Drone Technology (DI05000081)

Complete Lecture Deck – All 30 Lectures

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Definition of UAV and Drone

Unit 1: Introduction to Drone Technology

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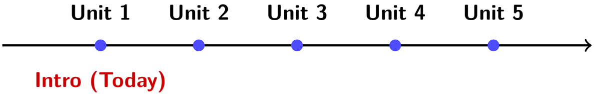
Course Overview

Course Overview & Today's Agenda

- Course spans 5 units across 15 weeks (30 lectures)
- Unit 1: Introduction to Drone Technology (8 lectures)
- Today: What is a UAV? What is a Drone?
- Why this distinction matters for the rest of the course



1.1 Definition of UAV and Drone

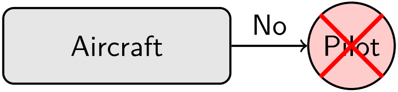
Learning Objectives

Objectives for Today

- Define UAV and Drone in technical terms
- Identify defining characteristics of unmanned aircraft
- Understand why terminology matters in this field

What is a UAV?

- **UAV** = Unmanned Aerial Vehicle
- An aircraft that flies without a human pilot on board
- Operated either by remote control from the ground or autonomously by onboard computers
- Formal/technical term used in aviation and engineering



What is a Drone?

- **Drone** is the popular/common name for a UAV
- Originally a military/informal term, now used widely for civilian UAVs
- Covers everything from small toy quadcopters to large surveillance aircraft
- In everyday language, ‘drone’ and ‘UAV’ are often used interchangeably

All are ”Drones”

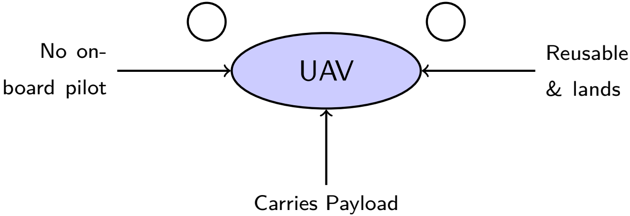
Toys	Quadcopter	Fixed-Wing	Military

UAV vs Drone: Side by Side

UAV	Drone
Formal/technical term	Informal/popular term
Used in engineering & regulation	Used in media & daily conversation
Both refer to the same physical unmanned aircraft	
No difference in the underlying technology	

Key Characteristics of a Drone/UAV

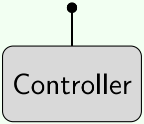
- No human pilot physically present on board
- Controlled remotely by a pilot on the ground, or flies autonomously
- Carries sensors and/or a payload (camera, cargo, sensors)
- Can be reused (unlike a missile) - returns and lands



Remote-Controlled vs Autonomous Operation

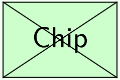
Remote-Controlled

- Pilot actively flies drone using a transmitter



Autonomous

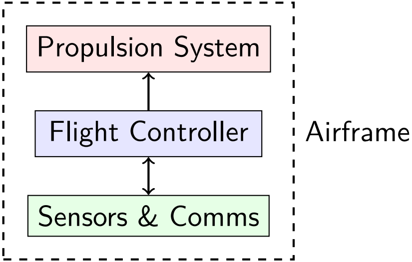
- Follows pre-programmed instructions with minimal input



- Many modern drones use a mix of both (semi-autonomous)
- Both fall under the definition of a UAV

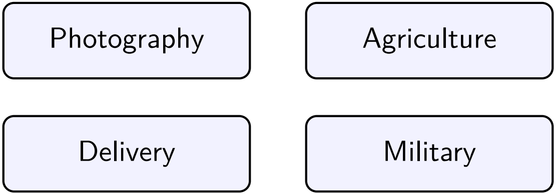
Drones at a Glance: Basic Building Blocks

- Airframe (body/structure)
- Propulsion system (motors + propellers)
- Flight controller (the ‘brain’)
- Sensors and communication link



Real-World Examples of Drones

- Consumer photography drones (e.g., quadcopter with camera)
- Agricultural spraying drones
- Delivery drones carrying small packages
- Military reconnaissance UAVs



Common Misconceptions

Myth

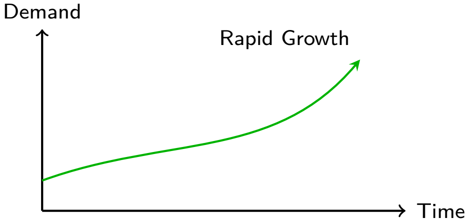
- All drones are toys
- Drones fly only by remote control
- UAV and drone are different machines

Fact

- Range from toys to industrial aircraft
- Many fly autonomously
- Same machine, different naming context

Why Study Drone Technology?

- Rapidly growing field with applications across industries
- High demand for skilled drone technicians and pilots
- Foundation for careers in aerospace, robotics, and automation
- Diploma engineers can design, build, and maintain drone systems



Quick Check: Define in Your Own Words

Pop Quiz

- **Q:** What does UAV stand for?
- **Q:** Give one characteristic that makes a drone 'unmanned'
- **Q:** Name two real-world drone applications

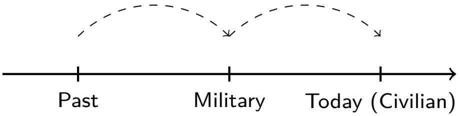
Summary & Key Takeaways

Key Takeaways

- **UAV** = Unmanned Aerial Vehicle: the technical term for a pilotless aircraft
- **Drone** = the common/popular name for the same aircraft
- **Key traits**: no onboard pilot, remote or autonomous control, reusable, carries sensors/payload

Next Lecture Preview

- Lecture 2: History and Evolution of Drones
- How drones evolved from military targets to everyday tools
- Key milestones from early 20th century to today



Thank You!

Any Questions?

History and Evolution of Drones

Drone Technology (DI05000081)

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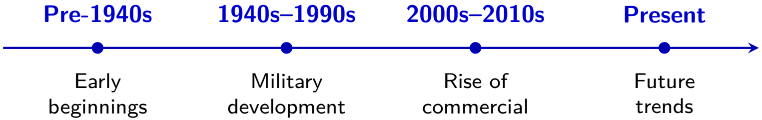
Recap

Recap: What is a Drone?

- UAV = formal term, Drone = popular term for the same unmanned aircraft
- Key traits: no onboard pilot, remote/autonomous control, reusable

1.2 History and evolution of drones

Today's Agenda: History & Evolution



- Early beginnings (pre-1940s)
- Military development (1940s–1990s)
- Rise of commercial drones (2000s–2010s)
- Present day and future trends

Early Beginnings: Pre-1940s

- Concept of unmanned flying devices dates back to early 20th century
- Early experiments: unmanned aerial targets for military training
- Radio-controlled aircraft demonstrated as early as the 1930s
- These were simple, single-purpose target drones

World War II Era

- Radio-controlled target drones used for training anti-aircraft gunners
- Early reconnaissance concepts explored by militaries
- Limited by primitive radio control and no onboard intelligence

Timeline: 1940s - The Target Drone Era

Cold War Reconnaissance Drones

- 1950s–1970s: UAVs developed for aerial reconnaissance and surveillance
- Used to gather intelligence without risking pilot lives
- Improved range, altitude, and camera/sensor payloads
- Marked the shift from simple targets to functional surveillance tools

Growth of Military UAVs (1980s-1990s)

- Continued advancement in reconnaissance and surveillance UAVs
- Improved navigation and communication systems
- Longer endurance and greater operational range
- Laid the groundwork for more sophisticated modern military drones

Modern Military Drones (2000s)

- Widespread military adoption for surveillance and combat support roles
- Integration of GPS, satellite communication, and advanced sensors
- Increased public awareness of drone technology through media coverage

Rise of Commercial and Consumer Drones

- 2010s: consumer quadcopters become affordable and widely available
- GPS stabilization, onboard cameras, and easy-to-use controls opened drones to hobbyists
- Rapid growth of applications: photography, agriculture, delivery, inspection
- Regulatory bodies begin framing civilian drone rules

Present Day Drones

- Drones now used across agriculture, construction, media, logistics, defense, and more
- Advances in AI enable smarter autonomous navigation and obstacle avoidance
- Swarm drone technology and long-endurance drones under active development
- Strong regulatory frameworks now govern civilian drone operations

Timeline Summary

Pre-1940s	1940s–1970s	1980s–2000s	2010s–Present
Early radio-controlled targets	Military reconnaissance	Advanced military UAVs	Commercial & consumer boom

Summary

Key Takeaways

- Drones originated as military training targets and reconnaissance tools
- Technology matured through the Cold War and into modern military use
- Miniaturization and GPS enabled the 2010s commercial drone boom
- Today drones serve civilian, commercial, and military purposes worldwide

Next Lecture Preview

Coming Up: Lecture 3

- Difference between UAV, UAS, and Drone
- Understanding the full ‘system’ behind a drone, not just the aircraft

Questions?

Difference between UAV, UAS, and Drone

Unit 1: Introduction to Drone Technology

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Recap

Recap: History of Drones

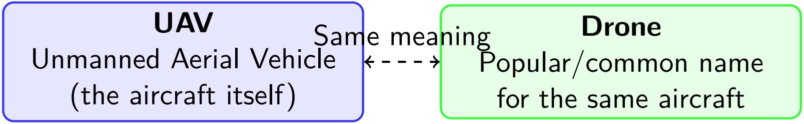
- Drones evolved from military targets to reconnaissance tools to consumer products
- Key turning point: 2010s commercial drone boom

Difference between UAV, UAS, and Drone

Today's Agenda

- Recall: what is a UAV and a Drone
- New term: UAS (Unmanned Aircraft System)
- Comparing UAV vs UAS vs Drone
- Why correct terminology matters

Quick Recall: UAV and Drone



- **UAV** = Unmanned Aerial Vehicle (the aircraft itself)
- **Drone** = popular/common name for the same aircraft

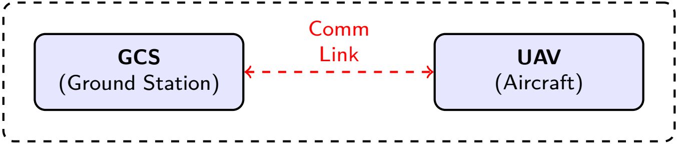
Introducing UAS

- UAS = Unmanned Aircraft System
- Refers to the ENTIRE system, not just the flying aircraft
- Includes: the UAV itself, the ground control station, and the communication link between them
- 'System' emphasizes that a drone cannot operate alone - it needs a pilot/controller and a link

Components of a UAS

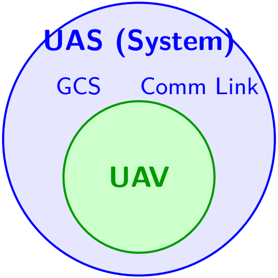
- **1. The unmanned aircraft (UAV)** - the flying vehicle
- **2. The ground control station (GCS)** - where the pilot/operator controls and monitors the flight
- **3. The communication link** - radio/data connection between aircraft and ground station
- 4. (Sometimes) the human operator/pilot as part of the operating system

UAS (Unmanned Aircraft System)



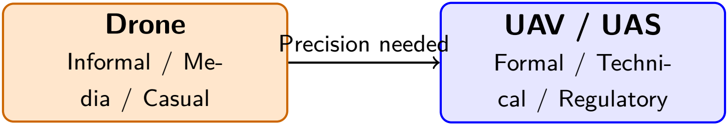
UAV vs UAS: The Core Distinction

- **UAV:** the physical flying aircraft ONLY
- **UAS:** the aircraft PLUS ground control station PLUS communication link
- *Analogy:* UAV is like a car; UAS is like the car plus the driver's controls plus the road communication infrastructure
- Every UAS contains a UAV, but a UAV alone is not a complete UAS



Where Does ‘Drone’ Fit In?

- **Drone** is an informal umbrella term
- Colloquially used to refer to either just the aircraft (like UAV) or the whole operation (like UAS)
- In casual conversation, precision is not required
- In technical, regulatory, and engineering contexts, UAV/UAS are preferred

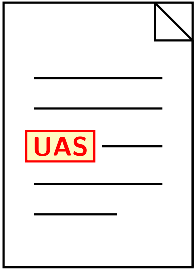


Three-Way Comparison Table

Term	Refers To	Usage Context
UAV	The aircraft only	Technical / engineering
UAS	Aircraft + GCS + comm link (full system)	Regulatory / systems engineering
Drone	Aircraft (informally, sometimes whole system)	Everyday / media language

Why Correct Terminology Matters

- Regulations (e.g., DGCA rules) are written using precise terms like UAS
- Engineers must know which subsystem they are discussing
- Miscommunication can cause confusion in technical documentation and compliance
- Using the right term signals professional competence



DGCA Rules

Example Scenarios

Scenario 1

'The **UAV** crashed due to a motor failure' - refers to the aircraft hardware issue

Scenario 2

'The **UAS** lost link because the ground station antenna failed' - refers to the whole system

Scenario 3

'I bought a **drone** for photography' - informal, refers to the aircraft

Quick Check

- **Q:** If the transmitter and ground station are included, which term applies?
  A: UAS
- **Q:** Is 'drone' a formal engineering term?
  A: No, it is an informal umbrella term.
- **Q:** Name the 3 core parts of a UAS
  A: Aircraft (UAV), Ground Control Station (GCS), Communication Link.

Summary

Key Takeaways

- **UAV** = aircraft only; **UAS** = aircraft + ground control station + communication link (the full system)
- **Drone** = informal umbrella term used for both, depending on context
- Precise terminology matters in engineering, regulation, and documentation

Next Lecture Preview

- **Lecture 4: Classification of Drone**
- How drones are classified by size/weight, type, altitude, and structure/design

Questions

Any Questions?

Thank You!

