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Design Trajectory Tracking of Quadrotor using PID controller

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Abstract: Autonomous Unmanned Aerial Vehicle (UAVs) have been increasingly employed by researchers, commercial organizations and the military to perform a variety of missions. Drones, also called unmanned aerial vehicles (UAVs), have no human pilot onboard, and instead are either controlled by a person on the ground. With six degrees of freedom (three translational and three rotational) and only four independent inputs (rotor speeds), quadrotors are severely under actuated in order to achieve six degrees of freedom, rotational and translational motion are coupled. This paper examines a conventional PID controller that utilizes a combination of accelerometer and gyro sensors to regulate the orientation of quadrotor UAV and keep the quadrotor auto leveling while flying.

Keywords: UAV, PID controller, quadrotors, accelerometer, gyro sensors.

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are defined as powered aerial vehicles which do not requirean on-board pilot to operate but are rather controlled autonomously or remotely. A typical UAVsystem is comprised of three major components: the aircraft, the ground control station and theoperator. Since UAVs can fly without a human pilot on board, they are helpful in missions thatdo not necessarily need a human's direct oversight. Based on UAVs' capabilities, they were first adopted for military and intelligence missions including deception operations, route and landing reconnaissance, and battle damage assessment. Recently, a large number of UAV applications have also emerged in civil markets. In [4], a camera-equipped mini UAV is used to support wilderness search and rescue. In [5], a large number of swarming UAVs are organized to establish an airborne communication relay. An application of UAV cooperative control is seen in [6], where multiple UAVs are collaborating for map building tasks and in [7] several mini UAVs function as a single unit for surveillance. As a UAV can be autonomously controlled, a powerful controller plays a crucial role in a UAV's development. One of the traditional methods of designing a UAV controller is based on the proportional-integral-derivative (PID) control theory which tunes out an "error" value between a measured state and a desired state of the UAV by adjusting its throttle and control surfaces such as ailerons, elevator, and rudder. Three separate parameters define the PIDcontroller calculation: the proportional value P, the integral value I, and the derivative value D.These values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D as a prediction of future errors. This method shows descent performance in short term control by gradually damping the control of the UAV. But a PIDcontroller is only a reactive system which depends on feedback and pre-defined constant parameters and thus it has no direct knowledge of the control process. This paper is organized as follows. Quadrotor UAV modelling that includes aerodynamics concept and configuration are described in Section II includes the conventional PID controller. The experimental testing and result are presented in Section III and conclusion is discussed in Section IV.

2. MODELLING OF A QUADROTOR UAV

2.1 Aerodynamics Forces and Torques

Quadrotor needs a mechanism for generating forces and torques that are required to control its horizontal and vertical movements. There are four main forces that exert on a quadrotor: gravity, lift, thrust and drag. Gravity is a force that pulls the quadrotor down because of its mass. Lift and thrust are the upward reaction forces acting on quadrotor due to the propellers.

Finally, drag is the backward force on the quadrotor due to air. Quadrotor mechanism is mainly based on its rotors and propellers that generate thrust perpendicular to its rotor. The main thrust is generated along Z axis that creates vertical movement. The horizontal movements along X and Y axes are resulted from directing the force or thrust vector in the appropriate direction. Therefore, quadrotor can be characterized by one main control force T b uF, and three main control torques. The four control inputs are obtained from independently controlling each motor speed. The collective lift u is the sum of the thrust generated by the four propellers.

$$\alpha = \sum_{i=1}^{4} f_i \tag{1a}$$

Torque produced by each axis is resulted from

$$\gamma_{\theta} = b(f_2 - f_4) \tag{1b}$$

$$\gamma_{\phi} = b(f_3 - f_1) \tag{1c}$$

$$\gamma_{\varphi} = Q_1 + Q_2 + Q_3 + Q_4 \tag{1d}$$

Where b is distance from the propellers to the center of mass of the quadrotor and Q is the fan torques due to air drag.

2.2 Quadrotor Configuration

Quadrotor UAV can be assigned to two different configurations; plus, and cross configuration. In this case, four brushless DC motors are mounted on quadrotor UAV in cross configuration. One pair of motors (1, 3) rotates in counter clockwise direction while the other pair of motors (2, 4) rotates in clockwise direction as shown in fig. The motion of quadrotor is achieved by varying the motor speed. Thus, increasing or decreasing the four motor's speeds together generates vertical motion. Increasing motor (1, 2) speed or motor (3, 4) speed produces roll rotation that results quadrotor to bend left or bend right. The same method is used for pitch control. Varying motors (1,4) and motors (2,3) speed conversely produce pitch rotation that results quadrotor to go forward or backward. Yaw rotation can be done by the difference in the counter-torque between each pair of motors.

