PID CONTROL FOR 1-DOF DRONE: SIMULATION AND EXPERIMENT

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Abstract: In this paper, we present a single input-single output (SISO) model – 1-DOF drone. This model is simple but difficult to be controlled due to its nonlinear characteristic. We also present a self-made hardware platform for this model in laboratory. Thence, classical PID control is examined on both simulation and experiment. This algorithm is proved to work well. Thence, this model is a nonlinear SISO solution for classical training model for laboratory.
Keywords: SISO model; PID control; 1-DOF drone; nonlinear model.

1. Introduction

Helicopter **[1]** and drone [2] are popular topic for algorithm research. Drone seems to be more popular than helicopter in recent studies [3]. However, both types are complicated for small laboratory and independent researchers who are lacked of financial supports. Thence, a more simple and easy-to-learn of these models are studied, such as, 1-DOF drone [4], [6],… In [6], a PCI card is used to provide hardware platform for training algorithms. However, this product of Quanser is expensive and hardware platform does not suit all computer/laptop hardware. Thence, in order to simplify this model and popularize it to learners in laboratories, in this study, we present a 1-DOF drone hardware platform which is based on Arduino processor. A classical PID controller is examined to control well this model in both simulation and experiment. The survey of this basic control algorithm satisfies theory of PID calibration. The success testing on this model prove the suitability of using it on training bachelor students.

2. Mathematical Model

Mathematical model of 1-DOF drone is shown in Fig. 1 below [6].

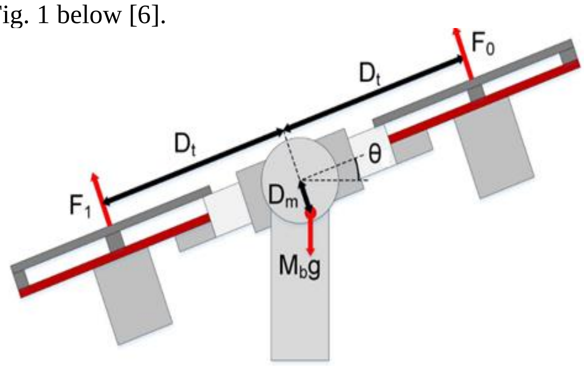

Fig. 1. Mathematical model of 1-DOF drone [6]

From [5], differential transfer function of this system is

$$J_p\ddot{\theta} = -M_b g D_m \sin\theta - b_p\dot{\theta} + \tau_p \tag{1}$$

where, θ (rad) is angle of pitch; J_p (kgm^2)is inertial moment of pitch; M_b (kg) is mass of body; b_p is viscous friction damping coefficient; τ_p (Nm) is torque acting on system; D_m (m) is distance from roational axis to center of model; g (m/s^2) is gravitational acceleration.
We obtain

$$\tau_p = F_1 D_t - F_0 D_t \tag{2}$$

where, D_t (m) is distance between rotational axis to motor; F_0 (N) is thrust from motor 0; F_1 (N) is thrust from motor 1.

These thrusts are calculated as

$$F_0 = K_t V_0 ; \ F_1 = K_t V_1 \tag{3}$$

where, K_t is thrust coefficient of motor; V_0 (V) and V_1 (V) are voltages
Substituting (3) into (2), we obtain

$$\tau_p = K_t D_t (V_1 - V_0) = K_t D_t V \tag{4}$$

Thence, V is control signal for this system.
From **(1)**, we obtain SISO nonlinear model of 1-DOF drone as

$$\ddot{\theta} = \frac{-M_b g D_m \sin\theta - b_p\dot{\theta} + K_t D_t V}{J_p} \tag{5}$$

3. Control Algorithm

Among control methods, PID is the most popular one [7]. Thence, any model which must be tested to be controllable by PID method to be a standard model for training in laboratories in universities. PID control is divided into continuous form and discrete form. In the past, when digital processor had not been invented yet, there is only continuous PID. However, under development of technology, the processors are used, and their speeds are improved through time. Thence, digital PID structure is utilized more popularly. A discrete PID structure is shown in Fig. 2.

