Design and Implementation for Multi-station Rotary Robotic Polishing System

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Abstract. In order to improve productivity and to solve the Potential shortage of skilled workers in polishing manufacturing, a new type multi-station rotary polishing robot was proposed. This robot mechanical structure was discussed in some detail. The kinematics of this robot was analyzed and the approximate workspace was obtained by Monte Carlo method. The workspace of this robot can meet the most products polishing requirement. a Master-slave control system (M/S) was designed to achieve the function of this polishing robot, Hardware and software structure of control system was discussed, An online teaching programming system for the system to generate the desired polishing path data was introduced simply in this paper, In order to evaluate the performance of the polishing robot system, a polishing experiment of faucet was done and it shows that the system reached design requirements

Introduction.

Polishing is a very important means of post-finishing processes. The existing polishing process is mainly applied to the out circle, inner circle and the plane parts with simple geometric shape, but for complex surfaces is powerless. These polishing is only by manual work. The polishing robot system can greatly reduce labor intensity, improve processing quality, consistency, and shorten product cycle [1~4].

Robot polishing system is integrated by the workpiece clamping system, polishing tool system, sensors and controllers. It can significantly improve production efficiency, process quality assurance, reduce production costs. complex surface robotic polishing can guarantee the workpiece surface quality and geometric precision ,so it is better than conventional mechanical polishing, especially in the complex shape of the workpiece surface polishing field has irreplaceable advantage[5~8].

Grinding and polishing process automation is an important development direction of grinding and polishing technology, the robot is a major breakthrough in the grinding and polishing process. Germany, Italy, Finland and other countries have developed commercial robotic grinding and polishing systems[9~10].

In our country the use of robotic polishing system for complex surface finishing is still in its infancy, research to improve the level of automation in manufacturing, and has important significance. Robot polishing system organically combines robotics, information technology and production technology, to improve China's aerospace and automotive fields the level of processing of complex surface parts has important practical significance. Recent studies on robotic polishing are focused on structural optimization, polishing force control[1~14].in order to improve robot polishing efficiency, complete machining process of workpiece from rough to finish machining, a multi-station rotary polishing robot was proposed in this paper.

Robot mechanical structure.

Robot polishing system mechanical structure is divided into two parts, one part is a middle rotary table which is planetary structure with 4 mounting stations to hold faucet to be polished, and the other part is the part of the polishing wheel robot which with 4 degrees of freedom (DOF) robot structure. There are 3 polishing wheel robot uniformly distributed around the rotary table, is shown in Fig.1.it can be used to polish 3 faucet simultaneously. The extra mounting stations is used for loading and unloading station. This structure robot can not only simultaneously be used to polish the same kind of workpiece with the same process but also can be used to process a workpiece in accordance with the different processes to complete a workpiece from rough machining to finish machining. The rotary table Rotate 90 degrees after workpiece was completed a process of processing on a station, then the workpiece come to the next station for the next process.

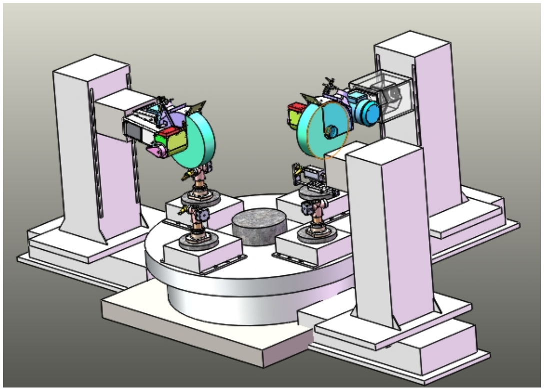


Fig.1 polishing robot structure

The main technical requirements of the polishing robot is shown in Table 1：

Table1 Main performance requirements of polishing robot

Workpiece to be machined	Faucets		
Number of stations	4	The number of workpiece Clamped in each station	1or 2
Station arrangement	Ring (Rotatable station)	rotating platform diameter	1600mm
Polishing wheel speed	750-1500rpm		
Polishing force range	50N~400N		
Workpiece length	110mm		
Fixture length	100mm		
Polishing wheel width	150mm		
Polishing wheel diameter	300mm-600mm		
Vibration requirements	30mm~60mm(adjustable)	Polishing wheel vibration frequency	0.5-4Hz

