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Design and Validation of Automatic Grasping Control System for Robotic Arm

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ABSTRACT

To improve the efficiency of automatic block grasping, this paper proposes a control method that changes the order of servo motor rotation to solve the problem of low grasping efficiency. The STM32 master control module is used in conjunction with the Open MV camera to construct an image recognition system platform. The system recognizes the color of the blocks and combines it with an edge detection algorithm to determine the centroid of the target block's top surface and collect its two-dimensional coordinates. An infrared ranging sensor is placed below the camera to measure the distance between the camera and the top surface of the target block, obtaining the three-dimensional coordinates of the centroid. By applying the principles of robotic arm kinematics and using the angle conversion formula, the rotation angles of each servo motor are controlled to determine the grasping coordinates and complete the block grasping. Experimental results show that by controlling the servo motor rotation sequence, the fastest grasping sequence can be determined, with a grasping time of 11.32 seconds. The order of servo motor rotation is servo motor 1, servo motor 4, servo motor 3, servo motor 2, servo motor 5, and servo motor 6. By controlling the order of servo motor rotation, the efficiency of block grasping can be effectively improved.

1. Introduction

In the process of intelligent production and manufacturing, robotic arms play a dominant role. By employing deep learning and trajectory planning methods, the automatic grasping process of robotic arms can effectively improve the accuracy and stability of block grasping [1]. Shu You Yu et al[2] proposed a three-step method for robotic arm trajectory tracking control, which solves the impact of uncertain end load mass on robotic arm grasping. Hong Tao Wang et al[3] proposed an algorithm for optimizing the stretch factor in robotic arm trajectory tracking. This algorithm demonstrates good control performance with fast response, no overshoot, and small steady-state error. Bao Cheng Xi et al[4] presented a segmented PD control-based vibration transmission robotic arm trajectory control algorithm. This algorithm effectively suppresses the impact of base vibration and load uncertainty and meets the requirements for precise and rapid trajectory tracking control in automatic loading machines, displaying good robustness. GuanYu Xu et al[5] proposed an algorithm improvement based on point pair features and applied it to robotic arm grasping. The algorithm achieves satisfactory pose estimation results in cluttered scenes. Peng Cheng Sun et al[6] proposed a fusion method combining visual recognition-based automatic grasp and structural robots. This technique enables complete isolation between the robot's operating area and the manual operation area, achieving better unmanned operations.

In summary, this paper proposes a control method for changing the rotation sequence of a servo motor to improve the efficiency and accuracy of block grabbing. The process utilizes an STM32 microcontroller as the main control unit. It uses a camera to prioritize the selection of block colors and extract the coordinates of the recognized face of the target block. By applying the angular transformation formula, the coordinates are converted into angle values. Combined with the principles of robotic arm kinematics, this method enhances the efficiency of automatic block grabbing.

2. Recognition Principle and Implementation

Image features are crucial in image recognition. During the process of camera recognition, different color thresholds correspond to different feature information, which can be captured and used for image recognition. In this experimental system, the Open MV camera is used as the image acquisition terminal, which is based on

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the Open CV database[7-8]. It can recognize target colors and features within the covered area defined by a rectangular box. For color recognition, the RGB color space is used, and different colors have different corresponding thresholds. Color recognition is achieved by adjusting these thresholds. The red threshold is defined as (44, 75, 8, 77, -44, 21), the green threshold is (50, 60, -48, -30, 15, 38), the blue threshold is (61, 95, -23, -10, -30, -10), and the yellow threshold is (36, 75, -20, 11, 23, 48). When the Open MV camera recognizes the color of a block, it automatically outputs the code value and compares it with a reference number to achieve the functionality of block color recognition.

3. Positioning and Pickup

3.1 Edge Drawing by Difference of Tri-angles with Edge Response

When performing edge detection on an image, the edge detection algorithm first detects some pixels that form the contours of the image. These pixels are then connected according to certain rules to form a continuous edge. After that, the algorithm can detect and connect any remaining unrecognized boundary points, remove false pixels and boundary points, and finally form a complete edge [9-10]. In conjunction with the recognized area of the Open MV camera, where the top-left corner of the display screen on the host computer is taken as the origin, when a block appears within the designated area, the corresponding block information is displayed on the host computer. The selected block is marked with a white frame around its perimeter, and a crosshair symbol appears in the central region of the block. This indicates that the block selection is correct within the given threshold range. This paper combines the edge detection algorithm (EDTER) to collect the coordinates of the center point on the top surface of the target block. The coordinate acquisition interface is shown in the following figure.

