Objects Grasping of Robotic Arm with Compliant Grasper Based on Vision

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ABSTRACT

To deal with the problem of slow recognition and poor adaptability in grasping for home service robots. In this paper, a robust robotic arm system based on vision is proposed. The system uses an OpenMV machine vision module to recognize and output the measured pose information of the AprilTag, which is attached on the corresponding object. Then a 4-DOF robotic arm with two-fingers compliant grasper is designed to grasp different objects with various shapes and sizes according to the certain trajectory planning from compliant grasper to the target. Moreover, the experiments are performed to validate the whole system. Results show that the system can recognize and locate the target objects quickly and accurately, as well as grasp and drop the objects in the expected position reliably.

KEYWORDS

Robotic arm, Compliant grasper, AprilTag, Object recognition, Grasping

1 Introduction

With the development of intelligent robots, its applications are gradually expanded. One of the most important technologies of intelligent robot is home service robot, which is aimed at assisting our daily lives [1]. The key technologies of home service robot include navigation, objects grasping and interaction with human. Among them, robotic grasping is the most fundamental in the complex home environment [2]. This requires service robots to recognize and locate quickly and accurately under the conditions of various objects， as well as achieve the purpose of grasping precisely [3].

In the robot grasping task, the traditional manipulator can only grasp the target according to the manual planned path, since it can not obtain external environment information. Therefore, when the surrounding environment is unknown or changed, the robotic arm can not grasp the objects. Vision-based grasping can solve this problem, the position of the target can be obtained through visual recognition and location algorithms, which lay the foundation for the success of grasping. Vision-based grasping not only enables the manipulator to perceive the surrounding environment autonomously, but also enhances the flexibility of the manipulator. At present, the grasping based on vision has been made great progress in the field of service robot [4]. In 2010, Carnegie Mellon University developed the Home Exploring Robotic Butler (HERB) robot, it is equipped with 7-degree-of-freedom manipulator, three-fingers grasper and three cameras on the mobile platform. These cameras pave the ability of positioning and grasping for service robots [5]. Waseda University have developed the TWENDY-ONE, which is a humanoid care service robot. It is equipped with two 7-DOF manipulator with four-fingers grasper and two CDD cameras on the head, which can accomplish the multifunctional tasks, such as picking the object from the floor and grasping a plate [6]. EL-E is a service robot, which have been developed for helping elderly and Disabled. EL-E accomplishes the detection through segmenting the objects from surface by using binocular vision sensor, and grasp horizontal objects on the table [7]. However, the problem of slow recognition and complicated grasping operation occurs when there are many kinds of objects with different shapes and sizes. Yuan et al. [8] use Naomark to solve the problem of identification variety objects for NAO robot grasping in home environment. Zhang et al. [9] use the QR code technique to achieve recognition and location of target objects for home service robots.

In this paper, A robotic arm system based on vision is intended to grasp different objects with various shapes and sizes in complex home environment. This system uses OpenMV machine vision module to achieve recognition and location of objects based on AprilTag, and then converts the pose information of the object into base coordinate system for robotic arm. Moreover, people usually use robotic arm with the rigid grasper in grasping, since it has advantages in grasping force. However, the rigid grasper has poor adaptability and is easy to damage the object. To solve this problem, a 4-DOF robotic arm with compliant grasper is designed to grasp and drop different objects in the expected position. The remainder of this paper is structured as follows: section 2 introduces the robotic arm system, section 3 introduces the process of head-eye calibration and details the inverse kinematics. In Section 4, the object recognition and robotic grasping process are discussed. In section 5, several experimental results are provided to verify the performance of the system. Finally, conclusion is given in section 6.

