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Robust Visual Servo control with Integral Action

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In this thesis, we deal with visual servo control law with integral action in 2DOF (Two Degrees Of Freedom) planar manipulator. We present the Lyapnov stability analysis including the manipulator dynamics with constant torque disturbances into the overall visual closed loop system. Further, we construct an experimental system using an industrial manipulator. Finally, experimental results are shown to illustrate the controller performance.

Recently, manipulator control schemes that utilize the visual information in the real time feedback, called *visual servo*, have attracted much attention. The manipulator is included into the visual closed loop system. Accordingly, it is important to perform the stability analysis of the visual system with the nonlinear manipulator dynamics.

For the joint space control, the recent approaches have been concerned with the SP-D (Saturated Proportional and Differential) control. The SP-D control method has some practical characteristics, for example, attenuation of undesired high torque and reduction of the undesired effect of friction. However, when there exist the constant torque disturbances, the stability analysis can not be carried out using the SP-D control method. Thus, an *integral action* was added to the previous SP-D controller in order to deal with the constant disturbances. Furthermore, it was introduced that the *integral action* reduces steady state errors. The SP-D control has been successfully applied to the visual servo control problem. However, the visual SP-D method does *not* provide the stability analysis in the case of the existence of the constant torque disturbances.

Therefore, in our thesis, the image based visual servo control for the 2DOF planar manipulator with the *eye-in-hand* configuration is treated by invoking the Lyapunov based method. The control method is the SP-D visual servo control law with integral action and the gravity compensation. The proposed control method is improved to be robust against the constant torque disturbances. The approach of the stability analysis of our controller is similar to the joint space SP-D controller case. Furthermore, the proposed SP-D visual servo control law with integral action is implemented on the industrial manipulator, and we confirm the previous controller's availability.

This paper is organized as follows. In section 2, an experimental setup and some physical parameters of the systems are described. The relations among the set of the joint angle and the position and the orientation of the camera become clear. Then the Jacobian of the manipulator is derived. It show the relation between the velocity in angular space and the velocity in Cartesian space. Furthermore, a calibration method for the physical parameters of the manipulator is described.

Section 3 formulates the visual servo control problem. We formulate some models. It has the pin hole camera model, the manipulator kinematics model and the manipulator dynamics model. Furthermore, we state the visual servo control problem.

In section 4, firstly, we show that, the stability analysis can not be carried out using the SP-D visual servo control method when there exist the constant torque disturbances. Secondly, we propose the SP-D visual servo control law with integral action and the gravity compensation for solution of the problem. Finally, we prove the asymptotic stability of the proposed SP-D visual servo control law with integral action. The proof of the control method is applied to the methods of the joint space SP-D control law with integral action. Moreover, the visual servo control method is stated to be robust against the focal length of lens of the camera, the distance between the object and the camera and the constant torque disturbances.

Usefulness of the proposed visual servo control law is verified by the experiments in Section 5. First, we compare the proposed visual servo control law and the SP-D visual servo control law with the gravity compensation. At that time, position gain error in the proposed visual servo control law is decided smaller than the SP-D visual servo control law with the gravity compensation. Second, we experiment with in case of the constant torque disturbances. Furthermore, we show the experimental results by some graph. As well, we show the consideration of the experimental results.

Finally, brief concluding remarks are offered in section 6. We showed that, the stability analysis cannot be carried out using SP-D visual servo control method when there exist the constant torque disturbances. We proposed the SP-D visual servo control law with integral action and gravity compensation for solution of the problem. We described the architecture of the target system and some physical parameters of the systems. The visual servo control method was improved to be robust against the focal length of lens of the camera, the distance between the object and the camera and the constant torque disturbances. The proposed visual servo control law was implemented on the industrial manipulator. And we confirmed the previous controller's availability.