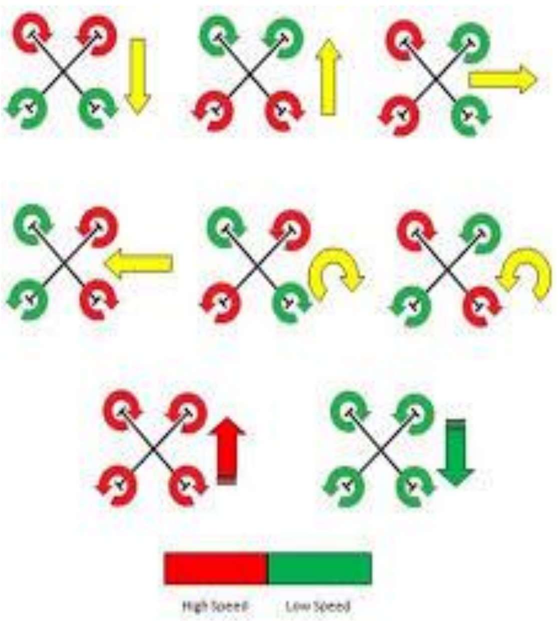

Figure 1. UAV Configuration

2.3 Conventional Pid Controller

The quadrotor in nature is very unstable. In order to stabilize the quadrotor, PID controller is needed to be developed within the system. PID controller is the most widely used controller because of its simplicity and robustness. The mathematical equivalent of PID control algorithm can be expressed as

$$\mu = k_p e + k_i \int edt + k_d \tag{2}$$

Where k_p, k_i , and k_d are the proportional, integral and derivative gains respectively.

To achieve stabilization, three PID controllers are implemented for three different axes: roll, pitch and yaw respectively. For a sensor feedback, we use gyro sensor which is three axes angular rate sensor. $\theta^{\circ}{}_{roll}$, $\theta^{\circ}{}_{pitch}$ and $\theta^{\circ}{}_{yaw}$ are the roll, pitch and yaw angular velocity that can be received from gyro sensor. The error values will be

$$e_{roll} = \theta^{\circ}{}_{rollde} - \theta^{\circ}{}_{roll} \tag{3a}$$
$$e_{pitch} = \theta^{\circ}{}_{pitchde} - \theta^{\circ}{}_{pitch} \tag{3b}$$
$$e_{yaw} = \theta^{\circ}{}_{yawde} - \theta^{\circ}{}_{yaw} \tag{3c}$$

where rollde $\theta^{\circ}{}_{rollde}$, pitchde $\theta^{\circ}{}_{pitchde}$ and yawde $\theta^{\circ}{}_{yawde}$ represent desired angular velocity. Using these error values in PID equation, it can be gained

$$\mu_{roll} = k_p e_{roll} + k_d \frac{de_{roll}}{dt} \tag{4a}$$

$$\mu_{pitch} = k_p e_{pitch} + k_d \frac{de_{pitch}}{dt} \tag{4b}$$

$$\mu_{yaw} = k_p e_{yaw} + k_d \frac{de_{yaw}}{dt} \tag{4c}$$

The propeller force on each propeller can be resulted from

$$f_1 \mu_{throttle} + \mu_{pitch} - \mu_{roll} + \mu_{yaw} \tag{5a}$$

$$f_2 = \mu_{throttle} - \mu_{pitch} - \mu_{roll} - \mu_{yaw} \tag{5b}$$

$$f_3 = \mu_{throttle} - \mu_{pitch} + \mu_{roll} + \mu_{yaw} \tag{5c}$$

$$f_4 = \mu_{throttle} + \mu_{pitch} - \mu_{roll} - \mu_{yaw} \tag{5d}$$

where u $_{throttle}$ is the signal pulse received from throttle stick of RC transmitter.

Figure 2 shows the block diagram of quadrotor control system using PID controller. A quadrotor is an under actuated system with four motor for system inputs while it has six degrees-of-freedom which are three translational and three rotational movements. The speed differences of the rotors can generate torques about the roll, pitch, and yaw axes in addition to the thrust that is obtained by the sum of the four rotating propellers.