2 System Design

The whole system consists of five parts: OpenMV Cam (machine vision modules), computer, controller based on STM32 microprocessor, stepper motor drive and 4-DOF robotic arm with a compliant two-fingers grasper. As shown in Figure 1. The OpenMV Cam is used to recognize object and send its pose information to STM32 microprocessor through serial port, at the same time, OpenMV Cam is connected to the computer for displaying images in real time. The STM32 microprocessor communicates with computer through USB bus. After receiving the grasping command from computer, it converts the pose information into rotation angel of each joint, and then controls each joint motor to realize rotation by PWM (pulse with modulation) signal

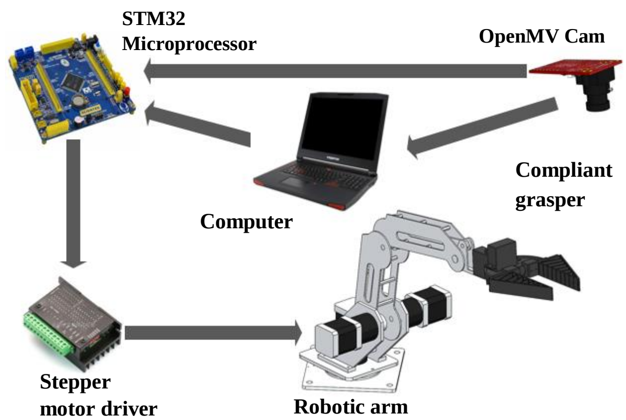


Figure 1: The robotic arm system structure

In order to accomplish the stable and effective grasping task. As shown in Figure 2, a 4-DOF robotic arm is designed by the modification of the Dobot [10]. The degree of freedom of joint1, joint2 and joint3 are realized the rotation by the stepping motor, the degree of freedom of joint4 is realized by the servo motor which has lighter quality. The payload at the end of the robotic arm can be reached 1.2Kg, and the repeating positioning accuracy of the end can reach 0.2mm. Since the manipulator adopts a parallelogram mechanism, the end of it can be kept parallel to the desktop all the time.

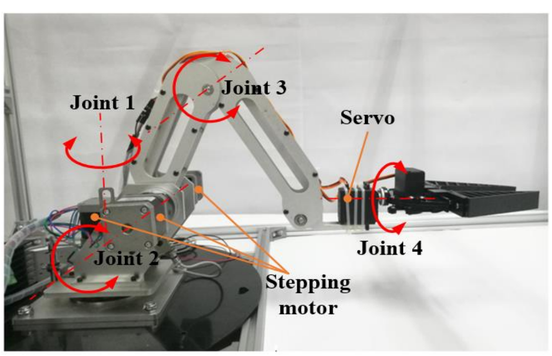


Figure 2: Configuration of the robotic arm

Then the prototype of compliant grasper is shown in the Figure 3. The power source of compliant grasper is servo motor, and its speed and rotation angle can be controlled by the PWM signal. The servo motor drive sliders on the bracket through the connecting link, so as to realize opening and closing of grasper, and the two compliant fingers based on bionic fin are 3D printing of TPU flexible materials. This compliant grasper has better self-adaptability when grasping different irregular objects, and it does not cause damage to the surface of the object, but also improve grasping reliability [11]. The compliant grasper grasp different objects with various shapes and sizes are shown in Figure 4.