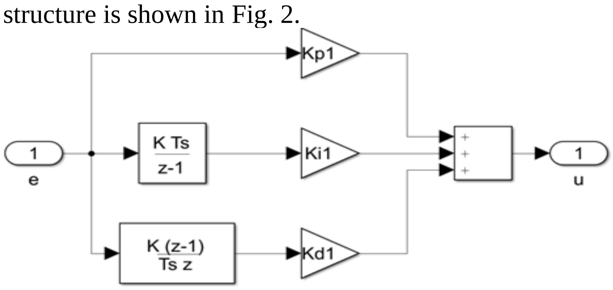

Fig. 2. **S**tructure of PID discrete

The set point of body of drone is the horizontal position. The control signal is the signal V in (4). The feedback structure of controlling this model is shown in Fig. 3 below due to SISO model as in (5).

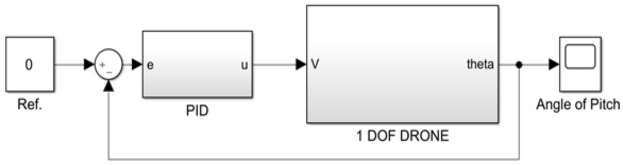

Fig. 3. PID control structure for 1-DOF drone

4. Simulation

For examining responses of system under calibration of PID parameters, a standard set of these parameters is selected as

Kp=5; Ki=0.08; Kd=1 (6)

And, two cases in which Kp is increased and decreased are shown in (7) and (8) when Ki and Kd are kept the same as in (6)

Kp=1; Ki=0.08; Kd=1 (7)

Kp=200; Ki=0.08; Kd=1 (8)

The pitch angles are shown in Fig. 4

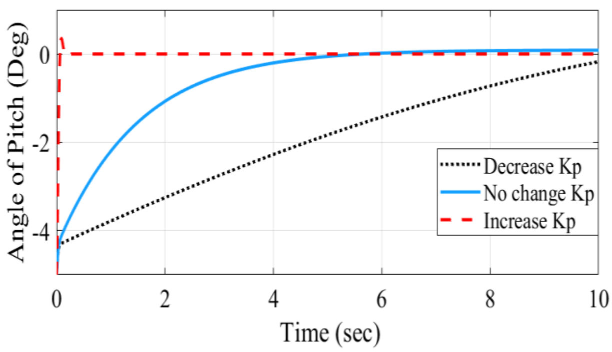

Fig. 4. Pitch angle under parameters in (6), (7), (8)

In Fig. 4, when Kp is increased, settling is shorter (from more than 10 sec to 6 sec and 0.3 sec. However, when Kp=200, overshoot exists.

And, two cases in which Ki is increased and decreased are shown in (9) and (10) when Kp and Kd are kept the same as in (6)

Kp=5; Ki=0.01; Kd=1 (9)

Kp=5; Ki=0.8; Kd=1 (10)

The pitch angles are shown in Fig. 5

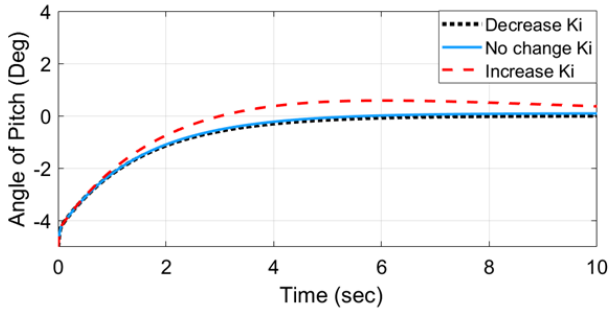

Fig. 5. Pitch angle under parameters in (6), (9), (10)

In Fig. 5, when Ki is increased, settling time is longer (from more than 7 sec to more than 10sec. Actually, if Ki≠0, there is no settling error. And, if Ki is big, there is overshoot.

