Investigating the Effectiveness of Different Control Algorithms on the Stability of Quadcopters

CS 03
Gao Wen Zhen, James (19S7J)
Roy Chenyu Luo (19S7J)

Introduction

Rationale

Visually observe the effects of tuning the Proportional Integral Derivative (PID) controller.

Quadcopters are **mechanically simpler** than helicopters and more **versatile** than fixed-wings.

Quadcopters are relatively **inexpensive** and easy to construct.

Quadcopter Components

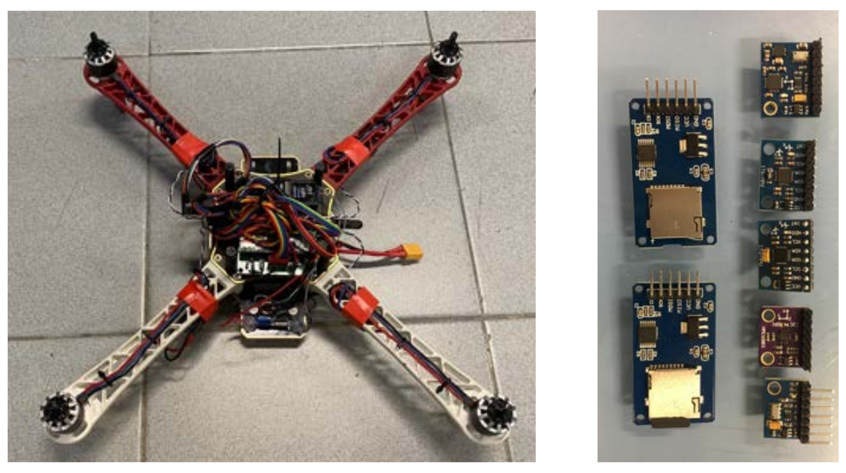

Figure 1: Quadcopter frame (left) and electrical sensors used by the quadcopter (right).

Aircraft Conventions

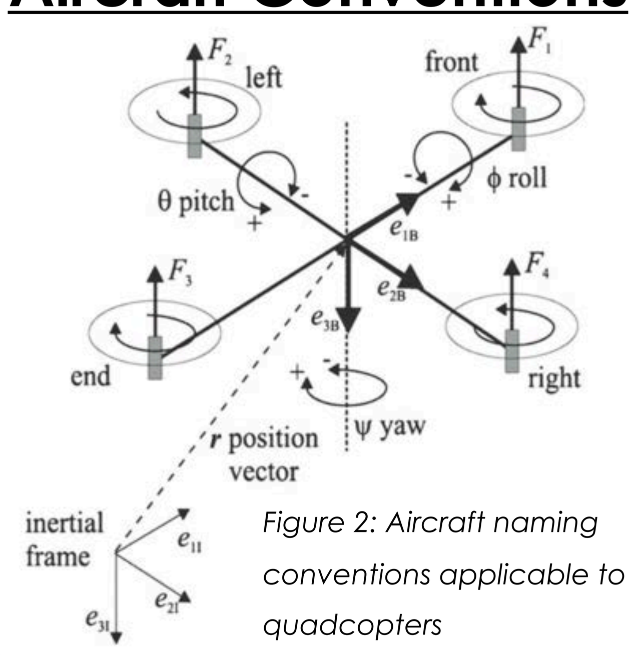

Figure 2: Aircraft naming conventions applicable to quadcopters

Objectives

To investigate the effects of changing the **P,I,D – gains** on the **accuracy** and the **latency** of the quadcopter.

P: $K_p \cdot e(t)$ I: $K_i \int_0^t e(t)\,dt$ D: $K_d \frac{de(t)}{dt}$

To investigate the different stability effects of a **rates controller** and an **angles controller**.

Accuracy: the degree to which the result of the angle of the quadcopter makes to the horizontal conforms with the setpoint, 0

Latency: the delay before reaching the setpoint after a deviation. The lower the latency, the faster the correction is made.

