OPTIMIZING P.I.D PARAMETERS IN CONTROL ACCELEROMETERS AND GYROSCOPESIN SELF - BALANCING QUADROTORS

Vu Van Thanh, Huynh Thanh Tung

The University of Danang, University of Science and Technology; httung@dut.udn.vn, vuvanthanh85@gmail.com

Abstract - The algorithm that calculates PID controller consists of three separate parameters, so sometimes it is also calledthree stage control: theproportion, integral and derivative values, referred to as P, I, and D.The proportion value determines the impact of the current uncertainty, the integral value determines the total impact of past errors and the derivative value determinesthe value of the differential impact of error variable speed. Total short of three effects are used to adjust the process via a control element such as the position of the control valve or the source of the heating element [1].In this paper the authors find and optimize 3 constants in the algorithm of the PID controller.The controller can be used in the designs that have special requirements. The response of the controller can be described in terms of the sensitivity of the controller error. The error values are compared with setpoint value of the controller and the value of fluctuations of Quadcopters.

Key words - PID digital; self-balancing robots; Quadrotor; IMU; optimize.

1. Introduction

In recent years, quadrotor and mobile robotics technology has gained popularity in both commercial and military use.There are a lot of techniques suggested to increase robotic mobility on dynamic environments. In particular, the most common techniqueis used to provide greater mobility to a robot platform based on inverted pendulum model.Quadcopter is operated by thrust that is produced by four motors that are attached to its body. It has four input forces and six output states (x, y, z, θ, ψ, ω) and it is an under-actuated system, since this enables Quadcopter to carry more load [1]. Quadcopter has the advantages over the conventional helicopter because the mechanical design is simpler. Besides, Quadcopter changes direction by manipulating the individual propeller's speed and does not require cyclic and collective pitch control [1],[2]. Nowadays, the research related to Quadcopter covers the areas of design, control, stability, communication systems and collision avoidance.

Reference [3] focused their study on the 3-DOF attitude that control free-flying vehicles. The characteristic is heavily coupled with inputs and outputs, and the serious non-linearity appears in the flying vehicle and due to this non-linear control, appears multi variable control or optimal control for the attitude control of flying Quadcopter. Reference [4] worked on intelligent fuzzy controller of Quadcopter. A fuzzy control is designed and implemented to control a simulation model of the Quadcopter. The inputs are the desired values of the height, roll, pitch and yaw. The outputs are the power of each of the four rotors that is necessary to reach the specifications. Simulation results prove the efficiency of this intelligent control strategy. References [5], [6] have done research to analyze the dynamic characteristics and PID controller performance of a Quadcopter.

This paper will provide the techniques involved in balancing an unstable robotic platform.The objective is to design a completed discrete digital control system that will provide the necessary stability.This paperal so designs a control system to balance the quadrotor using a 6-axis IMU sensor (MPU-9150) and Tiva™C SeriesTM4C123GXL microcontroller applied to PID control algorithm with optimal parameters.

The rest of the paper is organized as follows. Section 2 will describes the design of the quadrotor. Design of control unit for quadrotor are presented in section 3. Section 4 will study how to optimize PID parameters. Finally, section 5 provides some final conclusions

2. Designing quadrotor model

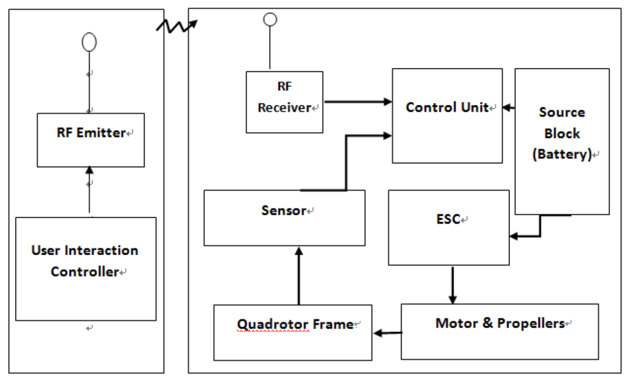

Figure 1. *Main block diagram of Quadrotor*

From Figure 1, the important parts of Quadrotor are included: Frame (includes motor and fans), controller, signal transceivers and battery source. With the target of designing a Quadrotot that is able to carry 2kg of load, flight time of at least 15 minutes, the mechanical structureof the frameis designedas follows:

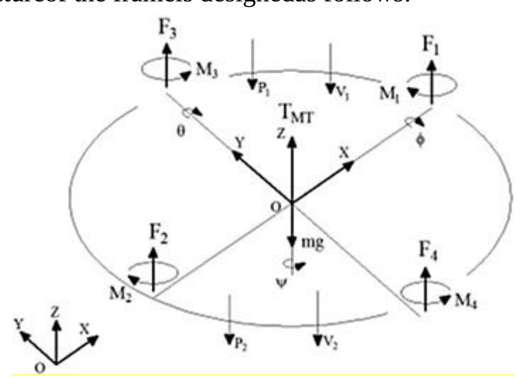

Figure 2. *The forces applying on Quadrotor*

From Figure 2: The main system gravity P = mg, and M isrotation momentum of motor. Force from propellers while rotatiing:

$$T_{MT}=2 * \rho_s * S * V_I^2 \text{ (N)} \quad (1)$$

ρ_s: (kg/m^3)air density, S (m^2) Area of propellers

Load each propeller can carry:

With $T_{MT} = W_P = \frac{m*g}{4}$ (2)

while m is the weight, g là earth gravity (g=9.8).

Based on the principles of aerodynamics we can calculate Quadrotor condition to lift off the ground.Area of propellers must conform to lift the plane dressed. We have an area of propeller $S = \pi *(D^2/4)$, with D as rotor diameter. Choose D = 0.33m to meet our design [9].

To satisfy the given parameters and calculations, we would choose the following components: Engine Tarot 4006-620KV as Figure 4a, with the given parameter.

Speed:620 rpm/v

Power: 1000W

Battery: 4 or 5cell of lipoly at least 19V supplied

Maximum current: 30A

Figure 4. *a) Engine HP2217-930KV, b) Propellers for the Quadrotor*

Eliminating torque by the rotary engine, we produce 1 pair of clockwise rotation and 1 pair of counter clockwise rotation motor as Figure 4b. So we chose two types of structure opposite wing. Wings are called pros and cons propellers. The frame is made of 2 aluminum 10mm x 15mm and 1mm thickness with high strength properties. Moving quadrotor safely, we must ensure the gap between the propellers. So the length of the aluminum bar must be greater than ($D_{propeller}/ / \sqrt{2}$) with D as rotor blades (254mm length). So we choose the 550mm for 2 aluminum bars[9].

From these requirements and reliability we have the following design parameters:

-Aluminum frame cross 550mm x 550mm length.

-Impeller type 10x4.5with pros and cons 2 wings each.

- The square phip substrate size100mm x 100mm.

- Triangular tripod 50mm x 100mm square size.

- The maximum weight of Quadrotor <2kg.

-Tarot 4006-620KVengine.

a) *b)*

Figure 5. *a) Design patterns in solid, b) Final Model Quadrotor*

3. Designing control unit for Quadrotor

The basic mechanical design includes invenSense MPU-9150: 3-axis gyro, 3-axis accelerometer, 3-axis compass 4 Bruhshless DC motor, one Tiva™ C Series TM4C123GXL microcontroller, IMU (inertial mass unit) sensor and motor driver ESC… IMU sensor which consists of accelerometer and gyroscope gives the reference acceleration and angle with respect to ground (vertical direction), and the encoder which is attached to the motor gives the speed of the motor. These parameters are taken as the system parameter and determine the necessary external forces to balance the quadrotor.