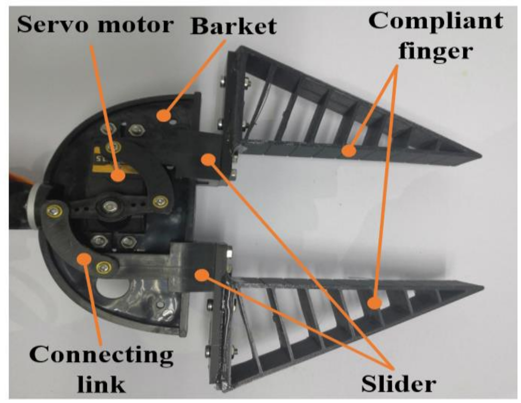


Figure 3: The prototype of compliant grasper

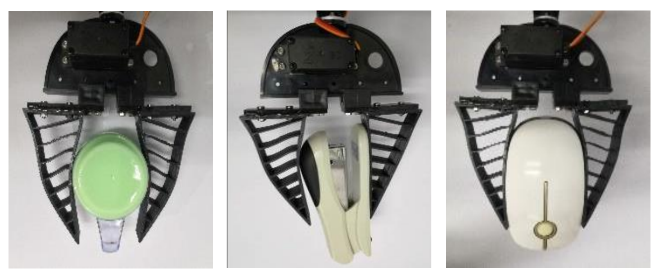


Figure 4: Compliant grasper grasp different objects

3 Hand-eye Calibration And Inverse Kinematics

3.1 Hand-eye Calibration

The hand-eye calibration matrix needs to be calculated, so as to accomplish the grasping task. As shown in Figure 5, the coordinate system of robotic arm, camera and target are established. Tc, Tp, Tw are the transformation matrix between different coordination systems. The relationship of them is as follows:

$$T_W = T_C \cdot T_P \tag{1}$$

If the target coordinate is (x_p , y_p , z_p). Firstly, it need to be converted into camera coordinate system. The measured coordinate (x_t , y_t , z_t) of the target relative to the camera can calculate directly by the detection algorithm when the AprilTag is recognized by the OpenMV Cam. So the coordinate transformation is as follows:

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = T_P \begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix} = K \begin{bmatrix} x_t \\ y_t \\ z_t \\ 1 \end{bmatrix} \quad (2)$$

where (x_c , y_c , z_c) is the coordinate in the camera system, T_p represent the external camera parameters. K is the proportional coefficient.

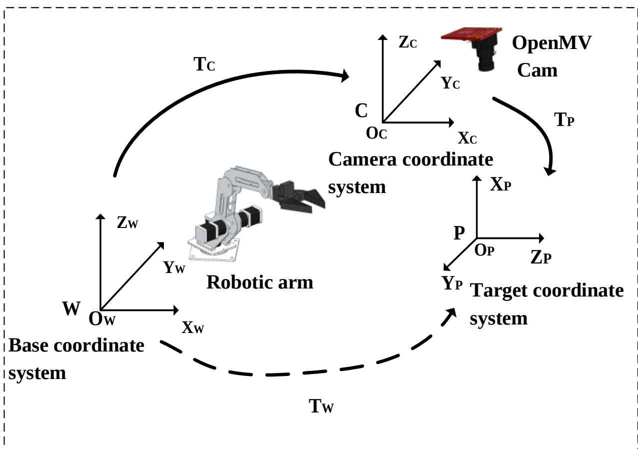


Figure 5: Coordinate system

And then the coordinate of target (x_c , y_c , z_c) is converted into the base coordinate system for robotic arm. The coordinate transformation is as follows:

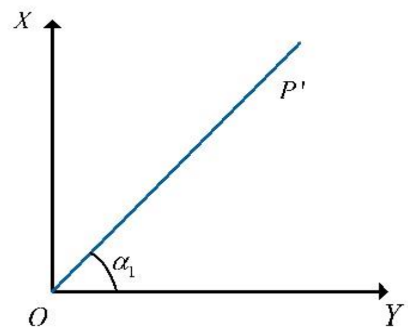
$$\begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} = T_c \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R_{3\times3} & T_{3\times1} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} \quad (3)$$

where (x_w , y_w , z_w) is coordinate of the target in the base coordinate system for robotic arm. T_c represents the hand-eye calibration matrix, $R_{3\times3}$ is a rotation matrix, $T_{3\times1}$ is a translation matrix.

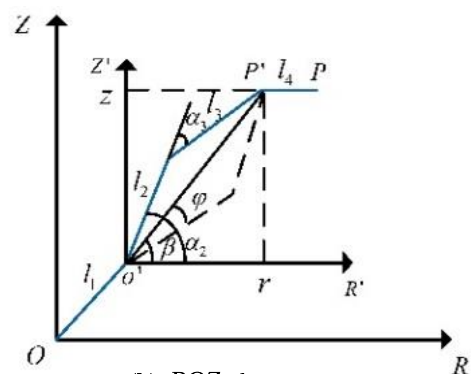
3.2 Inverse Kinematics

After getting the coordinate of target (x_w , y_w , z_w), the rotation angles of each joint need to be caculated by soving the inverse kinematics, so as to drive the end effector to reach the desired position. Since the special structure of Dobot, this can always keep parallel at end of arm. According to the above constrains, the geometric method is chosen to solve inverse kinematics. And the general situation of the manipulator is analyzed, the diagram of robotic arm is shown in Figure 6. Firstly the robotic arm is projected to the XOY plane of base coordinate system, meanwhile, the vector R is obtained. And then projecting to the ROZ plane, P' (x_p , y_p , z_p) is the end of the third link in base coordinate system for robotic arm.