Each DOF motion parameters are shown in Table 2

Table 2 Each DOF motion parameters

DOF	Motion range	Position accuracy	Rated speed	top speed	Maximum acceleration
X	900mm	±0.01mm	0~0.25m/s	0.5m/s	$1.5m/s^2$
Y	950mm	±0.01mm	0~0.25m/s	0.5m/s	$1.5m/s^2$
Z	800mm	±0.01mm	0~0.2m/s	0.3m/s	$1.2m/s^2$
A	0° -270°	$\pm 3'$	0~12rpm	15rpm	$90^\circ /s^2$
B	-360° -+360°	$\pm 4'$	0~30rpm	40rpm	$120^\circ /s^2$
C	-360° -+360°	$\pm 4'$	0~30rpm	40rpm	$120^\circ /s^2$

Each DOF is shown in Fig.2, it can be seen that the polishing wheel robot has X, Y, Z, A total 4 DOF and the clamping position on the rotary table has B, C 2DOF.

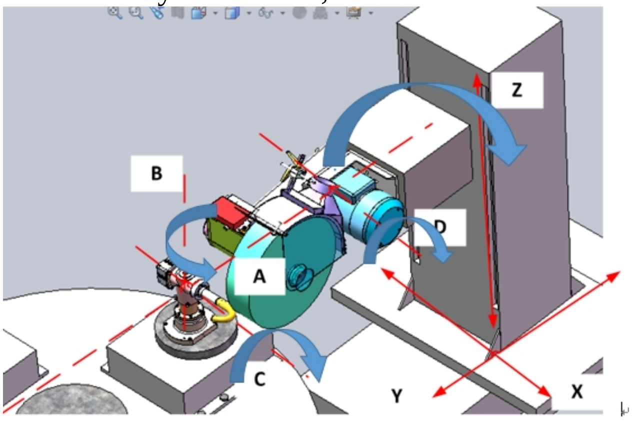


Fig.2 6 DOF

Kinematics and workspace analysis. Robot coordinate system is shown Fig.3, this robot D-H parameters is shown in Table 3

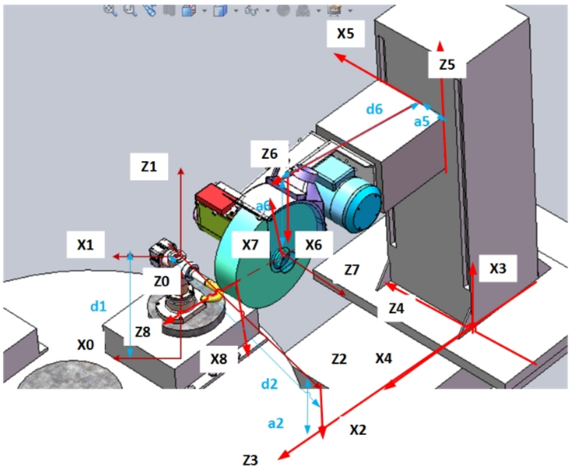


Fig.3 Robot coordinate system

Table 3 D-H parameters

DOF	a_{i-1}	α_{i-1}	d_i	θ_i
0	0	0	0	0
1	0	0	d1=310	θ_1
2	0	90°	d2=0	θ_2
3	a2=500mm	90°	X	90°
4	0	-90°	Y	90°
5	0	-90°	Z	-90°
6	a5=0mm	90°	d6=985	θ_3
7	a6=0mm	90°	0	θ_4
8	0	90°	R(150-300)	0

Each joint variable's range is shown in following table 4

Table 4 joint variable's range

joint variable	Min	Max
θ_1	0	2π
θ_2	0	2π
X	0	900mm
Y	0	950mm
Z	0	800mm
θ_3	$-\pi/3$	$\pi/3$
θ_4	$2\pi/3$	$330*\pi/180$