In this paper, to control Quadrotor altitude motion, PID controller has been developed and embedded in Tiva™ C Series TM4C123GXL microcontroller. PID control will maintain a stable equilibrium for Quadrotor when flying in the air, orbe affected by external forces such as winds ... based on the read value through the sensor MPU9150. MPU 9150 will provide Accel, Gyro, Mag to controllers to calculate the 3 values of angles Roll, Pitch, Yaw. Figure 6 shows ablock diagram of the control system for Quadrotor

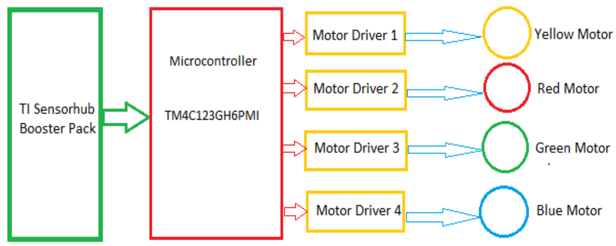

Figure 6. *Block diagram of the quadcopter hovering system*

3.1. The PID theory

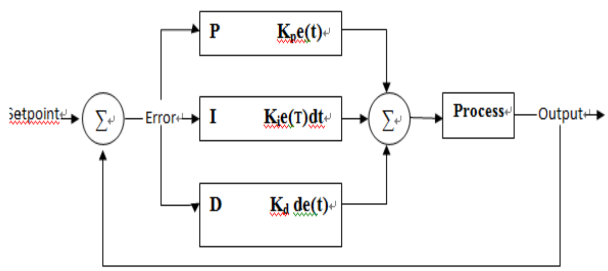

Figure 7. *The PID Theory*

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the ***proportional***, the ***integral*** and ***derivative*** values:

PID=P+I+D

P depends on the present error; I depends on the accumulation of past errors; D is a prediction of future errors, based on current rate of change.

PID can be described by equation:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \quad (3)$$

The weighted sum of these three actions is used to adjust the process via a control element

K_p: Proportional gain, a tuning parameter; K_i: Integral gain, a tuning parameter; K_d: Derivative gain, a tuning parameter

e: error; t: Time or instantaneous time (the present); T: Variable of integration; takes on values from time 0 to the present (t)

3.2. The influence of P.I.D gains in Quadrotor

3.2.1. Proportional Gain

Proportional control applies an effort in proportion to how far you are from the set-point. Its main drawback is that the closer you get to the set-point, the less it pushes. Eventually it does not push hard enough to move the variable, so the process can run continuously close to the setpoint, but is not quite there.

3.2.2. Integral Gain

Integral control tries to even out the difference of the time spend on both sides of the line. If you've spent a minute running at 98%, it will try to push you over to 102% for similar amount of time. This action compensates for P's inability to make that last effort

3.2.3. Derivative Gain

Derivative acts as a brake or dampener on the control effort. The more the controller tries to change the value, the more it counteracts the effort. In our example, the variable rises in response to the set-point change, but not violently. As it approaches the set-point, it settles in nicely with a minimum of overshoot

3.3. Building algorithm chart for the controlling quadrotor

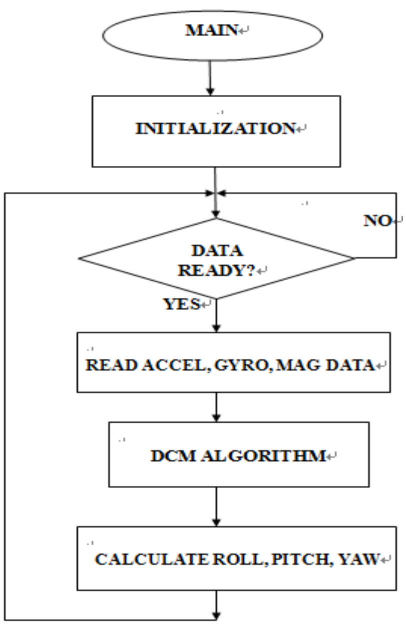

Figure 8. *The main control program*

Figure 8 shows the flowchart for the main program with the main purpose to initialize the values of PWM (originalpulse valueformotor control), declare I2C standard to connect with MPU 9150 sensor, initialize the library for sensors, and initialize data converters by Direction Cosine Matrix (DCM).The program will beallowed to interrupt timer A after sampling time t to perform PID function. Infinite loop will be performed involving waiting time to read data from sensors to calculate the angles Roll,Yaw, Pitch to supply the PID function. The Interrupt TimerA function of PID is given in Figure 9, with the main task to update velocity values of 4 motors to balance Quadrotor.

