Data-driven Control Experiments of a Quadrotor Drone

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Abstract

Multi-rotor unmanned aerial vehicle (UAV)have various advantages due to their high expected performance. Most conventional model-based design methods require the dynamic characteristics of UAV, whereas data-driven design methods allow the controller to be designed directly from flight data without a model. This study reports on the creation and flight experiments of a quadrotor drone with the aim of preparing an environment for implementing data-driven design for UAV. In addition, the usefulness of the controller directly designed from flight data is also reported.

Keywords: Quadrotor Drone, Data-driven Control

1. Introduction

Drones [1], which are expected to play a variety of roles, have been involved in crashes, so further improving their safety is an issue. Since many drones use an internal controller to achieve the movements expected by the operator, the design of the controller is important for safety.

Controller design methods can be broadly divided into model-based design and data-driven design. Since model-based design is based on identified models, control performance depends on the accuracy of model identification. However, obtaining a model with high accuracy requires a large amount of effort. Drones, in particular, are not only prone to deterioration of components such as motors and batteries, but also frequently change their dynamic characteristics due to differences in payload. In contrast to model-based design, data-driven design does not require the model of a controlled process because the controller is designed directly from experimental data.

Virtual Reference Feedback Tuning (VRFT) [2] and Fictitious Reference Iterative Tuning (FRIT) [3] are typical methods for data-driven design. Using these methods, a controller can be designed from a set of input/output data, where there are two types of data used in the design: open-loop data and closed-loop data. Since unstable drones require closed-loop data-based design, an attitude control method using FRIT [4] has been proposed. However, the barometer built into the flight controller used in previous studies [4] cannot accurately measure altitude indoors. Therefore, in this study, a motion capture system will be introduced to accurately measure the altitude, and data-driven flight control design methods are discussed. Finally, the effectiveness of the data-driven method is confirmed through experiments.

2. Drone used in experiments

To allow for flexibility in changing controllers, a research drone [4], shown in Figure 1, was developed, where thelist of partes are summarized in Table 1. The drone is a quad-rotor type, and an ESC (Electronic Speed Controller) is required for each motor, which controls the motor speed by adjusting the current according to the PWM signal calculated by the flight controller. The reference values determined by the pilot are communicated to the flight controller through the radio. The control system developed is equipped with two XBee (wireless communication devices), one for receiving advanced information and the other for transmitting control data, and the two XBee-compatible devices are connected to a PC to send and receive data.

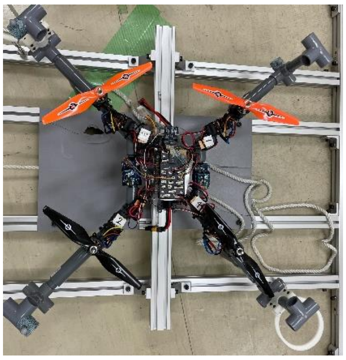


Fig. 1 Picture of the drone

Table 1 Done parts list

Parts name	Product name
Frame	RC Drone Frame Kits XL8 Carbon Fiber FPVRacing Frame Kit for RC Drone
Flight controller	Pixhawk4
Brushless motor	NTM Brushless Motor NTM Prop Drive Series 28-30 1200kv
Electronic speed controller (ESC)	FUTABA CORPORATION ESC Exclusively for brushless motors MC930A
Remote	FUTABA CORPORATION 8-Channel Digital Proportional R/C System T6K-V2
Lithium polymer battery	Zeee 11.1V 50C 3200mAh 3S Lipo Battery
Propeller	MASTER AIRSCREW MR Series 8×4.5 Prop Set Black
Wireless communication device	ZigBee wireless communication module XBee

3. Altitude Measurement using an Optical Motion Capture System

Figure 2 shows a motion capture system for drone altitude measurement. In this system, the four cameras are placed in the four corners of the room, and the cameras are adjusted so that the drone is positioned near the center of the shooting range. Five reflective markers are attached to the drone to create a rigid body on the motion capture software. The position coordinates of the rigid bodies measured in real time are captured by software (MATLAB by MathWorks) and sent to the flight controller of the drone via wireless transmitter to control the altitude.

