A Kinect-based Robot Grinding and Polishing Method

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Abstract: As the final step of metal cutting, the grinding and polishing process determines the surface quality and precision of the workpiece to be processed to a large extent. With the improvement of the intelligent degree of manufacturing industry, intelligent manufacturing equipment with adaptability and certain learning behaviors is the trend of future factories. Considering the low efficiency and large error of manual grinding and polishing, a grinding and polishing manipulator control method based on Kinect three-dimensional reconstruction is proposed. First, a depth map of the surface of the workpiece to be polished is obtained using a Kinect depth camera, and a series of processes are performed to obtain accurate surface information of the workpiece to be polished. Then the obtained information is compared with the ideal model of the 3D software. The n sets of parallel planes are intersected with the coincident model. Finally, the improved section method is used to determine the trajectory of the grinding and polishing manipulator, so as to achieve the purpose of grinding and polishing manipulator control.

1. Introduction

With the rapid development of manufacturing technology, more and more parts with complex curved surfaces have special functions in mechanical design and manufacturing, and their surface quality and precision requirements are also higher and higher [1]. Traditional CNC grinding machines are difficult to finish grinding and polishing these surfaces. At present, the grinding and polishing of complex curved surface parts in our country mostly relies on manual work. The manual grinding and polishing work pieces are not only inefficient, but also have poor precision and consistency. At the same time, the bad working environment has caused great damage to the health of workers [2]. Therefore, it is an urgent problem to replace manual polishing to grind complex surfaces on parts.

With the rapid development of information technology, three-dimensional model reconstruction technology will have broad application prospects in the field of manufacturing [3]. The acquisition of surface depth information of mechanical parts is to measure accurately, extract the geometric features of the parts, and calculate and analyze the feature parameters. So it is very meaningful to apply Kinect depth image to the control of grinding manipulator. Kinect is used to collect and process the depth image of the mechanical parts with complex surface, to restore the surface contour information, and a method of using the surface contour information in the path planning of grinding and polishing manipulator is proposed.

2. Kinect Sensor

As a 3D depth sensor device, Kinect has many applications in machine vision, computer graphics, virtual reality, reverse engineering and many other fields. Kinect is simple, powerful and inexpensive, including random infrared point cloud projectors, infrared cameras, color cameras and microphone arrays [4].In addition, there is a drive motor at the bottom of the device to focus on the

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object. It can also be used to adjust the pitch angle of the device to find the best angle of view.

The depth image acquisition and principle of Kinect, which is mainly used in the image acquisition process, the laser diode emits a pyramidal field of view in the infrared emitter. Infrared light encodes the field of view optically, forming a "volume coding" with three-dimensional coordinates. When the laser irradiates the surface of the object in the field of view, random diffraction speckles will be formed on the surface, and different patterns will be formed according to the distance of the speckles. The infrared camera records these speckle patterns and transmits them to the chip. The chip compares the speckle patterns on the surface of the object with those recorded in the whole space in advance, so as to obtain the spatial coordinate information of the object surface.

3. Acquisition and Processing of Point Clouds

3.1. Acquisition of Point Cloud Data.

Before obtaining the depth image, the source calibration is required, that is, the "volume coding" information in the Kinect working range is obtained. The specific method is to take n groups of reference planes and record the speckle information on each group of planes within the range of user activity specified by Kinect to get n-pair calibrated speckle images. The calibrated speckle pattern is used to compare with the speckle pattern of the object to be measured to restore the depth information of the object to be measured [6]. The range of activity prescribed by Kinect is certain, and the size of N determines the accuracy of depth information of the object to be measured. Since the part to be polished is being rebuilt, the value of n should be maximized to achieve satisfactory accuracy. The depth image contains three-dimensional coordinates in the depth map coordinate system, while the color image captures two-dimensional coordinates and color information in the color image coordinate system. The information contained in the two groups of pictures not only has the same two-dimensional coordinates, but also reflects the depth and color information. The three-dimensional point cloud generated by the combination of the two images not only corrects each other, but also combines the color and depth information, which is the basis of the three-dimensional reconstruction of the back object.

3.2. Matching of Color and Depth Data.

Because color cameras and infrared cameras have different positions on Kinect, the angle of data acquisition is different, and the sensing area is different, so the plane coordinates of the images obtained from them are also deviated. The parallax generated by the two cameras can be corrected by OpenNI correction function to align the object in the two pictures.