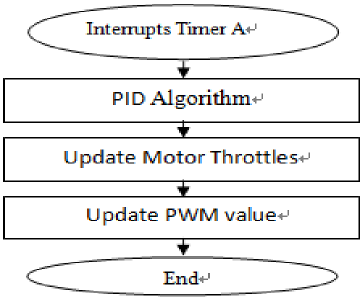

Figure 9. *Time interrupt PID function*

4. Result

In order to find the optimal value for quadrotor, we change the 3 values Kp, Ki [8] based on The Ziegler-Nichols' closed loop method.This is based on experiments executed on an established control loop (a real system or a simulated system. The tuning stepsare as follows:

Bring the process to (or as close to as possible) the specified operating point of the control system to ensure that the controller during the tuning is "feeling" representative process dynamic and to minimize the chance that variables during the tuning reach limits. You can bring the process to the operating point by manually adjusting the control variable, with the controller in manual mode, until the process variable is approximately equal to that of the setpoint.

Turn the PID controller into a P controller by setting set Ti = ∞ and Td = 0. Initially set gain Kp = 0. Close the control loop by setting the controller in automatic mode.

Increase Kp from 0 to a critical value Kpu at which the output first exhibits sustained oscillations with period Pu. (Pu is measured in sec.)

Measure the ultimate (or critical) period Pu of the sustained oscillations (In this paper, we chose Pu <2s).

Calculate the controller parameter values according to Table 1, and use these adjustment parameters in the controller to optimize the system.

Table 1. *Formulas for the controller parameters in the Ziegler-Nichols' closed loop method.*

	Kp	Ti	Td
PID	0.6Kpu	$\frac{Pu}{2} \sim 1$	$\frac{Pu}{8} = \frac{Ti}{8} \sim 0.25$

According to the results described below

4.1. All gains to 0 (Kp=Kd=Ki =0)

This condition means that there is no PID control to quadrotor.

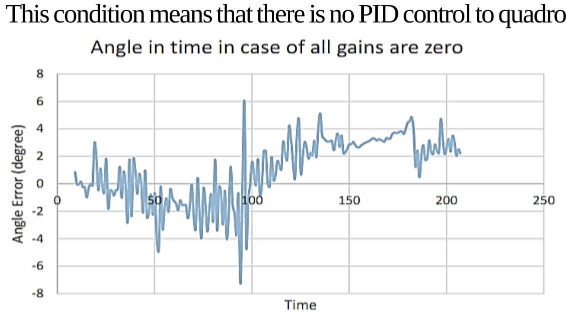

Figure 10. *All gain to 0(Kd=Ki=Kp=0)*

Observation: the max value is 6 and the min value is around -6 degree. However, the trend of this oscillation value makes the system one side deviated, this also makes Quadrotor fall down.

4.2. Increase the P gain until the steady oscillations occurs.

During increasing Kp from 0 to stable oscillation value, the most striking points are 2 values Kp= 1.5 and Kp=2. The comparison andevaluation of those results are described at Figure 10 below.

With Kp=2 the Quadrotor oscillates heavily from the equilibrium point. (Around -40 to 40). Using this result,Quadrotoris strongly shaking, but still remains balanced.

At Kp=1.5 the oscillation of Quadrotor is more stable at 5 degree from -10 to 10. This value is the most suitalble for Kp parameter, though it still has one side inclined.