Classification of Drone

Drone Technology (DI05000081) - Unit 1

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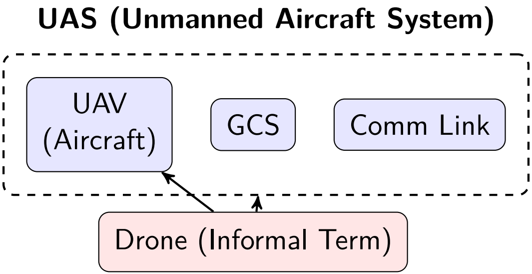
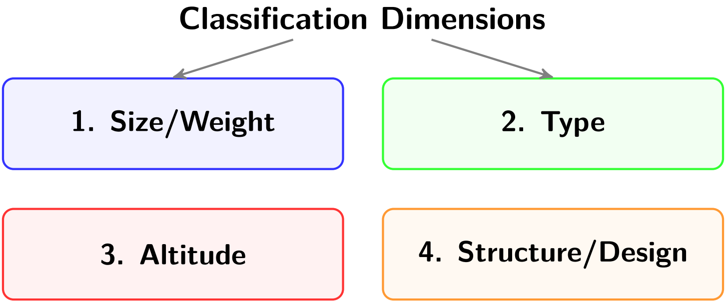
Recap

Recap: UAV vs UAS vs Drone

- **UAV** = aircraft only; **UAS** = aircraft + GCS + communication link
- **Drone** = informal term for either



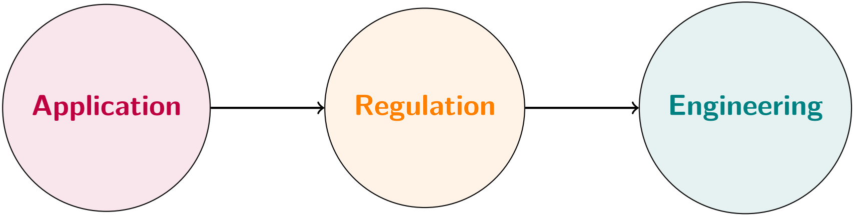
Classification of Drones



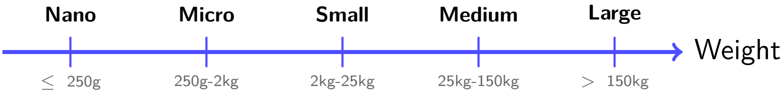
- Classification by Size/Weight
- Classification by Type
- Classification by Altitude
- Classification by Structure/Design

Why Classify Drones?

- ✓ Helps match the right drone to the right application
- ✓ Basis for regulatory categories (used later in Unit 5 for Indian drone rules)
- ✓ Helps engineers understand design trade-offs (weight vs payload vs endurance)



- **Nano drones:** very small, typically up to 250 grams
- **Micro drones:** small, roughly 250 grams to 2 kg
- **Small drones:** roughly 2 kg to 25 kg
- **Medium drones:** roughly 25 kg to 150 kg
- **Large drones:** above 150 kg



Size/Weight: Practical Implications

Smaller Drones

- Easier to fly
- Lower regulatory burden
- Limited payload & range

Larger Drones

- Greater payload & range
- Stricter regulation
- Higher cost & complexity

Weight class often determines required permits and pilot licensing!

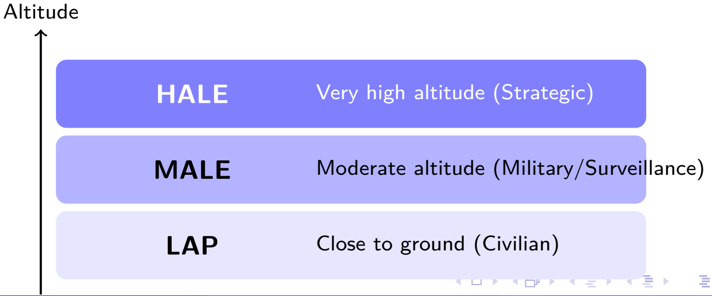
Classification by Type

- Types of drones grouped by their operational category and purpose
- Common groupings: consumer/hobby, commercial, military, industrial
- Each type is optimized for its intended use case (photography, surveillance, delivery, combat, etc.)

Consumer/Hobby (Photography, Racing)	**Commercial** (Delivery, Inspection)
Military (Combat, Surveillance)	**Industrial** (Mapping, Agriculture)

Classification by Altitude

- **Low Altitude Platforms (LAP):** operate close to the ground, typical for civilian drones
- **Medium Altitude Long Endurance (MALE):** operate at moderate altitude for extended durations, mainly military/surveillance
- **High Altitude Long Endurance (HALE):** operate at very high altitude for very long durations, used for strategic surveillance

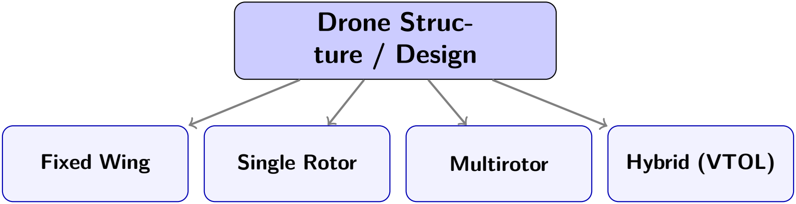


Altitude Classification: Applications

Altitude Band	Typical Applications
LAP (Low Alt)	Agriculture, photography, inspection (typical diploma-level applications)
MALE (Med Alt)	Border surveillance, long-range reconnaissance
HALE (High Alt)	Strategic/military surveillance, communications relay at very high altitude

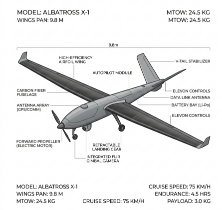
Classification by Structure/Design

- **Fixed wing:** rigid wing generates lift like an airplane
- **Rotary wing:** lift generated by rotating blades/rotors
- **Single Rotor:** one large main rotor (like a helicopter)
- **Multirotor:** multiple rotors (e.g., quadcopter, hexacopter)
- **Hybrid drones:** combine fixed-wing and rotary-wing features (VTOL capability)



Fixed Wing Drones

- Lift generated by forward motion over a fixed wing, like an airplane
- **Advantages:** longer range, higher speed, better endurance
- **Limitations:** requires runway or launcher, cannot hover



Rotary Wing Drones (Single Rotor & Multirotor)

- **Single rotor:** one main rotor + tail rotor (helicopter style) – efficient but mechanically complex
- **Multirotor:** multiple fixed-pitch rotors (quad/hexa) – simpler mechanically, very popular for civilian use
- Both can hover in place, unlike fixed-wing drones

Single Rotor

✓ Efficient forward flight

✗ Mechanically complex

✓ Heavy payload capability

Comparison

Multirotor

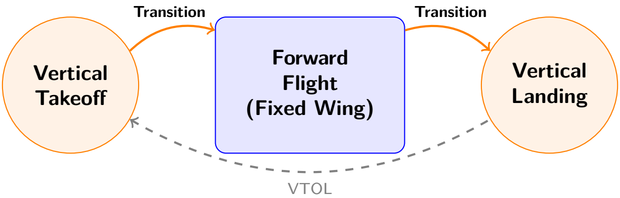
✓ Mechanically simple

✓ Very stable hover

✗ Lower flight efficiency

Hybrid Drones (VTOL)

- Combine fixed-wing efficiency with rotary-wing vertical takeoff/landing (VTOL)
- Take off and land vertically like a multirotor, then fly forward efficiently like a fixed-wing aircraft
- Best of both worlds: no runway needed, plus long range/endurance



Classification Summary Table

Dimension	Categories
Size/Weight	Nano, Micro, Small, Medium, Large
Type	Consumer, Commercial, Military, Industrial
Altitude	LAP, MALE, HALE
Structure/Design	Fixed wing, Single rotor, Multirotor, Hybrid

Summary & Next Steps

Key Takeaways

- Drones can be classified by size/weight, type, altitude, and structure/design
- Size/weight classes (Nano to Large) drive regulatory requirements
- Structural types include fixed wing, single rotor, multirotor, and hybrid VTOL designs
- Multirotor designs dominate the civilian/commercial market

Next Lecture Preview

Lecture 5: Basic Drone Terminology

- Pitch, Roll, Yaw, Throttle, and Altitude – the core control vocabulary of drone flight

Prepare for Flight Dynamics!

Questions?

Basic Drone Terminology

Unit 1: Introduction to Drone Technology

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Recap

Recap: Classification of Drones

- Drones classified by size/weight, type, altitude, and structure/design
- Multirotor designs dominate civilian use

Basic Drone Terminology

Today's Agenda: Basic Drone Terminology

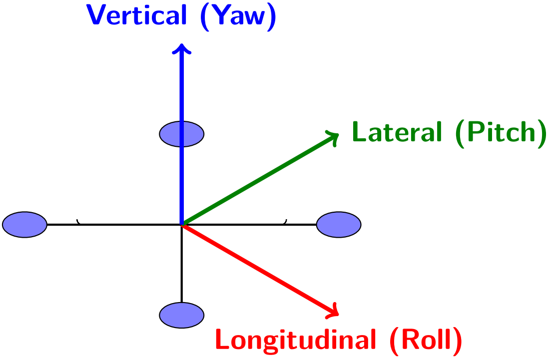
Core Terms

- Pitch
- Roll
- Yaw
- Throttle
- Altitude

Flight Vocabulary

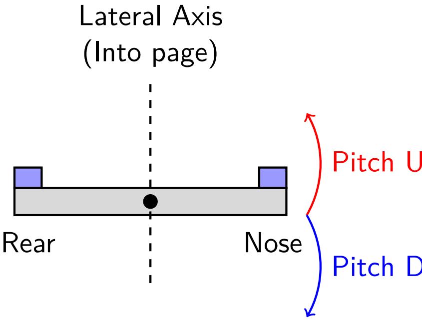
The Three Axes of Motion

- A drone can rotate about three axes: longitudinal, lateral, and vertical



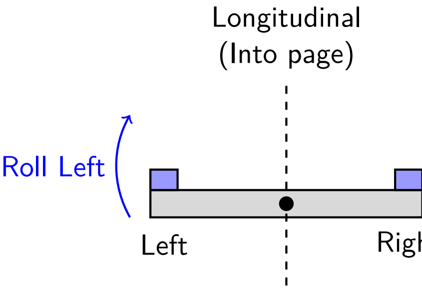
Pitch

- Pitch = rotation about the lateral (side-to-side) axis
- Causes the drone's nose to tilt up or down
- Nose-down pitch moves the drone forward; nose-up pitch moves it backward
- Controlled by adjusting relative speed of front/rear motors



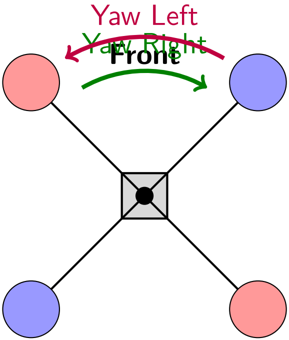
Roll

- Roll = rotation about the longitudinal (front-to-back) axis
- Causes the drone to tilt sideways, left or right
- Used to move the drone left or right
- Controlled by adjusting relative speed of left/right motors



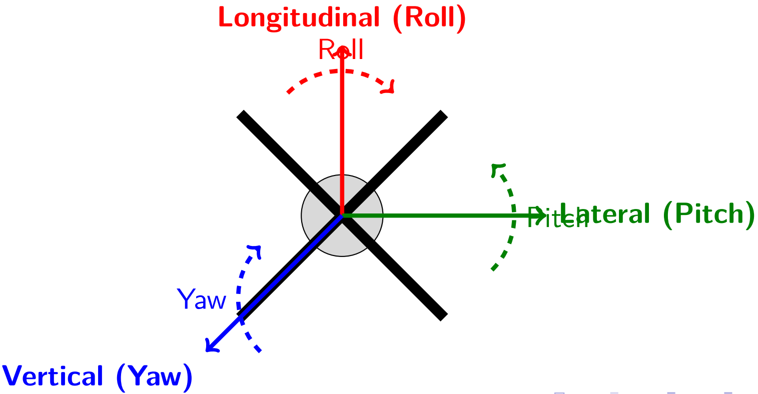
Yaw

- Yaw = rotation about the vertical (top-to-bottom) axis
- Causes the drone to rotate/spin left or right while remaining level
- Changes the direction the drone is facing (heading)
- Controlled by varying torque balance between CW and CCW rotors



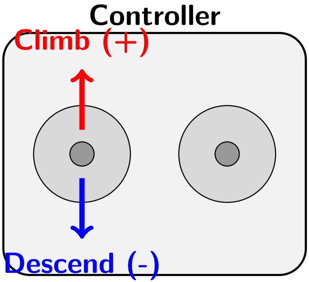
Pitch, Roll, Yaw: Combined View

- Pitch: forward/backward tilt (lateral axis)
- Roll: left/right tilt (longitudinal axis)
- Yaw: rotation/heading change (vertical axis)
- Together these three define a drone's complete orientation in space



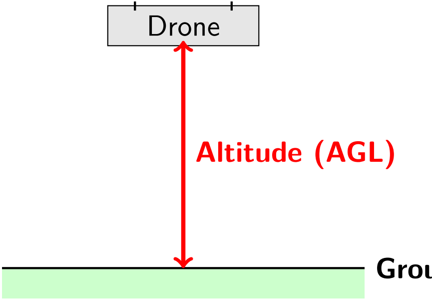
Throttle

- Throttle = control input that adjusts overall motor power/speed
- Increasing throttle increases lift, causing the drone to climb
- Decreasing throttle reduces lift, causing the drone to descend
- Unlike pitch/roll/yaw, throttle does not directly cause rotation - it controls vertical thrust



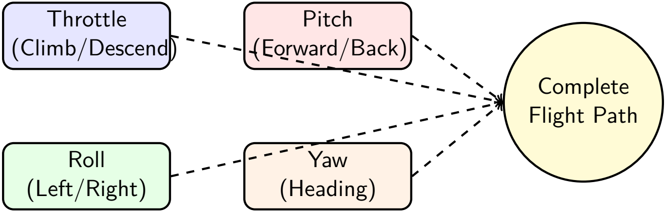
Altitude

- Altitude = height of the drone above a reference point (ground or sea level)
- A critical flight parameter monitored continuously during operation
- Controlled indirectly through throttle adjustments
- Regulatory limits (covered later in Unit 5) are often defined in terms of maximum altitude



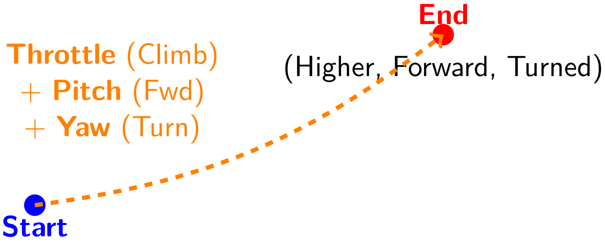
How These Terms Work Together

- Throttle: controls climb/descent (vertical motion)
- Pitch: controls forward/backward motion
- Roll: controls left/right motion
- Yaw: controls heading/direction the drone faces
- A pilot combines all four inputs to fly a complete flight path



Example: A Typical Maneuver

- To fly forward and climb: increase throttle + apply forward pitch
- To turn while flying: combine yaw with pitch/roll
- To hover in place: balance throttle exactly against gravity with zero pitch/roll



Summary

Key Takeaways

Summary of Terminology

- **Pitch, Roll, and Yaw** are rotations about the lateral, longitudinal, and vertical axes respectively
- **Throttle** controls overall motor power and vertical climb/descent
- **Altitude** is the drone's height above a reference point, both a flight parameter and a regulatory limit
- These five terms form the core vocabulary of drone flight control

Next Lecture Preview

Coming Up: Lecture 6

- **Forces Acting on a Drone**
- Lift, Drag, Thrust, and Gravity - the physics that keep a drone airborne

See you in Lecture 6!