Kinect sensor involves three coordinate systems in the process of collecting image and acquiring data: image coordinate system, camera coordinate system and world coordinate system. The image coordinate system refers to the image plane acquired by Kinect as the coordinate system, the upper left corner of the image is the origin, and the image pixels are the units. In the camera coordinate system, the optical neutral point of the camera is taken as the origin, the X and Y axes are parallel to the image coordinate system, and the Z axes represent the depth distance perpendicular to the image plane. The coordinate data acquired by Kinect depth camera can't be used directly, so it needs to be mapped to gray space [8-9]. It can be transformed by functions in OpenNI, that is, u and v coordinates in depth images are transformed into X and Y coordinates in world coordinates. The world coordinates here are based on the depth camera. Specific formulas are as follows.

$$X = (u - 320) \cdot Z \cdot \frac{1}{f_{xz}} \quad (1)$$

$$Y = (v - 240) \cdot Z \cdot \frac{1}{f_{yz}} \quad (2)$$

X, Y and Z are coordinates in the world coordinate system, and u and V are horizontal and vertical coordinates in the image coordinate system. Here f_{xz} and f_{yz} are the focal length of the corresponding depth camera, and the coordinates of the camera center are (320,240) (determined by the resolution of the image). The transformed coordinate values form a three-dimensional point cloud for subsequent processing.

3.3. Preprocessing of Point Cloud Data.

Once the color image is matched to the depth image, it needs to be processed. The process is divided into two steps: background segmentation and harmonic filtering.

Background segmentation divides the image into regions according to its nature, and then chooses the object to be studied. Each element must first be marked in the image. Then, the object to be identified, that is, the workpiece to be polished, is extracted from the background. In the following, threshold segmentation is used to separate the workpiece to be polished from the background [10].

In view of the excessive noise of the data collected by Kinect, a bilateral filtering algorithm is used to reduce the noise. This method can reduce the noise while preserving the edge information, so that the processed image is smooth but not blurred. For the principle of bilateral filtering, the following definitions are given.

$$g(x,y)=\frac{\sum_{ij}D(x,y)\omega(x,y,i,j)}{\sum_{ij}\omega(x,y,i,j)} \tag{3}$$

$$d(x,y,i,j)=\exp(-\frac{(x-i)^2+(y-i)^2}{2\sigma_r^2}) \tag{4}$$

$$r(x,y,i,j)=\exp(-\frac{\left\|D(x,y)-D(i,j)\right\|^2}{2\sigma_r^2}) \tag{5}$$

The weight coefficients $\omega(x,y,i,j)$ in the above formulas are determined by the product of the domain kernels d and r. D(x, y) represents the depth value corresponding to the pixels (x, y). The definition domain kernel represents the distance weight from the filter center pixel, and the range kernel represents the weight of similarity between two depth values. (i, j) denotes the radius of the filter template, usually using the eight-neighborhood method [11].

4. Path Planning of Grinding and Polishing Manipulator

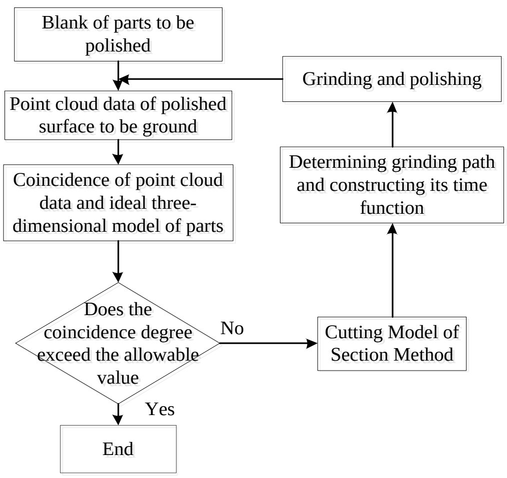

Figure 1. Overall planning of grinding and polishing process

The depth image of the coarse embryo of the workpiece collected by Kinect is obtained above and processed in a series of ways. This section describes how to use the Kinect point cloud data above for path planning of grinding manipulators. The overall planning process of the whole grinding and polishing process is shown in Fig. 1.

Combine point cloud data with an ideal 3D model. The ideal 3D model can be drawn from the part drawing and 3D modeling software, which is the size of the part that is expected to be obtained after polishing. The ideal 3D model and point cloud structure can reflect the surface size information of the part. It is therefore possible to use coordinate transformation to coincide them with the points on the non-machined surface as the origin.

The path planning of the grinding and polishing robot is carried out by the section method. The traditional section method shown in Fig. 2 uses a set of parallel planes intersecting with the ideal 3D model surface to obtain a series of intersecting lines along which the contact points between the tool and the workpiece surface move. The method has uniform tool path distribution and flexible tool path control, and is suitable for various types of surface. An improved cross-section method is presented below. On the basis of the ideal surface of the original part, a rough surface of the part is added (which is obtained by Kinect above). The improved cross section method is shown in Fig. 3, where the constraint surface intersects with the rough surface of the part and the ideal surface of the part to form two intersecting lines, which form a shadow part.