As shown in Figure 6(b), the coordination system $Z'O'R'$ is established, coordinate $o'(r_o, z_o)$ can be obtained by measuring the distance between first joint and second joint, and the blue lines represent each link of robotic arm, $l_i\,(i=1\sim4)$ is the length of them.



(a) XOY plane



(b) ROZ plane

Figure 6: The diagram of plane projection

According to the geometric relationship of the Figure 6, the following equations can be written as:

$$\alpha_1 = \tan^{-1}(y_P / x_P) \quad (4)$$

$$\cos\alpha_3 = \left(\frac{r^2 + z^2 - l_2^{\,2} - l_3^{\,2}}{2l_2 l_3}\right) \quad (5)$$

Where $r = \sqrt{x_p^{\,2} + y_p^{\,2}} - r_o$, $z = z_p - z_o$.

In order to get rotation angle α_2 , the angle β and φ need to be calculated.

$$\beta = A\tan 2\left(z / r\right) \tag{6}$$

$$\cos\varphi = \left(\frac{r^2 + z^2 + l_3^{\ 2} - l_2^{\ 2}}{2l_3\sqrt{r^2 + z^2}}\right) \tag{7}$$

From the Figrue 6(b), if the $\alpha_3 < 0$, $\alpha_2 = \beta + \varphi$,otherwise, $\alpha_3 > 0$, $\alpha_2 = \beta - \varphi$.

Because the parallel mechanism is established between second and third joint, the third link is affected by second link, the $\alpha_3 < 0$ is chosen, and the rotation angle $q_i\left(i\text{=}1\sim3\right)$ of each joint can get as follows:

$$\begin{cases} q_1 = \alpha_1 \\ q_2 = \beta + \varphi \\ q_3 = A\tan 2(\sin\varphi / \cos\varphi) + q_2 \end{cases} \tag{8}$$

Through the solving inverse kinematic of the manipulator, the optimal rotation angle of each joint can be found, which provides the basis for controlling the manipulator in the grasping task.

4 Object Recognition And Grasping

4.1 Object Recognition

AprilTag is a visual fiducail system designed by E. Olson, the applications of AprialTag are extremely extensive [12]. The AprialTag is used for real-time object recognition and location. It can produce fast and accurate recognition by encoding less information than other marker systems, and automatically detect and localize with OpenMV Cam by specific algorithm, even the tag is under situations of unevenly lit ,very low resolution or oddly rotated.

There are three families of commonly used AprilTag, they are as follows: Tag36h11, Tag25h9 and Tag16h5. Each tag has its corresponding ID, which can assist to distinguish different objects. The main differences of them are effective area and minimal Hamming distance. The effective area of Tag36h11 (6*6 square) is narrower than Tag16h5 (4*4 square). Moreover, Tag36h11 has more checking information than the other two families. Finally, the Tag36h11 is chosen, so as to have higher accuracy of object recognition and location.

The process of object recognition and location contain several steps. Firstly, the size of Tag36h11 needs to be chosen, since it can influence the proportionality coefficients K. And then attach the tag on corresponding object. After the image of tag is obtained by camera, the line segments in the image will be detected by computing the gradient direction and magnitude at every pixel. The next step is to find the quad of all line segments, and compute the homography matrix by using the Direct Linear Transform algorithm. Finally, the ID and relative pose of tag are used to recognize and compute the pose of object [12].

