Flight Controller and Sensors

DI05000081: Drone Technology — Unit 3

Drone Technology

Gujarat Technological University

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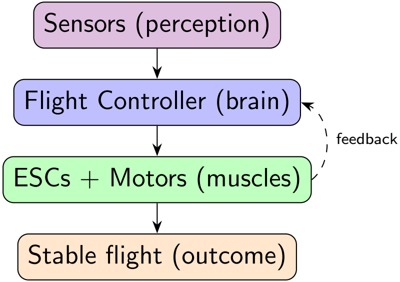
Unit 3 Roadmap

Topics Covered in Unit 3

1. **Flight controller concept** (the brain)
2. **Working of FC board** (microcontroller, interfaces)
3. **Sensors**: Accelerometer, Gyroscope, Magnetometer, Barometer, GPS
4. **Inertial Measurement Unit (IMU)**
5. **Stabilisation and PID control**

Central Question

How does a drone *know* where it is, how it is tilted, and how to stay stable automatically?



3.1 Flight Controller — The Brain of the Drone

Definition

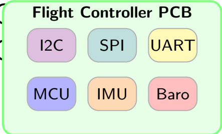
A **flight controller (FC)** is an embedded computer that reads sensor data and pilot commands, runs control algorithms, and outputs signals to the ESCs to maintain stable flight.

Inputs and Outputs

Inputs	**Outputs**
Receiver (pilot commands)	PWM/DSHOT to ES
Accelerometer data	PWM/DSHOT to ESC 2
Gyroscope data	PWM/DSHOT to ESC
GPS position	PWM/DSHOT to ESC
Barometer altitude	Servo signals (gimbal)
Magnetometer heading	Telemetry to GCS

Popular FC Examples

- **Pixhawk** — open-source, professional
- **ArduPilot / APM** — feature-rich autopilot
- **Betaflight F4/F7** — racing drones
- **DJI Naza / N3** — consumer/pro DJI drones
- **Ardupilot Kakute** — mid-range hobby



3.2 Working of the Flight Controller Board

Key Hardware Sections

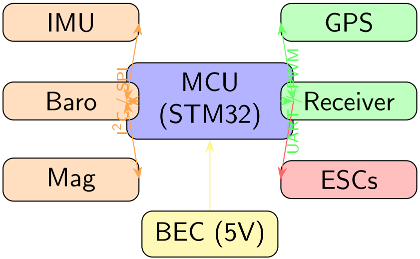
Microcontroller STM32 ARM Cortex-M; runs the control loop at 400–8000 Hz

Sensor Interface I^2C and SPI buses connect IMU, baro, magnetometer

Power Supply BEC provides regulated 3.3V / 5V to FC from battery

Output Pins PWM/DSHOT pins drive ESCs (one per motor)

UART ports Serial links to GPS, telemetry, OSD



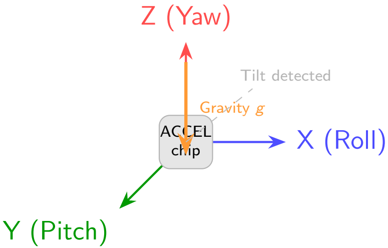
3.3 Sensors — Accelerometer

Definition

An **accelerometer** measures **linear acceleration** (and static gravity) along three axes (X, Y, Z). Units: m/s^2 or g.

Application in Drones

- Determines drone's **tilt angle** from gravity vector
- Detects **vibration** (used for motor health monitoring)
- Provides **velocity estimate** when integrated
- Part of the IMU (combined with gyroscope)



Analogy

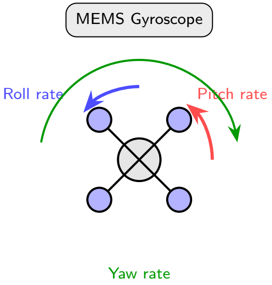
3.3 Sensors — Gyroscope

Definition

A **gyroscope** measures **angular rate of rotation** around three axes. Units: degrees/second ($^\circ$/s) or rad/s.