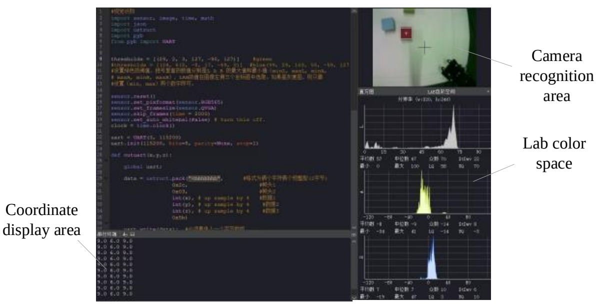

Fig. 1. Coordinate acquisition interface

3.2Applications of Kinematics

Link transformation is the fundamental concept in the kinematic analysis of robotic arms, involving coordinate rotations and translations[11]. Coordinate rotation transformation refers to the transformation around the X, Y, and Z axes of the coordinate system. In general, a rotation transformation can be composed of several basic rotation transformations. The robotic arm is depicted as follows.

In general, all link transformations can be obtained through coordinate rotations and translations, i.e., by combining the transformations of coordinate rotation and translation to obtain the link transformation matrix. Consider the transformation between two coordinate systems as shown in Figure 2. The transformation equation is given by：

$$ {}^{A}P = {}^{A}_{B}P\,{}^{B}P + {}^{A}P_{Bo} \tag{1}$$

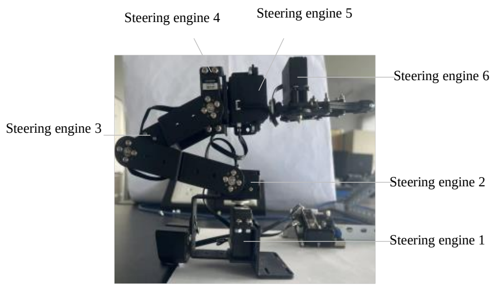

Fig. 2. Mechanical arm structure diagram

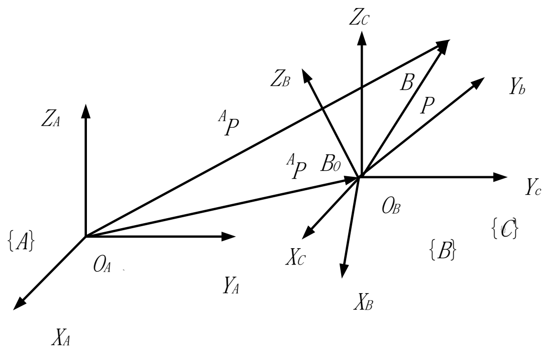

Fig.3. Transform diagram of coordinate system

Based on the established coordinate transformation diagram, we can establish the corresponding homogeneous link transformation matrices by considering the rotations and translations in each joint coordinate system:

$$A_1 = \begin{bmatrix} \cos(\alpha_1) & 0 & -\sin(\alpha_1) & 0 \\ \sin(\alpha_1) & 0 & \cos(\alpha_1) & 0 \\ 0 & -1 & 0 & L1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$A_2 = \begin{bmatrix} \cos(\alpha_2) & -\sin(\alpha_2) & 0 & -L2*\sin(\alpha_2) \\ \sin(\alpha_2) & \cos(\alpha_2) & 0 & -L2*\sin(\alpha_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$A_3 = \begin{bmatrix} \cos(\alpha_3) & 0 & \sin(\alpha_3) & -L3*\sin(\alpha_3) \\ \sin(\alpha_3) & 0 & -\cos(\alpha_3) & -L3*\sin(\alpha_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$A_4 = \begin{bmatrix} \cos(\alpha_4) & 0 & -\sin(\alpha_4) & 0 \\ \sin(\alpha_4) & 0 & \cos(\alpha_4) & 0 \\ 0 & -1 & 0 & L4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$$A_5 = \begin{bmatrix} \cos(\alpha_5) & 0 & \sin(\alpha_5) & 0 \\ \sin(\alpha_{55}) & 0 & -\cos(\alpha_5) & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$A_6 = \begin{bmatrix} \cos(\alpha_6) & 0 & -\sin(\alpha_6) & 0 \\ \sin(\alpha_6) & 0 & \cos(\alpha_6) & 0 \\ 0 & 0 & 1 & L5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

By using the homogeneous transformation matrices for each joint, the position equation of the robotic arm can be calculated. From the position equation, we can obtain the influence of joint variables on the end effector's pose [12]. By multiplying matrices A1 to A6 in sequence, we can obtain the position equation of the robotic arm. This also gives us the position and orientation of the end effector relative to the base coordinate system.

$$T_6 = A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5 \cdot A_6 \tag{8}$$

Once the coordinates of the grasping point are determined, they are fed back to the STM32 main control unit. The main control unit then passes the collected coordinates to the robotic arm. Based on the principle of inverse kinematics, the main control unit calculates the joint variables given the known coordinate information. When the target pose that the hand needs to reach is known, a large number of joint variables need to be solved in order to drive the servo motors of each joint. To satisfy the hand pose, the formula for solving is as follows:

$$\begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = A_1 A_2 A_3 A_4 A_5 A_6 \tag{9}$$

