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Experimental Studies of Interaction Control between a Quadrotor System and a Human Operator

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Abstract—**In this paper, contact force control of a quadrotor system is presented. Due to an expensive cost of sensors for localization, a camera system is used to locate the quadrotor system. Using a maker on the top of a quadrotor system, heading direction can be justified. Based on the localization, the position control of a quadrotor system is performed in indoor environment. In addition, contact force from a human operator is applied to the quadrotor system so that the feasibility of applying force control to the flying system is tested. Experimental studies of interaction control between a quadrotor system and a human operator are presented to confirm the proposed force control performance.**

I. Introduction

RECENTLY research on quadrotor systems has been rapidly increased in robotics and control communities. There are several reasons for active research on quadrotor systems. Quadrotor systems have several advantages over other aerial vehicles. Firstly, quadrotor systems provide the good maneuverability such that they can move in any direction in the air. Although quadrotor systems are an underactuated system, four rotors generate six-axis motions. Secondly, position control of quadrotor systems is relatively simple since its dynamic equation is simple. It can be modeled as an inertial system so that acceleration terms are dominant. Thirdly, hovering control performance can be better than other aerial vehicles. Four rotors can stabilize the system more easily. Lastly, contact force control is more feasible. The symmetrical structure of quadrotor systems allows to be equipped with manipulators on the top or the bottom of the center of the system.

The majority of research on quadrotor systems has been focused on navigation, which requires accurate position and hovering control techniques. Hovering performance is one of merits of quadrotor systems, and its concept leads to possible application of contact force control tasks. The quadrotor system under human environment has been presented for possible interaction[1]. Quadrotor systems play with environment by picking up objects [2].

Therefore, in this paper, contact force control of a quadrotor system with a human operator is presented [3]. Position control of a quadrotor system is accomplished *a priori*. Localization with a camera system which detects position and heading angle of a quadrotor system has been done in indoor environment to mimic GPS based localization. Since motion detecting systems are quite expensive, a camera is used to localize the quadrotor system by utilizing markers on the top of the system.

Fig. 1 shows the conceptual figure of the contact force control of a quadrotor system.

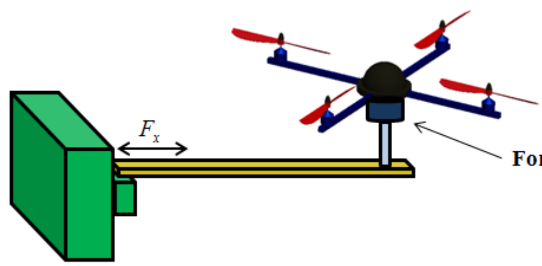

Fig. 1 Force control concept

II. Quadrotor system

| The quadrotor system is shown in Fig. 2. Markers are located on the top of the system to detect the heading angle and position. A rod is attached to the center of the system for interacting with a human operator. Colors of markers are differently set for distinction by a camera.

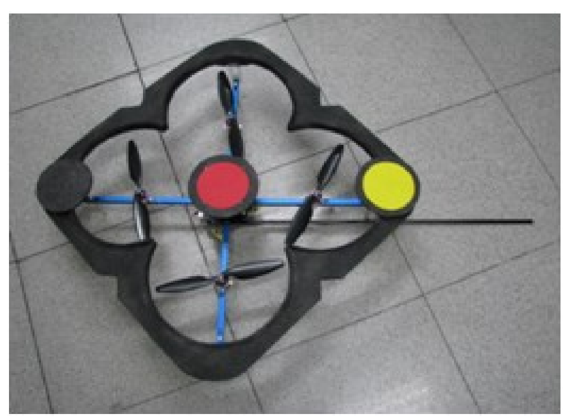

Fig. 2 Quadrotor system

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To detect the applied force induced from a human operator, the quadrotor system is equipped with a load cell as shown in Fig. 3. Whenever the operator pushes the rod, a load cell detects the applied force.

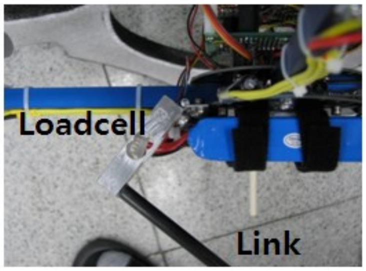
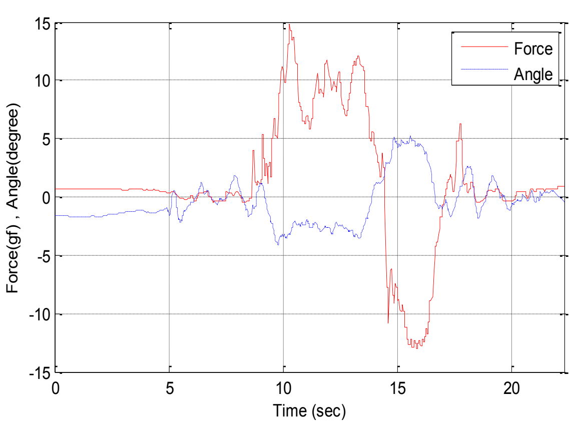


Fig. 3 Load cell

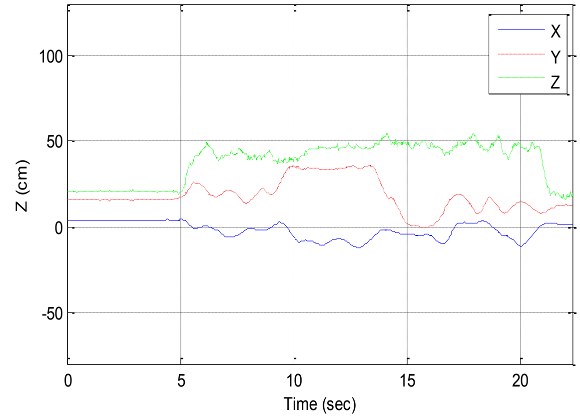
III. EXPERIMENTAL STUDIES

Initially the quadrotor system is tested for the attitude control performance under the camera. A human operator pushes and pulls the rod while the quadrotor is maintaining hovering posture. Fig. 4 shows the experimental video-cut images of interaction control between a quadrotor and a human operator.

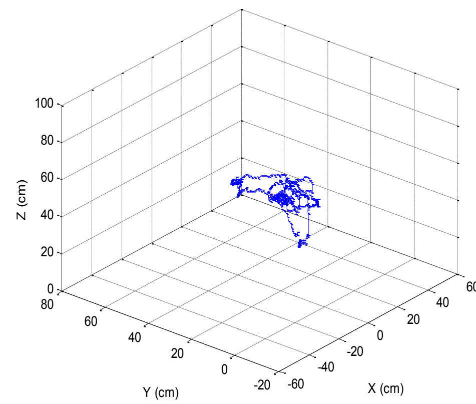
Fig. 4 Interaction control demonstration



(a) Force data



(b) Xyz position data



(c) Movements of the quadrotor system
Fig. 5 Results of Fig. 4

The quadrotor system maintains balance well. The corresponding plots are shown in Fig. 5. Fig. 5 (a) shows the applied force. Positions in x, y and z axis are plotted in Fig. 5 (b). The overall movement of the quadrotor system is described in Fig. 5 (c). We can imagine from Fig. 5 (c) that the operator pushes and pulls the quadrotor system.

IV. CONCLUSION

Contact force control of a qaudrotor system with a human operator has been demonstrated. The quadrotor system is localized under a camera first. The quadrotor system was stable enough to maintain hovering posture even though the operator applied a certain force to the system by a push and pull manner. This confirms that contact force control of a quadrotor system is feasible for the possible applications.

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