4.2 Grasping

In order to achieve stable and accurate grasping task, the grasping process of robotic arm system is divided into three steps: object recognition, pose conversion and robotic arm controlling. The first step is to acquire the image information and output the measured pose of tag. The second step is to compute the real pose in camera coordinate system and convert it into base coordinate system for robotic arm. Then send the pose data into controller. The last step is to receive the pose data of object and plan trajectory, then control the robotic arm movement to accomplish grasping and dropping task. The specific flow chart of grasping is shown in Figure 7.

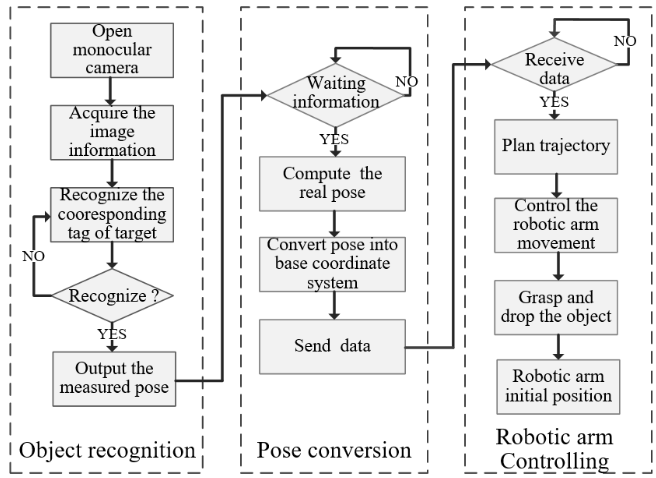


Figure 7: The process of object grasping

5 Experimental Results

5.1 Determination of Proportional Coefficient K

Due to the influence of camera internal parameters, the errors occur between measured depth information and actual depth information under different sizes of tag. In order to achieve accurate 3D positioning, the suitable size of tag need to be chosen, and its proportional coefficient K need to be determine . As shown in Figure 8, the experimental platform is mainly composed of a data display interface, a vertical mobile platform with scale and an OpenMV cam for determining the proportional coefficient K.

In this experiment, three sizes of tag are chosen and the initial distance between the OpenMV Cam and the tag is measured. Then the distance is changed through the vertical mobile platform, at the same time, the actual and the measured distance are recorded. Finally, the accumulative error is calculated at different heights of each tag by the proportional coefficient K. Then the error is taken as the vertical coordinate, and the distance between OpenMV Cam and tag as the horizontal coordinate. The changed curve of error is shown in Figure 9.

From the Figure 9, The changed trend of error is basically the same under the different sizes of tag, and it is relatively small in the height range of 90-120cm, we choose the proportional coefficient K, which is corresponding to the tag with the size of 2.5cm, because it have minimum error when the distance in 110cm.

