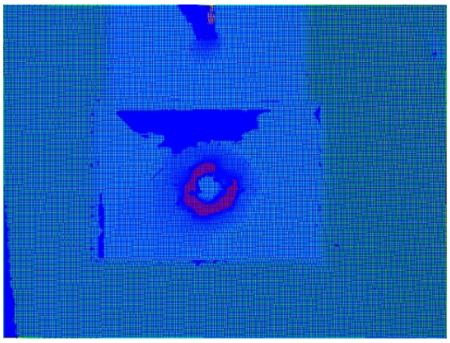

Figure. 4 Color image *Figure. 5 Aligned depth image*

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3.3 Depth image inpainting

In this paper, the method of joint bilateral filtering [13] is to improve the accuracy of depth image by combining depth image with intensity map. This kind of repair method can be roughly divided into two different repair ideas: neighborhood filtering and global optimization. Global optimization usually transforms the repair objective into an objective function related to image data items and regularities. By solving the optimal solution of the objective function, the defect in the image can be repaired or the result with higher resolution can be obtained. We use an adaptive joint bilateral filter to process the d435 data. By analyzing the edge uncertainty map and the detected foreground region, we effectively combine the depth and color. Distance related depth maps, spatial noise and temporal random fluctuations are significantly reduced; depth boundaries of objects are refined, and non measured depth pixels are interpolated. The repair effect is shown in the figure, which basically meets the requirements of depth information extraction in the measurement process.

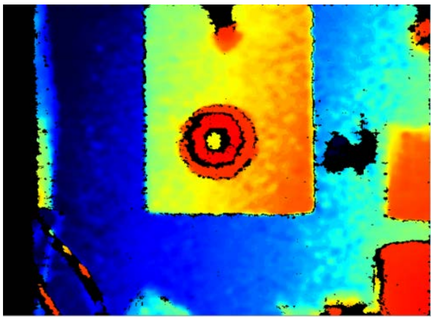


Figure. 6 Depth image

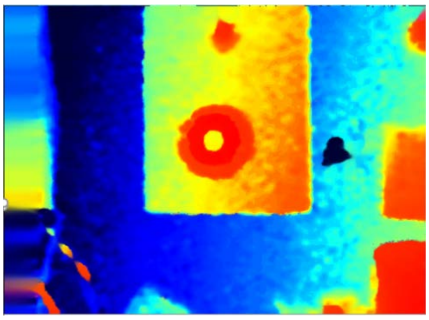
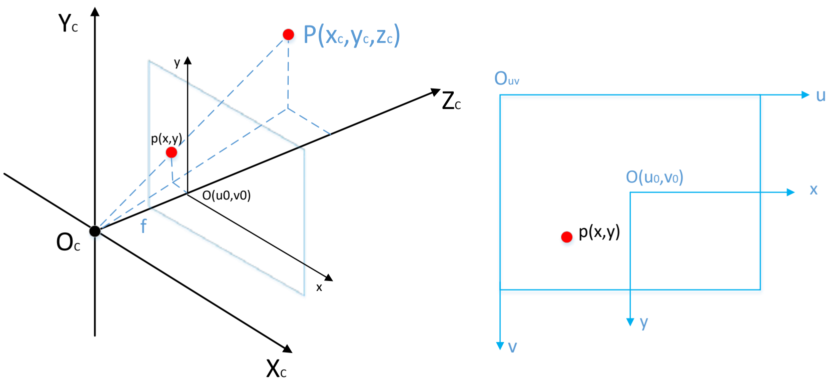


Figure. 7 Repaired depth image

3.4 3D coordinate acquisition and size measurement



ISSN 2616-5775 Vol. 3, Issue 4: 21-30, DOI: 10.25236/AJCIS.030403

Figure. 8 pinhole imaging model and projection transformation principle

In Figure 8, $Oc - YcXcZc$ is the camera coordinate system, $o - y_c x_c$ is the image coordinate system, and $o_{uv} - uv$ is the camera coordinate system, the derivation process is as follows (Formula 6, 7 and 8):

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} 1/dX & 0 & u_0 \\ 0 & 1/dY & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} Z_c/f & 0 & 0 \\ 0 & Z_c/f & 0 \\ 0 & 0 & Z_c \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} Z_c/f & 0 & 0 \\ 0 & Z_c/f & 0 \\ 0 & 0 & Z_c \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \tag{8}$$

