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Design of a small material handling robot gripping and storage system

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Design of a small material handling robot gripping and storage system

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Abstract - This paper completed the development status and working principle of the handling robot, analyzed the performance index parameters and system functional requirements of the robot, and proposed an overall design scheme of the handling robot control system. The mechanical structure design of the handling robot was developed, and the selection of the core components of the system was studied and designed in detail based on theoretical analysis and calculation. Secondly, this paper selected the STM32 microcontroller as the core of the handling robot. It completed the circuit schematic diagram of the systems, and investigated the selection of core sensors for the navigation and positioning module, obstacle avoidance module, and wireless communication module. Finally, this paper studied the automatic control part of the handling robot, which mainly included the modeling of the robot's manipulator, PID control, and MATLAB simulation verification. In addition, the application prospect of the handling robot was explored. It had the advantages of high efficiency, strong practicability, and perfect function, and had certain practical significance in the application of the logistics industry.

1. INTRODUCTION

With the gradual improvement of the national policy on industrial automation, worldwide industrial development is gradually showing the trend of automation and intelligence. In recent years, the development of national strategic emerging industries has been implemented and improved, and the e-logistics industry has been developing rapidly due to the rise of networks and e-commerce. With this, more automation equipment has been applied in the logistics field to make transportation and handling efficient and fast [1].

Automated Guided Vehicle (AGV) is a kind of handling machine used for equipment handling and assembly automation. Traditional handling robots must lay guide belts on the ground, making it difficult to meet the corresponding performance requirements when the logistics warehouse environment and logistics storage process change at the same time. The traditional AGV has the characteristics of towing, forklift, large volume, and wide road surface, which cannot meet the current logistics and storage conditions[1].

In 2021, at the fourth session of the 13th National People's Congress, the Ministry of Industry and Information Technology officially announced the "14th Five-Year Plan for the Development of National Strategic Emerging Industries" to further promote green and intelligent manufacturing, develop new service production models, and promote high quality and intelligence of green production. As shown in Figure 1, the establishment of intelligent production demonstration bases and the improvement of intelligent production standard systems have led to the increasing expansion of the mobile robot market. It can be seen that the mainstream direction of future development will shift to automation in the logistics industry[2].

In summary, the use of material handling robots in the logistics industry has played a positive role in reducing logistics sorting, loading, and unloading costs, reducing personnel, strengthening logistics management, reducing cargo transportation accidents, improving logistics and distribution efficiency, and promoting logistics development [4]. Logistics handling robots in the e-commerce logistics distribution work area neatly placed some shelves. The warehouse logistics handling robot in the shipping area waits for the staff's instruction, and after receiving the instruction to use at the bottom of the shelf, the mechanical claw grabs the goods and carries them for sorting [5]. After working in this area, it will return to its original state. For the needs mentioned above, the developed logistics handling robot control system needs to meet the following types of functions to achieve.

(1) Handling function: The material handling robot in this paper needs to complete the function of handling materials through the grasping of mechanical claws and the lifting of mechanical arms, so as to complete the handling work in each area and realize the demand.

(2) Navigation and positioning: The robot needs accurate navigation and positioning to complete its movement in each area, locate the robot's position, and determine the travel route. The positioning function is realized through sensors so that the robot can accurately navigate and position itself.

(3) Wireless communication function: The handling robot needs to complete its information interaction with the warehouse control center through wireless communication, so as to realize the communication between the robot and the manager.

(4) Obstacle avoidance function: The robot needs to have the ability to avoid obstacles safely to ensure the safety of people and goods in the work area and the safety of the robot itself.

2. MECHANICAL DESIGN

2.1. General structural design

The structure of the handling robot is as follows: the chassis structure of the body of the handling robot, the gripping mechanism, and the sensors carried. The structure diagram of the handling robot is shown in Figure 1.