Fig. 2 Environment of experiments

4. Data-driven Controller Design

The design objective is to improve control performance by tuning the controller directly from experimental data of an initial controller. Consider the model reference problem for the single-loop system in Figure 3. In the figure, $C(\Phi)$ denotes the controller, Φ the controller parameters, P the controlled process, r the reference input, u the input, and y the output, and e the error between r and y. M is the reference model, y_M is the reference model output, and G is the following closed-loop transfer function from r to y:

$$G(\Phi) = \frac{PC(\Phi)}{1 + PC(\Phi)}. \qquad (1)$$

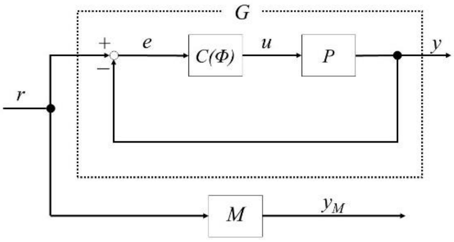


Fig. 3 Model reference problem

In general, the mathematical model of P is not known. To make the closed-loop system $G(\Phi)$ match the reference model M, we define the evaluation function $J(\Phi)$ as follows:

$$J(\Phi) = \|M - G(\Phi)\|_2^2. \tag{2}$$

Therefore, the controller parameter Φ is determined based on the minimization of this evaluation function. However, since $J(\Phi)$ contains the unknown P, which is it cannot be solved. In the present study, instead of $J(\Phi)$, the following function is used for determining the controller parameters:

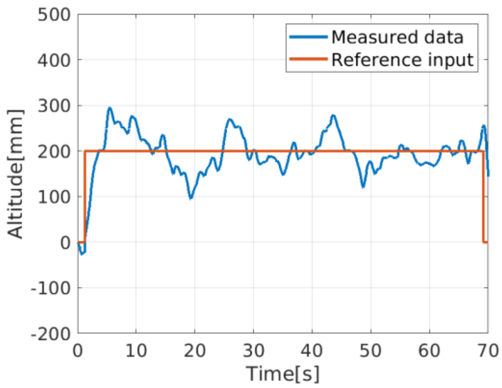
$$J_F(\Phi) = \|y_0 - M\tilde{r}(\Phi)\|_2^2, \tag{3}$$

Fig. 4 Scene of a flight experiment

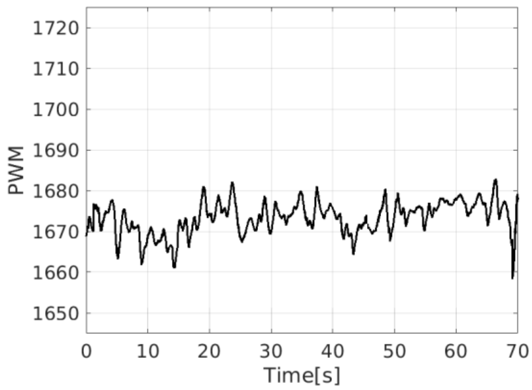
where $\tilde{r}(\Phi)$ is a fictitious reference input given as follows:

$$\tilde{r}(\Phi) = \frac{u_0}{C(\Phi)} + y_0. \tag{4}$$

u_0 and y_0 are the input and output data collected from an experiment using initial controller parameters. The controller parameters are obtained by solving the above evaluation function.



(a) Output



(b) Input

Fig. 5 Flight result before tuning

5. Experiment

5.1. Experimental conditions

Drone flight experiments were conducted as shown in Figure 4. The altitude of drone is controlled by PI-D control, and the control and sampling periods are 16 [ms]. The drone was allowed to hover at an altitude of approximately 1.25 [m] above the ground, and the altitude at the hovering point was used as the origin.