Select the intersection point between the optical axis of RGB camera and the phase plane (called the main point), as shown in Figure 7, which is the pixel coordinate $O(u_0, v_0)$. In the RGB image, the coordinates of the (u_p, v_p) pixel point to be measured are selected, and the coordinates are mapped to the depth map to obtain the depth value Z_p. According to the pinhole imaging model and projection transformation principle (as shown in Fig. 7), combined with the depth value Z_p, the pixel coordinate a of point (u_p, v_p) is transformed into the 3D coordinate $(x_{PC}, y_{PC}, Z_{PC})$of point P through projection transformation, which is derived from (1-8). The schematic diagram is shown in Figure 9.

ISSN 2616-5775 Vol. 3, Issue 4: 21-30, DOI: 10.25236/AJCIS.030403

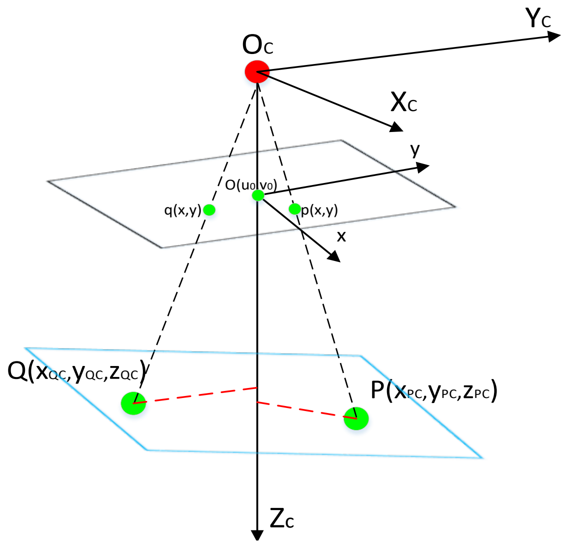


Figure. 9 Schematic diagram of 3D coordinate acquisition

Similarly, in the RGB image, select the q-pixel coordinate$(u_q, v_q)$of the point to be measured to obtain the depth value Z_q, and then calculate the 3D coordinate $(x_{QC}, y_{QC}, Z_{QC})$of the Q-pixel point of the camera coordinate. Finally, based on the Euclidean distance formula of three-dimensional space points, the point-to-point dimension measurement is calculated.

4. Experiment and conclusion

After the development of complex parts measurement system based on 3D depth vision, the feasibility of 3D dimension measurement algorithm based on 3D vision is verified by experiments. The gear is selected as the experimental object (as shown in Figure 10), and 50 times, 100 times and 200 times of measurement experiments are carried out respectively. The results show that the measurement accuracy of 3D depth vision measurement system is about 0.5%, and has good robustness. It can basically realize the size measurement of complex parts, which proves the effectiveness of the method.

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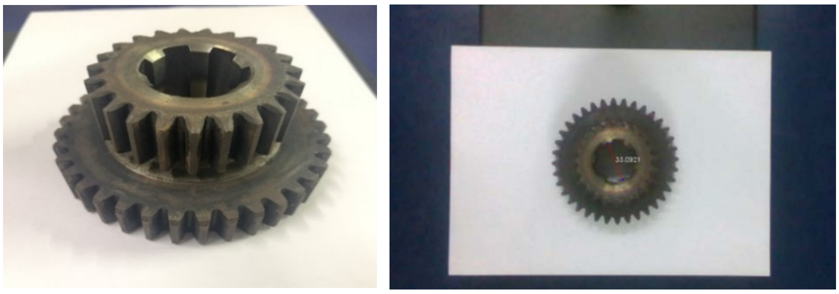

Figure. 10 Gear and measurement result

By analyzing the difficulties in the detection of complex parts, in-depth study of image processing theory, camera imaging calibration theory, visual dimension measurement technology, and the method of combining depth information with 2D vision measurement technology is proposed. Finally, a complex part size measurement system based on 3D depth vision is designed. The system basically meets the requirements of stability, reliability, high precision and strong anti-interference ability of complex parts dimension measurement.

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