Overview of Methods

Gyroscope

Figure 3: Roll, Pitch, Yaw represented on quadcopter

Calculating **angular displacement** from **angular velocity**:

$$\theta = \theta_k + \omega_x \Delta t$$

$$\phi = \phi_k + \omega_y \Delta t$$

$$\psi = \psi_k + \omega_x \Delta t$$

Accelerometer

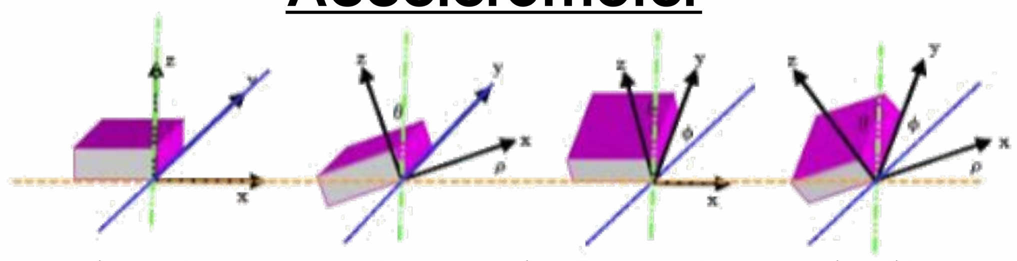

Figure 4: Accelerometer measuring 3 angles to determine tilt

Relating the **acceleration** in the roll, pitch and yaw axis to the **normalized accelerometer** reading, g :

$$\sqrt[2]{a_x + a_y + a_z} = 1g$$

Solving for **roll** and **pitch angles**:

$$\tan(\theta) = \frac{a_y}{a_z} \qquad \tan(\phi) = -\frac{a_x}{\sqrt[2]{{a_y}^2 + {a_z}^2}}$$

Experimental Setup

Figure 5: Quadcopter secured to a rod allowing for rotation about a single axis

PID Controller

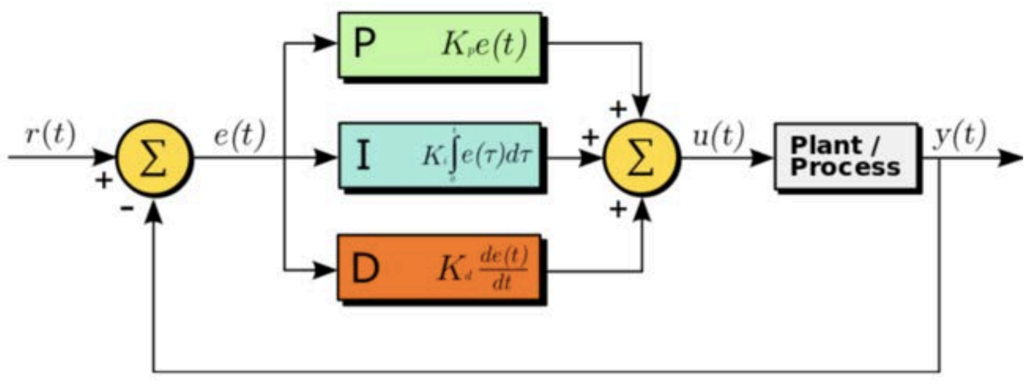

Figure 6: A block diagram of a PID controller in a closed feedback loop

P: produces an output **proportional** to the current error.

I: sums up all the previous error terms, allowing any residual error to be accounted for, eliminating **steady-state errors**.

D: produces an output based on the **current rate of change in error** to allow setpoint to be reached smoothly.

Rates controller and Angles controller

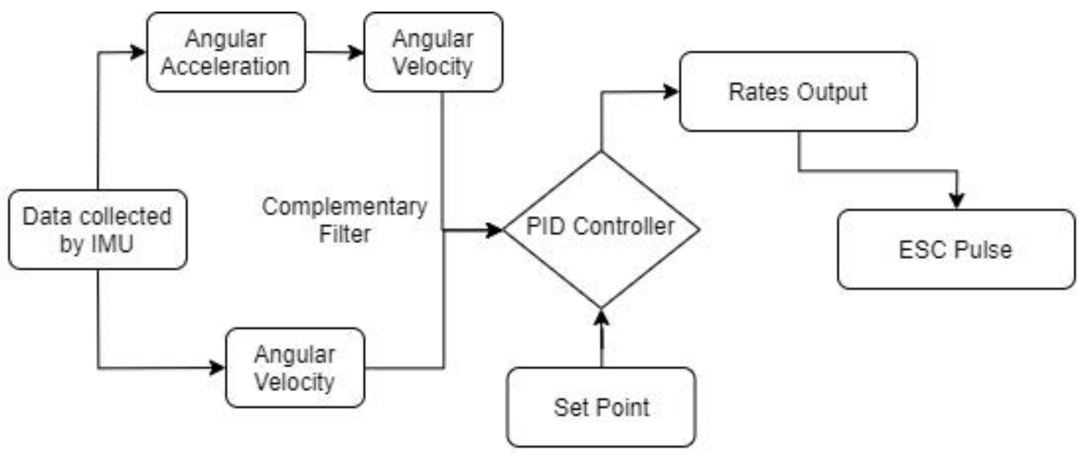

*Figure 7: A block diagram showing the data processing from input to output in a **rates controller***

