Design of a Sliding Mode Controller for Intelligent Drones

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Abstract

This study suggests the design of fuzzy estimated sliding mode controllers which can converge to a command value more quickly than general sliding mode controllers as well as reduce the chattering phenomenon in control input in order to achieve strong control of multi-rotor drones. In addition, the validity of the designed controller was verified through a field application experiment of the intelligent drone built after the modeling and simulation verification of a fuzzy estimated sliding mode control system.

Keywords*: UAV, Fuzzy, Sliding Mode, Drone, Control system*

1. Introduction

As the interest in drones has recently increased, studies using Unmanned Aerial Vehicles (UAVs) are actively conducted in various fields. UAVs are applicable to various fields such as military monitoring system, traffic condition monitoring, disaster relief site reconnaissance, agricultural disaster prevention, and environmental monitoring system. Unlike other UAVs, multi-rotor UAVs have relatively easy control, vertical takeoff and landing capabilities, and stable hovering, and thus, are greatly used for monitoring system configuration and fundamental studies on UAVs.

For the control of position and altitude of multi-rotors for vertical takeoff and landing and hovering, a PID control method and a backstepping control method were suggested. In the PID control method, it is difficult to adjust factors for a good control performance, while the backstepping control method is appropriate for underactuated systems, but as the order of systems increases, the order of virtual controllers increases, resulting in the difficulty in implementation of real controllers [1-4].

Using a sliding mode control method that is appropriate for intelligent drones, which consist in a nonlinear system, and that allows a relatively easy configuration of controllers, the present study drew a remote position control method for quadrotors, conducted a simulation, built an intelligent drone, and verified the validity of the designed controller.

2. Design of Fuzzy Estimated Sliding Mode Controllers for Intelligent Drones

Figure 1 shows the remote control platform for intelligent drones suggested in this study. Aerial vehicles can remotely exchange various sensor signals, control signals, and image signals with base systems, which can be monitored and controlled in user controllers.

The control inputs designed for stable altitude and position control for intelligent drones can be written as the equations below:

$$u = \frac{m}{\cos(\theta) + \cos(\phi)} (g - \ddot{z}_d + \alpha_1 e_z + k_1 sign(S_1) + k_1 S_1) \quad (1)$$

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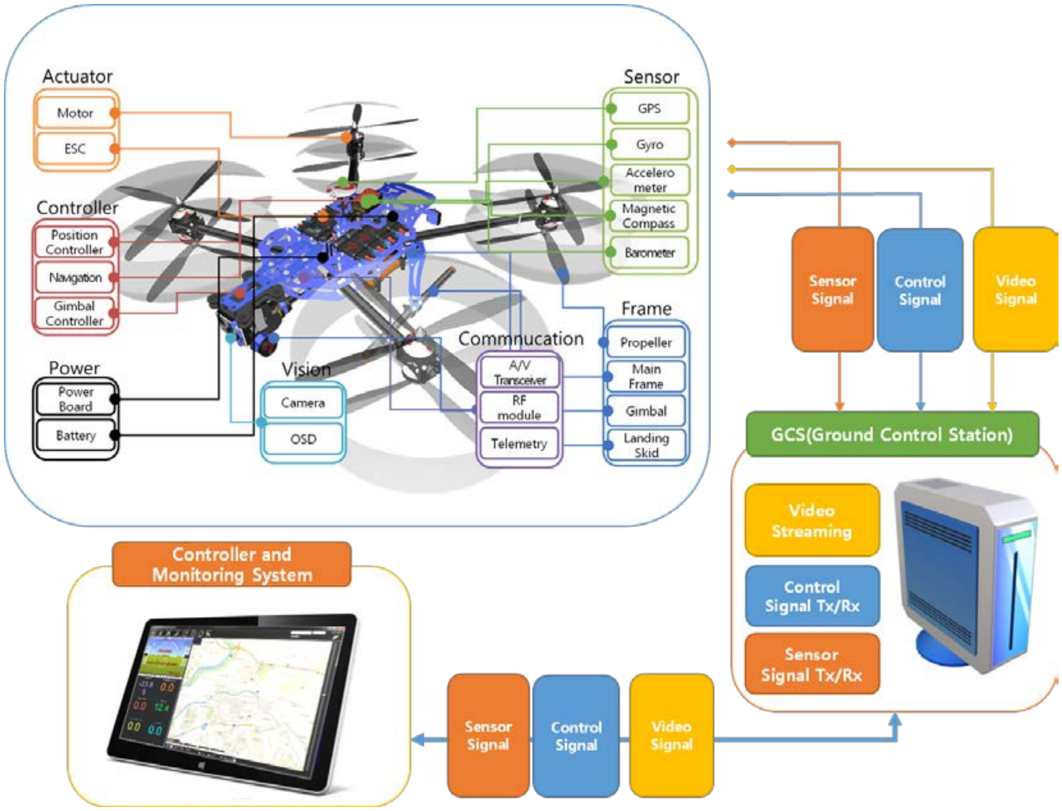

