A Direct Visual Servo Control Method for a SCARA Type Robot

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1 Introduction

Vision sensors have been applied extensively in robotic research labs and in industrial environments. A vision system not only can realize non-contact position measurement, but also supplies more flexibility for a robot, such as performing cooperative work between robots and other machines. Visual servo control is a technology that incorporates the vision information directly into the task control loop of a robot. This kind of control system is not a simple feedback system but the fusion of results from many elemental areas including high-speed image processing, kinematics, control theory and real-time computing [1]. In some visual servo control applications, the vision system recovers the actual position information of the robot end effector.

In this paper, the position information of every joint of the robot will be obtained directly from the vision system, so the control signal, which is calculated in image feature space, can be directly sent to the controller of every joint in order to reduce the computations of transformation between different space reference frames. Simulated error for the models is introduced into the robot kinematic model, dynamic model and camera projection model in order to test the feasibility of the proposed method.

2 Simulation Model

The simulation model of the visual servo control system used for a SCARA type robot is shown in Figure 1, which gives the relationship among the models.

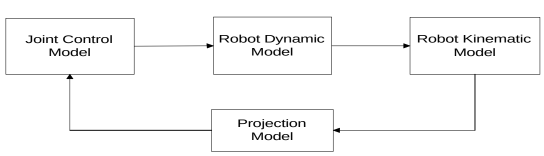

Figure 1 A visual servo control model.

2.1 Kinematic Model

The robot considered in this paper is a simplified SCARA type serial manipulator with three degrees of freedom (DOF), the structure of which is shown in Figure 2. The first two joints are revolute joints and the third one is a prismatic joint. The kinematic parameters with Denavit-Hartenberg representations are given in Table 1.

2.2 Dynamic Model

According to Lagrange-Euler dynamic model, the dynamic model of a robot can be represented as

$$\boldsymbol{\tau} = \mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{N}(\mathbf{q}, \dot{\mathbf{q}}) \tag{1}$$

where $\mathbf{q}$, $\dot{\mathbf{q}}$, $\ddot{\mathbf{q}}$ are the vectors of joint positions, velocities and accelerations; $\boldsymbol{\tau}$ is the vector of the joint torques and forces; **M** is the inertia matrix and **N** represents the effects of friction, gravity and Coriolis and centrifugal force.

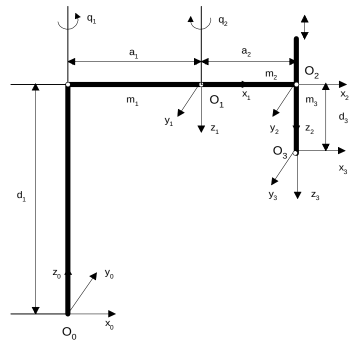

Figure 2 Example of three-DOF SCARA type manipulator.

Table 1 Kinematic parameters of the example manipulator.

θ	d	a	α
q_1	d_1	a_1	180°
q_2	0	a_2	0°
0	$d_3(=q_3)$	0	0°

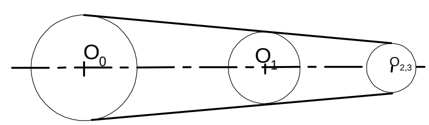

Figure 3 Overhead view of manipulator from the camera.

2.3 Projection Model

From the overhead, the ideal image of the top planes of the joints is shown in Figure 3. The circles on the top plane represent the joints, where each joint can be considered as a cylinder. The centers of the circles can be assigned as origins of the joint coordinate frames.

One camera will be placed overhead so that the image plane is parallel to the link plane, then the scaled orthogonal projection model is applied:

$$[u \quad v]^T = s[x \quad y]^T \tag{2}$$

where $[u, v]^T$ are the coordinates of the observed points in camera frame, which are the centers of the circles shown in Figure 3. Considering the digitization process, equation (2) will be:

$$[u \quad v]^T = s[x \quad y]^T = [(I - I_0)\Delta u \quad (J - J_0)\Delta v]^T \tag{3}$$

where (I, J) are the image coordinates of the points in the digital image; Δu and Δv are decided by the resolution of the image and the optical distortion of the camera along different directions; s is a fixed scale factor, which is decided by the focus length and the distance between the image plane and the object. Hough Transformation [3] will be a good method for recognizing those circles.

