Off-line programming of robot on laser cleaning for large complex components

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Abstract: Laser cleaning path planning is great for significance to the cleaning effect of component surface. In view of the fact that the cleaning head must keep a fixed focal length with the workpiece surface and keep a vertical angle with the workpiece surface at all times in the laser cleaning process, this paper introduces the numerical model of large components into the general off-line programming software, and according to the relevant laser cleaning process and setting specific parameters in the software, obtains the automatically planned machine. The human trajectory program is introduced into the robot to realize the surface cleaning of large and complex components. Finally, according to the actual cleaning effect in the field, the laser focal length deviation is controlled within $\pm$ 2mm, and the application of off-line programming of industrial robots in complex surfaces is summarized and prospected.
1. Introduction

(Industrial) Robot technology is a high-tech discipline which combines computer science, information science, mechanism science, control science, bionics, artificial intelligence and other disciplines. It represents the highest achievement of today's mechanical and electrical technology, and the research and application level of robots is an important symbol of the industrial automation level of a country[1]. Because of the robot's programmability, the flexibility and intelligence of its function depend on the programming ability of the robot system. With the industrial robot's application becoming more and more extensive, the difficulty of its corresponding task is increasing. How to complete the robot program quickly and effectively has become an urgent problem to be solved.

There are three programming languages for programming and robot teaching[2]. Among them, the teaching programming method has the disadvantages of low programming efficiency, insufficient precision and tedious operation in practical application, and it is difficult to start with the complex path and can not obtain satisfactory programming effect [3]; programming by robot language requires higher programming level of programmers, and the results of this method can only be verified by the final robot entity. The probability of out of business interference collision, singularity point and axis inaccessibility is high, which makes practical application more difficult. While the robot off-line programming is to use commercial off-line programming software, which uses computer technology to program and automatically generate trajectory path through the actual workpiece and robot's digital model on site without directly using the robot. Finally, the generated code (code file) is used to control the robot to complete the given task.

Compared with the former two traditional programming methods, the advantages of offline programming are obvious: it can effectively reduce the standby (shutdown) time of the robot and improve the application efficiency of the robot on site[4]; through the simulation of the simulation system, the robot trajectory path and programming effect can be viewed intuitively; the trajectory path planning of complex workpiece can be effectively solved, and the singularity can be avoided automatically. It can effectively improve the programming environment and keep the robot programmers away from the high-risk field environment [5].

In this paper, the 3D model of the workpiece is obtained by reverse modeling of the hand-held 3D scanner, and the off-line programming and simulation are completed by using the off-line programming software hedracam2019. Finally, the robot code program is obtained, which realizes the requirement of robot automatic laser cleaning for large complex components.

2. Introduction of laser cleaning robot system

2.1 Hardware system

The robot used in the system is mc20-01 robot produced by naghi bueryue company in Japan. Mc20-01 is a multi-functional universal robot, which has six motion joints and is flexible and accurate. It can make the movement and trajectory of the robot more smooth and flexible in the motion range, and is more conducive to the requirements of path planning. The overall dimensions and motion range of the robot are shown in Fig. 1.
Considering the cleaning environment and working process of large components, the system combines the robot and AGV platform, integrates the advantages of AGV and robot, and realizes the intelligent movement of the whole working platform. The whole motion unit extends the function of the robot greatly, which makes the robot have the function of mobile operation, and breaks the traditional fixed application of robot. The main structure of the cleaning system is shown in Figure 2.

The large component to be cleaned in this system is the cabin door of civil aircraft. According to the painting material on the door surface, the relevant laser cleaning process parameters are set. The laser cleaning head, tooling adapter plate, robot pipeline package and the overall system structure, large components and fixed devices are shown in Fig. 3.

2.2 Software system
The system uses the off-line programming software hedracam, which supports multi process environments such as multi axis NC milling, laser cutting, welding cladding, polishing, engraving and spraying. The system implementation process is shown in Figure 4.
3. Establishment of 3D model of workpiece
For the large workpiece without model, the point cloud model is obtained by 3D scanning, and then the point cloud model is instantiated by reverse modeling, and the specific 3D model is obtained by reverse modeling.