Robot kinematics analysis. According to the DH parameters of the robot, the kinematics equation of the robot is obtained as following Eq.1

$$
{}^{0}_{8}T = {}^{0}_{1}T\ {}^{1}_{2}T\ {}^{2}_{3}T\ {}^{3}_{4}T\ {}^{4}_{5}T\ {}^{5}_{6}T\ {}^{6}_{7}T\ {}^{7}_{8}T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)
$$

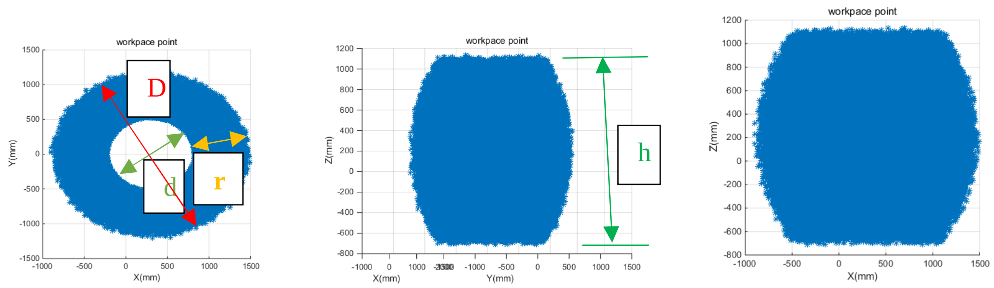
In Eq .1

$$
\left\{\begin{aligned}
& n_x = c_1 s_2 s_4 - c_4(s_1 s_3 - c_3(s_1 + c_1 c_2)) \\
& n_y = c_4(c_1 s_3 - c_3(c_1 - c_2 s_1)) + s_1 s_2 s_4 \\
& n_z = c_3 c_4 s_2 - c_2 s_4 \\
& o_x = c_3 s_1 + s_3(s_1 + c_1 c_2) \\
& o_y = -c_1 c_3 - s_3(c_1 - c_2 s_1) \\
& o_z = s_2 s_3 \\
& a_x = -s_4(s_1 s_3 - c_3(s_1 + c_1 c_2)) - c_1 c_4 s_2 \\
& a_y = s_4(c_1 s_3 - c_3(c_1 - c_2 s_1)) - c_4 s_1 s_2 \\
& a_z = c_2 c_4 + c_3 s_2 s_4 \\
& p_x = a_5(s_1 + c_1 c_2) - R(s_4(s_1 s_3 - c_3(s_1 + c_1 c_2)) \\
& + c_1 c_4 s_2) - Z s_1 + d_2 s_1 - a_6(s_1 s_3 - c_3(s_1 + c_1 c_2)) \\
& + Y c_1 c_2 + a_2 c_1 c_2 + X c_1 s_2 + d_6 c_1 s_2 \\
& p_y = R(s_4(c_1 s_3 - c_3(c_1 - c_2 s_1)) - c_4 s_1 s_2) - a_5(c_1 - c_2 s_1) + Z c_1 \\
& - d_2 c_1 + a_6(c_1 s_3 - c_3(c_1 - c_2 s_1)) + Y c_2 s_1 + a_2 c_2 s_1 + X s_1 s_2 + d_6 s_1 s_2 \\
& p_z = d_1 + R(c_2 c_4 + c_3 s_2 s_4) - X c_2 - d_6 c_2 + Y s_2 \\
& + a_2 s_2 + a_5 s_2 + a_6 c_3 s_2
\end{aligned}\right\} \quad (2)
$$

In Eq.2 s_i means $\sin\theta_i$, c_i means $\cos\theta_i$.

Work space analysis. The workspace of the robot can be analyzed by analytic method, numerical analysis method and geometric method and so on, although the kinematic equation of the robot is given, it's still very difficult to get the workspace use analytical method and geometrical method intuitively. Therefore, Monte Carlo method was used to analyze the reachable workspace of the robot.

