Research on Structure Design and Control Algorithm of Rubik's Cube Calculation Robot

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Abstract: The Rubik's Cube Solver is a robotic system that automatically recovers any scrambled cubes. As a kind of intelligent robot, Rubik's cube robot involves many disciplines such as robotics, computational science and machine vision. The Rubik's cube solving robot has been divided into three basic functional modules, namely the Rubik's cube state recognition module, the restoration step solving module and the restoration action execution module. This paper designs a smart recognition cube solving robot. The intelligent camera unit of the host computer recognizes the Rubik's cube color through python+opencv, and quickly collects the color information of the third-order cube, and converts it into the Mike Reid cube representation. The decision system calculates the optimal recovery scheme according to the recovery algorithm. After simulation test, the visual recognition algorithm can efficiently and accurately complete the restoration of the third-order Rubik's cube under the cooperation of the control motor, the steering gear and the mechanical clamping device, which is of great significance for improving the efficiency and accuracy of visual recognition.

1. Introduction

The research and design of Rubik's Cube computing robot involves knowledge and technology in multidisciplinary fields, including Rubik's cube state recognition, restoration algorithm, robot actuator design, etc. The existing Rubik's cube solving robot has become increasingly mature, but in mechanical cooperative motion and visual recognition, there is still room for development in terms of aspects. Some mechanical structures consist of multiple arms, which can cause motion crossover and even more complicated during the rotation process; some cannot complete the opening and closing and rotation of the mechanical gripping device at the same time, reducing work efficiency; the existing visual recognition scheme is limited to The Rubik's Cube of a specific color at a specific light intensity needs to be expanded.

With the continuous development of science and technology and manufacturing, robot applications are becoming more and more popular, and their design and processing methods are also diverse. From traditional milling to additive manufacturing and laser cutting, it provides a variety of solutions for the manufacturing industry. In this paper, a humanoid double-arm structure is designed for the Rubik's cube solving robot. Through the intelligent control of the algorithm, the Rubik's cube can be accurately and quickly restored. At present, a number of Rubik's cube robots have been developed in China, but generally have the characteristics of high degree of freedom, complicated structure and high cost. This type of structure is generally divided into two parts, to fix and to clamp, which increases the positioning error of the whole system. This type of structure can move at the same time with multiple axes and multiple faces, so the efficiency is higher, but the cost and processing complexity increase as well. The restored Rubik's cube robot designed in this paper adopts the human-like double-mechanical arm structure. It does not need a special support frame to fix the Rubik's cube. It only needs to install two 180° steering gears on both sides of the swivel arm to complete the Rubik's cube recovery, which can effectively avoid motion crossover. It is also possible to take care of opening and closing and rotation at the same time.

2. Mechanical Design

In this section, the structural design of the humanoid manipulator is mainly carried out, and the implementation scheme of the transmission mechanism is analyzed. The appropriate joint drive and reduction gear is selected to carry out bearing strength analysis to ensure stability. By improving the transmission mechanism, the gear transmission replaces the multi-joint transmission, which reduces the machining error at the joint and greatly improves the motion accuracy and speed.

2.1 Mechanical claw structure design

Firstly, the Rubik's clamping mechanism is designed. According to the size of the Rubik's cube, based on the functional requirements of “fast, accurate, easy to adjust and beautiful”, the Solidworks software is used as the main model tool, supplemented by AutoCAD and MATLAB for simulation and parameter optimization. In terms of material selection, we comprehensively consider the factors of material procurement and processing cost, mechanical properties of the material and overall stability of the mechanical claw. To ensure the overall strength, stability of the structure, maintain low price, light weight and high hardness, the majority is made of PC plastic processing, while some is made of ABS. In terms of the processing, the mechanical claws are entirely plastic-formed to ensure accuracy and strength. Some parts are molded by 3D printing to save overall processing time and are easy to adjust according to actual conditions. The servos are set in the fixed part of the steering gear to stabilize it and reduce the motion error.

2.2 Rack structure design

This paper uses Solidworks to build a three-dimensional model, comprehensively consider the overall size structure and layout of the device, determine the processing materials and processes, and then cooperate with the mechanical claws for overall function and stability debugging. After the overall performance is up to standard, the aesthetics and novelty are improved. Concerning material, in order to meet the load-bearing and stability requirements of the material, and to minimize the weight, reduce the volume, and optimize the appearance, the overall frame of the load-bearing frame is processed by aluminum alloy, and the burr-painting is unified in the later stage. In terms of the processing flow, considering load bearing and stability, the frame is machined to ensure its processing accuracy and strength. The overall internal hollow structure is designed to reduce the weight in the interior of the frame. The front and rear parts are welded, instead of the whole casing, to reduce the processing difficulty and improve the processing precision.