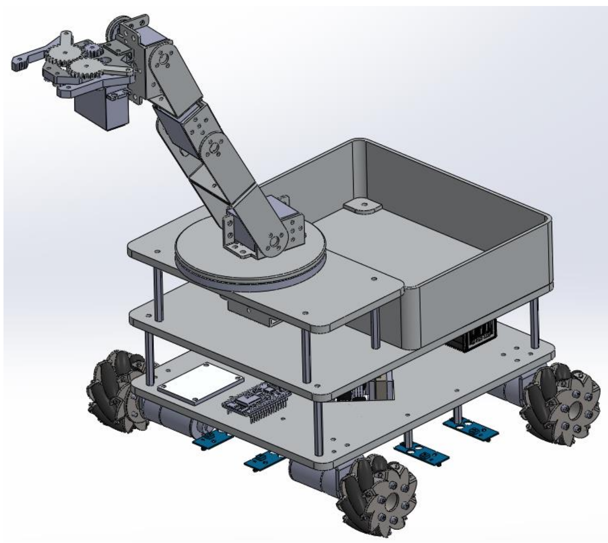

Figure 1: Solidworks 3D design rendering

The handling robot is capable of clamping materials at 360 degrees, in which there are two modules of mechanical arm and chassis, the mechanical arm completes the functions of stretching, contracting, and clamping through the servo, and the chassis completes the variable speed movement by McNamee wheel and motor.

1) Mechanical claw mechanism design. The mechanical claw is mainly made of the acrylic plate. The mechanical claw uses the servo as the power and the gears, metal rudder disk, etc. as the transmission mechanism, allowing the mechanical claw to complete the clamping motion. The mechanical claw wrist by the mounting buckle and mounting plate is directly connected to reduce the wrist degrees of freedom to make the mechanical claw more stable.

2) The mechanical arm mechanism design. The mechanical arm consists of an arm plate and two servos, the front, and rear servos are connected to the mechanical claw and the head. The arm plate is mainly made of acrylic plate, and the two arm plates are connected with a 10 mm acrylic plate in the middle to make the arm more solid and stable. Two servos control the mechanical arm and mechanical claw up and down movement.

3) The design of the head. The head is composed of an upper and lower base plate, a thrust ball bearing, a servo, metal rudder disk. The upper base plate is connected to the mechanical arm, the lower base plate is connected to the chassis, and the middle uses thrust ball bearings, and the rudder machine and metal rudder disk control the direction of the upper base plate. At the same time, two holes are reserved for the lower chassis.

4) The chassis design. Chassis for the upper and lower double chassis, lower the center of gravity to make the car stable, and the chassis between the 45 mm studs connected. The upper chassis connects the head to the connection plate. The lower chassis for the power supply design box, the installation hole of the motherboard, and the installation hole of the tracking module. Considering the thickness of the acrylic plate, the tracking module, and the height of the McNamee wheel has reserved 5 mm space for the lower chassis from the bottom of the car.

5) Wheel design. Wheel part of the 60 mm McNamee wheel, DC geared motor, motor mount.

2.2. Movement structure

Multidirectional wheel steering uses a universal wheel, a spherical wheel, and a McNamee wheel to move in any direction. The McNamee wheel consists of two parts, a hub attached to the motor shaft and a roller mounted at an angle to the hub. As the McNamee wheel rotates, the unique wrap-around roller mounting structure captures the force of one part in the normal direction and steadily controls the rotational speed of each wheel so that the forces generated in any direction can be synthesized to complete a 360-degree rotation. Gradual translational motion of the handling robot. In-place control, even in-place rotation, can be accomplished, as shown in Figure 2. In addition, the flexible, comfortable, and compact wheel body of the McNamee wheel is the best solution for real-time multidirectional body movements[3].

