Multi-robot Automatic Production Line

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Abstract. In order to make better research on the intelligent manufacturing process, the automatic production line based on multiple industrial robots is introduced. Firstly, the production line is constructed, and then the composition of each module in the line is described. Secondly, taking one of the six-axis robot as an example, the kinematics is analyzed with D-H method. The trajectory of the robot is planned and stimulated with the hybrid curve method as well as Matlab Robotics Toolbox. Finally, the communication and control process of the system is addressed.

1. Introduction

In manufacturing line, the processing and assembly of the products play an important role. However there are still some products processed manually, which bring the problems such as low efficiency, low qualification rate, and poor environment [1]. With the development of more new technology, industrial robots are widely applied in automatic production line which can solve those problems while meeting the requirements of production tasks. The application of industrial robot in the production line of motor shell is introduced [2]. Industrial robot applications based on intelligent manufacturing production line is proposed [3]. Automatic production line training system is controlled by PLC [4]. In this paper, the automatic production line based on multiple industrial robots is designed. The workpieces are transpoted, detected, polished and assembled by the industrial robots. The production line is controlled by PLC (Programmable Logic Controller) and HMI (Human Machine Interface). Through networked communication of PLC, touch screen, robot and the others, the human-machine interaction and real-time monitoring of the equipment can be carried out to realize the intelligent processing of the products.

2. Composition of multi-robot automatic production line

According to the processing, the automatic production line is composed of six modules and four industrial robots. PLC is taken as the control core by the control system of the line, and the network control is realized between the modules. The pneumatic control is adopted for the actuators of each module.

2.1. Feeding module & discharging module

The first module of the automatic production line is the feeding module. The workpieces are supplied by the feeding module, which comprises a frame, a sliding platform, the pallet support mechanism, a three-color alarm lamp, etc. The pallet support mechanism has two layers, and twelve workpieces per layer. When the workpieces on the upper pallet are emptied by the robot, the upper pallet is moved out as well as the lower pallet is moved in until all workpieces are transported. Three-color alarm light indicates
material shortage, pause or alarm. The discharging module is the last module. The structure and function of the discharging module are the same as the feeding module.

2.2. Conveying & detecting module
The conveying & detecting module mainly carries out sorting and conveying workpiece, including the conveyor belt, the cylinders, the waste chute, the sensors, etc. The middle and the end of the conveyor belt are respectively equipped with the photoelectric sensors to detect whether there are workpieces. The end effector of the robot is also equipped with the sensors to detect workpieces. One of the cylinders is used to intercept the subsequent workpieces, so as to avoid interference between the subsequent workpieces and the workpiece under detection.

2.3. Polishing module & assembly module
The polishing module is composed of a polishing table, the sensors, a vacuum generator and the like. When the sensors on the polishing table has detected there is workpiece, the robot polishes it and then moves it to be assembled.

The assembly module includes an arranging machine, the fixing device, the spring clip feeding mechanism, etc. The sensors on the array machine is used to detect whether the workpiece is placed on the assembly position, and then the cylinders is drived to fix the workpiece. The spring clip feeding mechanism ejects the parts to be assembled, and the robot installs the parts on the workpiece.

2.4. Operation module
The operation module consists of a frame, a touch screen, etc. When the line is powered on and the devices are in standby state, the condition of each working module is monitored and checked by the operation module. If there is any module that is not in the original position state, the module can be operated separately and returns to the initialization state. After the line is started, the whole equipment is in the running state, and the working condition and progress of each module are monitored through the touch screen.

Industrial robots in operation are very dangerous equipment, so two safety measures are designed: emergency stop switch and safety fence. If the fence is opened when the robot is working, the door switch signal will alarm and the production line will stop to ensure personnel safety.

The design of the automatic production line is shown in Fig. 1. The first is operation module, the second is feeding module, the third is robot I, the fourth is conveying & detecting module, the fifth is robot II, the sixth is polishing module, the seventh is robot III, the eighth is assembly module, the ninth is robot IV, the tenth is discharge module, the eleventh is safety fence, and the twelfth is 12-control box.

