An Experimental Study of Dynamic Visual Feedback Control with a Fixed Camera

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This paper deals 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.

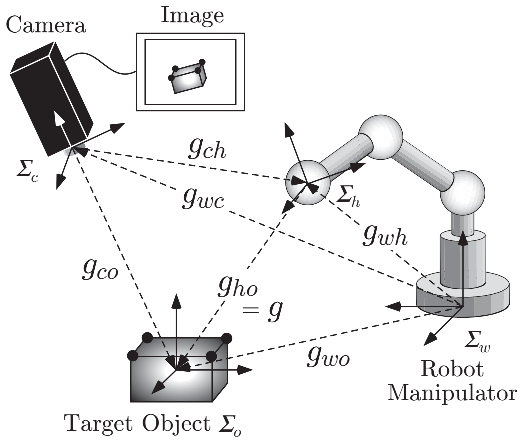

Figure 1: Visual feedback system with four coordinate frames

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. 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. Further, the dynamic visual feedback system is composed of the visual feedback system and the manipulator dynamics. Then, the whole system preserves both the passivity of the visual feedback system and the passivity of the manipulator dynamics. Based on the passivity, we propose a dynamic visual feedback control law which guarantees asymptotic stability of the overall closedloop 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.

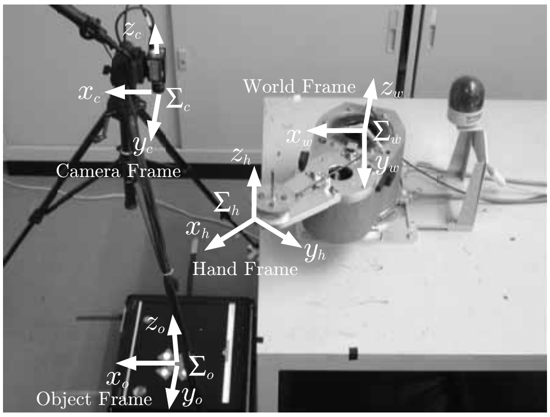

Figure 2: Experimental Arm.

In particular, we show the experimental results on SICE-DD arm with the fixed camera (see Fig. 2) in order to confirm the effectiveness of the proposed control law. We define the four coordinates which are described in Fig. 2. Let the target object have four feature points which are projected on the display. The object moves along a straight line (0≤t<4) and a "Figure 8" motion (4≤t<9.6). The objective of the visual feedback control is to bring the actual relative rigid body motion g to a given reference g_d. To achieve this aim, we have to reduce both the estimation error e_e and the control error e_c. In addition, the error of the joint velocities of the manipulator ξ must also be reduced. Here, we define z as the controlled output, which includes the states (involving e_e, e_c and ξ) and the inputs with weight matrices.

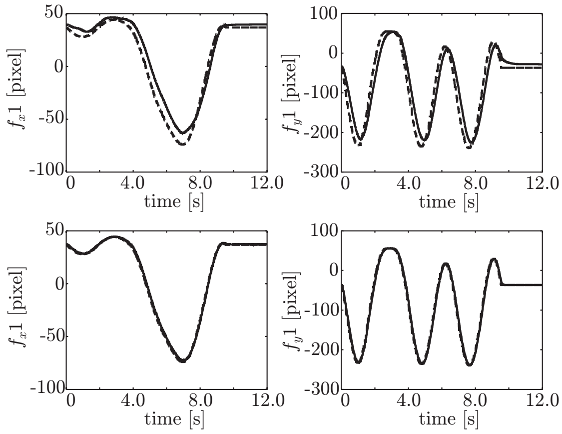

Figure 3: Estimated feature points (top: without weight matrices, bottom: with weight matrices).

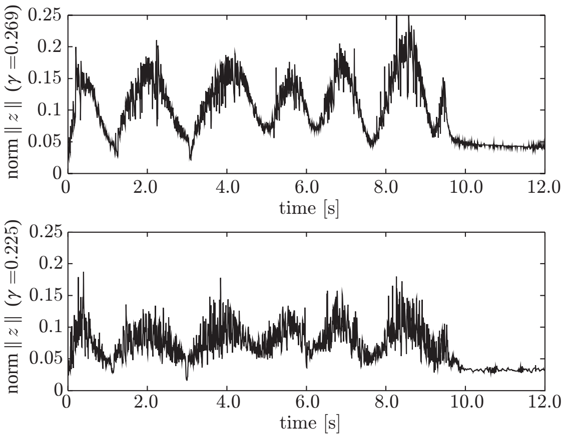

Figure 4: Euclid norms of z.

Fig. 3 presents one of the four estimated feature points. Top graph and bottom one show the estimated feature point without weight matrices and with ones, respectively. In this figure, dashed lines denote the feature points obtained by the actual image information and solid lines denote the feature points obtained by the estimated one. The estimation error of feature points can be decreased by using the weight matrices. Thus, we consider that the weight matrices play the role of the design parameter for the estimation. In Fig. 4, top graph and bottom one show the norm of z in the case of $\gamma = 0.269$ and $\gamma = 0.225$, respectively. In the case of static target object, i.e. after $t = 9.6$ [s], all errors in Fig. 4 tend to zero. It can be concluded that the equilibrium point is asymptotically stable if the target object is static. In the case of $\gamma = 0.225$, the performance is improved as compared to the case of $\gamma = 0.269$. After all, the experimental results show that L_2-gain is adequate for the performance measure of the dynamic visual feedback control.

The main contribution of this work is that the dynamic 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, the effectiveness of the proposed visual feedback control law is confirmed by the experiment on SICE-DD arm.

References

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