3.1 Point cloud acquisition of workpiece model
In the stage of point cloud acquisition of workpiece model, this paper uses Hangzhou non white hand 3D scanner to obtain the point cloud of the model. The light source of Hangzhou non white 3D scanner is 14 crossed laser lines with a resolution of 0.05mm and a maximum accuracy of 0.03mm.

Before the application of scanner scanning, the feature points of the plane are added by pasting points, so as to improve the recognition of the workpiece. The characteristic points of the cabin door before scanning preparation are shown in Figure 5.

3.2 Reverse modeling of point cloud model
The reverse modeling in this section is to reedit and process the point cloud file. The application software transforms the point cloud model of the hatch into triangular mesh, and then generates adaptive surfaces and composes them again.
The point cloud file is imported into Geomagic studio to optimize the point cloud by repairing, smoothing, noise reduction and other optimization methods, and then the solid cabin door model is obtained by constructing grid surface and combining surfaces. After modeling, the solid hatch model is shown in Figure 6.

![Fig. 6 Solid model of cabin door](image)

4. Establishment of simulation working environment for laser cleaning robot system

4.1 Point cloud acquisition of workpiece model

According to the digital model of Nazhi robot mc20-01, it is necessary to transform the output coordinate system and set the origin of the robot digital analog in the software, so as to ensure that the robot axis joint moves according to the standard digital model.

After the robot standard model is processed, the parameter data of each axis of mc20-01 is set (replaced), and the axis configuration and DH parameters are modified, as shown in Fig. 7.

![Fig. 7 Modification of robot system parameters](image)

4.2 Reverse modeling of point cloud model

The 3D digital model of laser cleaning tooling is shown in Fig. 8. The file is imported into the hedracam software to complete the parameter setting of tool coordinates.

![Fig. 8 3D model of laser cleaning tool](image)
According to the site large component model and the actual working position, the mapping data is set in the hedracam software. The final simulation layout of the robot laser cleaning system is shown in Figure 9.

Fig. 9 Simulation layout of robot laser cleaning system

5. Robot laser cleaning path generation

Due to the particularity of laser cleaning process, for the workpiece to be processed, the laser cleaning head should always keep a certain focal length with the workpiece, and the angle of laser output should be vertical to the surface of the workpiece, which needs to be set in the hedracam software.

5.1 Determination of laser cleaning path and end pose

According to the program structure of Nachi robot, the point data is determined by \( P = (X, Y, Z, R, P, Y) \), where \( XYZ \) is the spatial position coordinate and \( RPY \) is the Euler angle. The angle between the workpiece surface to be machined and the cutter is shown in FIG. 10.

Fig. 10 Laser cleaning head (cutter) and workpiece to be processed

Set \( P_j \) as a path point, as shown in Figure 11, and the coordinate vector is:

\[
P_j = [P_x, P_y, P_z, \theta_z, \theta_y, \theta_x]
\]

Where \( P_x, P_y \) and \( P_z \) are the values in the oxyz coordinate system, and \( \theta_z, \theta_y, \theta_x \) is the attitude angle of \( P_{ijk} \) expressed in Euler angle in Oxyz coordinate system.

Fig. 11 Path point vector analysis

5.2 Parameter setting of laser cleaning program

Establish the surface processing program format, determine the machining surface and reference curve of the workpiece to be processed, determine the control mode, simulation mode, processing mode and tool setting of the sixth axis, and complete the above settings in the hedracam software to meet the laser cleaning process requirements, as shown in FIG. 12.
5.3 Machining program and robot trajectory generation

After completing the relevant software settings, through the automatic calculation of the software system, after a short wait, the processing track will be automatically generated according to the settings. The path path is shown in Figure 13.

