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Optimization of PID Control Parameters for UAV Stability Analysis

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Abstract—*This research paper describes the system response of a PID controlled mini quadcopter UAV to various values of its gain constants. The work includes designing, fabricating and testing a miniature quadcopter UAV (Unmanned Aerial Vehicle) having stabilizing PID controllers in its control loop to regulate its basic movements: roll, pitch, yaw angles. Experiment observations were used to generalize the effect of variation of each parameter constant on the system stability.*

1. INTRODUCTION

UAV's are increasingly gaining popularity due to the technological advances in the fields of integrated electronics, providing a huge range of high-performance microcontrollers and sensors of several types, elements which are essential for its controlling. These technological advances also resulted in reduction of the involved costs, thereby making UAVs a technology more attractive to civilian areas and not only military, where they have already been employed in the last few decades.

The integration of an autopilot in the control loop of an UAV airframe provides complete set of avionics which enable the UAV to autonomously complete its mission. Most of modern autopilots incorporate control law algorithms to meet the demanding requirements of flight manoeuvres with high performance and to successfully accomplish the mission of autonomous flight.

1.1 PID controller

Mathematically, a PID controller can be described as:

$$\tau = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{\mathrm{d}}{\mathrm{d}t} e(t)$$

Where Kp, Ki and Kd represents proportional, integral and derivative gains respectively. The proportional term gives an output that is proportional to the error. Too high proportional gain K can give an unstable process. The integral term is proportional to both the duration of the error and the magnitude of it. The integral term deals with steady-state error by accelerate the movement of the process towards setpoint. It can contribute to an overshoot because it responds to accumulated error from the past which can be solved by adding the derivative term. The derivative term slows down the rate of change of the control signal and makes the overshoot smaller. The combined controller-process stability is improved by the derivative term, but it could make the process unstable because it is sensitive to noise in the error signal.

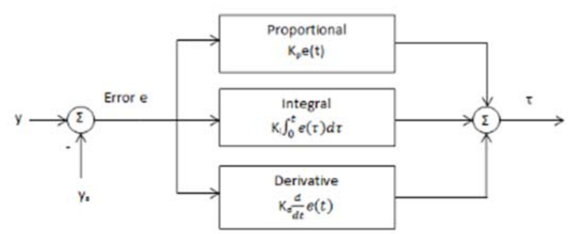

Figure 1: Block diagram of a PID controller, Johansen [2011]

The PID controller calculation involves three separate constant parameters, the proportional, the integral and derivative values, denoted P, I, and D. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors and D is a prediction of future errors, based on current rate of change.

1.2 Tuning

PID autopilots have been successfully integrated as real-time control and online navigation systems for UAVs. This is not only due to their simple structure and easy implementation, but also to their adequate performances. However, for successful implementation of such controllers, and without requiring complex mathematical development, parameter adjustment or tuning procedure is needed if enhanced performance is to be achieved through the operating envelope.

Tuning PID is to find the balance between the moment of inertia of the multicopter, and the force generated by the motors, which is also affected by other factors such as vibrations, frame rigidity etc. The moment of inertia is related the mass of quadcopter is, mass distribution and the properties of motors. Therefore PID gains vary for each individual quadcopter models.

The tuning process, whereby the optimum values for the controller parameters are obtained, is a critical challenge. Many studies has to be conducted to find the best way for tuning PID parameters in order to get adequate performances such as fast response, zero steady-state error, and minimum overshoot/undershoot. Even though there are only three parameters, PID parameter tuning is a difficult process because it must satisfying complex criteria within the limitations of system actuators. Also, the traditional PID controller only works for lower-order systems and lacks robustness against large system parameter uncertainties. This is due to the insufficient number of parameters to deal with the independent specifications of time-domain response such as settling time and overshooting.

1.3 Stability

Stability of a PID controller is maintained by tuning the Kp, Ki and Kd gains properly. They are to be tuned such that the error converges to zero. When the error converges to zero within a reasonable time and without too high overshoot and oscillations, the controller is stable.

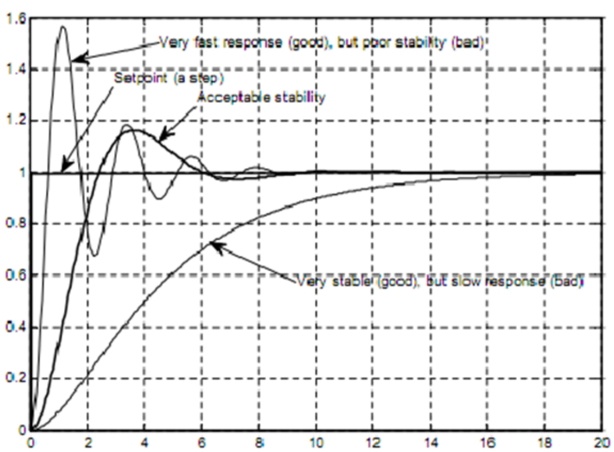

Figure 2: Stability of a PID controller.

1. Hardware implementation

In order to test the variation of PID values on the stability of a closed loop system, a hardware testing model with sensor feedback loop has to be implemented. We have developed a simple quadcopter model for which the gains are determined and controlled linearly by the out current from radio receiver. But when an autopilot was introduced into the system, the programming gives flexibility in changing the gain values to control flight. But still, finding the exact stability condition remains as the hard part. This adds up the option to add inertial sensors such are gyro and barometer into the system to makes it a closed loop system, which is necessary for the real time control of quadcopter.

For each of these PID gain values the overall controllability and stability of system varies. Also the values have to be fine-tuned for each hardware setup.

Figure 3: Hardware implementation

2. Observation

Once the quadcopter air frame was ready, autopilot having on board variable PID controller was integrated. The performance of system for varying pitch axis PID values was observed. The result of experiment with varying P value is shown below as sample observation in table 1. The experiment was repeated for different combinations of I and D values until an acceptable stability for the system was obtained.

Table 1: Stability observation table

	P	I	D	Stability
1	0.3	0.02	10	Flyable, Yet wobbling
2	0.4	0.02	10	Flyable, Less wobbling,
3	0.5	0.02	10	Better stability
4	1.0	0.02	10	Highly responsive
5	1.6	0.02	10	Wobbling, High responsive
6	2.0	0.02	10	Highly responsive, Not flyable

3. Conclusion

Even though the variation in P plays greater role in deciding the performance of system, I and D also has sole effect on stability.

The higher the P value, the harder it tries to stabilize the plane. But very high P values results in sensitive system, which tries to over-correct (overshoots) itself. This resulted in high frequency oscillations.

When I gain was introduced the aircraft started following the stick movements smoothly. But as value of I increases, inertia of copter get control over the copter. Ideal aircraft should have an optimized value for P and I for better stability.

The effect of D on system is to damp the oscillations. It damps the controls given from stick, acting opposite to that of P's variation on system. But only a slight variation in D value is preferable, higher value of D again results in unstable oscillations.

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