2.3 Tibetan wire box structure design

Using AutoCAD software to establish a two-dimensional model, with the main principles of aesthetics and lightness, comprehensively consider the overall size structure and layout of the device to determine the processing materials and processes. In terms of material selection, the storage box that does not require load-bearing is made of acrylic sheet as the raw material, keeping the overall appearance of the mechanism beautiful and light. The storage box plays a role of aesthetic optimization, using acrylic sheet laser cutting, and subsequent uniform painting. In the design process of the wire box structure, we use the snap-fit connection instead of the bonding, and each part of the plate is designed as a matching structure of the groove and the protrusion to meet the needs of disassembly and fixing.

2.4 Camera fixture design

We use Solidworks to build a 3D model, determine the processing materials and process with the consideration of stability and processing accuracy, and use the universal joint to adjust the position and angle of the camera. In terms of material selection, the weight of the camera is not large, but it requires a high degree of stability to ensure accurate identification, which provides the possibility for the correct operation of the subsequent procedures. We choose aluminum alloy material, which is unified with the frame on the one hand and meets the requirements of the rack on the other hand, which makes the whole equipment as light and low-cost as possible. The camera support frame should be as simple and light as possible to reduce the weight of the device after satisfying the stability and internal storage line design requirements.

2.5 Rotary steering gear fixed structure design

The linear steering gear is fixed by a porous countersunk nut to improve the position accuracy of the mechanical claw. The rotary steering gear and the lower frame are also fixed by porous screws, and the length of the control screw and the thickness of the frame are appropriately increased to improve the positional accuracy. The threaded hole depth is appropriately increased (to increase contact Area) to achieve the purpose of lower cost. At the same time, the application of the chute structure makes "one machine multi-purpose" possible. It is necessary to adjust the relative position of the bottom plate screw and the chute with the switching of the corresponding program, the restoration of other steps of the cube can be realized.

In summary, the design of the overall mechanical structure is based on the rubber pad of the mechanical claw, the steering gear and the excellent connection to the frame and the bottom plate. Based on the principle of stability, various reinforcement methods are adopted to reduce the systematic error of the whole device and improve Motion accuracy and overall stability. Starting from the inside of the rack, the storage box and the camera fixing device, the design is hollowed out inside the rack, so that all the steering lines can pass through the bottom hole through the internal structure to the bottom storage box, preventing the steering line from hanging in the air. Safety problems such as leakage or poor contact, while ensuring the overall simplicity and beauty; the introduction of the storage box makes the transfer station between the entire control device and the mechanism, on the one hand eliminate unnecessary external risks, on the other hand, the device is guaranteed. The same idea is used for the fixing device of the camera, and the windings are placed from the inside of the support frame. The aesthetic design avoids the cumbersome external winding and even affects the operation of the mechanism, and makes the mechanism simple and beautiful to a greater extent.

3. Rubik's Cube Model Establishment

3.1 Get images

This article uses python+opencv as a tool to place the cube on the robot arm and rotate the robot arm to shoot six faces. Fix the position of the camera, take and save six photos of rubik’s cube at fixed positions in the folder. Use the recognition program to distinguish and collect colors.

3.2 Analysis of images

The image analysis can be divided into four parts:

(1) Generate template: Generate a template of 6 face center patches. The template diagram should pay attention to the parameter selection. After theoretical research and experimental testing, the final choice is: the type of template map is RGB and the Feature Mode of the template is Color.

(2) Generate color block array: use pattern matching to identify the color distribution of the six faces of the cube, and convert the result into a 9*6 cube block. Since the distinction between red, orange, and yellow requires high color accuracy, the Color Sensitivity of the pattern matching function is set to High Sensitivity. Due to the close spacing of the searched patches, the Search Strategy is set to Conservative.

(3) Display the original state of the Rubik's Cube: use the color template to make up 6 faces.

(4) Calculate the initial state of the Rubik's cube: look up the table and convert the color block array into the canonical initial state string.

3.3 The establishment of the Rubik's Cube model

All the color information of the obtained six faces of the cube is converted into a digital mark by the distance vector method, and six colors are represented by 0, 1, 2, 3, 4, and 5 respectively. Use the two-dimensional list to save the six-sided color number markers in a nested list with the color identification information for the six faces. Finally, the obtained color list information is converted into Mike Reid representation, for example, UF UR UB UL DF DR DB DL FR FL BR BL UFR URB UBL ULF DRF DFL DLB DB. Where U: Up; F: Front; R: Right; L: Left; D: Down; B: Back means six faces.

When the data is represented last, we sequentially mark the color values in the middle of each color list in the nested list with the numbers 0~5. The purpose is to ensure the position of the Rubik's Cube. The value in the middle of the color list is also the middlemost color block of each face of the cube. The position between the six faces is fixed, so you can use it to determine the position of the cube space.

