DYNAMICS MODELING AND FEEDFORWARD CONTROL OF A COMPACT UAV (UNMANNED AERIAL VEHICLE)

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Abstract

In this paper, we modeled the dynamic characteristics of the drone type UAV (Unmanned aerial vehicle) moving in the lateral direction toward the front. Using this model, we constructed a control model for feed forward control to avoid obstacles from the front by step change of the speed target value. In this paper, the dynamic characteristics of the drone are modeled as the first-order lag transfer function when the left and right movement start by the stepwise change of the target speed value. Moreover, the dynamic characteristics at the end of flight where step change is returned to 0 are considered as transfer functions in which two first-order lag transfer functions are connected in series, and a model with continuity is constructed. The model was evaluated by comparing the actual data collection by experiments and numerical simulation. Moreover, using this dynamic characteristic, the control model that outputs the step-like speed change time was constructed with the movement distance required for avoidance as an input, and it was confirmed that it is useful for obstacle avoidance.

Keywords: *UAV, dynamics, dynamic modeling, obstacle avoidance, feed forward control*

1. INTRODUCTION

In recent years, the performance of drone type compact UAV (Unmanned Aerial Vehicle) has been remarkably advanced, research and productization for disaster relief, monitoring mission, and entertainment have been conducted both in Japan and overseas, and in the future there is also expectation for the delivery service etc. ([1] Nonami, K. 2017, [2] Suzuki, S. 2016).

On the other hand, the improvement of vehicle motion performance is expected by the development of on-vehicle sensors such as cameras and radars and recognition technology, but there is a problem of collision avoidance with obstacles as its task. As a countermeasure to the problem, researches have been proposed which propose the shortest avoidance control method for the problem of calculating the optimum trajectory and calculating the lateral force and yaw moment of the vehicle necessary for the trajectory([3] Ohmuro, A. & Hattori, Y. 2010).

For this, we are working on the development of the shortest avoidance control method using a drone. In this method, the trajectory of the obstacle is recognized by a camera mounted on the drone, and the aim is to avoid the obstacle by using a minimum necessary avoidance trajectory. Therefore, in the present method, when a lateral movement distance to be avoided is given, the purpose is to construct a mathematical model of how long a step change in speed should be added as feed forward control. And in this paper, the dynamic characteristic model of drone's transverse flight was constructed by experiment, the required step application time was obtained by the approximation method, and the evaluation was performed by the numerical simulation.

2. OUTLINE OF THE SYSTEM

Fig. 1 shows a conceptual diagram of the feed forward control system for obstacle avoidance. In order to fly the flight distance determined to avoid the obstacles with the risk of collision and the energy minimum, we perform feed forward control by step change of target speed without using a sensor. Therefore, we formulate the relation between time and movement distance at the time of step-like target value change to the speed control system, and generate the avoidance trajectory of drone (the relation between time and position). In this study, AR.Drone 2.0 by Parrot was used (Fig.2).

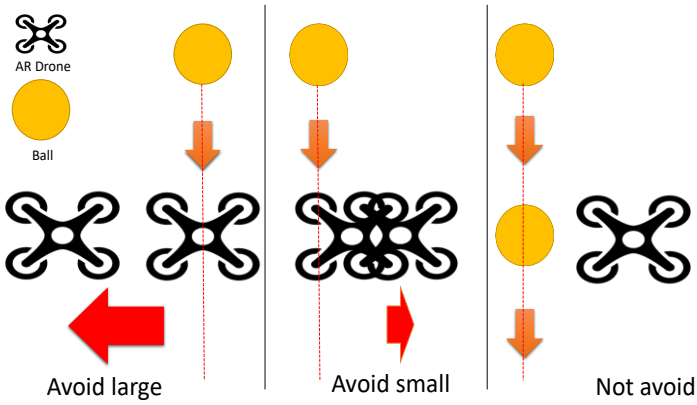


Fig. 1. Conceptual diagram of the feed forward control system for obstacle avoidance



Fig. 2. Drone type UAV (AR.drone by Parrot Ltd.)

3. BASIC EXPERIMENTS AND FORMULATION

In this study, we aim to avoid obstacles by flying to the left and right for obstacles coming from the front. Therefore, basic flight experiments were conducted to understand the dynamic characteristics of drone flight in the left and right direction.

In the experiment, data was collected by flying about 3 m to the left and right with the speed target value on the software system built in the drone at 1.0 (positive for left and negative for right).