Figure 1. Configuration of a remote control platform for intelligent drones

$$\tilde{\tau}_\phi = -(\alpha_2\dot{\theta}\dot{\psi} + \alpha_2\dot{\theta}(f_4 - f_2)l - \ddot{\phi} + \alpha_2\dot{e}_\phi + k_2 sign(S_2) + k_2 S_2) \tag{2}$$

$$\tilde{\tau}_\theta = -(\alpha_3\dot{\phi}\dot{\psi} + \alpha_3\dot{\phi}(f_3 - f_1)l - \ddot{\theta} + \alpha_3\dot{e}_\phi + k_3 sign(S_3) + k_3 S_3) \tag{3}$$

$$\tilde{\tau}_\psi = -(\alpha_4\dot{\phi}\dot{\theta} - \dot{\psi} + \alpha_4\dot{e}_\phi + k_4 sign(S_4) + k_4 S_4) \tag{4}$$

Equation (1) shows the input u for altitude control, and Equations (2)-(4) show the input torques ($\tilde{\tau}_\phi$, $\tilde{\tau}_\phi$, and $\tilde{\tau}_\psi$) for control of roll (ϕ), pitch (θ), and yaw (ψ) of each drone. m, g, and $f_1 - f_4$ are the weight of a drone, acceleration of gravity, and thrust to each motor, respectively. e is the error value calculated as the difference between the desired value and the current value. $\alpha_1 - \alpha_4$ are the sliding surface constants, and $k_1 - k_4$ are the sliding constants. Lastly, $S_1 - S_4$ are the sliding surfaces at which altitude and position can be stable.

The sliding mode controller designed as above has the chattering phenomenon in control input by nature. The chattering phenomenon in input causes high energy consumption for control. Therefore, we suggested a structure (Figure 2) to obtain gains of a sliding controller through a fuzzy estimator in order to reduce the chattering phenomenon and quickly approach sliding surfaces.

In order to generate fuzzy inputs of each sliding surface, values approaching the sliding surfaces were derived through a simulation, and the potential input values were finally selected from all constants. To select the input values for the fuzzy estimator, the triangular membership functions were used as shown in Figure 3 and the Fuzzy Rules were generated [6-9].

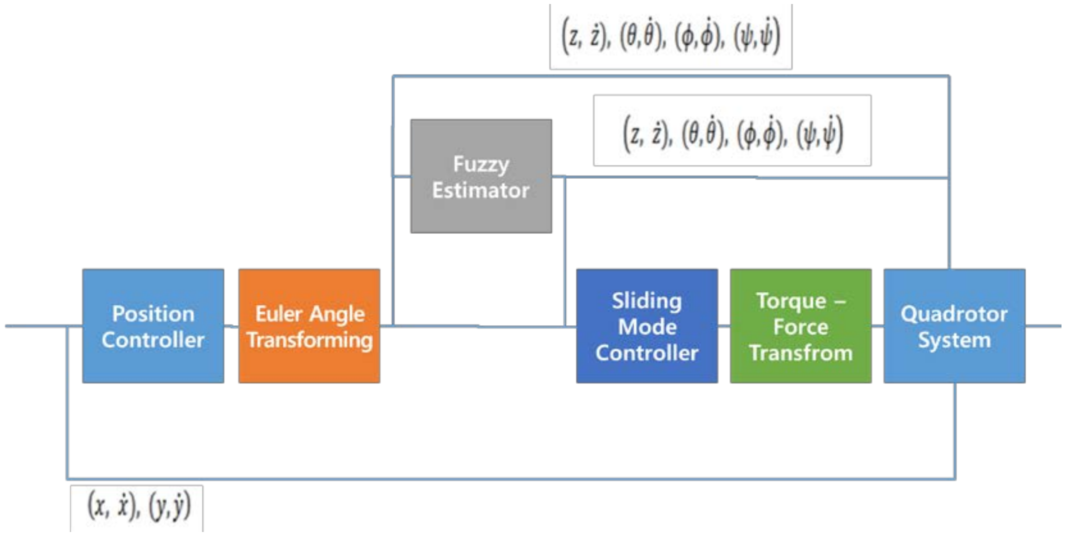

Figure 2. Structure of the fuzzy estimated sliding mode controller suggested in this study