![Figure 1. 3D model of automatic production line.](image-url)
3. Industrial robot

Industrial robot has similar functions as human arm, which can transport, polish and assemble the workpieces along the planned trajectory. Different end effectors are designed for the robots, which respectively realize the requirement of each module. Two kinds of robots are used in the line. One is scara robot, the other is the six axis robot. Take one of the six axis robots as the example for study in this paper.

3.1. Kinematics analysis

The analysis of robot kinematics is the basis of research on robot control. The D-H method is often used to analyze the kinematics of the robot. The rod coordinate system at each joint is established by D-H method, and then the relationship between this joint rod coordinate system and the previous one is shown. There are four parameters of each rod, the link length $a$, the link offset $d$, the link torsion angle $\alpha$ and the joint angle $\theta$. The position and attitude of the end effector can be determined by transformation matrix of coordinate system. The established coordinate system is shown in Fig. 2.

![Figure 2. Robot coordinate system distribution.](image)

The D-H parameters of the robot are shown in Table 1. The D-H matrix of the link $A_k$ is shown in formula (1), then the relationship between the coordinate system of the sixth rod and the $k$-th rod is given by formula (2). The position and attitude of the end effector is obtained from the formula (3), which is forward kinematics.

| Link | $\alpha$ | $a$ | $d$ | $\theta$ |
|------|---------|-----|-----|---------|
| 1    | 0       | $a_1$ | $d_1$ | $\theta_1$ |
| 2    | 0       | $a_2$ | 0   | $\theta_2$ |
| 3    | 90°     | 0   | 0   | $\theta_3$ |
| 4    | -90°    | 0   | $d_4$ | $\theta_4$ |
| 5    | -90°    | 0   | 0   | $\theta_5$ |
| 6    | 0       | 0   | $d_6$ | $\theta_6$ |

Given the position and attitude of the end effector, it is inverse kinematics to find all the joint angles of the robot corresponding to the position and attitude. The joint angles $\theta_1$ is given by formula (4). The joint angles $\theta_2$-$\theta_6$ can be solved by analogy[5].
\( \mathbf{A}_k = \begin{bmatrix} c\theta_k & -s\theta_k c\alpha_{k-1} & s\theta_k s\alpha_{k-1} & \alpha_{k-1} c\theta_k \\ s\theta_k & c\theta_k c\alpha_{k-1} & -c\theta_k s\alpha_{k-1} & \alpha_{k-1} s\theta_k \\ 0 & s\alpha_{k-1} & c\alpha_{k-1} & d_k \\ 0 & 0 & 0 & 1 \end{bmatrix} \)  

\( k^{-1}T_0 = A_k A_{k+1} ... A_6 \)  

\( T = A_1 A_2 A_3 A_4 A_5 A_6 \)  

\( A_1^{-1}T = A_2 A_3 A_4 A_5 A_6 \)  

3.2. Trajectory planning

In order to make the robot moves smoothly along the specified trajectory according to certain position and attitude in joint space, it is necessary to plan the trajectory of the robot. At present, the ideal trajectory planning is the hybrid curve method which is characterized by the middle line segment of the velocity curve being a straight line, and the line segments on both sides are acceleration and deceleration curve respectively. The function of the trajectory is \( S(t) \) [5]:

\[
S(t) = \begin{cases} 
S_0 + 1/2 \hat{S} t^2 & 0 \leq t \leq t_b \\
S_b + \hat{S} t_b (t - t_b) & t_b \leq t \leq t_f - t_b \\
S_f - 1/2 \hat{S} (t_f - t)^2 & t_f - t_b \leq t \leq t_f 
\end{cases}
\]  

subject to:

\[
\dot{S} \geq 4(S_f - S_0)/t_f^2
\]