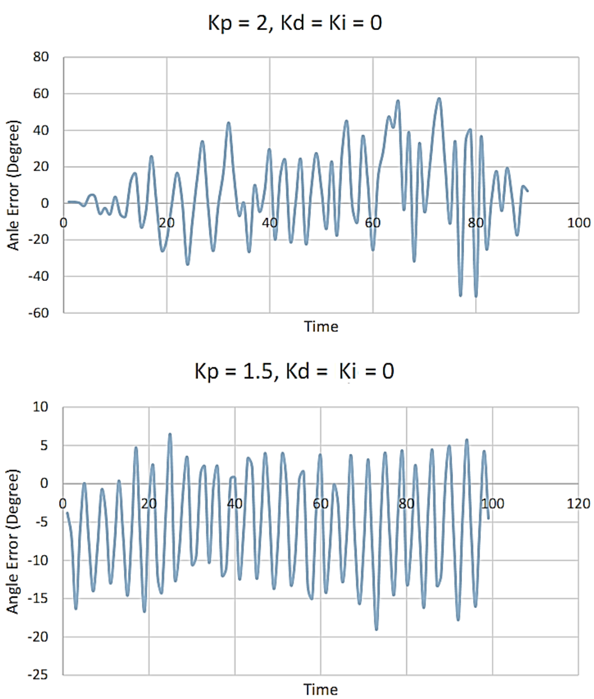

Figure 11. At Kp= 2 andKp=1.5

Observation: with Kp=2 the maximum value is 60 and the minimum value is around -40 degree. This is strong oscillation, so that we can set the maximum 40. The result is described below. Moreover, with Kp=1.5: the maximum value is 5 and the minimum value is around -15 degree and the motion is quite harmonic.

Table 2. Result of Kp=2 and Kp=1.5(Kd=Ki=0)

	Kp=2	Kp=1.5
Overshooting	20 degree	15 degree
Setting Time	Around 10 time unit	Around 15 time unit
Error	Maximum 40	Maximum 15

From above result, we notice that at Kp=1.5 oscillation is quite steady

4.3. Increase the D gain until the the oscillations go away.

We set the Kd to 1 and the Quadcopter's behavior is unpredictable.

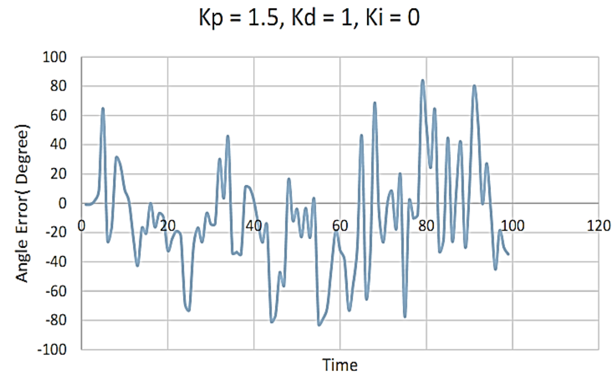

Figure 12. Increase the Kd to 1

Observation: the max value is 80 and the min value is around -80 degree.

Table 4. Result of Kd=1

Overshooting	*N/A*
Setting Time	N/A
Error	Maximum 80

From the Figure 12 and Table 4, we realize that the value Kd=1 is too high, so we decrease 10% of the last value. However, the oscillations still exist. We decrease it to just 0.05 that means 5% of the last value.At this point the oscillation does not disappear but with Kd = 0.03, we get the best performance of quadrotor.

4.4. Increase theI gain until it brings you to the set point with the number of oscillations desired

We start by putting Ki = 0.5. However the angle error is notreduced to zero, besides the Quadcopter oscillates again.

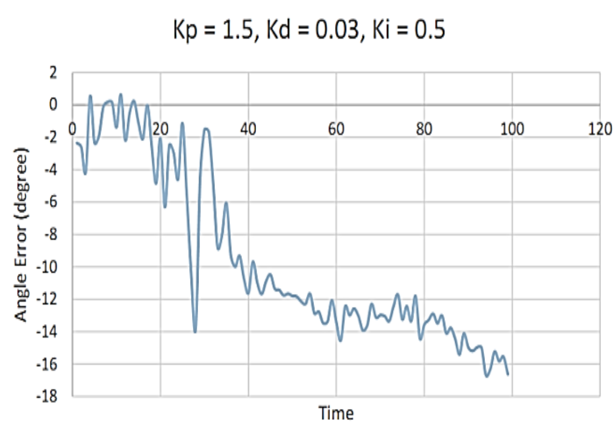

Figure 13. Increase the Ki value to 0.5

Observation: The angle error is stable at around -12 degree.