By taking 100000 data to calculate the X, Y ， Z coordinates of the end of the robot, the workspace point distribution projection is shown in Fig. 4. It can be seen that the reachable workspace of this robot is a ring.



(a)X-Y plane projection (b) Y-Z plane projection (c) X-Z plane projection

Fig.4 workspace point scatter

This robot reachable workspace is shown in table 5. It can be seen that this robot's reachable workspace is much larger than the size of the workpiece.so this robot can be sure to complete the assigned workpiece polishing.

Table 5 reachable workspace range

workspace	（mm）
The inner diameter of the ring(d)	1000
The outer diameter of the ring(D)	2000
The diameter of the ring(r)	500
The height of the ring (h)	1600

Control system design.

According to the mechanical structure of the robot the robot control system is designed to Master-Slave structure

Hard ware structure. Hard ware structure is shown in Fig.5. CAN bus is used to communication between master and slave system, All motors are also controlled by bus. Slip Ring was used in rotary table to transfer power and control signals between M/S systems.

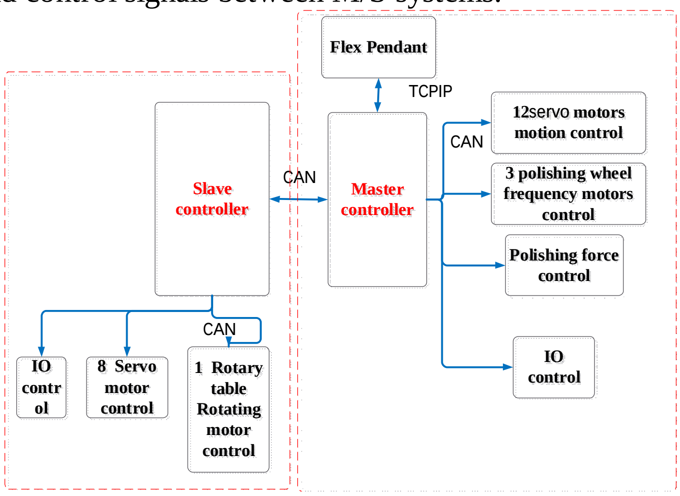


Fig.5 control system structure

Software structure. Software structure is shown in Fig.6.acord to this structure developed control software and teaching software.

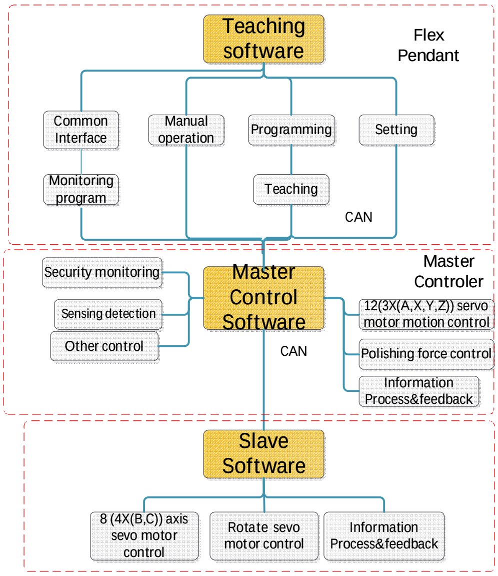


Fig.6 Software structure

Experiment.

The workpiece after this polishing robot machining is shown in Fig.7, it can be seen the polishing effect is good.

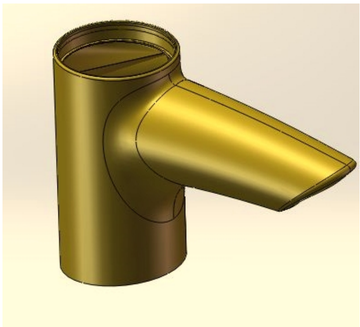


Fig.7 the workpiece after polished

Conclusion.

The following conclusions are drawn:

- Design a new structure robot used to polish faucet.
- This polishing robot has a big working space and good flexibility.
- The control system of this robot has been designed.
- This robot with good polishing effect after experiment has been verified.

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