The velocity of linear segment could be adjusted for making the robot run at the maximum velocity for the longest time. Matlab Robotics Toolbox is used to simulated the hybrid curve planning of the robot. Three kinds of velocity are selected. The first is normal velocity, the second is 0.16, the third is 0.23, which are superimposed in the curves of joint position \( S \), velocity \( \dot{S} \) and acceleration \( \ddot{S} \) respectively, and then displayed in Fig. 3. It can be found that when the velocity of the straight line segment increases, the time occupied by this part decreases. Therefore the velocity must be adjusted in accordance with necessity, and cannot change arbitrarily [6].
4. Control system

4.1. System communication

It is necessary to study the control system of the production line and the robot if we want to run the production line. The motion control card of each robot performs calculation according to the spatial position. It calculates the angle of each axis to be moved, and then issues the position control command to the corresponding servo driver. The movement of the servo motors is controlled by the servo drivers according to the position control instruction. The overall coordinated movement of the servo motors achieve the requirements of the position and attitude. The remote IO card can communicate with PLC and control the corresponding load, such as the second, the third and the fifth axis brake relays of the robot, solenoid valves, and so on.

According to the controlling requirement of the production line, the control mode of “PLC+HMI” is adopted. As the host computer, the touch screen is mainly responsible for writing data and receiving real-time collected data. The slave computer is PLC, which control the robots and the other devices. There are four PLCs in this system, therefore the communication mode based on RS-485 serial communication is applied, namely one master station and three slave stations. The control system architecture is shown in Fig. 4.
4.2. Design of the control process
The production line can be selected by manual mode or automatic mode. After the automatic mode is activated, the robot I picks up the workpieces from the feed module and places the workpieces on the conveyor belt. After the workpiece arrives the position of the belt end, the blocking cylinder extends to block the subsequent workpieces. The robot II starts to detect automatically. If the workpiece is not qualified, the robot II will transport it to the waste chute. Otherwise it will be sucked to the polishing table. The robot III starts to polish. After polishing, the robot III carries the workpiece to the assembly module, and then returns to the safety point of the polishing module, waiting for the next polishing and transportation. At that time, the arranging machine sends out the part, which is sucked and installed on the workpiece by the robot IV, and then the assembled product is sucked to the discharging module. The control flow chart is shown in Fig. 5. The production line has been applied and implemented, as shown in Fig. 6.

Figure 4. Control system architecture.
5. Conclusion
The automatic production line is addressed which is composed of four industrial robots and supporting equipment in the paper. The composition of the production line is analyzed. The kinematics of the six-axis robot is studied by D-H method. Furthermore, the hybrid curve planning is used to adjust the velocity and acceleration of industrial robot in the joint space. Finally, the control system of the production line is designed. After implementation, it shows that the production line has strong openness, expansibility, easy maintenance and long-term stable operation, which has realized the automation and unmanned production.
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References
[1] A.J. Tang, J.C. Zhu, Development & Application of Robotic Sanding for Mobile Phone Shell, Mechanical & Electrical Engineering Technology, 47(2018):24-26.
[2] Y.J. Luo, J. Zhang, Y.H. Ning, D.X. Pu, Application of industrial robot in the production line of motor shell. Modern Manufacturing Engineering, 12 (2017):48-53.
[3] J. Xiong, Industrial Robot applications based on intelligent manufacturing production line. MACHINE TOOL & HYDRAULICS, 46(2018):91-94.
[4] N. Liang, J. Xiao. Design of Automatic Production Line Training System Based on PLC. Sensors & Transducers, 155 (2013): 271-277.
[5] M. Tan, D. Xu, Z.G. Hou, S. Wang, Z.Q. Cao, Advance Robot Control, first ed., Higher Education Press, Bei Jing, 2012.
[6] P. Corke, Robotics, Vision and Control: Fundamental Algorithms in Matlab, first ed., Springer-Verlag Berlin Heidelberg, Belin, 2011.