Table 5. Result of Ki=0.5

Overshooting	-14 degree
Setting Time	20 time unit
Error	Maximum -17

4.5. The optimum parameter adjustment:

Therefore we put Ki just less than Kd, Ki = 0.01. The Quadcopter is stable at the angle error around 2.3 degree,which is very good.

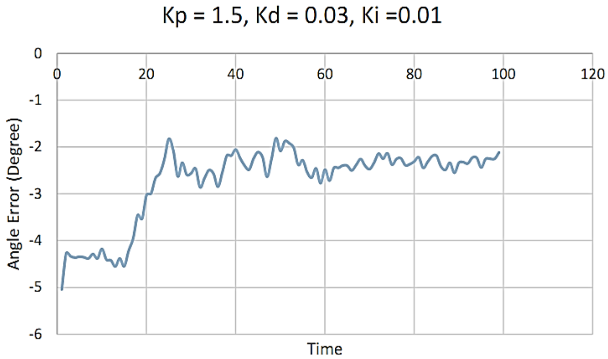

Figure 14. *The optimum parameter*

Table 6. *Result of optimum parameter Kp,Kd,Ki*

Overshooting	1 degree
Setting Time	22 time unit
Error	Maximum -2

From the achieved results, Quadrotor has stable equilibriumin flight with minimum vibration though a slight drift caused by the offset between the system and ground of 2 degrees. This case can be overcome by utilizing the GPS data to update the coordinates to find the suitable position against the drift when Quadrotor is flying.

5. Conclusion

This paper proposes the method of adjusting the value in optimizing P.I.D controller in gyroscopes and accelerometers by applying The Ziegler-Nichols' closed loop method in the experiment.With method of trials and errors, we come out of three P.I.D gains Ki = 1.5, Kd = 0.03 and Ki = 0.01. Despite the fact that the error is still not zero and setting time is not so quick, these gains are our best effort, and we can control the balance of quadrotor quite well. In the future,we can apply this method not only in self-balancing quadrotors but also in balanced auto robots

REFERENCES

[1] A. Z. Azfar and D. Hazry, "Simple GUI Design for Monitoring of a Remotely Operated Quadcopter Unmanned Aerial Vehicle," *Proceeding of the 7th International Colg and its Applications (CSPA)*, 23-27.

[2] K. W. Weng, "Quadcopter," *Robot Head to Toe Magazine*, Vol. 10, 2011, pp. 1-3.

[3] D. Park, M.-S. Park and S.-K. Hong, "A Study on the 3-DOF Attitude Control of Free-Flying Vehicle," *Proceeding of the IEEE International Symposium on Industrial Electronics (ISIE)*, Pusan, 12-16 June 2001, Vol. 2, pp. 1260-1265.

[4] M. Santos, V. López and F. Morata, "Intelligent Fuzzy Controller of a Quadrotor," *Proceeding of the IEEE International Conference on Intelligent Systems and Knowledge Engineering (ISKE), Hangzhou*, 15-16 November 2010, pp. 141-146.

[5] I. Morar and I. Nascu, "Model Simplification of an Unmanned Aerial Vehicle," *Proceeding of the IEEE International Conference on Automation Quality and Testing Robotics (AQTR)*, Cluj-Napoca, 24-27 May 2012, pp. 591- 596

[6] [13] J. Li and Y. T. Li, "Dynamic Analysis and PID Control for a Quadrotor," *Proceeding of the International conference on Mechatronics and Automation (ICMA)*, Beijing, 7-10 August 2011, pp 573-578.

[7] P. Cominos and N. Munro, "PID controllers: recent tuning methods and design to specification", *IEE Proceedings - Control Theory & Applications 149*, 2002, pp. 46–53.

[8] D. Wang and Qing-Guo, "PID tuning for improved performance." Control Systems Technology, IEEE *Transactions on 7.4*, 1999. pp. 457- 465.

[9] A. L. Salih, M. Moghavvemi, H. A. F. Mohamed, and K. S. Gaeid, "Flight PID controller design for a UAV quadrotor," *Scientific Research and Essays*, vol. 5, pp. 3360–3367, 2010.

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