Any Questions?

Introduction to Drone Technology

Forces Acting on a Drone

Milav Dabgar

GP Palanpur

July 22, 2026

Recap

Recap: Basic Drone Terminology

- Pitch, Roll, Yaw = rotations about lateral, longitudinal, vertical axes
- Throttle = power control; Altitude = height above reference

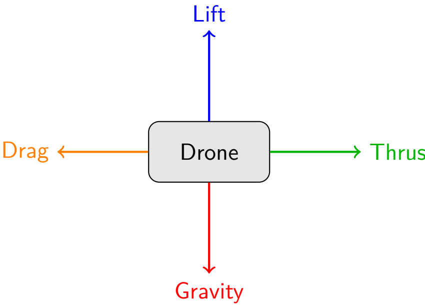
Forces acting on Drone

Today's Agenda: Forces Acting on a Drone

- Lift
- Drag
- Thrust
- Gravity
- How these four forces balance during flight

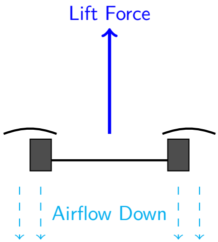
The Four Fundamental Forces

- **Lift:** upward force opposing gravity
- **Gravity:** downward force (weight) pulling the drone down
- **Thrust:** forward/propulsive force generated by motors
- **Drag:** resistive force opposing motion through air



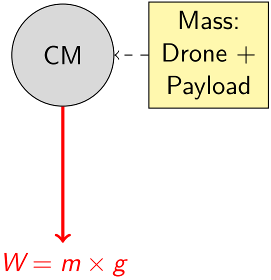
Lift

- Lift = the upward force that opposes gravity and keeps the drone airborne
- In multirotor drones, generated by the spinning propellers pushing air downward
- Must equal or exceed the drone's weight for it to take off or hover
- Increasing throttle increases propeller speed, which increases lift



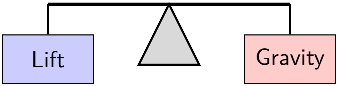
Gravity

- Gravity = the downward force due to the drone's weight (mass × gravitational acceleration)
- Constant force always pulling the drone toward the earth
- Must be overcome by Lift for the drone to fly
- Total weight includes airframe, battery, and any payload



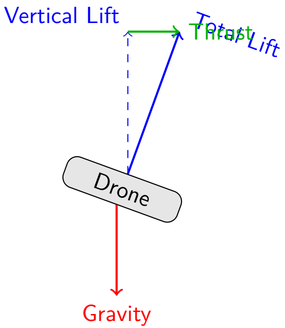
Lift vs Gravity: Vertical Balance

Condition	Flight Behavior
Lift > Gravity	Drone climbs (ascends)
Lift = Gravity	Drone hovers at constant altitude
Lift < Gravity	Drone descends



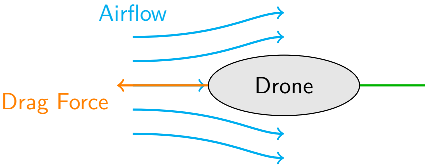
Thrust

- Thrust = the propulsive force that moves the drone forward (or in any horizontal direction)
- Generated when the drone tilts (via pitch/roll) so part of the lift force is redirected horizontally
- Greater tilt angle produces greater horizontal thrust component
- Works together with pitch and roll controls from Lecture 5



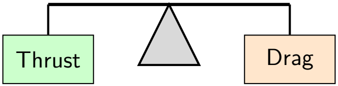
Drag

- Drag = the resistive force opposing the drone's motion through air
- Increases with speed - faster motion means greater air resistance
- Affected by drone shape, frontal area, and air density
- Limits maximum achievable speed and reduces flight efficiency



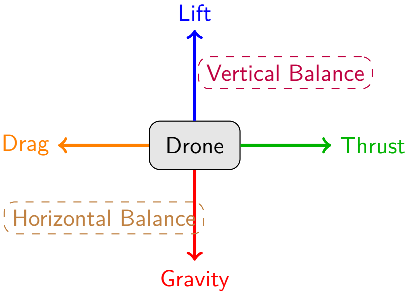
Thrust vs Drag: Horizontal Balance

Condition	Flight Behavior
Thrust $>$ Drag	Drone accelerates forward
Thrust $=$ Drag	Drone moves at constant horizontal speed
Thrust $<$ Drag	Drone decelerates



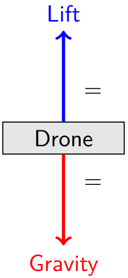
All Four Forces Together

- Vertical balance: Lift vs Gravity determines climb/hover/descend
- Horizontal balance: Thrust vs Drag determines accelerate/constant speed/decelerate
- Stable flight requires continuous adjustment of these balances
- Flight controller and sensors (Unit 3) help maintain this automatically



Real-World Example: Hovering Drone

- A drone hovering in place has Lift = Gravity and Thrust = Drag = 0 (no horizontal motion)
- Any wind gust temporarily disturbs this balance, requiring a quick throttle/tilt correction
- This is why stabilization systems (Unit 3) are essential for real-world flight



Summary

Key Takeaways

- Four forces act on a drone: Lift, Gravity, Thrust, and Drag
- Vertical motion is governed by the Lift vs Gravity balance
- Horizontal motion is governed by the Thrust vs Drag balance
- Stable flight requires continuous, dynamic balancing of these forces

Next Lecture Preview

- Lecture 7: Advantages and Limitations of Drones
- Understanding where drones excel and where their constraints lie

Questions?

Advantages and Limitations of Drones

Introduction to Drone Technology

Milav Dabgar

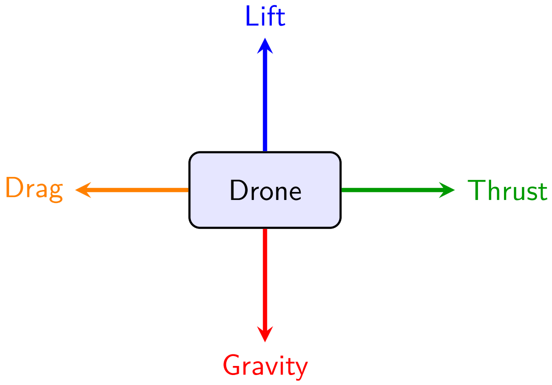
GP Palanpur

July 22, 2026

Recap

Recap: Forces Acting on a Drone

- Lift vs Gravity controls vertical motion
- Thrust vs Drag controls horizontal motion



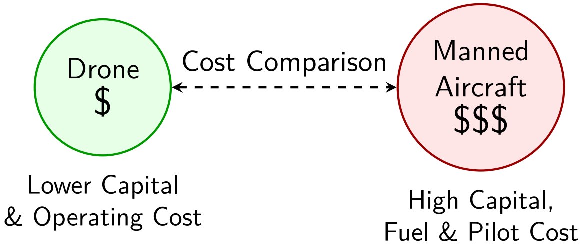
Today's Agenda

- Advantages of drones
- Limitations of drones
- Weighing trade-offs for real applications

Advantages of Drones

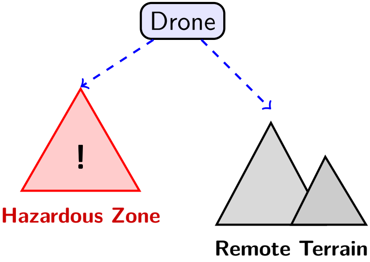
Advantage: Cost-Effectiveness

- Drones are generally far cheaper to purchase and operate than manned aircraft
- No need for a human pilot on board reduces operating costs
- Lower fuel/energy consumption compared to helicopters or planes for similar tasks



Advantage: Access to Hazardous/Remote Areas

- Can operate in dangerous environments without risking human life (disaster zones, high-voltage lines, chemical spills)
- Can reach remote or difficult-to-access locations (mountains, dense forests)

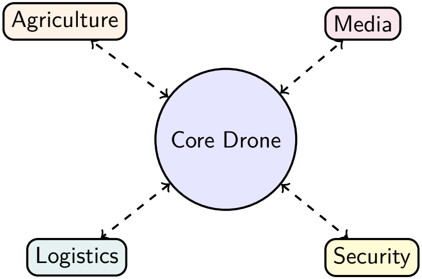


Advantage: Real-Time Data and Rapid Deployment

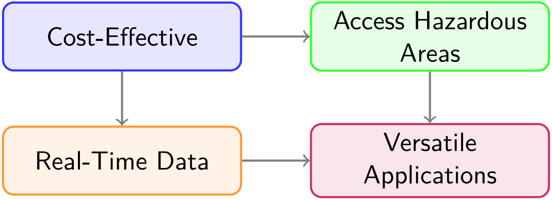
- Provide real-time aerial imagery and sensor data
- Quick to deploy compared to manned aircraft (no runway, minimal setup time)
- Enable faster decision-making in time-critical situations (search and rescue)

Advantage: Versatility

- Adaptable to many industries: agriculture, construction, media, logistics
- Interchangeable payloads (camera, sensors, sprayers) increase flexibility
- Scalable from small hobby drones to large industrial systems



Summary: Key Advantages

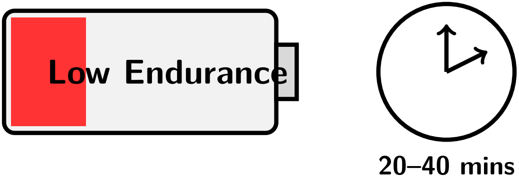


- Drones offer transformative benefits over manned alternatives.

Limitations of Drones

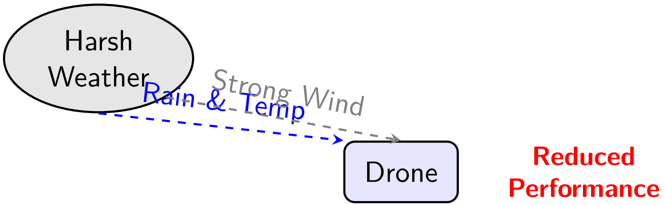
Limitation: Flight Time and Battery Life

- Most electric drones have limited flight endurance (often 20-40 minutes)
- Battery weight vs capacity is a constant design trade-off
- Limits range and mission duration compared to manned aircraft



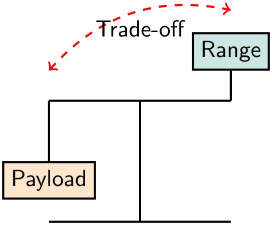
Limitation: Weather Sensitivity

- Performance degrades significantly in strong wind, rain, or extreme temperatures
- Many drones are not rated for all-weather operation
- Weather constraints reduce operational reliability



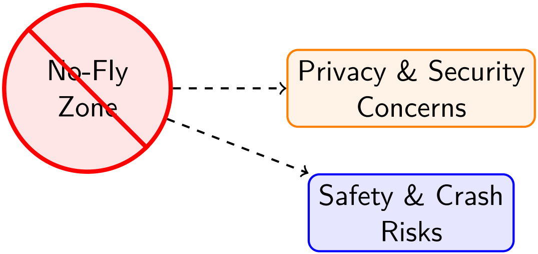
Limitation: Payload and Range Constraints

- Limited payload capacity restricts what a drone can carry
- Communication range limits operation distance
- Larger payload/range requires a more expensive drone

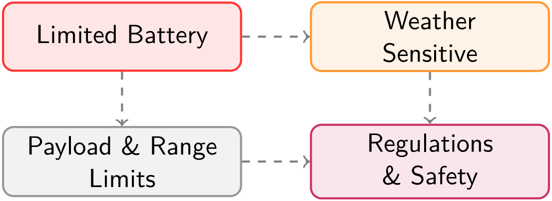


Limitation: Regulatory and Safety Concerns

- Airspace restrictions and no-fly zones limit where drones can legally operate
- Risk of accidents/crashes affecting people or property
- Privacy and security concerns around aerial surveillance



Summary: Key Limitations



- Acknowledging limitations is crucial for safe operations.

Trade-offs

Weighing Advantages vs Limitations

- Choosing a drone for a task means weighing these trade-offs against the mission requirements.