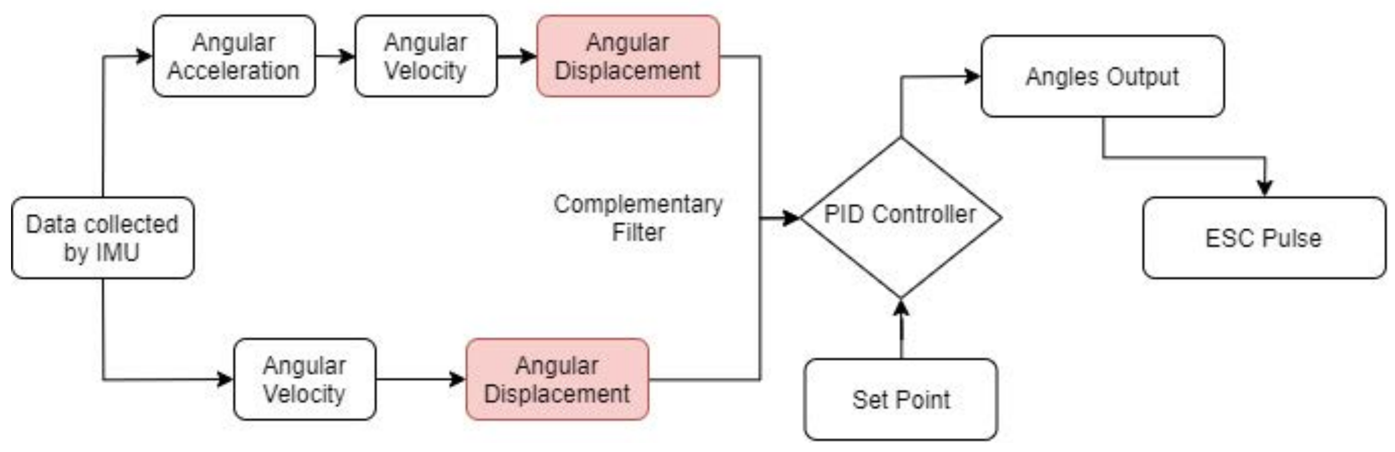

*Figure 8: A block diagram showing the data processing from input to output in an **angles controller***

Results and Discussion

Comparison of P-Gain on the stability of quadcopter

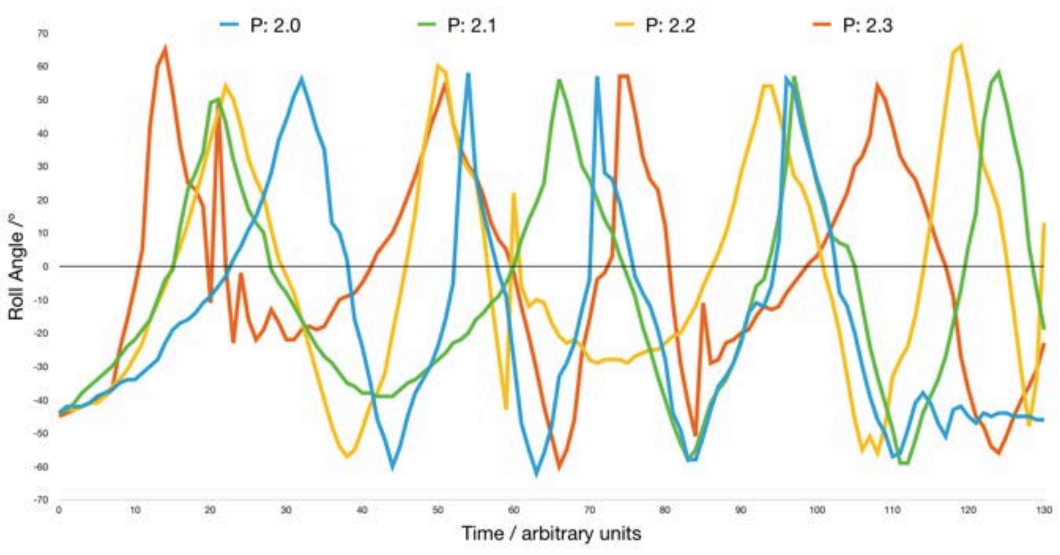

Figure 9: Comparison of different P-gain values on the stability of the quadcopter