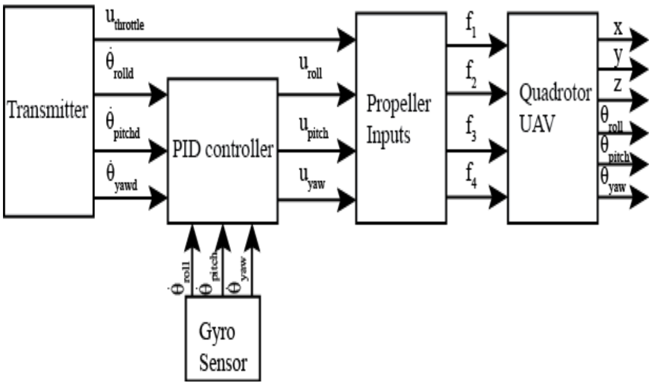

Figure 2. Control scheme of proposed system

3. EXPERIMENTAL RESULTS

For experiment, Arduino Uno which has a clock frequency of 16MHz is used as a microcontroller board. IMU 6050 six DOF sensor is implemented on quadrotor to detect any angle deviation. Four 980 KV brushless DC motor is mounted on each corner for generating thrust that need to lift the quadrotor into the air. For varying the speed of brushless DC motor, electronic speed controller (ESC) is connected to each motor. In order to manage the quadrotor to track the desire position, 2.4GHz 6 channel transmitter is used. The power source for quadrotor is acquired from 3-cell Li-Po battery. All these components are attached firmly to 450mm quadrotor frame and finally the PID controller design is embedded in Arduino controller. The experiment takes place in indoor area and PC is connected to quadrotor via USB cable to collect data while testing.The experiment has been carried out with three different gain tuning methods. The result plots are illustrated to compare the outcome by employing each method.

Table 1. P gain value

	Roll	Pitch	Yaw
P	5	5	2
I	0	0	0
D	0	0	0

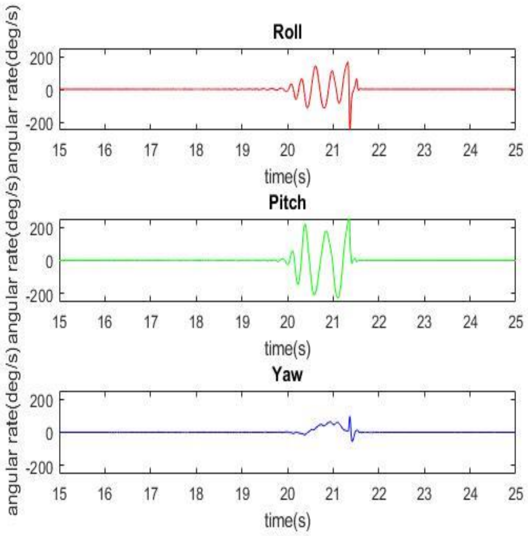

Figure 3. Result of P gain value

1) This result shows the P gain value of time 22s the system is stable for roll, pitch and yaw value. Roll represent for red colour, pitch represent green colour and yaw for blue colour. To start the experiment, the transmitter throttle stick is moved up to let the quadrotor take off vertically and allow the quadrotor to fly about 30 seconds. When the quadrotor reach about one foot above the ground, it becomes vibrate and oscillation occurs. This is because of high proportional gain that creates system overshoot. The angular rate detected by gyro sensor for each axis is represented by individual plot.

Table 2. P gain value

	Roll	Pitch	Yaw
P	1.3	1.3	4
I	0	0	0
D	0	0	0

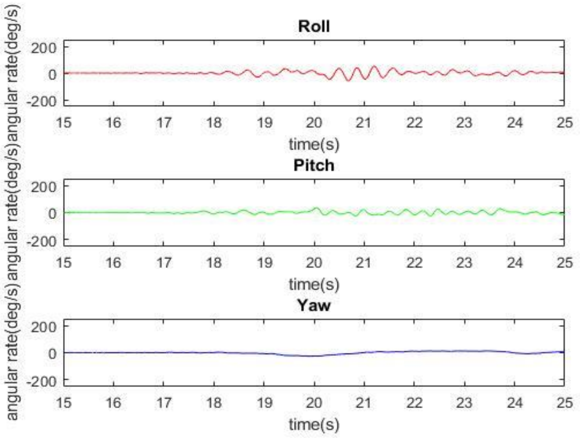

Figure 4. Result of P gain value

2) This result shows the P gain value lower the time of time 24s the system is stable for roll, pitch and yaw value.The data are collected for 10 seconds duration and the experimental plot for manual gain tuning approach.the proportional gain is set to low proportional gain. Error value can be obtained from difference between P gain value for 1.3 and 5 for roll and pitch. Yaw value for 4 and 2.When the absolute error is less than error threshold level, the proportional gain is set to low proportional gain.