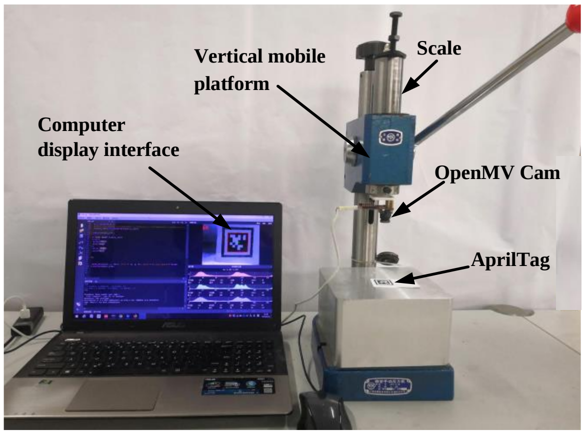


Figure 8: Experimental platform

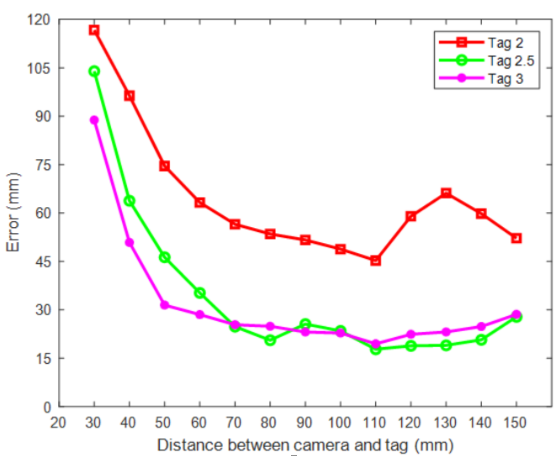


Figure 9: Relationship between distance and error

5.2 The Grasping Results

In order to verify that the robotic arm is feasible and the grasper is self-adaptable when grasping the objects, the experiment of grasping object in realistic scene is conducted. The OpenMV Cam is used to capture image information, which is fixed at on the top of experimental table. At the same time, the 640×320 resolution RGB image is chosen, so as to reduce processing time and the cost of computing.

As shown in Figure 10, the results show that the target can be recognized by OpenMV Cam based on AprilTag, and the red rectangular bounding-box and category of object are accurately labeled, the green cross represents the center of tag. And then robotic arm opens the compliant grasper and converts the position information of the target into rotation angle of each joint. After receiving the rotation data, the controller controls the robotic arm movement stably, so as to make the compliant grasper closed to the target. when the compliant grasper reaches the target position it closes and grasps the object by servo motor. After dropping the object in the desired position., the robotic arm returns to the original position automatically after accomplishing task.

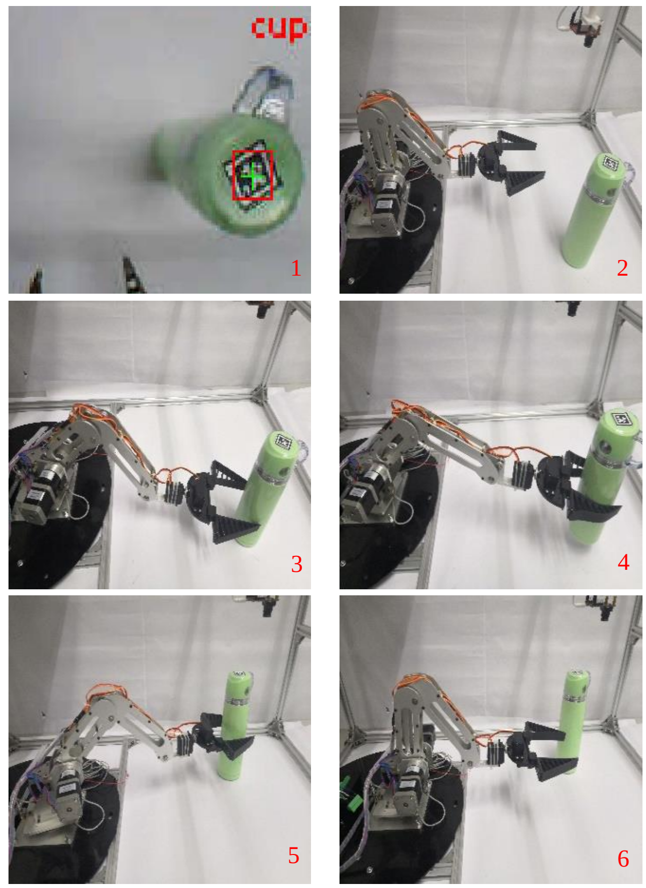


Figure 10: The process of grasping experiment

6 Conclusions

In this paper, a robotic system based on machine vision is proposed in an attempt to solve the problem of slow recognition and poor adaptability in grasping task. The OpenMV machine vision module is used to recognize and locate the AprilTag, which is attached on the corresponding object. After receiving the position of object in the base coordinate system for robotic arm, the rotation angle of each joint is obtained by solving inverse kinematics. And then a 4-DOF robotic arm with two-fingers compliant grasper is used to grasp different objects.

The grasping results on the robotic arm system show that the system can recognize quickly and label the category of object accurately. According to the accurate position of target object, the grasping task is achieved stably by the 4-DOF robotic arm. In particular, the envelope surface of compliant fingers can vary with the shape and has better self-adaptability when grasping irregular objects. Moreover, the process of grasping is reliable. In the future, the robotic arm will be installed on the different mobile platforms to realize autonomous mobile grasping in complex home environment.

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