Advantages	**Limitations**
Cost-effective	Limited flight endurance
Access hazardous & remote areas	Weather sensitivity
Rapid deployment & real-time data	Payload and range constraints
Versatile across industries	Regulatory and safety concerns

Conclusion

Key Takeaways

- Drones offer cost-effectiveness, access to hazardous areas, real-time data, and versatility
- Key limitations include limited flight time, weather sensitivity, payload/range constraints, and regulatory restrictions
- Effective drone use requires weighing these trade-offs against mission needs

⇒ Coming Up Next

Lecture 8: Applications of Drones

Exploring 7 major real-world application areas, and wrapping up Unit 1 with a recap

Questions?

Applications of Drones

Unit 1: Introduction to Drone Technology

Milav Dabgar

GP Palanpur

July 22, 2026

Recap

Recap: Advantages and Limitations

Advantages

- Cost-effectiveness
- Access to hazardous areas
- Speed and real-time data
- Versatility

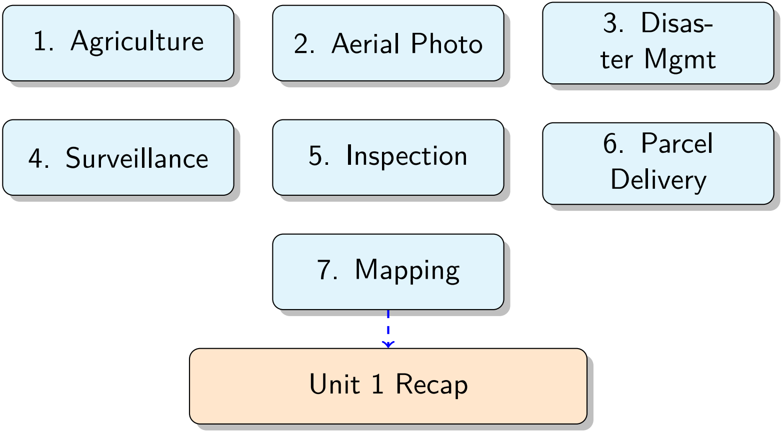
Limitations

- Endurance (Flight time)
- Weather sensitivity
- Payload/range constraints
- Regulatory restrictions

Goal: Maximize Advantages while Mitigating Limitations

1.8 Various Applications of Drone

Today's Agenda: Applications of Drones

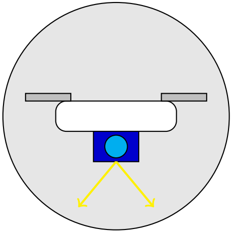


Application 1: Agriculture Monitoring

- Crop health monitoring using aerial imagery and multispectral sensors
- Precision spraying of pesticides/fertilizers, reducing waste
- Irrigation monitoring and yield estimation
- Reduces manual labor and improves farming efficiency

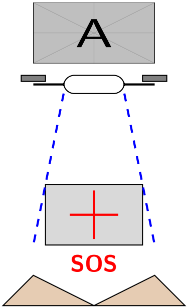
Application 2: Aerial Photography and Videography

- Capturing high-quality aerial images and video for media, events, and real estate
- Enables camera angles and perspectives previously requiring expensive helicopters
- Widely used in filmmaking, tourism promotion, and social media content



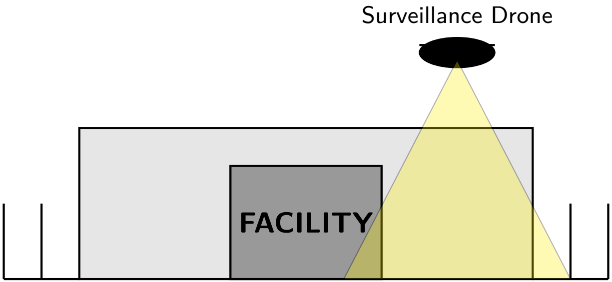
Application 3: Disaster Management

- Search and rescue operations in disaster-affected areas
- Damage assessment after floods, earthquakes, or fires
- Delivering emergency supplies to inaccessible areas
- Reduces risk to human rescue teams during hazardous operations



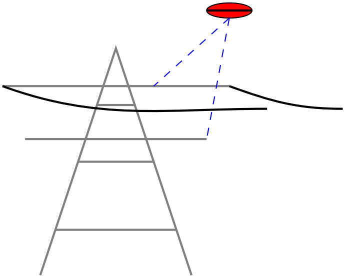
Application 4: Surveillance and Security

- Perimeter monitoring for facilities, borders, and events
- Crowd monitoring during large public gatherings
- Law enforcement support for tracking and monitoring



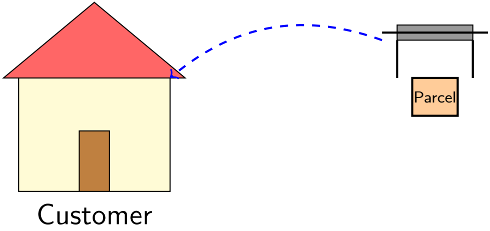
Application 5: Infrastructure Inspection

- Inspecting bridges, towers, pipelines, and power lines without scaffolding or manned aircraft
- Identifies structural damage, corrosion, or wear early
- Reduces cost and risk compared to manual inspection



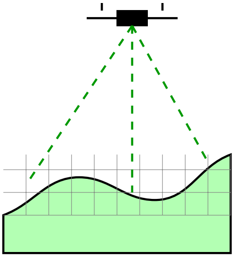
Application 6: Parcel Delivery Systems

- Delivering small packages directly to customers, especially in hard-to-reach areas
- Reduces delivery time compared to road transport in congested or remote areas
- An emerging application actively being trialed by logistics companies worldwide



Application 7: Mapping and Surveying

- Creating detailed topographic maps and 3D terrain models
- Land surveying for construction, mining, and urban planning
- Faster and often more accurate than traditional ground survey methods



Applications Summary Table

Application	Key Benefit
Agriculture monitoring	Precision farming, reduced waste
Aerial photo/video	New perspectives, cost savings
Disaster management	Safe search & rescue, rapid assessment
Surveillance & security	Continuous perimeter/crowd monitoring
Infrastructure inspection	Safer, cheaper structural checks
Parcel delivery	Faster last-mile delivery
Mapping & surveying	Fast, accurate terrain data

Applications Recap Quiz

Question 1

Which application reduces risk to human rescue teams?

Question 2

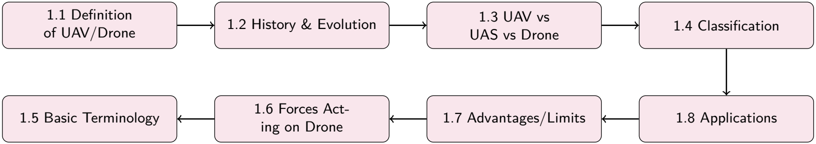
Which application uses multispectral sensors on farmland?

Question 3

Which application creates 3D terrain models?

Unit 1 Recap

Unit 1 Recap: The Big Picture

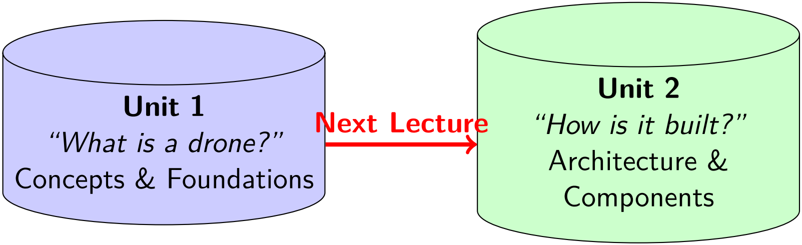


Unit 1 Key Concepts Consolidated

- A drone is an unmanned aircraft (UAV); UAS is the full system including ground control
- Drones are classified by size/weight, type, altitude, and structural design
- Flight is described using Pitch/Roll/Yaw/Throttle/Altitude and governed by Lift/Drag/Thrust/Gravity
- Drones offer major advantages but also carry real limitations
- Applications span agriculture, media, disaster response, security, inspection, delivery, and mapping

Next Lecture Preview

Next Lecture Preview: Unit 2 Begins



Lecture 9

Basic Architecture of a Drone System

Questions?

Basic Architecture of a Drone System

Unit 2: Drone Components and Architecture

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July 22, 2026

Recap

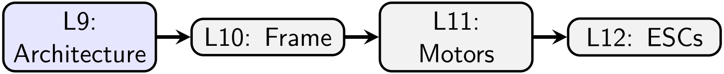
Recap: Unit 1 Summary

- Unit 1 covered definitions, history, classification, terminology, forces, advantages/limitations, and applications.
- We now shift from **'what is a drone'** to **'how is a drone built'**.

Unit 2 Overview

Unit 2 Overview & Today's Agenda

- Unit 2: Drone Components and Architecture (7 lectures)
- Today: **Basic Architecture of a Drone System**
- Block diagram of a complete drone system
- How subsystems connect and communicate



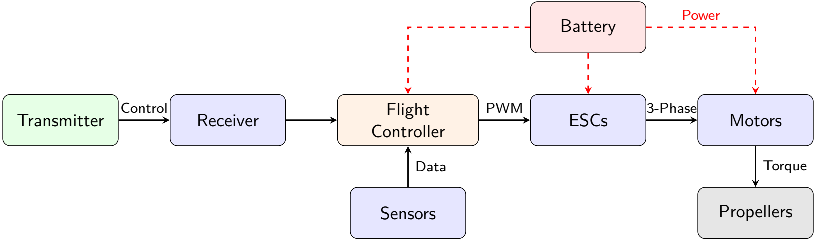
Drone System Architecture

What Makes Up a Drone System?

A drone is made of several interconnected subsystems working together:

Mechanical Frame, Motors, Propellers	**Electrical/Power** Battery, ESCs
Control Flight Controller, Sensors	**Communication** Transmitter, Receiver, Telemetry

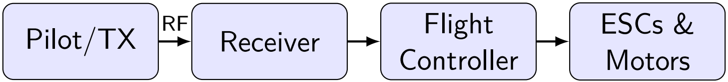
Basic Block Diagram of Drone System



- **Control:** Pilot → Receiver → FC → ESCs → Motors → Propellers
- **Feedback:** Sensors → FC
- **Power:** Battery powers ESCs, Motors, FC, and Payload

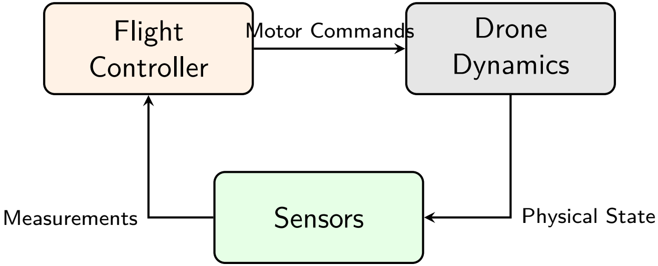
Signal Flow: Control Path

- Pilot input via transmitter is sent wirelessly to the receiver onboard the drone.
- Receiver passes the control signal to the flight controller.
- Flight controller processes the signal along with sensor feedback.
- Flight controller sends commands to ESCs, which drive the motors.



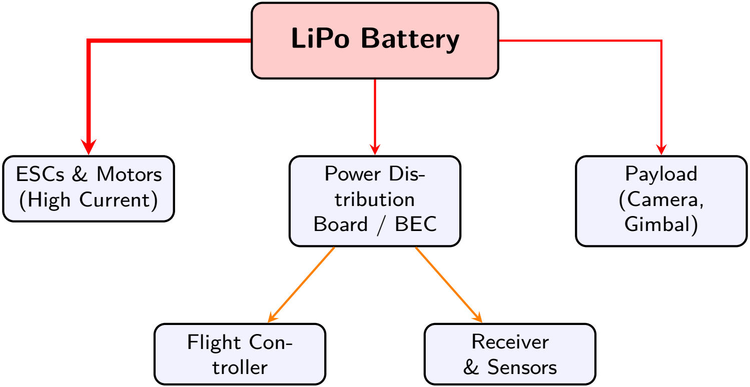
Signal Flow: Sensor Feedback Path

- Onboard sensors (to be detailed in Unit 3) continuously measure orientation, altitude, position.
- Sensor data flows into the flight controller in real time.
- Flight controller uses this feedback to correct motor commands for stable flight.



Power Distribution in the System

- Battery is the single power source for the entire drone.
- Power is distributed to: ESCs and motors (largest consumers), flight controller, sensors, receiver, and payload.
- Voltage regulation circuits ensure sensitive electronics (FC, receiver) get stable, lower voltage.



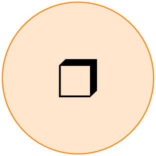
Major Subsystems Overview

Frame (L10) Provides structural support	**Motors** (L11) Generate rotational force	**ESC** (L12) Controls motor speed
Propellers (L13) Convert rotation to thrust	**Battery** (L14) Powers the entire system	**Payload** (L15) Cameras, mission equipment

- Each of these subsystems will be explored in detail in the upcoming lectures of Unit 2.

Why Understanding Architecture Matters

- **Troubleshooting:** Helps troubleshoot failures by isolating which subsystem is responsible.
- **Building & Maintenance:** Essential for assembling or repairing a drone.
- **Foundation:** Forms the foundation for understanding flight controllers and sensors in Unit 3.



System-level Thinking

Example: Tracing a Command Through the System

1. Pilot pushes throttle stick up on the transmitter.
2. Signal travels wirelessly to the receiver onboard the drone.
3. Receiver forwards the signal to the flight controller.
4. Flight controller increases the command sent to all ESCs.
5. ESCs increase motor speed, propellers spin faster, lift increases.

Summary & Preview

Key Takeaways

Summary

- A drone system consists of mechanical, power, control, and communication subsystems.
- The block diagram shows signal flow: transmitter $\rightarrow$ receiver $\rightarrow$ flight controller $\rightarrow$ ESC $\rightarrow$ motor.
- Sensors provide continuous feedback to the flight controller for stable flight.
- The battery powers all subsystems through a distribution network.

Lecture 10

Frame and Mechanical Structure

Types of frames and materials used in drone construction.

