Design of Robot Vision Servo Control System Based on Image

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Abstract. Visual servo is a closed-loop control system of robot, which takes the image information obtained by visual sensor as feedback. Generally speaking, visual servo plays an important role in robot control, which is one of the main research directions in the field of robot control and plays a decisive role in the development of intelligent robots. In order to make the robot competent for more complex tasks and work more intelligently, autonomously and reliably, it is necessary not only to improve the control system of the robot, but also to obtain more and better information about the working environment of the robot. This paper introduces the principle and basic realization method of robot visual servo based on image, and expounds the problems and solutions in image feature extraction and visual servo controller design. In order to further expand the application field of robots and improve the operation performance of robots, robots must have higher intelligence level and stronger adaptability to the environment, so as to manufacture intelligent robots that can replace human labor.

1. Introduction
In order to solve the problem of labor shortage in the period of high-speed social and economic development, robots are introduced into industrial production. Nowadays, robots are widely used in various industries and fields. With the intelligent improvement of robot control system, the number and application range of robots are still increasing [1]. Robot visual servo is to control the position and posture of the robot end actuator by using visual information. On the one hand, such design can adapt the robot to the changes of environment and operation object, on the other hand, it can overcome the influence of robot calibration error on control accuracy [2]. With the development of computer technology, electronic technology, sensor technology and artificial intelligence technology, people are no longer satisfied that robots can only complete repetitive operation in a fixed environment according to the set procedures. They begin to study intelligent robots with strong adaptability and high sensitivity [3-4]. Robot technology is the frontier field of high-tech and it is the cross integration of many subjects. In industrial applications, most robots work in an orderly industrial environment. The program executed by robots is basically triggered to perform a repeat process of reset [5]. In order to make robots competent for more complex tasks and work more intelligently, autonomously and reliably, not only the control system of robots should be improved, but also the environment information of robot work should be better obtained [6].
Since the first robot came out, robots have been developing continuously, and have been replacing the dominant position of human in various fields [7]. With the development of industrial technology and the continuous expansion of robot application, people put forward higher requirements for robot technology, and hope that robots have higher environmental adaptability and intelligent decision-making ability [8]. But even the most advanced robot in the world has not met the expected goal and expectation for the adaptability of the robot to the external environment. 80% of the external information obtained by human beings comes from vision, and the importance of visible vision is [9]. Visual sensor has become one of the central contents of information research in robot intelligent control because of its characteristics of fast and large amount of external information and high information integrity [10]. In the process of modern industrial automation, machine vision is becoming a key technology to improve production efficiency and ensure product quality. The robot with sensors can make the robot estimate and detect the external environment. Although it will increase in cost, it can be applied to more complex and dangerous work, and improve the intelligent level of the robot [11]. This paper introduces the principle and basic realization method of robot vision servo based on image, and expounds the problems and solutions in image feature extraction and visual servo controller design.

2. Image processing in robot visual servo

2.1. Image recognition of visual servo system

When the task of robot is to track the dynamic target, it is necessary to predict the feature trajectory of image features to meet the real-time and stability requirements of robot visual servo. According to whether the object to be operated is dynamic or static, the task of target recognition is divided into static target recognition and dynamic target recognition. In the visual servo control system, it is necessary to obtain the actual relative position of the target object. This position is directly related to the robot’s terminal control. If there is a calibration error in the parameter calibration stage, it will directly affect the trajectory of the robot’s terminal TCP, resulting in inaccurate spatial transformation. The main task of image recognition of moving target is to detect whether the target exists or not from the real-time image video sequence. If it exists, the moving area of the target is extracted by the video detection algorithm. By extracting and distinguishing the features of this pixel area of the target, the interference or interference features are ignored, and the target is determined to be the desired tracking target [11].

One of the basic tasks of computer vision is to calculate the geometric information of objects in three-dimensional space from the image information obtained by the camera, and then reconstruct and identify objects. The relationship between the three-dimensional geometric position of a point on the surface of a space object and its corresponding point in the image is determined by the geometric model imaged by the camera. Figure 1 shows an open CNC system for robots.
Figure 1. Robot open CNC system body system

Feature extraction is to extract the parameters reflecting the target feature state from two-dimensional image data. These parameters should not only describe the target feature accurately and completely, but also be convenient for calculation. Edge feature and region feature are basic image features, which are reliable feature conditions to distinguish between target object and background, as well as between target object and interfering object. The purpose of tracking and positioning moving targets is to collect the image sequences of moving targets continuously by sensory sensors, analyze the image sequences, calculate the two-dimensional position of the targets on each image, and associate the same moving target in different inclinations in the image sequences to obtain the complete motion trajectory of each moving target. Under most conditions, these parameters can only be obtained through experiments and calculations. This process is called camera calibration. Camera calibration includes internal parameter calibration and external parameter calibration. The calibration of internal parameters refers to the internal geometric and optical characteristic parameters of the camera, and its purpose is to correct various parameter errors of the finished camera.

2.2. Target image feature selection

The real-time performance and stability of visual servo system are closely related to the speed and stability of image feature extraction. Image features that can be used in the design of visual servo controller include simple geometric features of objects, local and global features and their combinations, and features transformed into other feature spaces by features. Visual information has become the main information of robot closed-loop control because of its large amount of information and high accuracy, and visual servo attracts more and more researchers’ attention. The essence of moving target tracking and positioning is to calculate the position, size and moving speed of the target in each image by analyzing the video sequence captured by the image sensor. The selection of visual image features determines the accuracy and stability of the visual servo system. Inappropriate features may lead to wrong target recognition, complex calculation of target feature extraction, or uncontrollable and uncertain conditions of the desired image features by adjusting the robot position.

