Control and Estimation of Visual Feedback Systems with a Fixed Camera for Trajectory Tracking Problems

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In this paper, we deal with the control and the estimation of visual feedback systems with a fixed camera. The rigid body motion (involving both translation and rotation) control problem of visual feedback systems with Eye-in-Hand configuration has been discussed in our previous works [1, 2]. This configuration has only three coordinate frames, while visual feedback systems typically use four coordinate frames which consist of a world frame Σ_w , a target object frame Σ_o , a camera frame Σ_c and a hand (end-effector) frame Σ_h as in Fig. 1. Because the camera is attached to the end-effector of robots, the camera frame represents the hand one in Eye-in-Hand configuration. This paper will give a visual feedback system with the four coordinate frames. Extending the number of the coordinate frames from three to four, this framework can generalize our previous works. Specifically, we consider the trajectory tracking problem of visual feedback systems with a fixed camera.



Figure 1: Visual feedback system with four coordinate frames

Firstly, we consider the estimation problem of the relative rigid body motion $g_{co} \in SE(3)$ between the camera frame Σ_c and the target object frame Σ_o , because g_{co} can not be measured directly in visual feedback systems. Where $g_{ab} \in SE(3)$ is the homogeneous representation of the configuration of a frame Σ_b relative to a frame Σ_a [3]. The observer is constructed by using visual information in order to exploit the estimated relative rigid body motion \bar{g}_{co} . Secondly, the control problem of the relative rigid body motion $g_{ho} \in SE(3)$ between the hand frame Σ_h and the target object frame Σ_o is addressed in order to achieve the desired motion g_d . In particular, we do not assume that the desired motion g_d is constant for trajectory tracking problems, while our previous works have been discussed on this assumption [1, 2]. We construct a visual feedback system by combining the model of the estimation error and the model of the control error. For this system, we lead a structural passivity property with an energy function. Based on the passivity, we propose a visual feedback control law which guarantees asymptotic stability of the overall closed-loop system using the energy function as a Lyapunov function. L_2 -gain performance analysis for the proposed control law is discussed with the energy function as a storage function. Finally simulations are presented to verify the stability and L_2 -gain performance of the visual feedback system with a fixed camera.

The main contribution of this work is that the visual feedback system with four coordinate frames is constructed in order to generalize our previous works. In this framework, we can design the control gain and the observer gain separately from each other, while the control problem and the estimation problem of the visual feedback system are considered in the same strategy. Moreover, trajectory tracking problems of the visual feedback systems can be treated using the desired motion g_d which depends on the time.

References

- H. Kawai, S. Izoe and M. Fujita, "A Passivity Approach to Vision-based Dynamic Control of Robots with Nonlinear Observer," In:A. Bicchi, H. I. Christensen and D. Prattichizzo (Eds), *Control Problems in Robotics*, Springer-Verlag, pp. 199–213, 2003.
- [2] H. Kawai and M. Fujita, "An Interpretation of Vision-based Control for Rigid Body Motion: A Geometric Framework," Proc. of the 48th Internationales Wissenschaftliches Kolloquium, Paper ID 11-02-02, 2003.
- [3] R. M. Murray, Z. Li and S. S. Sastry, A Mathematical Introduction to Robotic Manipulation, CRC Press, 1994.