→

Questions?

Frame and Mechanical Structure

Unit 2: Drone Components and Architecture
Lecture 10

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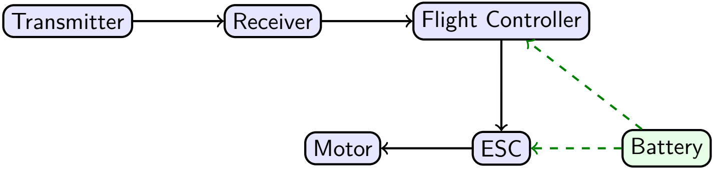
GP Palanpur

July 22, 2026

Introduction

Recap: Basic Drone Architecture

- Signal flow: transmitter → receiver → flight controller → ESC → motor
- Battery powers all subsystems

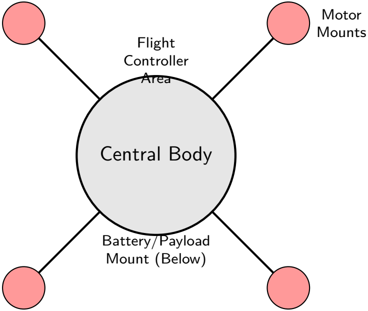


Today's Agenda: Frame and Mechanical Structure

- Role of the frame in a drone
- Types of frames
- Materials used in frames
- Trade-offs in frame design

Role of the Frame

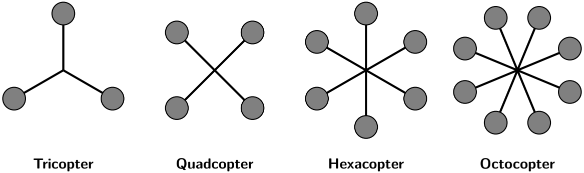
- The frame is the structural backbone that holds all components together
- Mounts motors, flight controller, battery, and payload
- Must be rigid enough to resist vibration and flight loads
- Must be light enough to maximize payload capacity and flight time



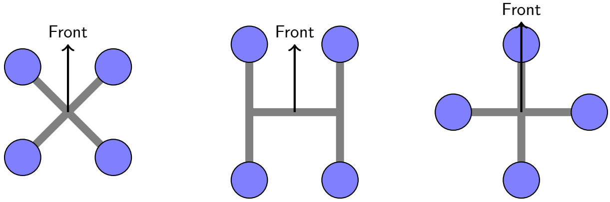
Types of Frames

Types of Frames: By Arm Count

- **Tricopter:** 3 arms/motors
- **Quadcopter:** 4 arms/motors (most common civilian configuration)
- **Hexacopter:** 6 arms/motors (added redundancy and payload capacity)
- **Octocopter:** 8 arms/motors (maximum payload/redundancy, higher cost)



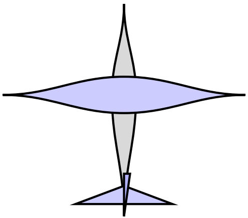
- **X-frame:** arms arranged in an X pattern, motors evenly distributed for agile flight
- **H-frame:** arms arranged in an H pattern, often used for larger payload space
- **Plus (+) frame:** arms arranged in a + pattern, simpler control mapping



X-Frame **H-Frame** **+ Frame**

Fixed-Wing Frame (Brief Note)

- Fixed-wing drones use an airplane-like frame with a single rigid wing
- Different structural demands than multirotor frames - built for aerodynamic lift, not rotor mounting
- Recall from Lecture 4: fixed-wing is one of the structural classification categories

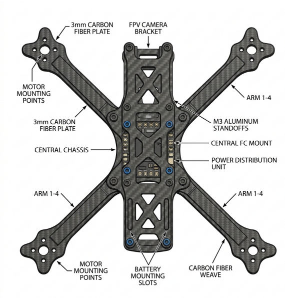


Airplane-style Fixed-Wing Frame

Materials Used in Frames

Materials Used in Frames: Carbon Fiber

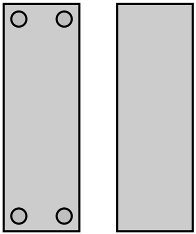
- Lightweight yet very strong and rigid
- Excellent vibration dampening, improving flight stability and sensor accuracy
- More expensive than other materials
- Preferred choice for professional and commercial drones



Carbon Fiber Frame

Materials Used in Frames: Aluminum

- Good strength-to-weight ratio, moderately priced
- Heavier than carbon fiber but more impact-resistant in some designs
- Common in mid-range and industrial drone frames



Aluminum Extrusions

Materials Used in Frames: Plastic/ABS and Others

- **Plastic/ABS:** low cost, lightweight, but less rigid - common in hobby and toy drones
- **Wood:** very low cost, used in basic DIY builds, limited durability
- **Composite materials:** engineered blends offering customized strength/weight trade-offs

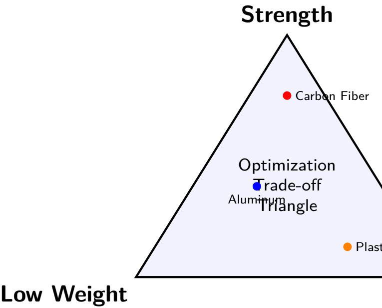
Material Comparison Table

Material	Weight	Strength	Cost
Carbon Fiber	Very Low	Very High	High
Aluminum	Moderate	High	Moderate
Plastic/ABS	Low	Moderate	Low
Wood	Low	Low	Very Low

Frame Design and Trade-offs

Choosing a Frame: Design Trade-offs

- More arms (hexa/octo) = greater payload and redundancy, but more weight and cost
- Lighter material = longer flight time, but potentially less durability
- Frame choice depends on application:
  - Racing drones favor light/agile frames
  - Industrial drones favor rigid/durable frames



Example: Matching Frame to Application

Racing Drone

- **Type:** Quad-copter
- **Shape:** X-frame
- **Material:** Carbon fiber
- **Priority:** Agility & low weight

Agri Drone

- **Type:** Hexa/Octocopt
- **Material:** Aluminum / Composite
- **Priority:** High payload

Hobby Drone

- **Type:** Quad-copter
- **Material:** Plastic
- **Priority:** Low cost & safety

Summary

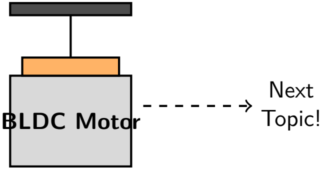
Key Takeaways

- The frame is the structural backbone connecting all drone components
- Frame types vary by arm count (tri/quad/hexa/octo) and shape (X, H, +)
- Common materials: carbon fiber (light & strong), aluminum (balanced), plastic/ABS (cheap), wood (basic)
- Frame and material choice depend on the application's weight, strength, and cost priorities

Next Lecture Preview

Lecture 11: Brushless DC Motors

- Construction of BLDC motors
- Working principle
- KV rating of drone motors



Questions?

Brushless DC Motors

Drone Components and Architecture

Milav Dabgar

GP Palanpur

July 22, 2026

Recap

Recap: Frame and Mechanical Structure

- Frame types: tri/quad/hexa/octocopter, X/H/+ shapes
- Materials: carbon fiber, aluminum, plastic/ABS, wood

Introduction to BLDC Motors

Today's Agenda: Brushless DC Motors

- Why brushless motors are used in drones
- Construction of a BLDC motor
- Working principle
- KV rating and its significance

Why Brushless Motors?

Brushed Motors

- Physical brushes for commutation
- More friction & wear
- Lower efficiency

Brushless (BLDC) Motors

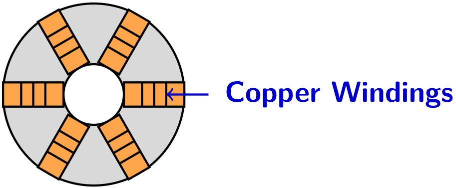
- Electronic commutation
- Higher efficiency & less wear
- Better power-to-weight ratio

Standard choice for virtually all modern multirotor drones!

Construction of a BLDC Motor

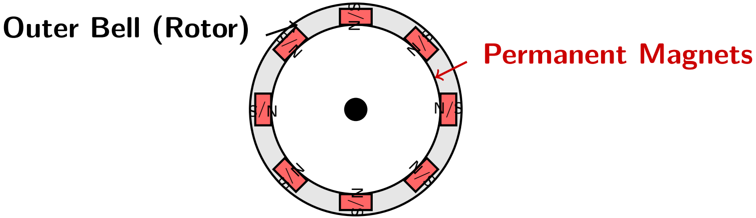
Construction of a BLDC Motor: Stator

- Stator: the stationary part of the motor
- Contains copper windings arranged around a core
- Windings are energized in sequence to create a rotating magnetic field



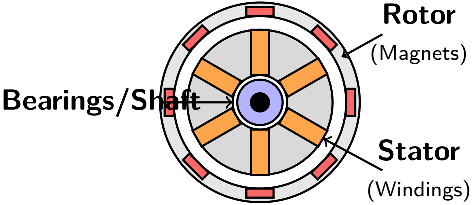
Construction of a BLDC Motor: Rotor

- Rotor: the rotating part of the motor
- Contains permanent magnets
- In most drone motors, the rotor is the outer “bell” that spins around the stationary stator (outrunner design)
- Propeller is mounted directly to the rotor



BLDC Motor: Complete Construction Overview

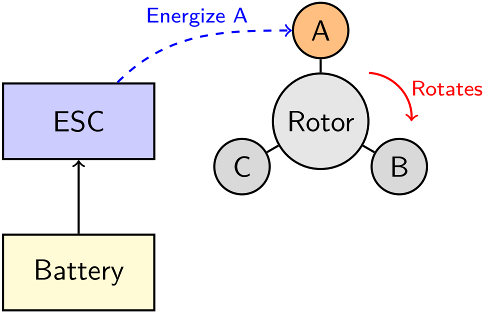
- Stator (windings) - stationary, energized in sequence
- Rotor (permanent magnets) - rotates around/with the stator
- No brushes or commutator - electronic commutation replaces mechanical contact
- Bearings allow smooth rotor rotation with minimal friction



Working Principle

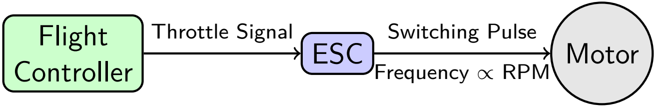
Working Principle: Electronic Commutation

- The ESC energizes stator windings in a specific timed sequence
- Sequential energizing creates a rotating magnetic field
- Rotor's permanent magnets are attracted/repelled, causing spin
- Commutation is done electronically, not mechanically



Working Principle: Speed Control

- Motor speed is controlled by how fast the ESC switches/energizes the windings
- Faster switching sequence = faster rotor rotation = higher RPM
- This switching is controlled by signals from the flight controller via the ESC



KV Rating

KV Rating: Definition

What is KV Rating?

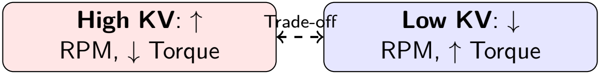
KV rating = RPM (revolutions per minute) per volt applied, with no load and no propeller attached.

- Example: a motor rated 1000KV will spin at approximately 1000 RPM per volt supplied
- KV is a key specification printed on every drone motor

KV Rating: Effect on Performance

- Choosing the right KV rating is essential for matching motor to propeller size and application.

Motor Type	Speed (RPM)	Torque	Application
High KV	High	Low	Small, light props (Racing
Low KV	Low	High	Large, heavy props (Cargo



Matching Motor KV to Propeller Size

Racing Drones

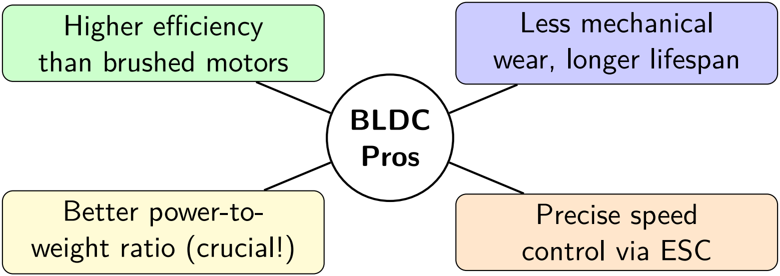
- Small, light
- High KV motor (e.g., 2300KV)
- Small propeller
- Goal: Speed & Agility

Cargo/Photography Drones

- Large, heavy
- Low KV motor (e.g., 400KV)
- Large propeller
- Goal: Lift & Efficiency

Warning: Mismatched KV/propeller combinations can overheat or underperform!

BLDC Motor Advantages Recap



Summary

Key Takeaways

- BLDC motors use a stator (windings) and rotor (magnets) with electronic commutation instead of brushes.
- Working principle: ESC energizes windings in sequence, creating a rotating magnetic field that spins the rotor.
- KV rating = RPM per volt at no load.
- Higher KV = higher speed / lower torque.
- Lower KV = lower speed / higher torque.
- Motor KV must be matched to propeller size and application.

Next Lecture Preview

Lecture 12: Electronic Speed Controller (ESC)
How the ESC controls motor speed and
connects to the flight controller

Questions?