Relation to Pitch, Roll, Yaw

Axis	Motion detected
X-axis	Pitch rate (nose up/down)
Y-axis	Roll rate (bank left/right)
Z-axis	Yaw rate (heading change)



Application in Drones

- Primary sensor for **attitude stabilisation**

Magnetometer (Compass)

- Measures strength of Earth's magnetic field
- Determines drone's **heading** (direction it faces)
- Used for: **yaw correction**, waypoint navigation
- Affected by metal objects and ESC cables (must be mounted away)

Barometer

- Measures **atmospheric pressure**
- Pressure decreases with altitude: $P = P_0 e^{-h/H}$

GPS (Global Positioning System)

- **Satellite-based** positioning system
- Provides: Latitude, Longitude, Altitude
- Needs lock on $\geq$4 satellites for 3D fix
- Accuracy: $\pm$2–5 m (standard), $\pm$10 cm (RTK)

GPS Applications in Drones

- **Position Hold** (Loiter mode)
- **Return to Home** (RTH)
- **Waypoint navigation**

3.4 Inertial Measurement Unit (IMU)

Introduction

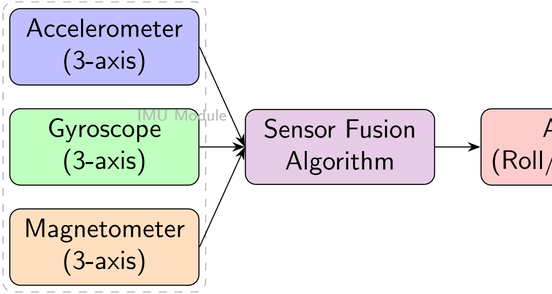
An **IMU** is a sensor module that combines:

- 3-axis **Accelerometer**
- 3-axis **Gyroscope**
- (sometimes) 3-axis **Magnetometer**

Total up to **9 degrees of freedom (9-DoF)**

Function and Working Principle

- Provides complete **attitude estimation** (roll, pitch, yaw)
- Uses **sensor fusion** (complementary / Kalman filter)
- Gyro: fast response; Accel: removes drift

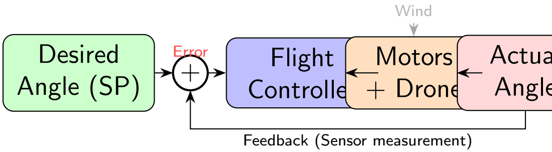


What is Drone Stabilisation?

Maintaining the desired **attitude** (orientation) and **position** automatically, even when disturbed by wind or payload shifts.

Role of Sensors + Controller

1. Sensors measure **current state** (e.g., tilt angle)
2. FC compares with **desired state** (level)
3. FC computes **error** = desired − actual
4. FC adjusts motor speeds to **reduce error**
5. Loop repeats hundreds of times per second



Example

PID Controller

$$u(t) = K_P\, e(t) + K_I \int_0^t e(\tau)\, d\tau + K_D \frac{de}{dt}$$

P (Proportional) Correct **immediately** based on current error; larger error → larger correction

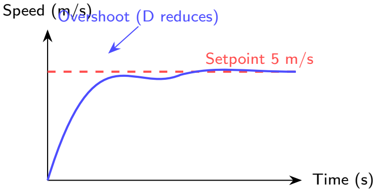
I (Integral) Correct **accumulated** error over time; removes steady-state offset

D (Derivative) Correct based on **rate of change**; damps oscillation, predicts overshoot

Velocity Hold Example

Setpoint: 5 m/s constant speed

Error	= 5 − actual speed
P term	pushes throttle hard if slow
I term	corrects persistent slow-flying
D term	reduces throttle as speed nears 5 m



Unit 3 — Summary

Key Takeaways

- FC = brain; reads sensors, outputs motor commands
- **Accelerometer**: measures linear acceleration / tilt
- **Gyroscope**: measures angular rotation rate
- **Magnetometer**: measures compass heading
- **Barometer**: measures altitude via air pressure
- **GPS**: latitude, longitude, altitude from satellites
- **IMU** = Accel + Gyro (+ Mag), fused for attitude
- **PID**: P=proportional, I=integral, D=derivative control

Review Questions

1. What is the role of a flight controller in a drone?
2. Distinguish between Accelerometer and Gyroscope.
3. What is an IMU? Name its components.
4. Draw a closed-loop feedback control diagram for a drone.
5. Explain the role of P, I, and D in a PID controller with a drone