And, two cases in which Kd is increased and decreased are shown in (11) and (12) when Kp and Ki are kept the same as in (6)

Kp=5; Ki=0.8; Kd=1 (11)

Kp=5; Ki=0.8; Kd=1 (12)

The pitch angles are shown in Fig. 6

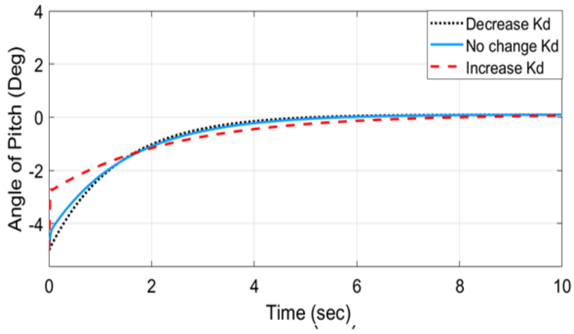

Fig. 6. Pitch angle under parameters in (6), (11), (12)

In Fig. 6, when Kd is increased, settling time is longer (from 7 sec to more than 8 sec). But, the output signal seems to be more stable. The settling error is unaffected.

Thence, through simulation, the responses of system under calibration of PID parameters satisfy the theory of PID methods. Depending on expected quality of project, control parameters are calibrated to obtain suitable settling time, setting error and overshoot.

5. Experiment

An experimental model is presented in Fig. 7.

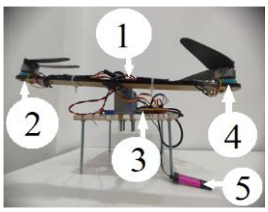

Fig. 7. Experimental model of 1-DOF drone

Components in Fig. 7 are:

1- Axis which keeps body of drone to rotate around.
2- Left motor which controls left pinwheel
3- Arduino board and control driver of motor
4- Right motor which controls right pinwheel
5- Lypo pin

Connection of hardware is described as in Fig. 8. Experimental results are shown in Fig. 9 to Fig. 11. In experiment, standard set of PID controller is chosen by trial-and-erro test as

$$Kp=4;\ Ki=1.5;\ Kd=3 \tag{13}$$

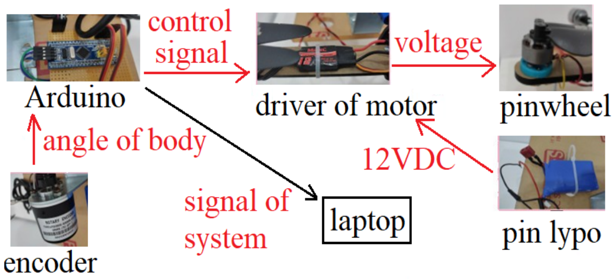

Fig. 8. Connection of hardware

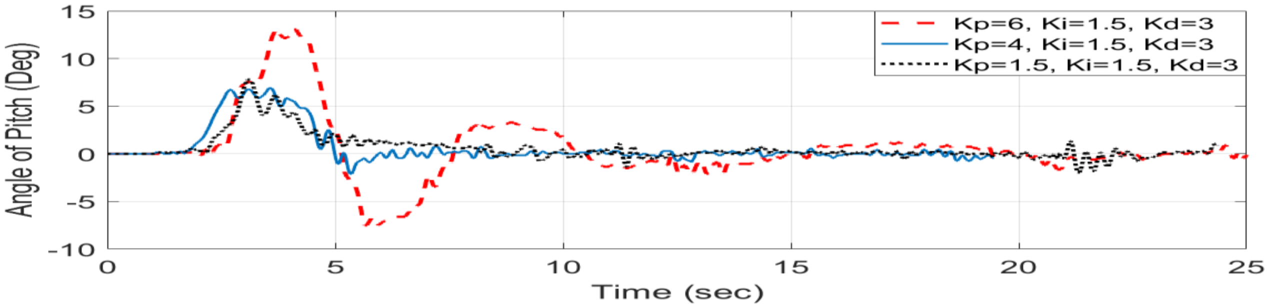

Fig. 9. Angle of pich (degree) when adjusting Kp when maintaining Ki, Kd as in (13)

In Fig. 9, when Kp is increased, vibration of system is bigger (from 5 degrees to 14 degrees). Thence, system needs more time to be stable. Settling time is 25 sec instead of 10 sec). This result suits the theory of PID calibration. When Kp is decreased, vibration of system is maintained and the settling time begin being longer. This result shows that too small value of Kp does not support response of system but causing longer settling time (from 10 sec to 12 sec).