Unit 2: Drone Components and Architecture
Electronic Speed Controller (ESC)
Drone Technology (DI05000081)

Milav Dabgar

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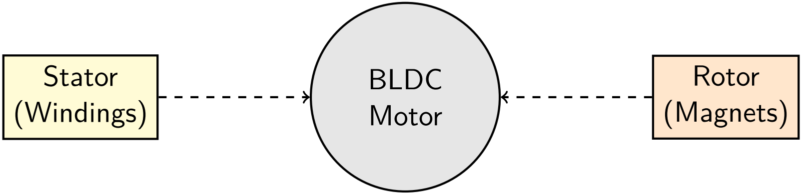
July 22, 2026

Recap

Recap: Brushless DC Motors

- BLDC motors use electronic commutation (stator windings + rotor magnets, no brushes)
- KV rating: higher KV = higher speed/lower torque



Agenda

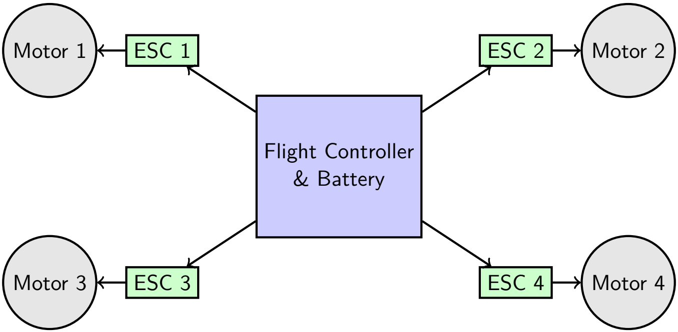
Today's Agenda: Electronic Speed Controller (ESC)

- What is an ESC and why is it needed
- Function of the ESC
- Connection with motor and flight controller
- ESC and battery power (BEC)

Electronic Speed Controller (ESC)

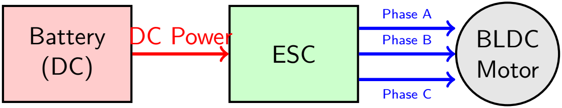
What is an ESC?

- **ESC** = Electronic Speed Controller
- An electronic circuit that controls the speed of a BLDC motor
- Sits between the battery, the flight controller, and the motor
- Each motor on a drone has its own dedicated ESC



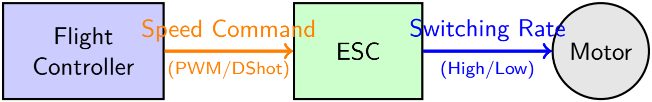
Function of the ESC: Power Conversion

- Converts DC power from the battery into the precisely timed switching signals needed to drive a BLDC motor
- Performs the electronic commutation discussed in Lecture 11 - energizing stator windings in the correct sequence
- Regulates how much power reaches the motor at any instant



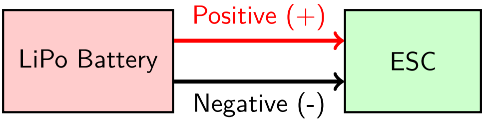
Function of the ESC: Speed Control

- Receives a speed command signal from the flight controller
- Translates that command into the correct switching rate for the motor windings
- Higher commanded speed = faster winding switching = higher motor RPM
- Enables extremely fast and precise speed adjustments (many times per second)

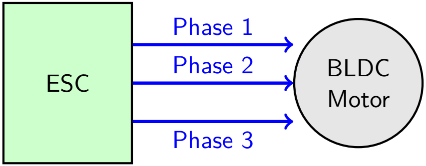


ESC Connections: Battery Side

- ESC connects directly to the battery's positive and negative terminals
- Draws the main power current needed to drive the motor
- Must be rated for the current draw of its motor (measured in Amps)

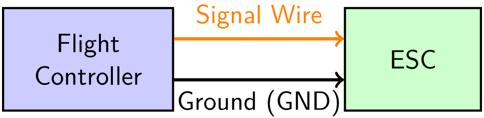


- ESC outputs three phase wires connected to the BLDC motor's three windings
- The timed switching between these three phases creates the rotating magnetic field
- Swapping any two of the three wires reverses the motor's rotation direction (useful for CW/CCW propeller setup)



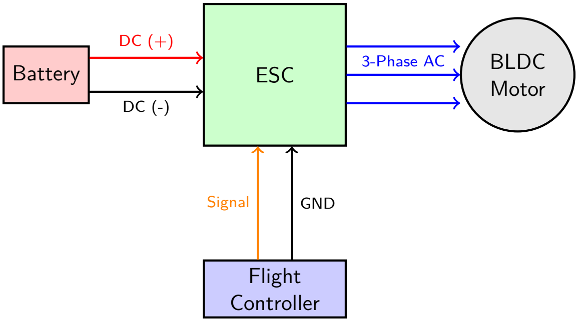
ESC Connections: Flight Controller Side

- ESC receives a control signal wire from the flight controller (one per ESC)
- Common signal protocols: PWM, OneShot, or DShot (digital)
- This signal tells the ESC exactly how fast to spin its motor at any given moment



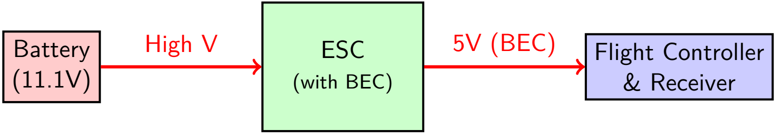
Complete ESC Connection Diagram

- Battery → ESC (power input)
- Flight Controller → ESC (speed command signal)
- ESC → Motor (three-phase power output)
- One ESC per motor; all ESCs receive commands from the same flight controller



The Battery Eliminator Circuit (BEC)

- Many ESCs include a built-in BEC (Battery Eliminator Circuit)
- BEC steps down the main battery voltage to a lower, stable voltage (e.g., 5V) for the flight controller and receiver
- Eliminates the need for a separate battery to power these sensitive electronics



Example: ESC in Action

1. Pilot increases throttle on the transmitter

↓

2. Flight controller receives this and sends a higher speed command to each ESC

↓

3. Each ESC increases its switching rate to its motor

↓

4. Motors spin faster, propellers generate more lift, drone climbs

Summary

Key Takeaways

- The ESC converts battery DC power into precisely timed signals that drive a BLDC motor
- ESC connects to three points: battery (power), flight controller (speed command), and motor (three-phase output)
- Many ESCs include a BEC to power the flight controller and receiver from the main battery
- One ESC is required per motor on the drone

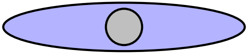
Note

The ESC is the crucial link that translates the Flight Controller's "thoughts" into the Motor's "action".

Next Lecture Preview

Lecture 13: Propellers and Thrust Generation

- Types of propellers
- Size and pitch notation
- Clockwise (CW) and Counter-Clockwise (CCW) rotation



Propeller Preview

Any Questions?

Propellers and Thrust Generation

Drone Components and Architecture (Unit 2)

Milav Dabgar

GP Palanpur

July 22, 2026

Recap

Recap: The Electronic Speed Controller

- ESC connects battery, flight controller, and motor
- Converts speed commands into motor drive signals

Today's Agenda

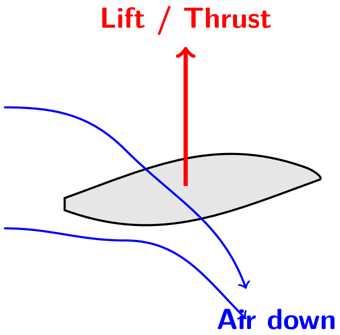
Today's Agenda: Propellers and Thrust Generation

- Types of propellers
- Propeller size and pitch notation
- Clockwise vs counter-clockwise propellers
- How propellers generate thrust

Main Content

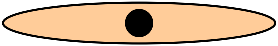
How Propellers Generate Thrust

- Propeller blades are angled airfoils, similar in principle to an aircraft wing
- As the motor spins the propeller, blades push air downward
- By Newton's third law, the reaction pushes the drone upward - this is the Lift force from Lecture 6
- Faster rotation (higher RPM) generates more thrust

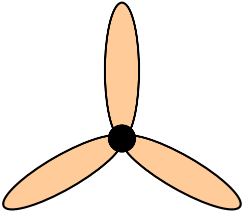


Types of Propellers: Blade Count

- 2-blade propellers: most common, efficient, lower drag
- 3-blade propellers: more thrust at the same diameter, but slightly less efficient
- More blades generally trade some efficiency for more thrust in a compact size



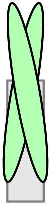
2-Blade



3-Blade

Types of Propellers: Folding Propellers

- Folding propellers: blades fold against the arm when not in use
- Common on portable/compact consumer drones for easy transport and storage
- Unfold automatically or manually before flight due to centrifugal force or manual setup



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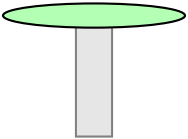

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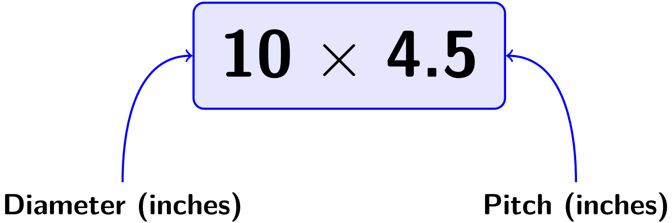
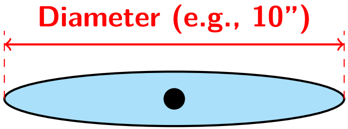
Propeller Size and Pitch: Notation

- Propellers are labeled with two numbers, e.g., '10x4.5'
- First number = **diameter** (length of propeller in inches, tip to tip)
- Second number = **pitch** (in inches)
- This notation appears on virtually every propeller package



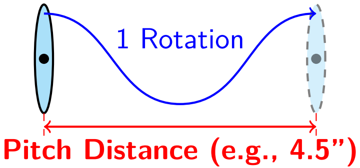
Understanding Diameter

- Diameter = the total length of the propeller from tip to tip
- Larger diameter propellers move more air, generating more thrust at lower RPM
- Larger propellers generally pair with lower KV motors (recall Lecture 11)



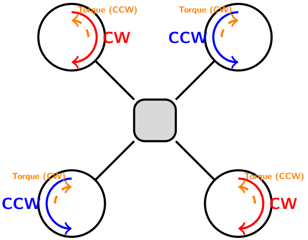
Understanding Pitch

- Pitch = the theoretical distance the propeller would move forward in one full rotation through a solid medium
- Higher pitch = more forward thrust per rotation, but requires more power
- Lower pitch = more efficient/gentler thrust, common for hovering-focused drones



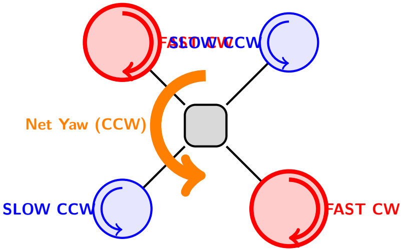
Clockwise and Counter-Clockwise Propellers

- Multirotor drones use a mix of clockwise (CW) and counter-clockwise (CCW) propellers
- Each spinning propeller creates a reaction torque on the drone body, opposite to its spin direction
- Using equal numbers of CW and CCW propellers cancels out the net torque, keeping the drone from spinning uncontrollably



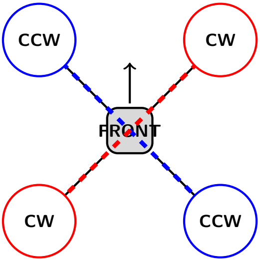
CW/CCW and Yaw Control

- Recall Yaw from Lecture 5: rotation about the vertical axis
- Yaw is controlled by intentionally unbalancing CW vs CCW motor speeds
- Speeding up CW motors relative to CCW (or vice versa) creates a net torque that rotates the drone's heading



Propeller Arrangement on a Quadcopter

- Front-left and rear-right motors: spin in one direction (e.g., CCW)
- Front-right and rear-left motors: spin in the opposite direction (e.g., CW)
- This diagonal pairing pattern is standard across virtually all quadcopters



Choosing the Right Propeller

Racing Drone

- **Prop:** Small diameter
- **Motor:** High-KV
- **Purpose:** Agility

Camera Drone

- **Prop:** Large diameter
- **Motor:** Low-KV
- **Purpose:** Stable lift

Golden Rule

Always match propeller size/pitch to motor KV rating and frame size for safe, efficient operation.

Summary

Key Takeaways

- Propellers generate thrust by pushing air downward, producing an upward reaction force (Lift)
- Propeller notation (e.g., 10x4.5) specifies diameter and pitch in inches
- Multirotor drones use equal numbers of CW and CCW propellers to cancel out reaction torque
- Intentionally unbalancing CW/CCW motor speeds is how yaw rotation is achieved

Next Lecture

Next Lecture Preview

Lecture 14: Power System

- Li-Po battery construction
- Capacity and voltage ratings
- Charging safety and maintenance

Questions?

Power System (Li-Po Battery)

Drone Components and Architecture - Lecture 14

Milav Dabgar

GP Palanpur

July 22, 2026

Recap

Recap: Propellers and Thrust

- Propellers generate thrust by pushing air downward
- CW/CCW propeller balance cancels reaction torque

Agenda

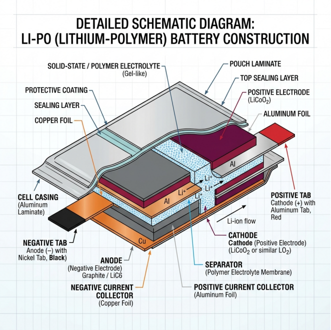
Today's Agenda: Power System

- Li-Po battery construction
- Battery capacity and voltage rating
- Battery charging and safety

Li-Po Battery Fundamentals

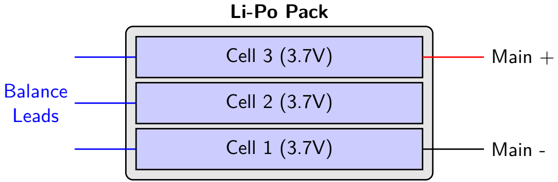
Why Li-Po Batteries?