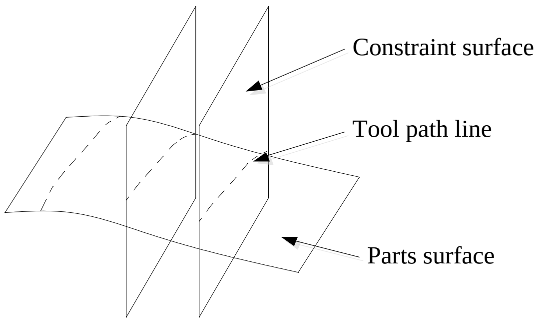

Figure 2. Traditional Section Method

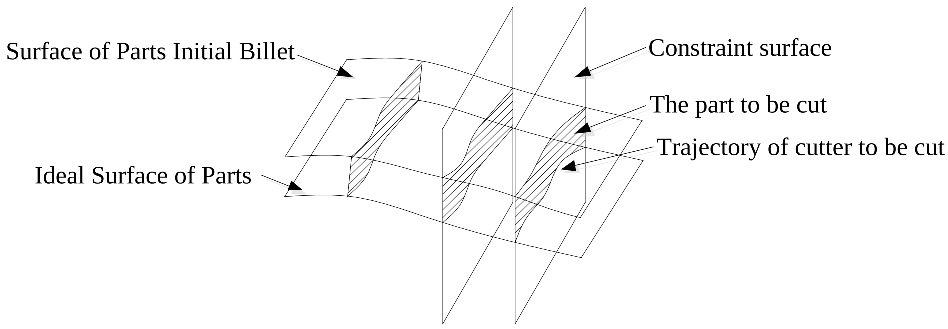

Figure 3. Improved Section Method

Take a cross section to analyze the information in Figure 3.4 as follows. The coordinate system represents the plane of a section. The shadow part is the part to be polished, the upper boundary line is the intersection of rough surface and cross-section of the part, and the lower boundary is the intersection of ideal surface and cross-section of the part. The height difference between the two lines at a certain position is recorded as h_x. The lower boundary of the shaded portion is used as the path of the polishing tool, and then the time-dependent tool path equation is constructed by combining the height differences. Finally, the trajectory equation is characterized by slow speed, long time in places with large height difference, and fast speed and short time in places with small height difference, which fully saves time to a certain extent. The height difference at a certain point is proportional to the time of polishing here, i.e. $t_x = kh_x$, while the value of k is related to the material of the part.

The whole grinding and polishing process is approximated by a set of curves obtained from such cross sections to replace the surface, and the grinding and polishing process is completed by connecting the trajectories of the curves. So the distance between sections is particularly important.

In theory, the smaller the distance between sections, the more curves approximate to replace the surface, and the more accurate the final polishing results. However, due to the limitation of polishing tools, if the distance between interfaces is too small, the polishing between adjacent curves will produce too much interference, and will greatly increase the polishing time. Therefore, the distance between adjacent sections is determined by the tool width, part accuracy and the change of surface curvature. Once these factors are determined, the shortest polishing path and time can be obtained to meet the accuracy requirements.

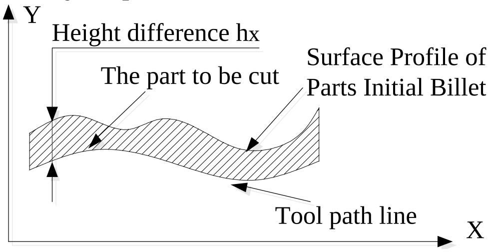

Figure 4. Block n Cross Section Diagram

After the first polishing process is completed, a set of lines of surface point cloud information can be obtained by Kinect after collecting one image information, and then the above operations are repeated until the information of surface point cloud collected and processed by Kinect is controlled within a reasonable range with the ideal surface information of parts, then the polishing is finished.

In addition, in order to make the path planning control system have a certain adaptive and learning ability. It is proposed to build a database of three-dimensional models with many common parts. The three-dimensional models in the database are all completed by three-dimensional drawing software. By training the system, when the surface information of the parts to be polished is obtained by Kinect scanning, the system will automatically find a three-dimensional model with the highest coincidence degree as the result of polishing, and make path planning by coincidence with it.

5. Conclusion

The above proposes a method for obtaining surface depth information of a workpiece to be polished using Kinect, which is applied to the path planning of a series of processed grinding robots. This method can realize the path planning of the manipulator during grinding and polishing process, and can fully save time under the premise of meeting the accuracy. For those small batches of non-standard parts with complex surface and difficult to measure manually, it has great use value.

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