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Research on Pneumatic Manipulator Control Methods

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Abstract: With the rapid development of pneumatic technology, there has been an increasing focus on leveraging pneumatic manipulator equipment that offers a blend of affordability, high performance, and numerous advantages, catering to the diverse needs of modern production practices. Pneumatic manipulators stand out among controlled manipulators due to their cost-effectiveness, straightforward design, impressive power-to-volume ratio, environmentally friendly operation, and robust resilience to external interference. This paper delves into addressing significant control deviations encountered during the dynamic movement of pneumatic manipulators, aiming to optimize the manipulator's structure and devise an efficient pneumatic system circuit. Additionally, it harnesses PLC control technology to devise a comprehensive control ladder diagram for the pneumatic manipulator, thereby ensuring precise control over its motion. By validating the feasibility and accuracy of the designed motion control methods, this study contributes to enhancing the overall efficiency and reliability of pneumatic manipulator systems in industrial settings.

Keywords: Robotic Arm; Pneumatic Control; Programmable Logic Controller (PLC)

Introduction

The application of robotic arms in industrial automation has become widespread. Due to variations in industrial distribution across different countries and the diverse demands for robotic arms in various industries, their utilization varies accordingly. Robotic arms are primarily employed for tasks that are either impractical or time-consuming for human workers[1]. They offer advantages in terms of precision and durability, reducing unforeseeable human errors. Since the invention of the first industrial robot, their applications have expanded beyond traditional industries such as automotive, mold manufacturing, and electronics processing, to include sectors like agriculture, healthcare, and service industries[2]. Reference [3] adopts PID and ESO control methods to achieve nonlinear control of the motion tracking trajectory of pneumatic manipulators. The feasibility of the control algorithms was validated on the MATLAB simulation platform. Reference [4] designs a suction cup-based pneumatic manipulator controlled by PLC. Through the construction of a comprehensive drive system and control system, the material handling actions of the pneumatic manipulator are achieved. Reference [5] utilizes PLC control technology and rotary encoders to achieve precise position control of reciprocating pneumatic manipulators.

After analyzing the performance of pneumatic manipulators in this study, the design of the manipulator's structure is conducted. Subsequently[6], the pneumatic control system of the manipulator is designed, followed by the completion of PLC software programming. This provides a feasible solution for pneumatic manipulators[7].

1. Related Work

The robotic arm primarily consists of actuation mechanisms, drive systems, control systems, and position detection devices. The interrelationships between these systems are illustrated in the block diagram shown in Figure 1.

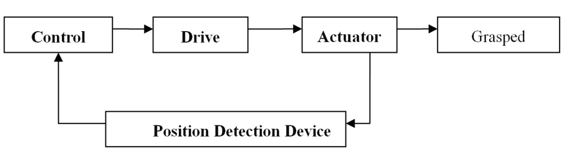

Figure 1: Block Diagram of Robotic Arm Components

Actuation Mechanisms: The actuation mechanisms of the robotic arm include components such as the hand, wrist, arm, and column. These components work together to enable the movement and manipulation of the robotic arm[8]. The hand serves as the end effector of the robotic arm, responsible for interacting with objects in the environment. The wrist allows the robotic arm to rotate and orient the end effector for precise positioning and manipulation tasks. The arm forms the main body of the robotic arm, providing structural support and housing the actuators responsible for its movement[9]. The column provides vertical support for the arm and may include additional actuators or mechanisms for lifting or adjusting the height of the arm. These components work collectively to enable the robotic arm to effectively perform various tasks[10].

2. Hand and Wrist Structure Design

The hand design for the robotic arm is specialized for efficient handling of rod-shaped workpieces, featuring a clamping-type hand with gear rack transmission for effective gripping. Key considerations include optimizing gripping force, finger movement angle for smooth handling, accurate positioning for different workpiece shapes, and maintaining structural strength and rigidity, while keeping the design simple and compact to accommodate cylindrical workpieces. The wrist, connecting the hand and arm, adjusts the workpiece orientation with independent degrees of freedom to meet complex motion requirements. To grip horizontally placed workpieces, the wrist must rotate around the x-axis, typically achieved with a rotary cylinder for its compact structure, although it has a rotation angle smaller than 360° and requires strict sealing. Driving torque for wrist rotation must overcome inertia, friction at pivot points, and imbalance torque. The Assembly Diagram of Hand and Wrist as shown in Figure 2.