Figure 3 shows the data based on acceleration sensor built into the drone. And using the camera function of the smartphone, we shoot the drone flight on a horizontal plane from above, and the data calculated based on the analysis of the video data is shown in Fig.4 (velocity was obtained by built in sensor).

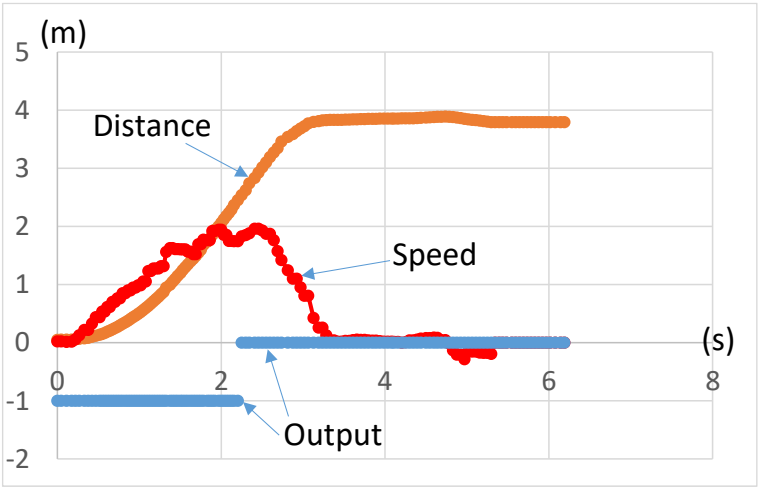


Fig. 3. Data using drone's built-in acceleration sensor

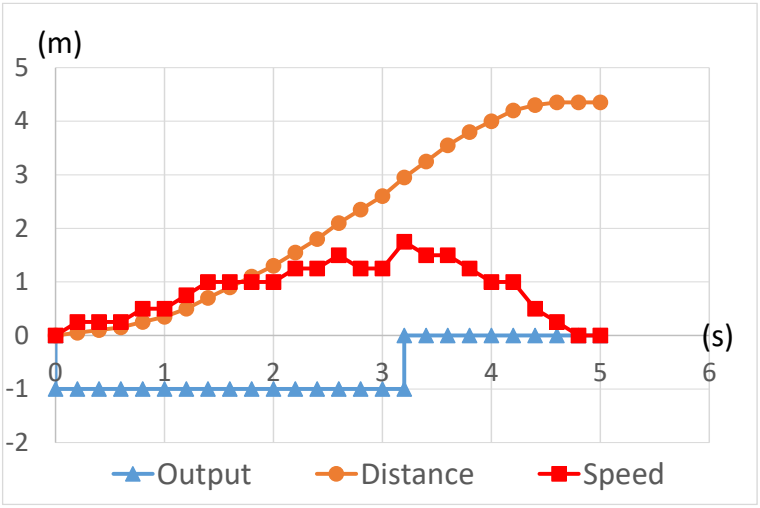


Fig. 4. Data based on a video taken with a smartphone

The shooting method was to put a red tape on the floor every 10 cm and mark it with a white tape every 1 m, and shot from right above the drone flying and the data was collected while letting the smartphone follow manually according to the movement of the drone.

As a result, since the accuracy was insufficient with the data of the built-in acceleration sensor, the dynamic characteristics were modeled based on the data with a smartphone of Fig.4.

From the data, the dynamic characteristic model was divided into ON period (state during acceleration) and OFF period (state during deceleration) of the output (When changing the speed target value in the lateral direction from 0 in a step-like manner into a non-zero value, it is “ON”, when changing from a non-zero value in step-like manner into 0, it is “OFF”).

First, it is considered that when the drone accelerates (ON), it accelerates in the first-order lag system, and during deceleration (after the time when the speed target value is changed from non-zero value to 0) it decelerates in the second-order lag system (Considering that two first order lag systems are connected in series), the dynamic characteristic was modeled by Eqs. (1) and (2). Furthermore, the equations (3) and (4), which are relational expressions of time and distance, were derived by integrating the obtained velocity ([4] Control System,[5] Second-order lag system).

V_1 is the speed at which the outputis being produced(ON: speed target value on built in software is changed from 0 to nozero value), and X_1 is the distance of V_1.