Table 3. PI gain value

	Roll	Pitch	Yaw
P	1.3	1.3	4
I	1.5	1.5	5
D	0	0	0

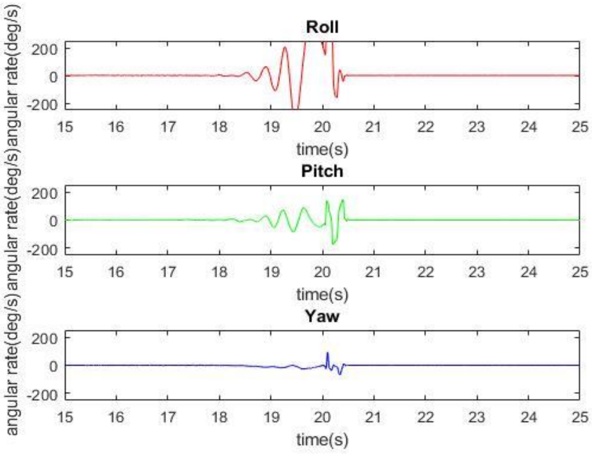

Figure 5. Result of PI gain value

3) This result shows the PIgain value of time 20s the system is stable for roll, pitch and yaw value. proportional gain values for third tuning method.ESC can generate signal pulses from the range of 1000 microsecond to 2000 microsecond.

Table 4. PI gain value

	Roll	Pitch	Yaw
P	1.3	1.3	4
I	1.5	1.5	5
D	0	0	0

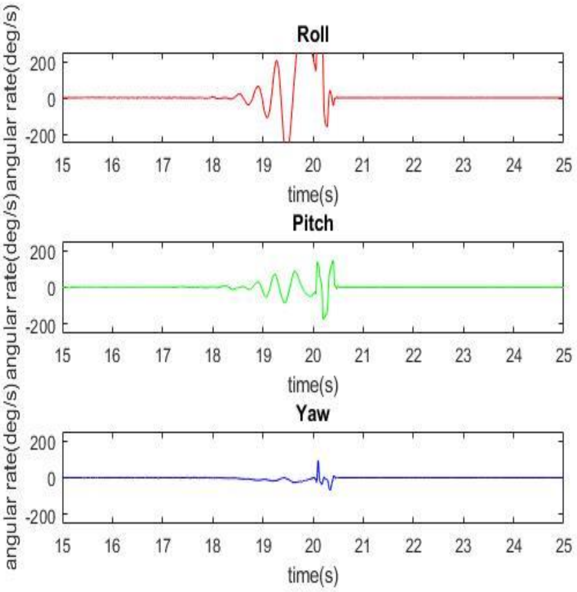

Figure 6. Result of PI gain value

Table 5. PID gain value

	Roll	Pitch	Yaw
P	1.3	1.3	3
I	10	10	5
D	0.08	0.08	0

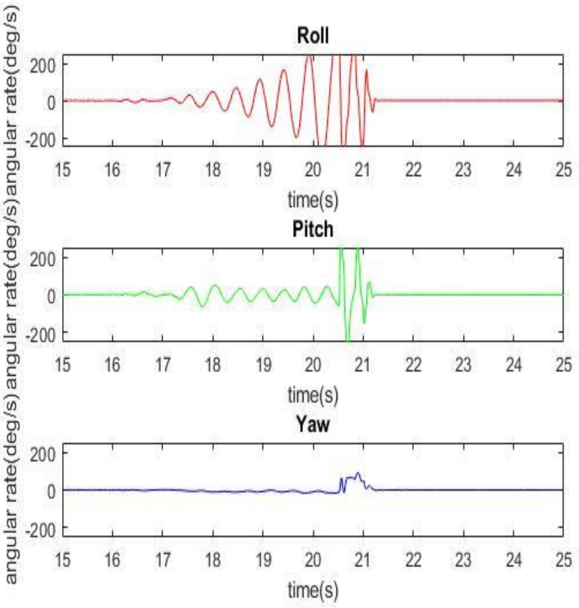

Figure 7. Result of PID gain value

4) This result shows the PID gain value of time 21s the system is stable for roll, pitch and yaw value. proportional gain values for third tuning method.ESC can generate signal pulses from the range of 1000 microsecond to 2000 microsecond. Error value can be obtained from difference between P gain value for 1.3 ,I gain for 10 and D gain for 0.08 for roll and pitch. Yaw for P is 3 and I is 5.

4. CONCLUSION

In this paper three different gain tuning method is used. These are presented to achieve quadrotor stabilization. The experimental tests using three different tuning methods have been carried out to compare the response of quadrotor. Also it can be seen that the quadrotor can manage to stabilize without flipping and crash during indoor testing that has no effect of external disturbances such as wind and other environmental conditions. The next objective is to perform an outdoor flying test in order to justify which tuning method provides better performance with system enhancement.

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