- Li-Po = Lithium Polymer battery
- High energy density: stores a lot of energy relative to its weight
- Can deliver high discharge currents needed for motors
- Standard power source for the vast majority of drones



Li-Po Battery Construction

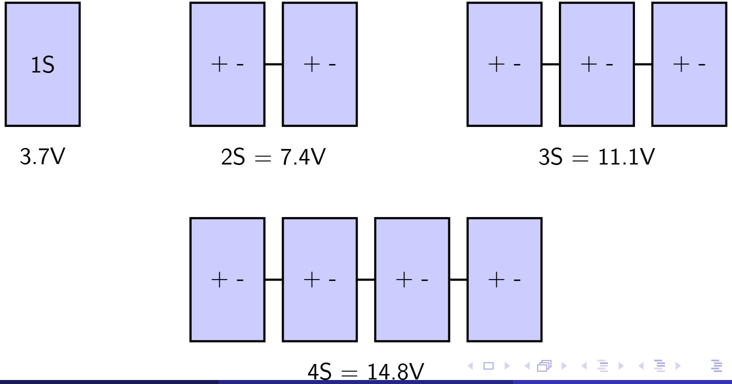
- Made of individual cells, each with a nominal voltage of about 3.7V
- Cells are packaged together and connected in series and/or parallel
- Each cell is a thin, flexible pouch containing lithium polymer electrolyte (hence 'polymer')
- A protection circuit/balance connector is usually included



Battery Specifications & Ratings

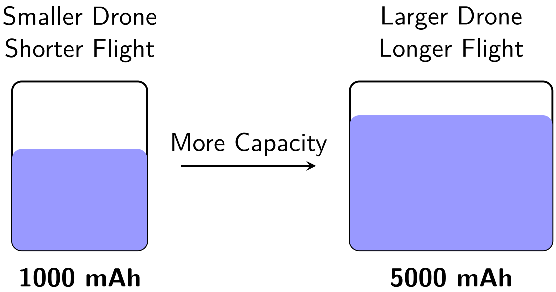
Battery Voltage Rating: S Rating

- 'S' indicates the number of cells connected in Series
- 1S = 3.7V, 2S = 7.4V, 3S = 11.1V, 4S = 14.8V, and so on
- More cells in series = higher voltage = generally more power for larger motors
- Voltage rating must match what the ESC and motor are designed for



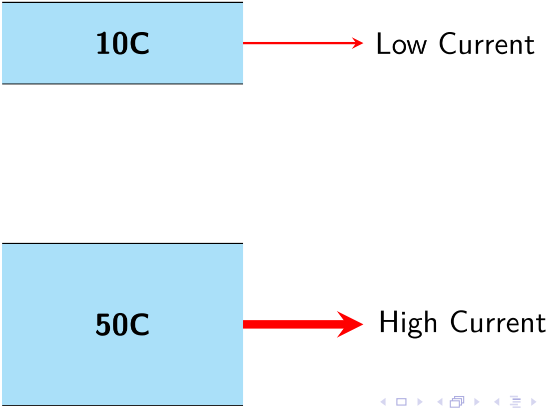
Battery Capacity Rating: mAh

- Capacity is measured in milliamp-hours (mAh)
- Indicates how much energy the battery can store/deliver over time
- Higher mAh = longer flight time, but also more weight
- Common drone battery capacities range from a few hundred to several thousand mAh

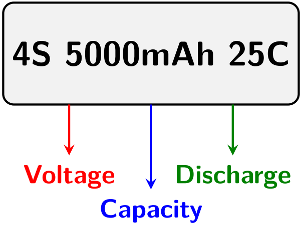


Battery Discharge Rating: C Rating

- C rating indicates the maximum safe discharge rate of the battery
- Higher C rating = battery can safely deliver higher current (needed for powerful motors)
- Exceeding the C rating can overheat or damage the battery



Battery Ratings: Putting It Together

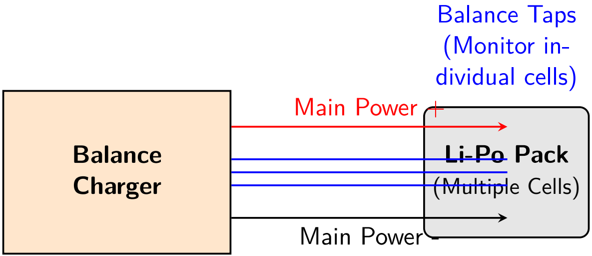


Specification	Meaning
4S	14.8V nominal voltage
5000mAh	Capacity (energy storage)
25C	Max safe discharge rate

Charging & Safety Guidelines

Battery Charging Safety: Balance Charging

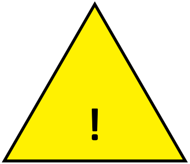
- Li-Po packs must be charged using a balance charger
- Balance charging ensures each individual cell in the pack reaches the same voltage
- Prevents individual cells from being overcharged or undercharged, which can damage the pack or create a safety hazard



Battery Charging Safety: General Precautions

- ✗ Never overcharge or over-discharge a Li-Po cell (stay within safe voltage range per cell)
- ✓ Charge in a fire-safe Li-Po charging bag or fireproof container
- ✗ Never charge unattended
- ✗ Avoid puncturing, crushing, or exposing batteries to extreme heat
- ✓ Store batteries at a safe ‘storage voltage’ if not used for extended periods

Consequences of Unsafe Battery Handling



- Overcharging or physical damage can cause a Li-Po cell to swell, catch fire, or explode ('thermal runaway')
- Deep over-discharge permanently damages cell capacity and lifespan
- Following manufacturer guidelines and safe practices greatly reduces these risks

Summary

Key Takeaways

Summary

- Li-Po batteries are built from cells (nominal 3.7V each) connected in series/parallel
- Voltage rating (S) and capacity (mAh) together with discharge rating (C) define battery performance
- Balance charging and safe handling practices are essential to prevent damage or hazards
- Battery choice must match the power/current demands of the motors and ESCs

Lecture 15: Payload Systems

Camera, gimbal, and additional sensors/components
Plus a recap of Unit 2

Questions?

Payload Systems

Unit 2: Drone Components and Architecture

Milav Dabgar

GP Palanpur

July 22, 2026

Recap

Recap: Power System

- Li-Po batteries: cells at 3.7V nominal, rated by S (voltage), mAh (capacity), C (discharge)
- Safe charging requires balance charging and fireproof handling

Key Concept: A stable power system is essential for carrying additional payload.

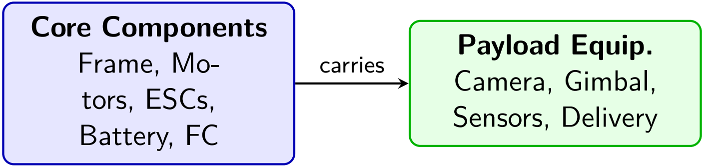
2.7 Payload Systems

Today's Agenda: Payload Systems

- Camera
- Gimbal
- Additional sensors/components
- Unit 2 recap

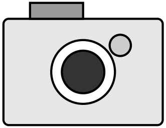
What is a Payload?

- Payload = any additional equipment a drone carries to perform its mission
- Distinct from the core flight components (frame, motor, ESC, battery, flight controller)
- Payload choice depends directly on the application (recall Lecture 8's application areas)



Payload: Camera

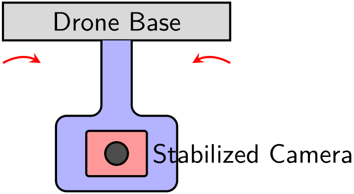
- Most common drone payload, used for photography, videography, inspection, and mapping
- Ranges from basic fixed cameras to high-resolution, zoom-capable professional cameras
- Some cameras include thermal or infrared imaging for specialized applications



Drone Camera

Payload: Gimbal - Purpose

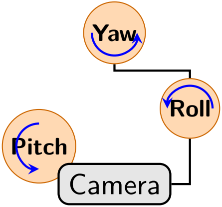
- A gimbal is a mechanical mount that stabilizes the camera (or other payload) during flight
- Counteracts drone vibration, tilting, and sudden movements
- Keeps captured images/video smooth and level regardless of drone motion



Vibration isolated

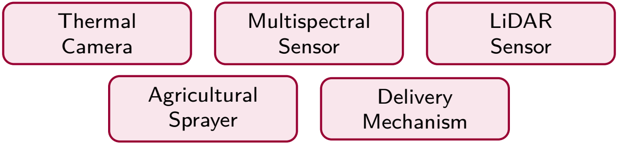
Payload: Gimbal - How It Works

- Uses small motors to counter-rotate the camera mount opposite to drone movement
- Typically available in 2-axis (pitch and roll) or 3-axis (pitch, roll, and yaw) configurations
- 3-axis gimbals provide the smoothest, most professional-quality stabilization



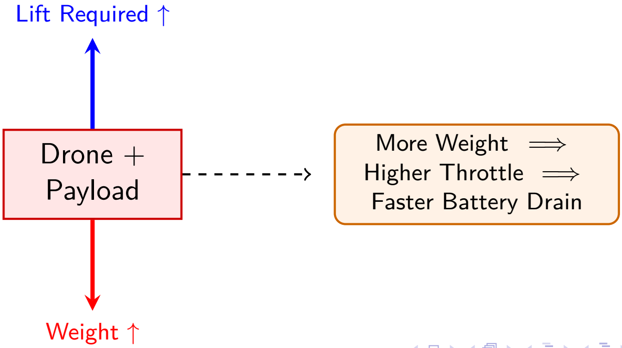
Payload: Additional Sensors and Components

- Thermal cameras: detect heat signatures, useful for search and rescue, inspection
- Multispectral sensors: used in precision agriculture for crop health analysis
- LiDAR sensors: generate precise 3D terrain/structure data, useful for mapping
- Specialized equipment: sprayers, delivery mechanisms, speakers/lights



Payload Weight Considerations

- Every additional payload item adds weight, which increases the Gravity force
- Heavier payload requires more Lift, meaning higher throttle and more battery drain
- Payload capacity is a key design/selection factor - tied to frame, motor, battery



Example: Payload Configuration by Application

Application	Typical Payload
Aerial Photography	High-res camera + 3-axis gimbal
Precision Agriculture	Multispectral sensor + spray payload
Mapping/Surveying	LiDAR sensor or mapping-grade camera
Search and Rescue	Thermal camera + speaker/light

Payload Systems Summary

Camera
Primary imaging payload

Gimbal
Stabilizes camera against motion

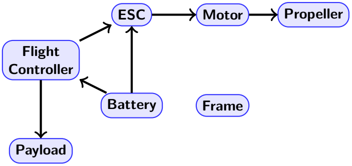
Sensors
Thermal, LiDAR, multispectral

Payload determines the drone's capability to perform specific applications!

Unit 2 Summary

Unit 2 Recap: The Big Picture

- 2.1 Basic architecture
- 2.2 Frame & structure
- 2.3 BLDC motors
- 2.4 ESCs
- 2.5 Propellers & thrust
- 2.6 Power system
- 2.7 Payload systems

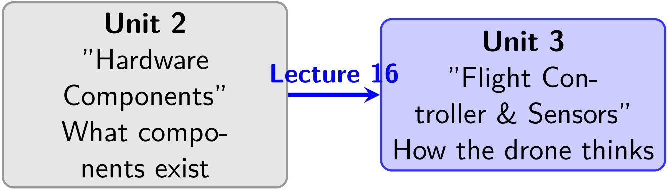


Unit 2 Key Concepts Consolidated

- A drone's architecture connects frame, motor, ESC, propeller, battery, flight controller, and payload
- Motor + ESC + propeller together generate and control thrust (recall Lectures 11-13)
- The Li-Po battery powers the entire system, with careful attention to ratings and safety
- Payload (camera, gimbal, sensors) is what enables the drone to perform its specific mission

Next Lecture

Next Lecture Preview: Unit 3 Begins



Questions?

Lecture 3.1: Flight Controller Concept

Unit 3: Flight Controller and Sensors

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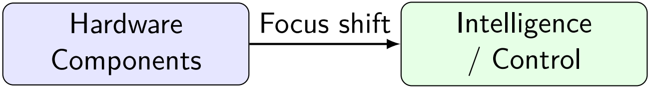
July 22, 2026

Introduction

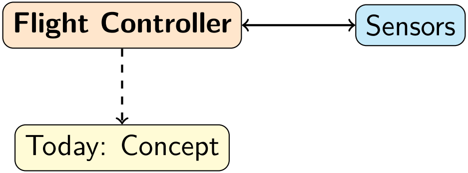
Recap: Unit 2 Summary

- Unit 2 covered drone architecture: frame, motors, ESC, propellers, battery, and payload
- We now move from components to the intelligence that controls them



Unit 3 Overview & Today's Agenda

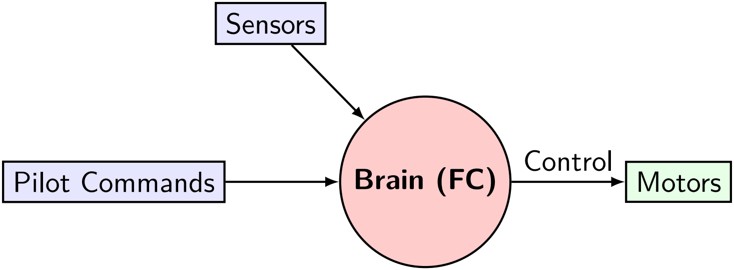
- Unit 3: Flight Controller and Sensors (6 lectures)
- Today: Flight Controller Concept
- Definition, block diagram, inputs, outputs, and examples of flight controllers



3.1 Flight Controller Concept

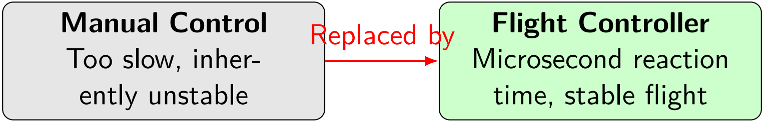
Flight Controller: The 'Brain' of the Drone

- The flight controller (FC) is the central computer that manages every aspect of drone flight
- Continuously processes pilot commands and sensor data
- Calculates precisely what each motor must do, many times per second
- Without the FC, a multirotor drone cannot fly in a stable, controlled manner



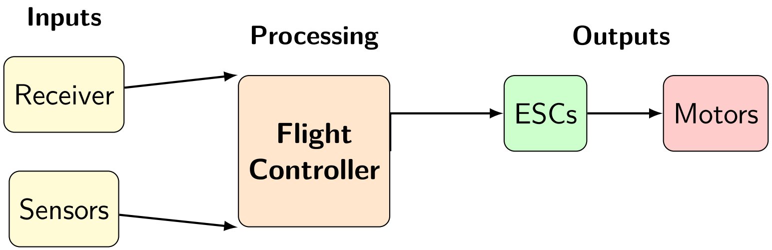
Why Multirotors Need a Flight Controller