V_2 is the velocity of inertia after turning off the output(speed target value on built in software is changed 0), and X_2indicates the distance of V_2.

$$V_1 = K \times \left(1 - e^{-\frac{t}{T_1}}\right) \tag{1}$$

$$V_2 = V_p - V_p \times \left\{1 - e^{-\frac{t}{T_2}}\left(\frac{t}{T_2} + 1\right)\right\} \tag{2}$$

$$X_1 = K \times \int_0^t \left(1 - e^{-\frac{\tau}{T_1}}\right) d\tau$$

$$= K \times \left(t + T_1 e^{-\frac{t}{T_1}} - T_1\right) \tag{3}$$

$$X_2 = V_p \times \int_0^t \left(e^{-\frac{\tau}{T_2}} + \frac{\tau}{T_2} e^{-\frac{\tau}{T_2}}\right) d\tau$$

$$= V_p \times \left\{-te^{-\frac{t}{T_2}} - 2 \times \left(T_2 e^{-\frac{t}{T_2}} - T_2\right)\right\} \tag{4}$$

Where

K: steady state gain

T_1, T_2:time constant

Vp:final value of V_1

The time t in Eqs. (1) and (3) is 0 when the target value is changed from 0 to nonzero value, and the time t in Eq.(2) and (4) is 0 when the target value is returned to 0. Since the distance X_1 can be obtained from the output time T_p(Time when the speed target value was changed to 0), the total distance $X = X_1 + \lim_{t\to\infty} X_2$ can be described by equation (5).

$$X = X_1 + \lim_{t\to\infty} X_2$$

$$= K \times \left(T_p + T_1 e^{-\frac{T_p}{T_1}} - T_1\right) + V_p \times \{-2 \times (-T_2)\}$$

$$= K \times \left(T_p + T_1 e^{-\frac{T_p}{T_1}} - T_1\right) + 2T_2 \times K \times \left(1 - e^{-\frac{T_p}{T_1}}\right)$$

$$= K \times \left\{T_p - T_1 + 2T_2 + (T_1 - 2T_2) \times e^{-\frac{T_p}{T_1}}\right\} \tag{5}$$

4. MODELING AND VERIFICATION BY SIMULATION

Considering that the distance data based on velocity in Fig. 4 is close to the true value, the distance in Fig. 4 is differentiated to calculate velocity, and the graph in Fig. 5 is created.

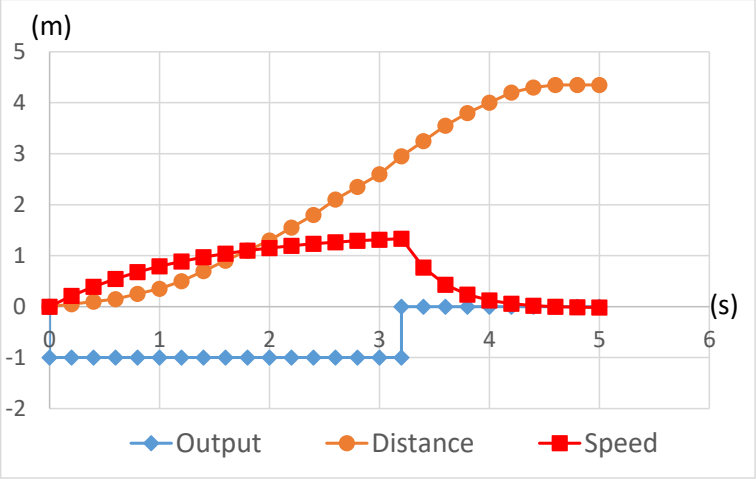


Fig. 5. Differentiate the distance

A graph obtained by fitting the model to the speed shown in Fig. 5 by putting values ($K = 1.45, T_1 = 1.27, T_2 = 0.5$) obtained from the graph into the equations (1), (2), (3) and (4) of the drone dynamic characteristic model obtained in Chapter 3 is Fig.6.