	Accuracy /°	Period /au
P: 2.0	-17.4 ± 60.0	34.2
P: 2.1	-8.1 ± 58.5	31.0
P: 2.2	-4.3 ± 61.5	28.9
P: 2.3	-2.8 ± 62.5	25.5

Accuracy: Unchanged

Latency: Decreased

Higher **P-gain**, quadcopter reacts more **aggressively** and **faster** to changes.

Auto-correction only stops when setpoint is reached, **inertia force** causes quadcopter to **overshoot**.

Can be resolved by using appropriate **D-gain**, which acts as **"resistance"** to the motion.

Comparison of I-Gain on the stability of quadcopter

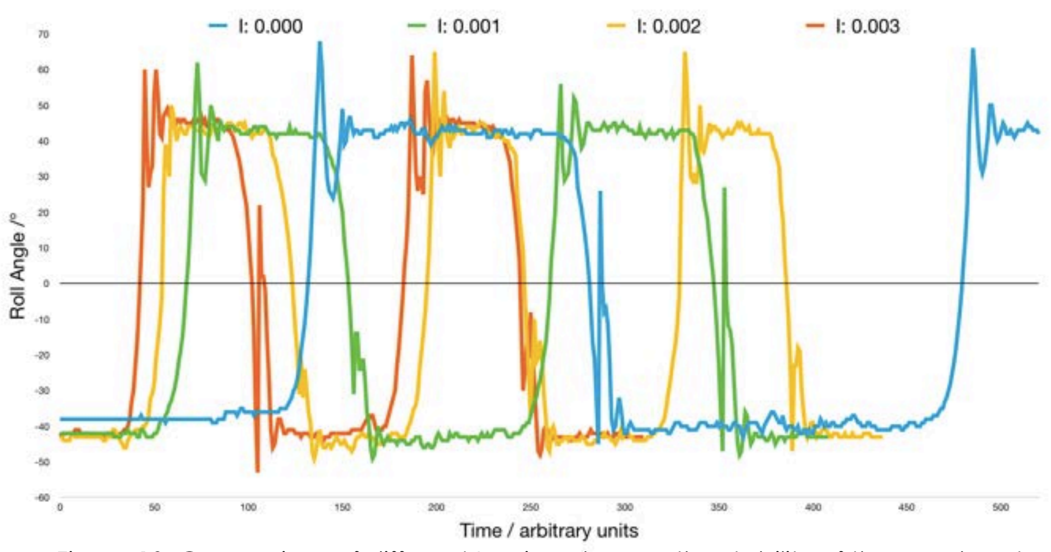

Figure 10: Comparison of different I-gain values on the stability of the quadcopter

	Accuracy /°	Period /au
I: 0.000	-8.5 ± 56.5	123.5
I: 0.001	-5.8 ± 55.5	56.5
I: 0.002	-7.2 ± 57.0	49.5
I: 0.003	-7.7 ± 58.5	39.0

Accuracy: Unchanged

Latency: Decreased

I-gain slowly sums up **past deviations** and produces a correction value.

I-gain is effective in correcting **small systematic errors**, but ineffective in accurately making **large corrections** to the deviation of the quadcopter.