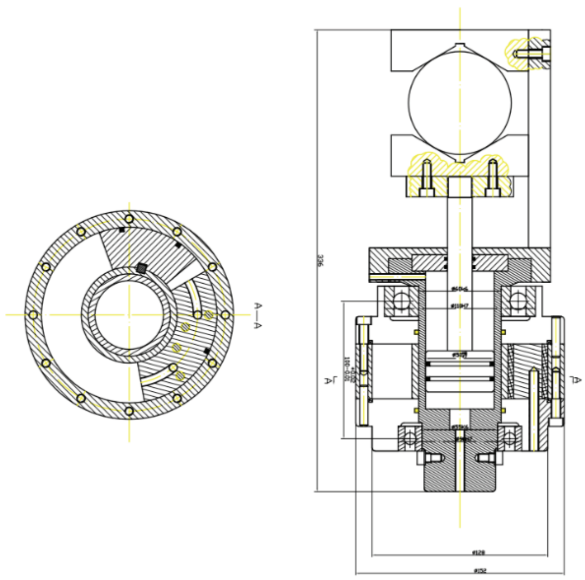

Figure 2: Assembly Diagram of Hand and Wrist

3. Pneumatic System Design

The schematic diagram shown in Figure 3-1 illustrates the working principle of the pneumatic transmission system for this robotic arm. Its air source is supplied by an air compressor (with a pressure of approximately 3 to 8 Kgf/cm2), entering the air reservoir via quick-change connectors. The compressed air passes through a water separator filter, pressure regulator valve, and oil mist lubricator before reaching the electromagnetic valves on parallel air circuits, thereby controlling the actions of the cylinders and the hand. The Schematic Diagram of the Pneumatic Transmission System for the Robotic Arm as shown in Figure 3.

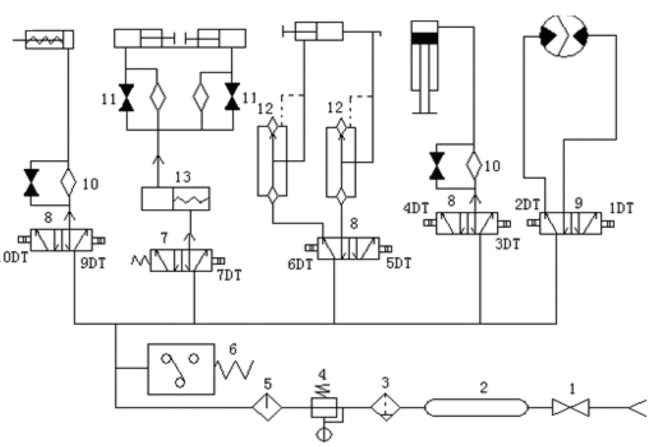

Figure 3: Schematic Diagram of the Pneumatic Transmission System for the Robotic Arm

4. PLC Control System

4.1 Input/Output Point Allocation

To implement control logic for a robotic arm using a PLC controller like the FX2N-64MT, efficient allocation of input and output points is crucial. At least 10 input points are required, including start and stop buttons, along with eight control switches for specifying actions like movement and gripping. Four output points are needed to control motion actuators, enabling precise execution of arm movements. This setup ensures seamless integration and reliable operation, facilitating precise and efficient control of the robotic arm. The Input/Output Point Allocation Table as shown in Table 1.

Table 1 Input/Output Point Allocation Table

Input			Output		
Device Code	Address Table	Function Description	Device Code	Address Table	Function Description
Switch 1	0	Start button			
SQ1	1	Arm forward movement cylinder switch	YV4	Y4	Arm left movement
SQ2	2	Arm backward movement cylinder switch			Arm right movement
SQ3	3	Arm downward movement cylinder switch	YV5	Y5	Arm ascend
SQ4	4	Arm upward movement cylinder switch			Arm descend
SQ5	5	Arm clockwise rotation cylinder switch	YV6	Y6	Counter-clockwise rotation
SQ6	6	Arm counterclockwise rotation cylinder switch			Clockwise rotation
SQ7	7	Robotic hand relax cylinder switch	YV7	Y7	Clamp
SQ8	10	Robotic hand clamp cylinder switch			Relax
Switch 2	11	Stop button			