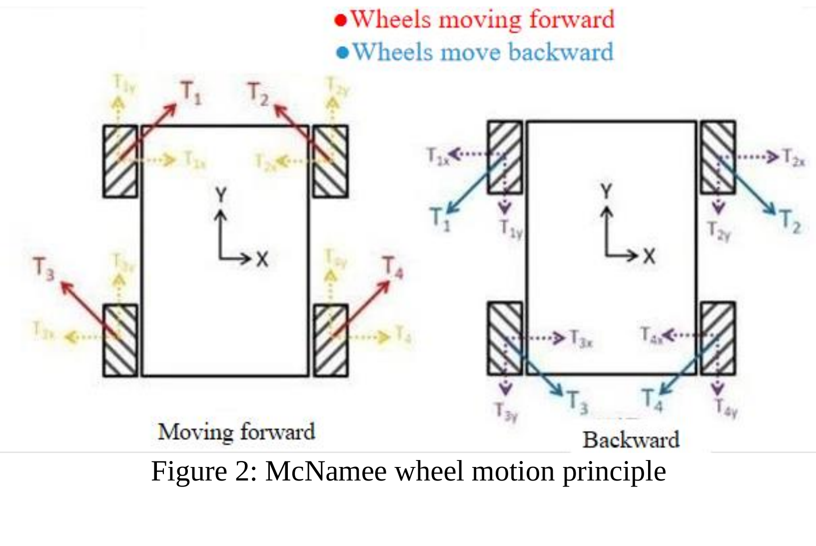

Figure 2: McNamee wheel motion principle

2.3. Motor design

The motor is the actuator of the manipulator, and the motors it uses are mainly stepper motors, AC servo motors, and DC motors. Stepper motors do not require feedback signals and have a simple control structure, but it is difficult to achieve high-performance control. AC servo motor is an AC power source, and it is not suitable for transport robots in modern logistics [6]. Therefore, brushless DC motors are chosen as actuators in this thesis. This brushless DC motor has the advantages of simple structure, rapid response, easy control method, and speed regulation during operation [7].

According to the design of this paper, the principal weight m1 of the transport robot is 15 kg, the maximum transport weight m2 is 5 kg, the rated speed v is 0.2 m/s, and the acceleration is 0.2. Assuming that the power characteristics and dynamic characteristics of the four drive motors are the same under ideal operating conditions, the total drive power required by the robot is under normal operation. The power is four drive motors[8]. The sliding friction coefficient μ is taken as 0.2, the margin k is 2, and the mechanical efficiency η is 0.8. From the obtained motor power for the next calculation to find the motor torque T, according to the design of the McNamee wheel in this paper, the diameter d is 60 mm and the maximum torque required is as follows:

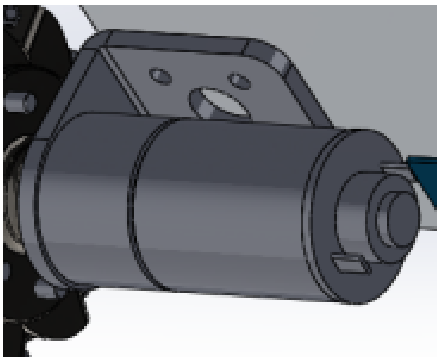

Figure 3: DC Brushless Motor.

$$T = fr = \mu(m_1 + m_2)gr = 0.2 \times (15 + 5) \times 9.8 \times 0.03 = 1.176N * m \tag{1}$$

3. AUTOMATIC CONTROL DESIGN

3.1. Robotic arm mathematical modeling

To facilitate the description of the positional relationship of two adjacent links, the corresponding spatial coordinate system must be established for each link. One can locate each joint axis of the manipulator and extend the corresponding axis to the corresponding position to facilitate the establishment of the coordinate system, draw the common plumb line at the intersection of the joint axis i and the hinge axis i+1, in the absence of an intersection, starting at the intersection of the common plumb line and the hinge axis [9].

Determine the positive direction of Z_i, generally parallel to the axis of the joint, as required. Determine the positive direction ofX_i, X_i generally perpendicular to the plane in which the two joint axes are located, when the extensions of adjacent joint axes intersect [10].

Direction of Y_i is generally determined by the right-hand rule. After establishing the coordinate system, the schematic diagram shown in Figure 4 can be obtained, in which, for the sake of illustration, the said coordinate system also contains intermediate transformation coordinate systems such as p, q, and r. And for simplicity, here, each coordinate system represents only the z and x axes [11]. As can be seen from Figure 4, the following four transformation procedures are required to transform the coordinate system i-1 to the position of the coordinate system i.

The coordinate system i-1 is rotated by an angle α_{i-1} around the coordinate axis X_{i-1} to the coordinate system r. The coordinate system r translates a_{i-1} length along axis X_r to coordinate system

q. The coordinate system q rotates by an angle i around the coordinate axis Z_q to the coordinate system p. The coordinate system p is translated by d_i lengths on axis Z_p to coordinate system i.