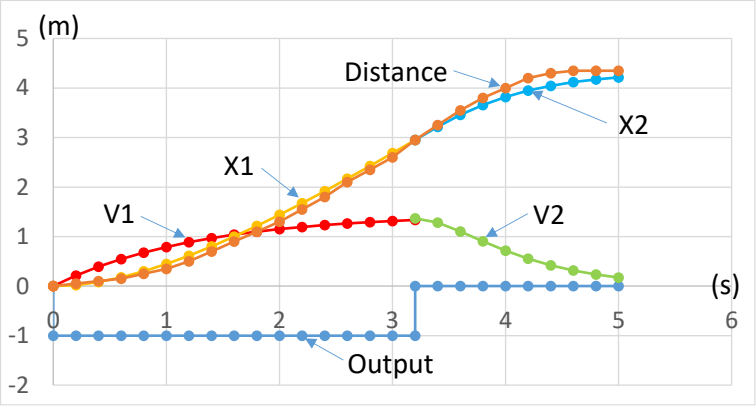


Fig. 6. Dynamic characteristics model

Using the simulation software MATLAB & Simulink (The MathWorks, Inc.), the equation of the dynamic characteristic model in Fig. 6 was applied to MATLAB, and the drone flight distance was verified by simulation as a control system of continuous time system (Fig.7).

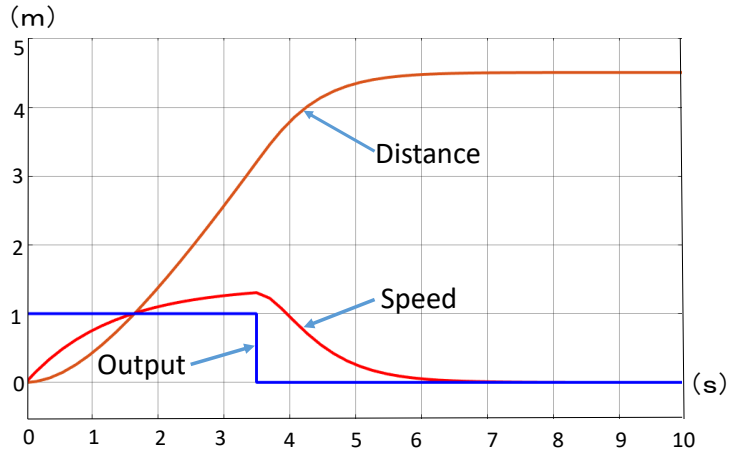


Fig. 7. MATLAB simulation

5. CONTROL MODEL FOR FEED-FORWARD CONTROL

Feed-forward control for obstacle avoidance in this paper is control that moves a given avoidance distance laterally, it is necessary to find the time to maintain the speed target value at a predetermined value according to the avoidance distance.

Therefore, Fig. 8 shows the relationship between time and distance obtained in the previous chapter, with the horizontal axis representing distance and the vertical axis representing time. Equation (6) shows the result of finding an approximate straight line with the distance as the input variable and the time as the output variable from this graph.

$$y = 0.0017x^3 - 0.0263x^2 + 0.8253x + 0.0106 \quad (6)$$

where x: distance

y:output time

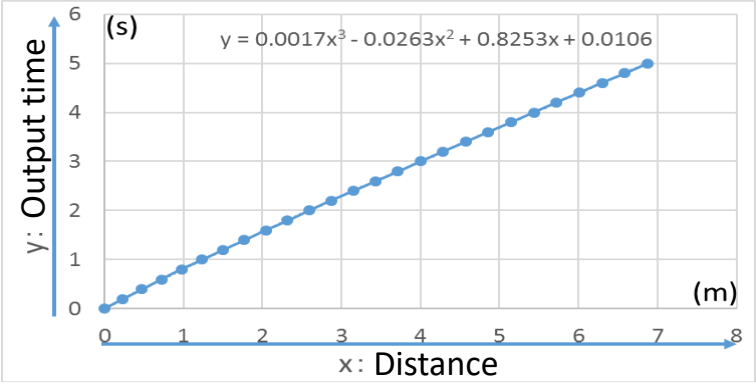


Fig. 8. Output time and Avoidance distance

6. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results in Chapter 3 show that the drone speed is a first-order lag system during acceleration, and the drone speed is second-order lag system during deceleration. As for the speed of the second-order lag system during deceleration, it is thought that the drone itself performed the self-

stabilizing control as the original function after turning off the output and the dynamics of deceleration was not the first-order lag system but the second-order lag system.

It is thought that the measurement instrument built into the drone did not work well because the measurement was affected by the lack of accuracy of the drone's accelerometer.

7. RESULTS

We constructed a control model to realize feedforward control for obstacle avoidance. This model is based on the dynamic characteristics of the drone and outputs the time to change the lateral velocity stepwise for a given avoidance distance. The dynamic characteristics were modeled by experimental data, and its effectiveness was confirmed by simulation.

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