6. Simulation optimization and program output of robot laser cleaning

Through the simulation function of the software, the generated path and the robot motion state can be seen intuitively. According to the actual working environment, the generated processing curve is optimized and adjusted to reduce the collision, singular points and inaccessible phenomena. After automatically generating the avoidance line, the tool path is generated again.

After the machining curve is optimized, the system will automatically generate the program code according to the robot program format. The generated program code can be modified by text document. The program is mainly composed of motion instructions, including interpolation method, acceleration, smoothness, accuracy, speed and tool coordinate number, as shown in Figure 14.
After the unified modification of the program code, the program code is transmitted to the robot through the U disk, and then it is converted into the robot's execution program after compiling in turn. After importing, the execution program display interface of Nachi robot teaching device is shown in Figure 15.

![Fig. 15 Robot execution program interface (part)](image)

7. Verification of laser cleaning effect

After the manual operation of the inspection program is correct, the specific position of the laser on and off is determined according to the cleaning area of the workpiece to be processed on site. The robot outputs a delay pulse command to control the turning on and off of the laser.

Combined with the corresponding laser cleaning process, adjust the robot running speed to complete the laser cleaning of large workpiece. By using the above method, the laser cleaning of complex track surface on the curved surface of large components is realized. After adjusting the relevant laser cleaning parameters, the color effect of the workpiece substrate metal after cleaning is shown in FIG. 16.

![Fig. 16 Workpiece effect after cleaning (partial area)](image)

After cleaning, the effectiveness of the cleaning effect was verified. The workpiece was taken as shown in Figure 17. The surface elements and content before and after cleaning were detected, and the surface micro morphology after cleaning was detected. The results show that the paint layer on the surface of the workpiece can be effectively removed after laser cleaning.
Fig. 17 before and after cleaning

(a) Surface morphology after cleaning  (b) Surface morphology after cleaning

From the surface morphology analysis results as shown in Fig. 18, the sample surface is relatively flat after cleaning, and the cleaning effect is ideal.

The cleaning effect is determined by comparing the contents of Al, O and C before and after cleaning, as shown in Fig. 19. The surface element analysis and EDS scanning comparison of the samples before and after cleaning prove the cleaning effectiveness.

Fig. 18 morphology after cleaning

(a) Before cleaning  (b) After cleaning

Fig. 19 Surface elements of front and rear samples

Table 1 content of main elements on sample surface before and after cleaning

| element (WT%) | C | O | Al |
|--------------|---|---|----|
| Before cleaning | 37.9 | 30.6 | 0.9 |
| After cleaning | 8.7 | 8.3 | 81.5 |

As shown in Table 1, as long as the elements C and O are stripped from the substrate, the original color of the substrate is exposed, thus the aluminum content is significantly increased. The effect of laser cleaning is proved.

Compared with the robot off-line programming, the traditional teaching programming needs to adjust the posture of the laser cleaning head and measure the laser focal length at all times, so that the laser beam can keep perpendicular to the surface of the workpiece. This method has huge workload, tedious and poor effect, which fully proves the advantages of robot off-line programming.

8. Conclusion
Using hedracam software and 3D scanner, reverse modeling of large components and offline planning
of surface cleaning path are realized. According to the actual cleaning effect, the cleaning focal length is controlled within the error of ± 2mm, and the off-line programming method can obviously improve the position accuracy of laser cleaning track, and is not limited by the size of workpiece and the complexity of the track, which provides a technical means for laser cleaning of large-scale component surface and complex special-shaped surface.

However, it is worth mentioning that the accuracy of the workpiece model to be processed and the layout of the simulation environment will directly affect the off-line programming effect, and the off-line programming software ontology function and the proficiency of the application software will also have a certain impact on the programming effect. At the same time, the relevant cleaning process for different component surface materials also has a decisive role in the final experimental effect.

Therefore, the final effect of laser cleaning based on robot not only depends on the planning and control of offline trajectory, but also depends on the mature laser cleaning technology. Therefore, in order to get good laser cleaning effect, both skilled robot off-line programming and perfect laser cleaning technology are indispensable.

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