The above four transformation processes are represented by the following four matrices in turn.

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha & 0 \\ 0 & \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} \cos\alpha & -\sin\alpha & 0 & 0 \\ \sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

The coordinate system transformation process is simplified and can be expressed in equation 6.

$$8.{}^{i-1}_{i}T = \begin{bmatrix} \cos\theta & -\sin\theta * \cos\alpha & \sin\theta * \sin\alpha & a * \cos\theta \\ \sin\theta & \cos\theta * \cos\alpha & -\cos\theta * \sin\alpha & a * \sin\theta \\ 0 & \sin\alpha & \cos\alpha & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

3.2. MATLAB simulation verification

Using the MATLAB Robotics Toolbox Robotics Toolbox, the spatial joint planning of the robot joints was implemented. If the robot moves from route A to route B, the movement time is about 2 s. The specific operating parameters of the robot arm at routes A and B are shown in Table 1, and the speed and acceleration design parameters of each joint of the moving robot arm are shown in Table 2.

Table 1: Operating parameters of each joint

Route Points	Joint1 (degrees)	Joint2 (degrees)	Joint3 (degrees)	Joint4 (degrees)	Joint5 (degrees)
A	0	-90	0	0	90
B	45	-60	36	90	-45

Table 2: Velocity and acceleration parameters of each joint

Design maximum parameters	Joint1	Joint2	Joint3	Joint4	Joint5
Velocity (rad/s)	2.8	2.3	1.9	4.0	4.0
Acceleration (rad/s)	2.0	1.7	1.4	2.9	2.9

To meet the relevant operational requirements, it is necessary to plan the motion parameters such as displacement, velocity, and acceleration of the robot end operator during operation. Figure 5 shows the trajectory of the robot arm' 's endpoint in Cartesian space, Figure 6 and Figure 7 denote the velocity and the acceleration curve, respectively.