3.4 Call rubik's cube restoration algorithm

After the transformation identification string obtained after the Rubik's cube model is established is input into the Rubik's cube restoration algorithm, the restoration step of the Rubik's cube will be carried out. The Rubik's Cube algorithm is from Stefan Pochmann's algorithm in the International Rubik's Cube algorithm recovery competition. Stefan Pochmann was awarded for implementing the Thistlethwaite algorithm in C++. Who ranked No.2 by 15278 scores? The test program totaled 1311 characters with time of 197 milliseconds and on average of 16.72 steps per cube. The purpose of his algorithm is to find solutions quickly and accurately.

4. Rubik's Cube Control Algorithm

The entire recovery process is fully automated. We transported the program to the Raspberry Pi and connected all the devices to the Raspberry Pi. After inputting the start command, the entire machine automatically completes the photo shooting, recognizes the Rubik's cube, and solves the rotation steps. Concerning hardware, the four PWM pulses are outputted as the four servo signals through the pins of the Raspberry Pi, and the four servos are supplied by the 220v to 5v DC power. In regard to software, the jitter-free control of the steering gear is achieved by using a servo control library function Servoblaster of the Raspberry Pi. The entire rotation algorithm is done by using the Raspberry Pi Linux system and Python.

4.1 Recovery rubik's cube rotation algorithm

The main idea of the algorithm is to first specify the initial state of the cube, and after each step of rotation, the cube is restored to the initial state. The advantage of this is that the algorithm is easy to implement, but it brings the tedious process of the whole rotation. The shortcomings of this algorithm must be restored to the original state after each step of rotation. This study will eliminate the process of restoring the original state. First, the transfer function is defined, the main work of this function is to deduce the current state from the last state after each rotation, and to deduce the rotation algorithm of the next rotation. This part includes two types of operations: turning and flipping. These two operations will continue to alternate until the end signal of the PC is received. This study stipulates that the F plane is the front of the machine. The left arm is grasped on the L side and the right arm is grasped on the D side. First, write the simplest left and right arms at any angle and any direction of the rotation function L and D other plane rotation, first convert the surface to the L or D plane and then according to the rotation path to judge the rotation step on the L and D planes .Finally, return to the original state and wait for the next instruction.

(1) Flipping: In this section, we need to reverse the face to the bottom in the simplest step and update the coordinate array. The coordinate array holds the original position of the surface of the six positions U, D, L, R, F and B. Flipping magic cube uses the combination of four kinds of manipulation of robot: (1) manipulator push; (2) chassis turn 90 degrees clockwise; (3) chassis turn 90 degrees counterclockwise; (4) chassis turn 180 degrees clockwise.

(2) Turning: This part of the program only needs to rotate the chassis 90 or 180 degrees counterclockwise and 90 degrees clockwise according to the number of rotations received, respectively, when the mechanical arm is stuck on the upper two layers of the magic cube.

4.2 Nonlinear SVM algorithm

The clustering idea is applied in Nonlinear SVM algorithm. The RGB information of the cube is converted into a digital identifier by a mathematical method, and the color information of the magic square is extracted and placed in the color list. It is compared with all the color information in the previous list once one has been extracted. If it did not exist, join the list and do not join if it already exists. By calculating whether the vector value of the color of the two Rubik's cube RGB colors is less than a fixed value (the value is the best color distance vector value), so that two different colors can be distinguished, instead of setting the color threshold. At the same time, an algorithm for automatically adjusting the color distance vector value is proposed. The program automatically adjusts the optimal color distance vector value before each rotation, starts to preset a small value, and then starts to increase gradually until the color information of the six sides of the cube completely matches, and the color list contains only six color values, which is equivalent to the narrowing range of values in the KNN algorithm.

5. Conclusion

At present, the result of the system is greatly affected by mechanical factors. In addition to the improvement of the machine, it can be improved from the improvement of the pattern matching algorithm, the change of the color recognition mode, the increase of the sensor, and the increase of the remaining time display. This paper studies and designs a solution based on Nonlinear SVM recognition algorithm. It uses the intelligent camera unit as core parts, cooperating with the actuator to quickly collect the color information of each third-order cube. The decision system calculates the optimal restoration scheme according to the reduction algorithm, and uses the algorithm to control the steering gears and the robot to work together to complete the cube restoration. Rubik's cube automatic recovery robot involves robot visual perception, computer algorithm, motion control and mechanism design, which has excellent academic research value in robot fields. The overall architecture design of this paper is reasonable, the mechanism is stable, the algorithm is reliable, and it is willing to be applied in education and scientific research fields.

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