4.2 Program Design for PLC-Controlled Robotic Arm

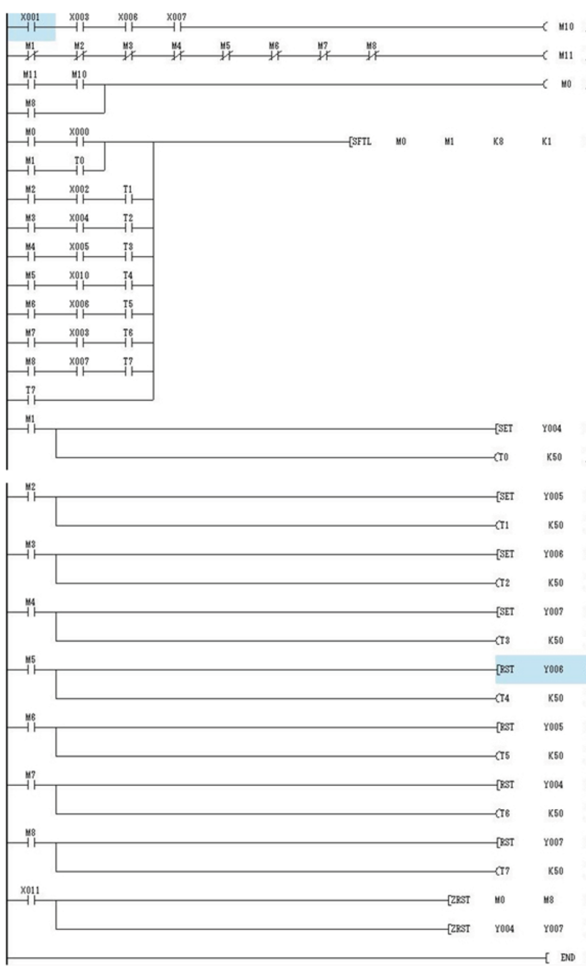

Figure 4: PLC ladder diagram

The ladder diagram, a graphical programming language, describes logic control systems. In PLC-controlled robotic arm applications, it depicts actions, states, and logic governing operations. For example, pressing start initiates actions until stop or conditions are met. Designing the ladder diagram involves connecting logic elements based on specific control logic, including inputs (buttons, switches), outputs (motion control), and intermediate logic (sequential, conditional). Each element serves specific functions like activating outputs or performing conditional checks. The PLC ladder diagram as depicted in Figure 4.

5. Conclusion

This study addresses significant control deviations in pneumatic manipulators' dynamic movement by proposing structural optimization and designing corresponding pneumatic system circuits. PLC control technology is utilized to construct a ladder diagram, enhancing motion control precision, stability, and reliability. Validating the designed motion control methods lays a foundation for efficient pneumatic manipulator motion control. These findings offer valuable insights for optimizing and improving pneumatic manipulators, with future efforts aimed at enhancing performance to meet evolving production needs.

References

[1] Hao, F. (2018). Design of Precise Position Control System for Pneumatic Manipulator Based on PLC[J]. Machine Tool & Hydraulic, 46(11), 79-81.

[2] Wang, H., Hu, G., & Zhou, Q. (2012). Design and Research of Pneumatic Manipulator Control System Based on PLC[J]. Hydraulic and Pneumatic, (9), 38-40.

[3] Wang, W., & Hu, C. (2018). Simulation Analysis and Experimental Study of Pneumatic Manipulator Control Based on PID+ESO Controller[J]. Hydraulic and Pneumatic, (5), 107-113.

[4] Li, W., Feng, Y., & Zhang, J. (2016). Design of Suction Cup Pneumatic Manipulator Controlled by PLC[J]. Hydraulic Pneumatics & Seals, 36(12), 35-38.

[5] Li, J. (2015). Design of Precise Position Control System for Reciprocating Pneumatic Manipulator[J]. Machine Tool & Hydraulic, 43(3), 89-91.

[6] Chen, Q., Feng, Y., & Li, W. (2018). Design of Pneumatic Manipulator Based on Single Chip Microcomputer Control[J]. Hydraulic Pneumatics & Seals, 38(2), 59-61.

[7] Dong, S., Wu, G., Geng, D., Wang, J., & Wang, M. (2017). Design of Pneumatic Manipulator Control Experimental System[J]. Laboratory Research and Exploration, 36(11), 77-81.

[8] Tang, S. (2016). Design of Pneumatic Manipulator Control System Based on PLC[J]. Mechanical Design & Manufacturing Engineering, 45(5), 51-53.

[9] Liu, R., Tong, L., Gong, G., Xu, Y., & Ren[J]. Fault Diagnosis Method of Composite Power System Based on UDS Protocol. Laboratory Research and Exploration, 38(5), 4-7.

[10] Zhang, P. Design of Pneumatic Manipulator Control System Based on PLC[D]. Chengdu: University of Electronic Science and Technology of China, 2013.