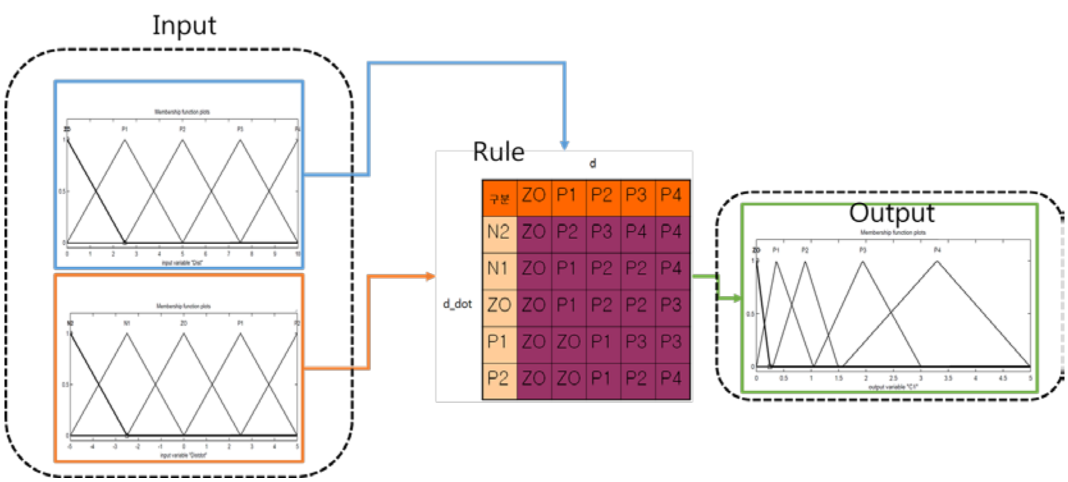

Figure 3. Input and output membership functions of the fuzzy estimator and the used rules

3. Results of the Simulation and the Field Application Experiment

When comparing the simulations of the sliding mode controller and the fuzzy estimated sliding mode controller suggested in this study, the chattering in control input was greatly reduced in the latter one, and the desired yaw value was also reached about 50% more quickly, demonstrating that it has superior control performance.

Figure 5 presents an intelligent drone built with the controller suggested in this study and a user controller with a remote control platform. A 4K resolution aerial photograph from an altitude of 50 m using the control platform is presented in Figure 6.

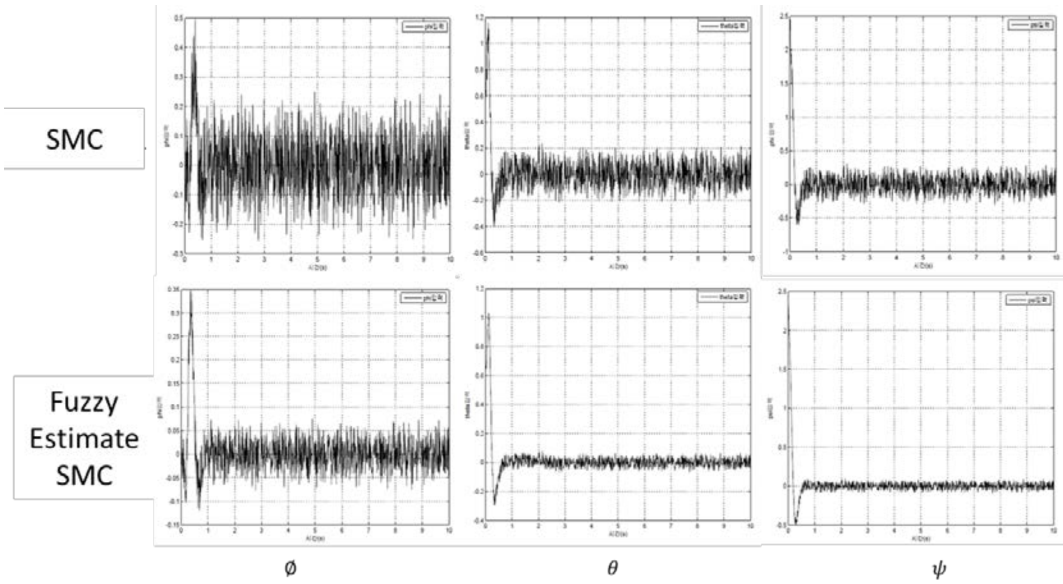

Figure 4. Comparison of the input torques between the sliding mode and the fuzzy estimated sliding mode

Figure 5. The built intelligent drone and remote user controller

Figure 6. The 4K resolution aerial photograph using the intelligent drone

4. Conclusions

In order to overcome the uncertainty and achieve strong control, this study conducted the simulation of the fuzzy estimated sliding mode controller and confirmed that it had the reduced chattering phenomenon and better control performance, compared to the sliding mode controller. In addition, we applied it to the real drone and confirmed that it can perform strong control operations in various conditions. Further study will be conducted, aimed at the use of the research results for environmental monitoring studies using drones equipped with optics-based sensors. Moreover, the results of such study will be applicable to various fields such as traffic condition monitoring, military area monitoring, environmental monitoring of polluted areas, and various control systems.

5. References

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