Table 2 PID gains for experiments

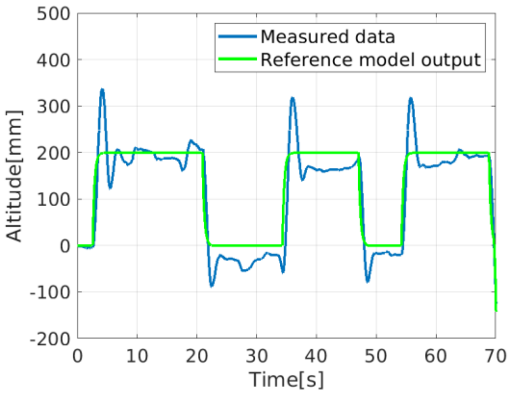
Parameters	P	I	D
Initial	0.05000	4.000×10^{-4}	5.000
Tuned using Eq. (5)	0.1534	1.417×10^{-4}	0.9548
Tuned using Eq. (6)	0.1090	1.866×10^{-4}	3.112

5.2. Initial experiment and parameter tuning

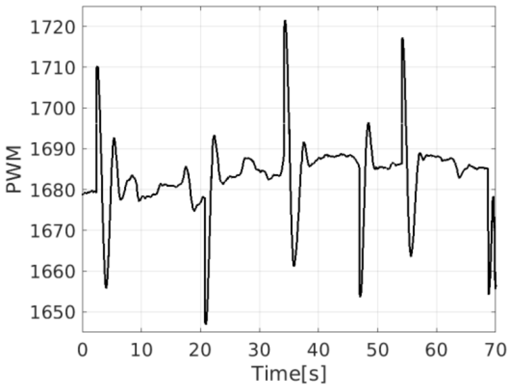
An experiment was conducted with initial parameters shown in Table 2 with a reference altitude of 200 [mm] to obtain data used for controller tuning. The control result is shown in Fig. 5 here the red and blue lines show the reference input and the measured altitude, respectively. Based on the collected data, the PID parameters are tuned using FRIT [3] for the fast and slow reference models (5) and (6), respectively, where CMA-ES [5] is used for optimizing the objective function (3).

$$M(s) = \frac{1}{0.3s+1}e^{-0.096s} \quad (5)$$

$$M(s) = \frac{1}{0.5s+1}e^{-0.096s} \quad (6)$$

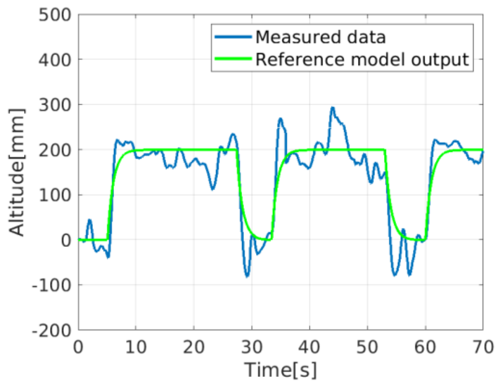


(a) Output

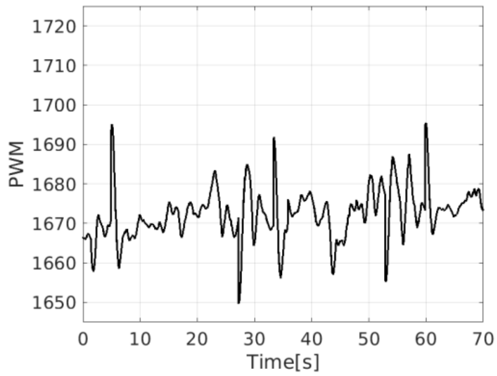


(b) Input

Fig. 7 Flight result after tuning (fast reference model (5))



(a) Output



(b) Input

Fig. 6 Flight result after tuning (slow reference model (6))

The obtained PID parameters are shown in Table 2.

5.3. Experimental results using tuned parameters

The experimental results using the tuned parameters are shown in Fig. 6 and Fig. 7, where the green line shows the reference model output. The control result based on the fast reference model shows that the altitude trajectory tracks the reference model output well in steady state. However, each time the reference input switches, an overshoot occurs. On the other hand, the experimental result for the case based on the slow reference model shows that the overshoot is suppressed, while the altitude oscillates around the reference input. These results show that there is a trade-off between the speed of tracking to the reference input and vibration suppression.

6. Conclusion

This study has reported on the implementation of drone altitude control using a motion capture system. Since the controller for operating the drone was designed based on flight experimental data, the controller is designed directly form the data without using the model of the drone. Finally, the flight experiments confirmed that control performance is improved using the tuned controller parameters.

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