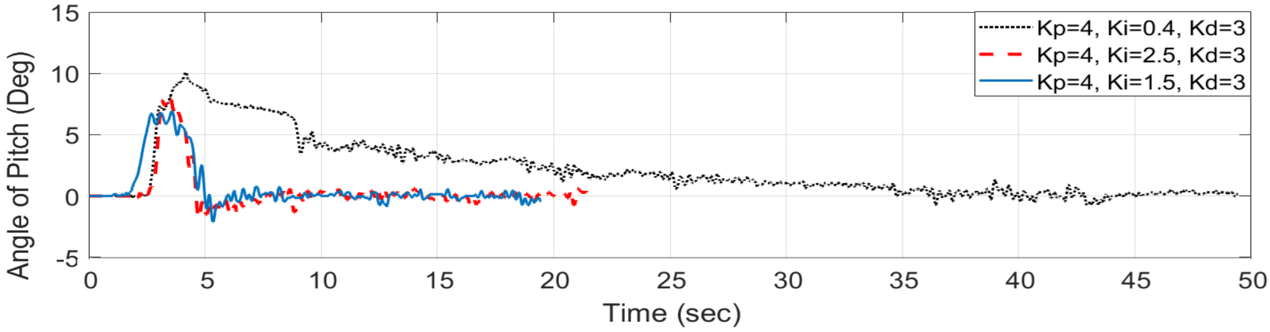

Fig. 10. Angle of pich (degree) when adjusting Ki when maintaining Kp, Kd as in (13)

In Fig. 10, when Ki is too small (Ki=0.4), then, settling time is longer (35 sec instead of 3 sec), vibration is bigger (10 degrees instead of 8 degrees). This result differs from theory. When Ki is bigger, the response is not changed. Thence, by experienece, Ki should be chosen around 1 to 3 due to characteristics of this experimental model).

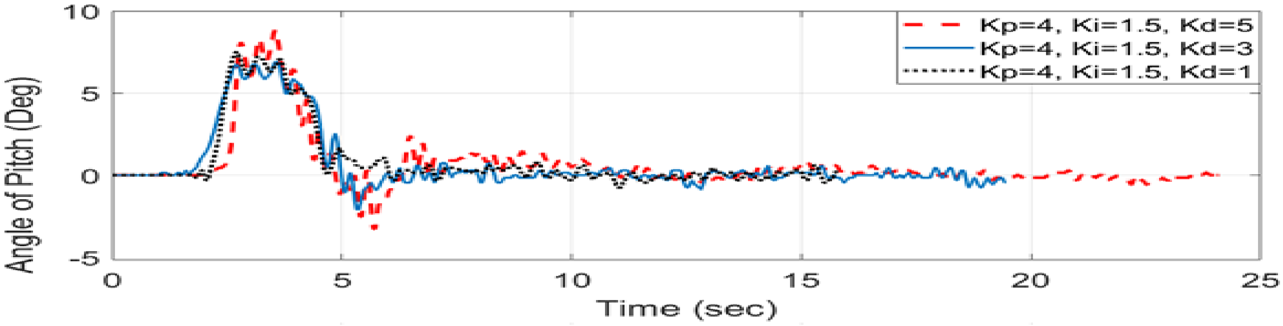

Fig. 11. Angle of pich (degree) when adjusting Kd when maintaining Kp, Ki as in (13)

In Fig. 11, too big Kd (Kd=5) causes more vibration (9 degrees instead of 7 degrees). This differs from theory. And, due to experience, Kp should be between 0.5 to 3. Thence, from experiment, Kp is the only components following PID theoretical calibration. Ki and Kd must be chosen by trial-and-error test to get suitable values.

5. Conclusions

1-DOF drone is focused in this study. Mathematical model of this system is analyzed. Thence, classical PID controller is used to balance this model at horizontal position. Simulation results prove the suitability of PID calibration and theory. However, experiment only approves the suitability of Kp to theory.

The calibration of Ki and Kd in experiment does not follow theory and these parameters can only be selected through trial and error test. Thence, hardware platform in this system is a basement for testing PID control. PID controller is shown to work well on this model. Video of system operation is shown in link: https://www.youtube.com/watch?v=23Um9Et516w

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