Design of spraying robot end actuator and experimental study on motion trajectory simulation

ChenZhang1*, XuewuXu1,2, GuopingWang1, JingMen1

1Mechanical Engineering, Xi’an Jiaotong University City College, Xi’an, Shaanxi Province, 710018, P. R. China
2Xi’an Jiaotong University Intelligent Robot Innovation Institute, Xi’an, Shaanxi Province, 710018, P. R. China
*Corresponding author’s e-mail:1620507728@qq.com

Abstract. This paper aims to design the end actuator of the spraying robot for the six-axis industrial robot with the GSK RB08 as an example, and carry out the planning and simulation of the end trajectory of the painting robot, and verify its effectiveness and feasibility. Firstly, based on the end size and technical parameters of the GSK RB08 robot flange, the structure of the end actuator is designed in combination with the spray gun installation size. Secondly, based on the NURBS interpolation algorithm, the industrial robot spray path is planned by UG and imported into RobotAssist for 3D simulation; Finally, the end actuator is physically installed and debugged. The planning path is imported into the GSK RB08 robot to demonstrate the effectiveness of the end actuator and the planned spray path, providing a solution for the optimization of the spray path.

1. Introduction
With the gradual improvement of industrialization and automation, the pollution and dangerous work like painting is gradually replaced by robots[1]. The use of industrial robot painting mainly has the following advantages: improved polishing quality, extended uptime, reduced paint consumption, significant cost and energy savings, rapid increase in productivity, and reduced surface unevenness caused by manual painting. It has been time-consuming and expensive to apply robotic motion by means of trial and error trials to apply a uniform thickness coating on the part[2, 3], so trajectory planning is critical in order to achieve desired paint thickness and uniformity[4-6]. The design of the end actuator of the spray robot and the experimental study of the trajectory simulation provide a high quality solution for the painting operation.

2. End actuator overall structural design
2.1 Selection and modeling of the spray gun
Since the spray gun is installed on the GSK RB08 industrial robot, the following points should be considered when selecting the spray gun: 1). It can be installed on the end of the robot; 2). The spray gun can be programmed to control the start and stop; 3). The composition is simple and stable. Good performance, easy to install and debug later; 4). Spray width and flow can be adjusted. Through the investigation to grasp the parameters of various types of spray guns and the later use, the WA-101 series automatic spray gun was finally selected. The model of the spray gun was
established in SolidWorks according to the parameters and dimensions of the spray gun as shown in figure 1.

![Figure 1. spray gun model](image)

2.2 *design scheme of end actuator structure of industrial robot*

This design is based on the GSK RB08 industrial robot. The designed end-mounting dimensions of the robot must meet the end-mounting requirements of the RB08 industrial robot, the dimensions of the end flange of the GSK RB08 industrial robot are shown in figure 2.

![Figure 2. GSK RB08 Industrial Robot End Flange](image)

At the beginning of the design, in order to unify the standard and be more standardized, the end fixture design was split into two parts, one part was the end coupling flange, one part was connected to the spray gun, and the end coupling flange was designed to be uniform.

In order to ensure the stability of the spray gun during the painting process, the spray paint and the path will not reversely interfere, so consider mechanical tightening, artificial replacement and clamping, to ensure the strength and the working stability of the spray gun. The structure of the clamp is symmetrically clamped. The flange chassis is designed to be rectangular and easy to connect with the end of the robot flange and the L-bracket. The connection is fixed by M6×20 screws and flanges. The bracket is designed as L-shaped. Symmetrical, both sides are symmetrical, the force is stable, the connection between the bracket and the flange base is fixed by the M3×20 screw, and the nut is fixed at the upper end of the L-shaped bracket, and a double-headed stud is used to pass through the bracket and the spray gun. Fix the hole, fix the position of the spray gun with the hex nut in the two sections of the bracket, and fix the spray gun with the screw below the spray gun hole, and ensure that the paint spray hole of the spray gun is in line with the center hole of the flange base to facilitate the planning and installation of the spray gun path, the structure diagram is shown in figure 3.
2.3 End actuator specific connector structure design

As shown in figure 2, there are four M6 deep 8 screw ports on the flange end connection port and a Φ6H7mm deep 8 positioning pin hole. We first design the diameter of the flange according to the size of the flange base joint. The initial flange base is Φ50mm, according to the threaded hole of the M6, the hexagon socket screw is also selected as the flanged set screw. In the end we chose to use the hexagon socket head cap screws of GB/T 70.1-2000.

As can be seen from figure 4, the center of the threaded hole of M6 is distributed on a circle of Φ40 mm concentric with Φ50mm. At the same time, according to the parameters of M6 in GB/T 70.1-2000, the hole punching simulation is carried out. It is found that the M6 screw head will follow the initial size of Φ 50mm flange base interference occurs, when processing the M6 screw hole damage the original flange base outer wall. Therefore, the size of the flange bottom should be increased to enhance the strength of the flange base to prevent damage during installation and use.

The countersunk hole is made on the flange base, since the maximum size of hexagon socket screw head depth is 6mm, and the maximum depth dimension of M6 on the flange of the RB08 is 8mm. If the thickness of the flange base is \( h \) mm, the length of the selection screw \( L \) is \( L \geq (h-8-6) \) mm. Therefore, the thickness of the flange base is \( 14 \leq h \leq (L+14) \). Refer to the \( L \) length selection given in GB/T 70.1-2000 for 8, 10, 12, 16, 20, 25, 30, etc. respectively. Since the flange base is subjected to countersinking treatment, the remaining thickness should be considered to ensure that the remaining thickness is sufficient to ensure the strength of the flange. The length of the final \( L \) is chosen to be 8 mm and the thickness of the flange is 14 mm < \( h \) < 26 mm. Finally choose \( h = 20 \) mm.