Probabilistic tracking method has become the mainstream tracking method because of its stable and reliable tracking performance, which is suitable for tracking in complex environment and can recover from short-term failure. The network infrastructure is shown in Figure 2.
Almost all control methods need to assume that the joint speed of the robot is known, but in practice, this undoubtedly increases the control difficulty. On the one hand, the sensor outside the denomination will increase the control cost, on the other hand, the speed sensor may introduce noise and reduce the control accuracy. In order to describe the different postures of connecting rods at the same position, a coordinate system is usually fixed on each connecting rod [12]. Therefore, the position of the connecting rod of each joint in the operating space can be described by the coordinate values fixed at the origin of the connecting rod coordinate system in the operating space, and its posture can be given by the coordinates of the coordinate vector of the coordinate system in the operating space. For the image features of the moving target, its dynamic features, i.e. the moving speed and acceleration of the target, must also be considered together, so as to obtain the latest image features of the target in time and reduce the overall delay of the visual servo system.

3. Image based visual servo control
Among them, in the process of camera calibration, the parameters of the camera can’t be achieved, and the least square method has its own errors, so this is one of the influencing factors. In the position-based control structure, the visual processing outputs the coordinates of the moving target, and then estimates the relative pose between the target and the robot to control the robot’s motion in rectangular coordinate space. It separates the visual processing from the robot’s motion control, and can intuitively describe the desired relative trajectory in rectangular coordinate system. Robot system provides an important research background for modern control theory, intelligent control and artificial intelligence, especially the introduction of visual information greatly improves the application scope and flexibility of robot [13]. Image-based visual servo control, if there is a deviation between the actual image features and the expected image features, the deviation is taken as an input, and the desired joint angle change is obtained by an appropriate algorithm, which is transmitted to the robot controller to control the manipulator to move until the deviation of the image features is zero.

Different from position-based visual control, image-based control system compares the current image feature set with the ideal image feature set, and does not need to estimate the three-dimensional pose, so it has low requirements for camera calibration and strong robustness. Figure 3 shows the structure of agent node of servo system.
**Figure 3.** The structure of the intelligent body node of the servo system

For a calibrated system, the calibrated system parameters can be directly substituted into the analytic formula of Jacobian matrix to obtain the current specific matrix value, and the estimation accuracy of Jacobian matrix directly depends on the calibration accuracy of system parameters. Because the accuracy of system parameter calibration is inevitably affected by various factors, the robot vision servo method based on calibration is greatly limited. Image Jacobian matrix is the basis of image-based visual servo method. However, according to the definition of image Jacobian matrix, it is time-varying and nonlinear, so it is inevitable to encounter many problems in practical calculation and application. The core task of image-based visual servo system is the processing of visual images [14]. The primary task of image processing is how to select image features, and how to find a way to establish a connection with the robot's end pose after processing the image accordingly, that is, to construct the image Jacobian matrix. Uncalibrated technology refers to the robot vision servo method, in which the internal and external parameters of the camera and robot are not calibrated in advance, and the image feedback control law is designed directly through the system state error signal on the image, so as to drive the robot to move and make the system error converge to an allowable error domain. Figure 4 shows the formation tracking of servo control system.

**Figure 4.** Formation tracking diagram of servo control system

Among the servo control methods that replace image Jacobian matrix, the research based on neural network and fuzzy logic system is mostly. In fact, image Jacobian matrix reflects the nonlinear mapping relationship between image space and robot space, and neural network is just a good nonlinear function approximator. When the robot is performing a task, the camera determines the relative position between the end and the target object, which requires knowing the relative
position between the camera and the end effector, which is called the robot hand-eye relationship [15]. For the camera, we can only calibrate its posture in the object coordinate system, so we can’t directly calculate the coordinate transformation relationship between the camera and the manipulator after calibrating their postures in the same coordinate system. Calibration-based visual servo refers to calibrating the internal and external parameters of the camera beforehand, and then designing the visual controller according to the known model and calibrated camera parameters. Although uncalibrated visual servo does not take time to calibrate parameters, the control performance and convergence speed of the system will be affected because of the large error in the initial values of the estimated parameters.

4. Conclusions

With the increasing application of robots in modern industrial production and life, the research and development of robots in environment perception and human–computer interaction is an important part of modern robot research field, and how to use robots to perform more complex and dangerous tasks is also the development direction of robots in the future. For a long time, the nonlinearity and strong coupling of robot dynamics, as well as the operation accuracy and speed of image processing, are all urgent problems to be solved in the control of robot visual servo system. There are many research fields of robot visual servo control, including computer vision, image processing, robot kinematics, robot dynamics, control theory, real-time calculation and so on. Visual sensors have a certain range of applications. If they can be effectively combined with other sensors and take advantage of their complementary performance, the uncertainty can be eliminated. When robots work in complex environments or complete demanding tasks, they need a variety of sensors to feed back more information. Therefore, it is the key for the robot to complete its operation in dynamic environment to analyze the characteristics and relationship of multi-sensors with different sampling frequencies and establish a set of control algorithms for multi-sensor information fusion.

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