Comparison of D-Gain on the stability of quadcopter

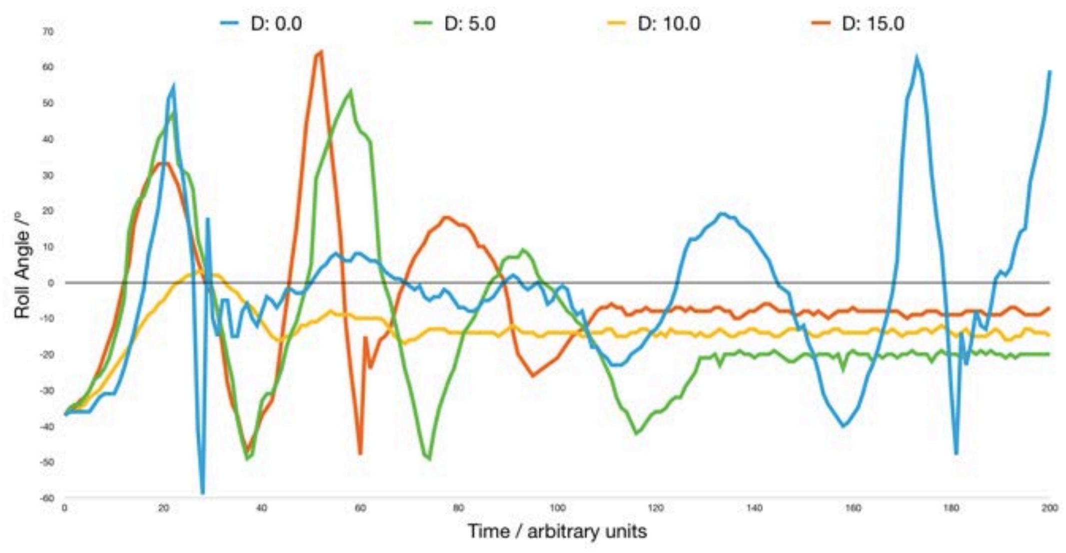

Figure 11: Comparison of different D-gain values on the stability of the quadcopter

	Accuracy /°	Period /au
D: 0.0	-2.9 ±37.0	36.4
D: 5.0	-23.4 ± 1.0	43.3
D: 10.0	-14.0 ± 1.0	40.1
D: 15.0	-8.3 ± 1.5	31.7

Accuracy: Increased

Latency: Increased, then decreased

D-gain acts as "resistance", **opposing the change** in any direction or orientation.

Higher D-gain **slows down** the correction in deviation of angle of the quadcopter

Higher resistance towards correction means **more time** required to reach setpoint

Comparison between Rates controller and Angles controller

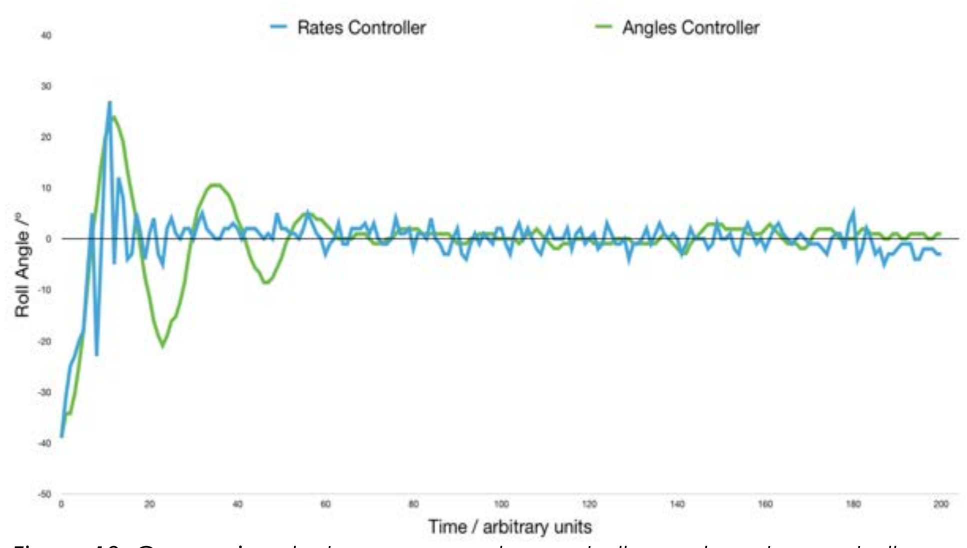

Figure 12: Comparison between an angles controller and a rates controller on the stability of the quadcopter

	Accuracy /°	Latency /au
Rates Controller	-0.3 ± 5.0	25.0
Angles Controller	0.3 ± 2.9	70.0

Rates: Less accurate, Less latency

Angles: More accurate, Higher latency

Angular displacement **mathematically filtered** more times than angular velocity

Value of angular velocity would mathematically change at a **greater rate** than value of angular displacement

Future Work

1. Utilizing more IMUs to **increase redundancy** and **reliability**.
2. Implementing additional sensors like **barometers** and **GPS**.

Conclusion

Rates: Less accurate, Less latency

Angles: More accurate, Higher latency

Successfully **visualised** tuning of PID controller to obtain stable test flight

Selected References

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