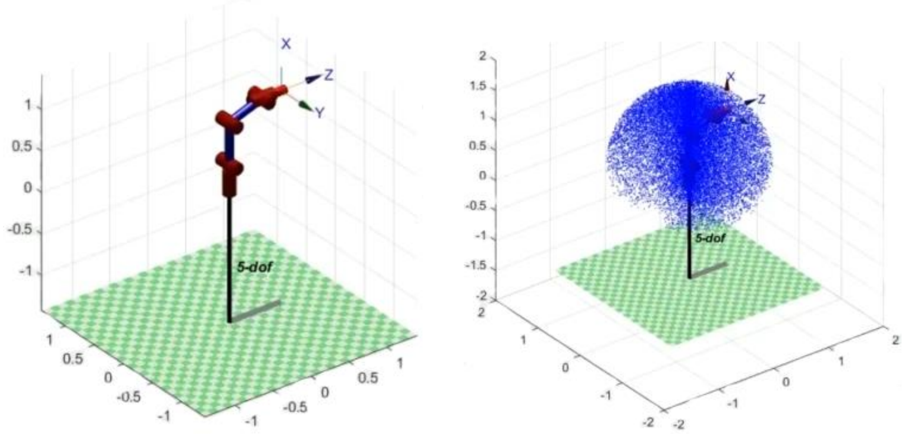

Figure 4: Robot arm modeling and its workspace

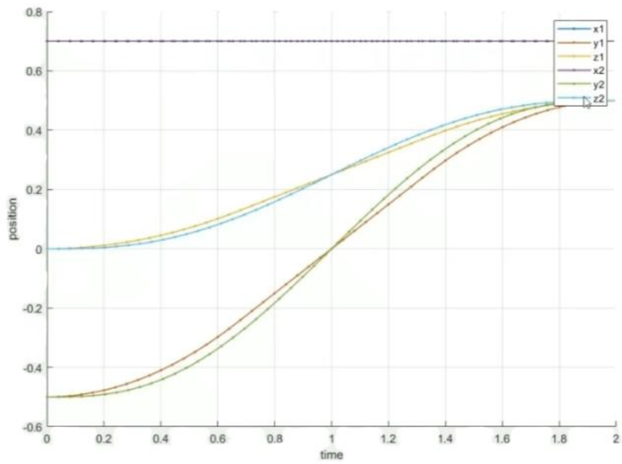

Figure 5: Trajectory of the end-effector in Cartesian space

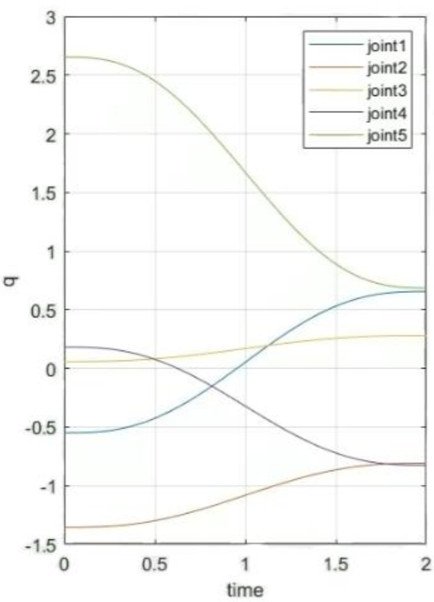

Figure 6: Velocity of each joint;

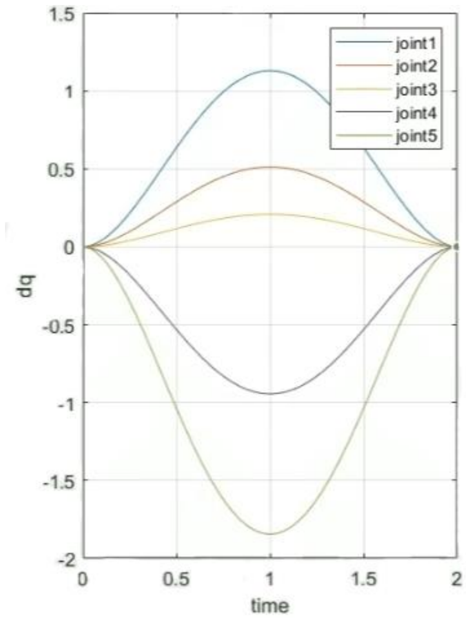

Figure 7: Acceleration of each joint

It can be concluded from the figure that the angular velocity and angular acceleration of each joint of the robot are continuous and without sudden changes, so its running trajectory is smooth and without jumps, and the strong vibration phenomenon of the robot during operation is reduced.

4. ANALYSIS AND DISCUSSION

Based on the development of warehouse-handling robots in the modern logistics industry, this paper proposes an operational robot suitable for warehouse operations based on the functional requirements of warehouse-handling robots and the characteristics of the operating environment. This system uses a grayscale sensor, an infrared distance measurement sensor, and a wireless communication module to complete the commands issued by the terminal. The following research work is carried out in this paper.

(1) The overall design of the material handling robot control system was completed. The control system of the processing robot to be used in the logistics environment was designed for the actual needs of the warehouse mobile robot, combined with its operating parameters. Finally, the mechanical design of the material handling robot and the structural design of the gripping robot were carried out according to the design scheme.

(2) The design of the hardware circuit of the control system was completed. Based on STM32, the design of the MCU circuit schematic of the handling robot was completed. Finally, the selection of key sensors for the navigation and positioning module and obstacle avoidance module was completed.

(3) The design of the control system automatic control is completed. In this paper, a method of indoor navigation and positioning completed by using grayscale tracking sensors is proposed. The principle of the PID control algorithm is also analyzed, and a flow chart of PID control of the robot arm grasping action is made briefly. The mathematical modeling of the robot arm of the handling robot is completed, and the simulation is verified.

5. CONCLUSION

Although the material handling robot control system designed in this paper has met the functional requirements, however, the lack of theory and practical experience, as well as the complex control system, research time, and other reasons, have led to the defects and perfection of the material handling robot control system.

(1) By combining more intelligent algorithms with the motion control of the robot, the motion stability and accuracy of the robot can be improved.

(2) It can improve the mechanical structure and increase its load-bearing capacity.
(3) By optimizing the control algorithm, the sway of the shelf can be reduced.

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