3.3Coordinate Transformation

The robotic arm determines its final position through angle calculations. The coordinate conversion is the process of converting the three-dimensional coordinates recognized by the camera into angle values using a specific formula. The calculated angle values are then used to control the rotation of each servo motor [13]. The obtained angle information is transmitted to the robotic arm through the main control unit, which controls the servo motors' movement to achieve the desired control effect. The conversion formula is as follows:

$$\cos\phi = \frac{L_2^2 - (x^2 + y^2) - L_1^2}{-2L_1\sqrt{x^2 + y^2}} \tag{10}$$

4. Experiment and Test

The equipment required for the experiment includes a six-axis robotic arm, an Open MV camera, a camera mounting bracket et al. The objects used in the experiment are three square blocks of different colors, with each block having a side length of 35mm. The STM32 micro controller is chosen as the main control unit for this experimental platform. The system is shown in the diagram below.

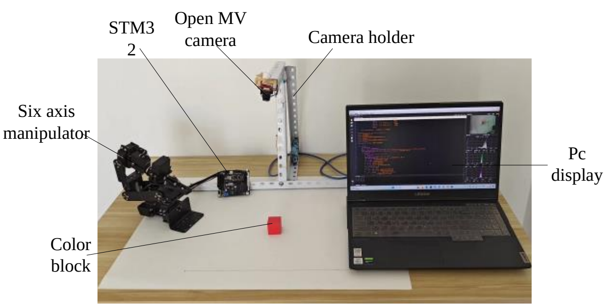

Fig.4.experimental platform

The program identifies the position of the blocks and transfers the block position information to the main control unit. By using the angle conversion formula, the coordinates extracted by the camera are converted into angle values, which determines the rotation angles of the robotic arm' s servo motors. This ultimately completes the grasping task. In order to verify the effect of controlling the sequence of servo motor movements on the grasping time during the process of the six-axis robotic arm grasping the blocks, this experiment fixes the base and gripper servo motors while controlling the sequence of movement for the remaining four axis servo motors. The grasping time is recorded accordingly. The grab time is as follows:

Tab. 1. Single capture time

Base rudder machine	Sequence of steering gear movement（order number）	The starting steering machine	time (s)
Base rudder machine(steering engine 1)	steering engine 2、3、4、5	The gripper supports the rudder machine(steering engine 6)	11.45s
	steering engine2、3、5、4		11.43s
	steering engine2、4、3、5		11.35s
	steering engine2、4、5、3		11.37s
	steering engine2、5、4、3		11.38s
	steering engine2、5、3、4		11.41s
	steering engine3、2、4、5		11.42s
	steering engine3、2、5、4		11.41s
	steering engine3、4、2、5		11.36s
	steering engine3、4、5、2		11.39s
	steering engine3、5、2、4		11.40s
	steering engine3、5、4、2		11.35s
	steering engine4、2、5、3		11.41s
	steering engine4、2、3、5		11.36s
	steering engine4、3、2、5		11.32s
	steering engine4、3、5、2		11.37s
	steering engine4、5、2、3		11.43s
	steering engine4、5、3、2		11.42s
	steering engine5、2、4、3		11.45s
	steering engine5、2、3、4		11.37s
	steering engine5、3、2、4		11.38s
	steering engine5、3、4、2		11.44s
	steering engine5、4、2、3		11.43s
	steering engine5、4、3、2		11.37s

The experimental results indicate that controlling the sequence of servo motor rotations has an impact on the grasping time, thereby improving the grasping efficiency. Through observation of the experimental data, it is found that the fastest grasping time is 11.32 seconds, achieved by following the sequence of servo motor movements as steering engine 1,steering engine 4, steering engine 3, steering engine 2, steering engine 5, and steering engine 6.

5. Conclusion

To improve the efficiency of automatic block grabbing and enhance grabbing accuracy, the first step is to determine whether there are blocks present within the camera' s recognition area.

Adjusting the threshold helps identify the target for grabbing and solves the problem of difficulty in determining the target due to the presence of multiple blocks and colors in the area.On this basis, an experimental platform is built, where the principles of robotic arm kinematics are employed. Using the coordinates captured by the camera, the angles required by the servo motors are calculated using angle conversion formulas. Based on this, the sequence of servo motor movements for each joint of the robotic arm is controlled to enhance the efficiency of automatic block grabbing.Experimental results demonstrate that the proposed method of controlling the sequence of servo motor movements for the robotic arm achieves a fastest single-grabbing time of 11.32 seconds. The servo motor sequence is as follows: servo motor 1, servo motor 4, servo motor 3, servo motor 2, servo motor 5, and servo motor 6. This method can improve the speed of single block grabbing and help further enhance the efficiency of block grabbing.

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