The GSK RB08 robot flange joint has Φ25H7 depth 10mm countersunk hole, so when designing the flange base, the corresponding clearance fit boss must be designed to ensure the rigidity and strength of the joint. At the flange connection, there is a Φ25mm height 4mm boss. Since the end flange is 95mm long and 50mm wide, there is enough space. Therefore, when designing the flange base, design a Φ25mm depth 3mm countersunk hole, and have a wrapping effect on the Φ25mm boss, and at the same time to improve the strength of the joint.

The design of flange base adopts universal coupling, which can save the number of fixing screws and has higher joint strength and stiffness. The initial cuboid size is 95mm×50mm×23mm (length×width×height), and the concave rectangle is connected with the bracket at both ends. After the above comprehensive consideration, the final design structure is shown in figure 4(a).
When designing the bracket, if a straight bracket is selected and the nozzle of the gun is aligned with the center of the flange, the size of the base connected to the flange below is larger, which may affect the installation of the gun tube and beautiful, inconvenient to use, the second is to increase the end load of the robot, so choose the L-shaped bracket. In order to ensure the strength is enough to install the spray gun, the bracket adopts a bilateral symmetrical structure with a width of 16 mm and a thickness of 10 mm. At the upper end, a hole with a diameter of 16mm is used for the installation of the jet. In terms of length, the design is 105mm, so that the bottom of the spray gun is slightly spaced from the base of the disc, which facilitates the fixed installation of the screw at the end of the base and the flange of the robot flange. The rectangular parallelepiped with a length of 21mm×16mm×10mm is fixedly connected to the concave base of the flange base, and its structure is shown in figure 4(b). Select the screw at the joint, and consider the wall thickness of the end joint. Because when the screw and nut are used for fixing, the joint between the screw head and the nut needs to be countersunk in advance. The size of the countersunk hole should be greater than or equal to the wall thickness, leave enough wall thickness for the joint. At the same time, when designing the position of the screw hole, the end of different models can be removed and installed later. For ease of installation, the position of the screw holes is relatively symmetrical and centered relative to the cuboid. The Phillips pan head screws of GB/T 818-2000 size M3 were finally selected. A rectangular parallelepiped extending 21 mm×16 mm×10 mm below the bracket is fixedly connected to the flange base recessed table.

3. Spray robot motion trajectory simulation

Based on the NURBS interpolation algorithm, the UG is used to plan the spray path of the industrial robot. The off-line programming path planning software supported by the GSK RB08 robot is UGNX8.0 and above. The motion trajectory simulation in this paper is based on UGNX12.0. Use SolidWorks software to build a real-sized box model, import it into UGNX12.0 for spray robot painting path planning, generate files, put it into the root directory of the GSK RB08 robot RobotAssist software, and then open RobotAssist software to import GSK RB08 robots model and the model corresponding to the actual scene are then simulated in the RobotAssist software. The motion trajectory is further optimized by verifying that the simulated path meets the requirements, thereby giving an optimal solution for the actual operation. The path planning process is shown in figure 5, which is simulated in RobotAssist software as shown in figure 6.
Create a 3D model using SolidWorks

Import UG for path planning

Import RobotAssist for motion path simulation

Whether the simulation path meets the requirements

Generate offline programming program

Import into the robot teaching box

Experimental demonstration whether the requirements are met

Figure 5. Path planning flow chart

Figure 6. Motion trajectory simulation

4. Spraying robot installation, commissioning and experimental research

4.1 End actuator installation
The end actuator connectors are 3D printed. The final assembly drawing is shown in figure 7. Since the gun is light in weight, only 0.5 kg, the strength of the connector is sufficient to support the painting operations.

4.2 Overall spray installation and commissioning
In the debugging of the spray gun, the 2/3-way solenoid valve is used to control the opening and closing of the spray gun, and the PRV is used to control the pressure entering the spray gun, and the air compressor provides the pressure required for the spray gun work.

The connection diagram of each component of the painting robot is shown in figure 8. The specific connection method is as follows:

a). The air compressor and the solenoid valve are connected by a gas pipe, and the solenoid valve is connected with one end of the gas pipe and the two PRVs, and the other end of the two PRVs is connected with the CAP port and the CYL port of the spray gun.

b). The feedstock end of spray gun is connected to the water pump through the pipeline, and the water pump is completely immersed in the water.

c). Connect the solenoid valve terminal to the I/O in the robot control cabinet, and control the on/off of the solenoid valve by programming.

d). Connect the design connector to the spray gun and the end flange of the robot, and fix it into one by using standard parts.

4.3 Feasibility verification
After the components were installed and debugged, the experimental demonstration is shown in figure 9, we verified the following work:

a). The spray gun can spray paint normally, and the spray paint adjustment button can control the spray paint amount.

b). The solenoid valve is connected to the robot I/O port, and the start and stop of the painting work can be controlled by programming.
c). The size and stability of the intake air can be controlled by the air pressure reducing valve.

d). End actuator can be installed and fixed with the robot flange, and the structure is reasonable.

e). The end actuator is strong enough to clamp the gun and ensure that the center of the nozzle and flange are in a straight line.

f). Offline programming allows the spray gun to paint according to a predetermined trajectory.

5. Conclusion
The mechanical spray gun fixture designed in this paper is relatively simple, the design is reasonable, the fixture is simple to process, which can meet the requirements of clamping the spray gun and installed at the end of the robot flange. The industrial robot spraying path planned by UG is imported into the RobotAssist, the 3D animation simulation shows the simulation process intuitively and effectively. The spray gun and the end actuator are physically installed and debugged, and the UG planned path is imported into the GSK RB08 robot for painting experiments to verify the rationality of the entire structure and the feasibility of the painting operation.

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