The displacement of the prismatic joint will be recorded by another camera, which will recognize a mark at the end of the cylinder. The mark could be a circular line around the pistol of the prismatic cylinder. The vertical position of this line represents d_3 which is the third joint variable.

2.4 Control Model

In some visual servo control systems, the vision system has been used to recover the position information of the robot end effector and then transform it into the joint space by inverse kinematics computations. However in this article position information of every joint will be obtained directly from the vision system. The control signal, which is calculated in image feature space, can be directly sent back into the controller of every joint. In the simulation PD (proportional and derivative) control strategy was used in the joint controller.

3 Simulation Results

In this simulation, the robot is required to follow various trajectories in order to test the performance and feasibility of the visual servo control model. Due to the space limitation, the model parameters are not given here.

Figure 4 shows the simulation results with ideal models, where no error has been introduced into the kinematic model and camera projection model. Figure 5 shows the simulation results including errors of camera projection model, which are assumed to be a distortion along two orthogonal axes with a normal distribution. The endpoint of the third joint (prismatic joint) is desired to track a circle in a plane parallel to x_0y_0 plane while it moves along the z_3 axis. So the trajectory of the endpoint is a spiral curve. Figures 4a and 5a show the desired and real trajectories of the endpoint of the third joint. Figures 4b and 5b, and 4c and 5c show the desired and real trajectories of the origins of the first and second joints, respectively. Figures 4d and 5d, 4e and 5e, and 4f and 5f show the position error of the first, second and third joints, respectively.

In Figure 4, the effect of the digitization due to image processing is obvious. The maximum angular error is 0.003 rad. The error along z_3 axis is less than 1.000 mm.

In Figure 5, the result shows stronger fluctuation of the error function. By adjusting the control parameters and robot velocity, the steady state error and the frequency of the fluctuation can be reduced. During a short interval for a specific task, the camera distortion is limited and constant, then the distortion can affect the desired and real pictures at the same time. So the results will show a constant error, which might be compensated for according to a “teaching” procedure. The constant errors can also be compensated for by applying calibrating a more precise camera model.

The effects of the kinematic dynamic disturbance on the visual servo control model have also been simulated, but are not given here due to the space limitation.

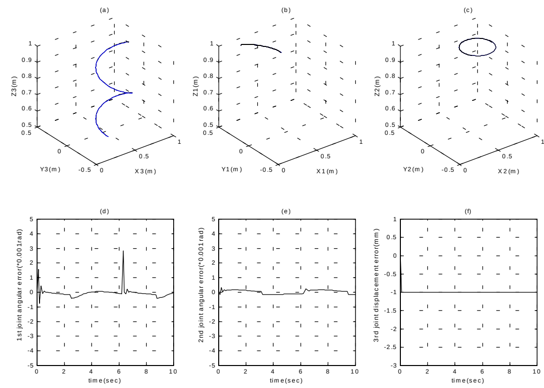

Figure 4 Simulation results with ideal camera model.

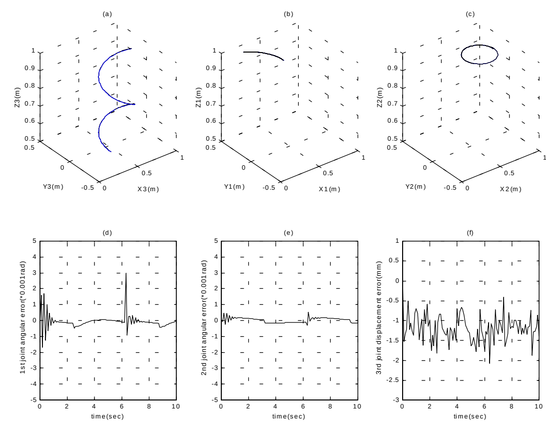

Figure 5 Simulation results with random camera error.

4 Discussions and Conclusion

A direct visual servo control system model for a SCARA type robot was developed and simulated. The simulation results of the tracking prove that this system model is feasible. If the delay in the tracking task is not very important, the simulation shows good performance for point-to-point tracking. To implement this model into a real-time situation, better control algorithms should be investigated to deal with the fluctuations caused by camera distortion and digitization in image processing system. For simulation purpose other error models could also be investigated and tested.

The proposed visual servo control method integrated with the joint sensor based control could increase the reliability and fault tolerence of the robot. The non-contact measurement and the overview of the robot/enviroment obtained from vision system could help with the decision procedure for the safe operation of the robot.

References

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