- Unlike a helicopter with mechanical rotor tilt, a multirotor is stabilized purely through differential motor speeds
- Requires extremely fast, continuous calculations to stay balanced
- Human reaction time is far too slow to manually balance a multirotor - the FC does this automatically



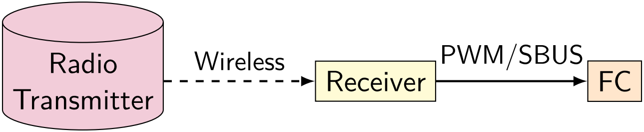
Block Diagram of Drone Control System

- Inputs: Receiver (pilot commands) + Sensors (orientation/position data)
- Processing: Flight Controller (runs control algorithms)
- Outputs: Signals to ESCs, which drive the motors
- This mirrors and expands on the architecture block diagram from Lecture 9



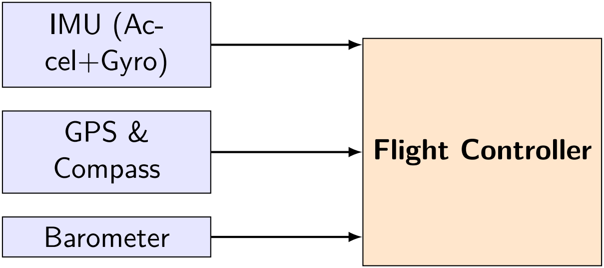
Inputs to the FC: Receiver Signals

- The receiver (recall Lecture 9's architecture) passes the pilot's control commands to the FC
- Includes throttle, pitch, roll, yaw commands (recall Lecture 5 terminology)
- Also includes switch positions for flight modes and auxiliary functions



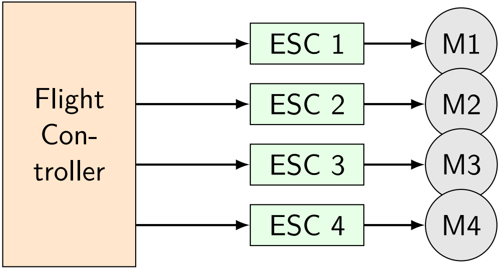
Inputs to the FC: Sensor Data

- Onboard sensors continuously feed real-time data to the FC
- Includes orientation, rotation rate, altitude, and position data
- This sensor data will be studied in detail in Lectures 18-20 (accelerometer, gyroscope, magnetometer, barometer, GPS, IMU)



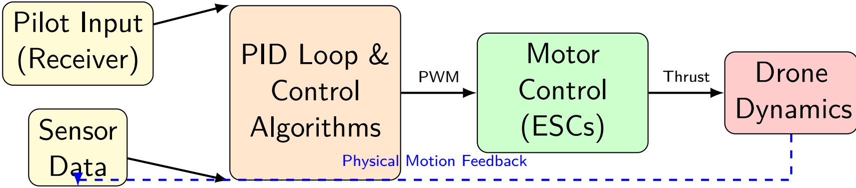
Outputs from the Flight Controller

- The FC processes all inputs and computes the required speed for each motor
- Sends individual speed command signals to each ESC (recall Lecture 12)
- ESCs then drive their respective motors to achieve the commanded flight behavior



Complete Input-Process-Output Flow

- Input: Receiver signals + Sensor data
- Process: Flight controller runs control algorithms (detailed in Lecture 21)
- Output: Individual speed commands to each ESC → motors → propellers → flight motion



Examples/Types of Flight Controllers

- **ArduPilot**: open-source flight control software used across many drone types
- **PX4**: another popular open-source autopilot platform
- **Betaflight**: popular for racing/freestyle drones, prioritizing responsiveness
- **Pixhawk**: a widely used flight controller hardware board running open-source firmware
- **Proprietary systems**: e.g., DJI's own flight controllers used in their consumer products

Open-Source vs Proprietary Flight Controllers

Open-Source (ArduPilot, PX4, Betaflight)	**Proprietary (e.g., DJI)**
Customizable	Closed system
Community-supported	Optimized by manufacturer
Used in hobby/DIY/research drones	Common in commercial consumer products
High flexibility, requires tuning	Easy to use, plug-and-play

Summary

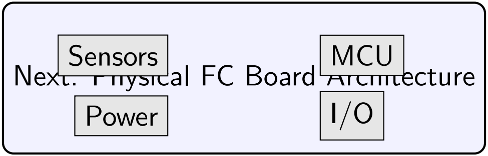
Key Takeaways

Summary

- The flight controller is the 'brain of the drone', processing inputs and generating motor commands
- Inputs: receiver signals (pilot commands) and sensor data (orientation, position)
- Outputs: individual speed signals to each ESC, which drive the motors
- Common flight controller platforms include ArduPilot, PX4, Betaflight, and Pixhawk hardware

Next Lecture Preview

- **Lecture 17: Working of Flight Controller Boards**
- Microcontroller, sensor interface, power supply, and output pins in more detail



Questions?

Working of Flight Controller Boards

Unit 3: Flight Controller and Sensors

Milav Dabgar

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July 22, 2026

Recap

Recap: Flight Controller Concept

- FC = brain of the drone; inputs = receiver + sensors; outputs = ESC commands
- Examples: ArduPilot, PX4, Betaflight, Pixhawk

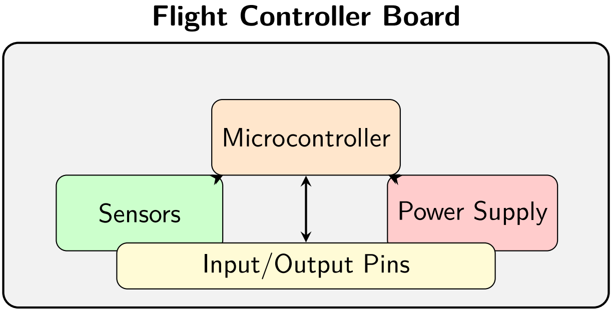
3.2 Working of flight controller boards

Today's Agenda: Working of FC Boards

- Microcontroller (basic role)
- Sensor interface (I2C/SPI basic idea)
- Power supply section
- Output pins for ESC

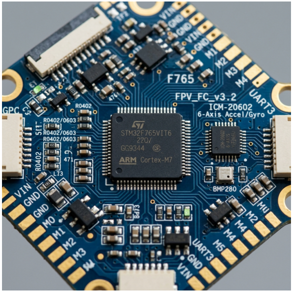
Anatomy of a Flight Controller Board

- A physical FC board integrates: a microcontroller, sensor chips, a power supply section, and various input/output pins
- All of these are mounted on a single small circuit board
- Today we look at each of these four sections individually



Microcontroller: Basic Role

- The microcontroller is the small onboard computer chip that runs the flight controller's firmware/software
- Executes the control algorithms (introduced conceptually in Lecture 16) many times per second
- Reads sensor data, processes it, and generates the output commands to the ESCs
- Note: this course covers only the basic role, not detailed internal architecture

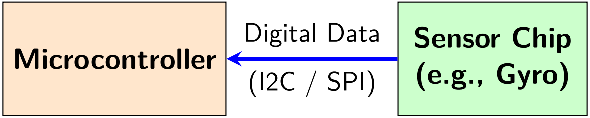


Microcontroller: Why It Matters

- Speed of the microcontroller determines how quickly the FC can react to disturbances
- Faster processing enables smoother, more precise stabilization
- Common flight controller platforms (ArduPilot, PX4, Betaflight from Lecture 16) all run on such microcontrollers

Sensor Interface: The Basic Idea

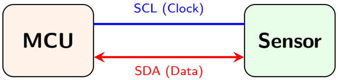
- Sensors (accelerometer, gyroscope, etc. - covered in Lecture 18-20) must communicate their data to the microcontroller
- This communication happens over a digital interface/protocol
- Two common interface types: I2C and SPI (basic idea only, not deep protocol detail)



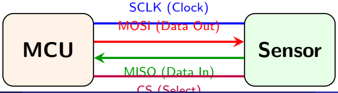
I2C and SPI: Basic Concept

- **I2C (Inter-Integrated Circuit):** a simple 2-wire digital communication protocol, commonly used for lower-speed sensors
- **SPI (Serial Peripheral Interface):** a faster digital communication protocol, often used for sensors needing quicker data updates
- Both allow the microcontroller to read numeric sensor values (e.g., acceleration, rotation rate) digitally

I2C (2-Wire)

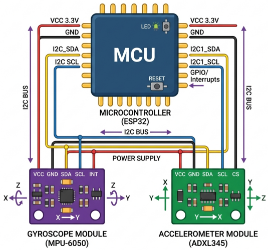


SPI (4-Wire)



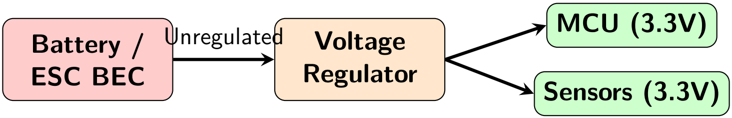
Sensor Interface: Why It Matters

- Reliable sensor communication is essential for accurate flight control
- Interface speed affects how quickly sensor updates reach the microcontroller
- This sensor data feeding is the same 'sensor data' input described in Lecture 16's block diagram



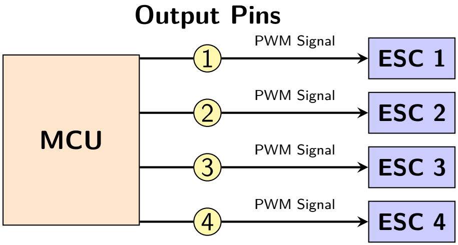
Power Supply Section

- The FC board needs stable, regulated power to operate reliably
- Power typically arrives from the ESC's BEC (recall Lecture 12) or a dedicated regulator
- Voltage regulators convert the main battery voltage down to levels the microcontroller and sensors need (e.g., 5V, 3.3V)
- Unstable power can cause sensor errors or FC malfunctions - a safety-critical section



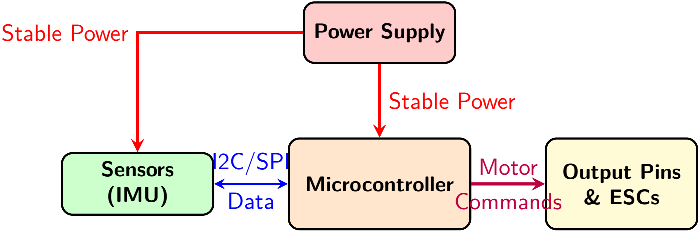
Output Pins for ESC

- The FC board has a set of output pins, typically one per motor/ESC
- Each pin sends the individual speed command signal to its corresponding ESC (recall Lecture 12)
- Number of output pins generally matches the number of motors (e.g., 4 for a quadcopter)



Putting the Board Together

- Power supply section powers the microcontroller and sensors
- Sensors communicate data to the microcontroller via I2C/SPI
- Microcontroller processes data and computes motor commands
- Output pins send these commands to the ESCs



Summary

Key Takeaways

- The microcontroller runs the FC's firmware, executing control algorithms at high speed
- Sensors communicate with the microcontroller via digital interfaces like I2C or SPI
- The power supply section regulates battery power into stable voltages for the board
- Output pins send individual speed commands to each ESC, matching the number of motors

Next Lecture Preview

Lecture 18: Types of Sensors - Part A

Accelerometer, Gyroscope, and Magnetometer

Questions?

Types of Sensors - Part A

Accelerometer, Gyroscope, Magnetometer

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July 22, 2026

Recap & Agenda

Recap: Working of FC Boards

- Microcontroller runs FC firmware; sensors connect via I2C/SPI
- Power supply regulates voltage; output pins send commands to ESCs

Today's Agenda: Sensors - Part A

- Accelerometer
- Gyroscope
- Magnetometer
- Note: Barometer and GPS are covered in the next lecture

Introduction

Why Drones Need Multiple Sensors

Comprehensive Data

A drone needs to know its orientation, rotation, heading, altitude, and position to fly safely

- No single sensor can measure all of these - each sensor specializes in a specific type of measurement
- The flight controller (Lectures 16-17) combines data from all sensors for complete situational awareness

Accelerometer

Accelerometer: Definition

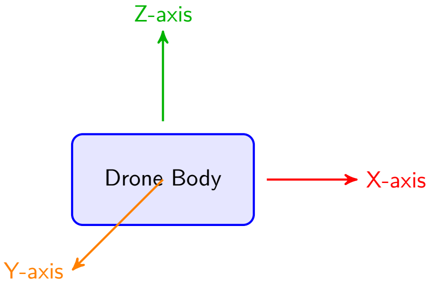
Accelerometer

An accelerometer measures linear acceleration - the rate of change of velocity

- Measures acceleration along three perpendicular axes: X, Y, and Z
- Can detect both dynamic acceleration (movement) and static acceleration (gravity)

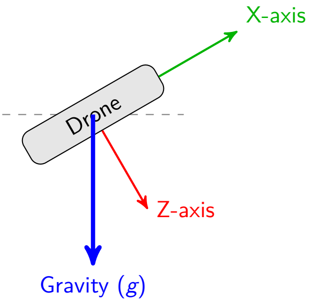
Accelerometer: 3-Axis Diagram

- **X-axis**: measures acceleration forward/backward
- **Y-axis**: measures acceleration left/right
- **Z-axis**: measures acceleration up/down
- Combined X/Y/Z readings reveal the drone's tilt relative to gravity



Accelerometer: Application in Drone

- Detects the drone's tilt angle by sensing the direction of gravity
- Helps the flight controller understand orientation changes (recall pitch/roll from Lecture 5)
- Contributes to stabilization by detecting sudden accelerations, such as impacts or aggressive maneuvers



Gyroscope

Gyroscope: Definition

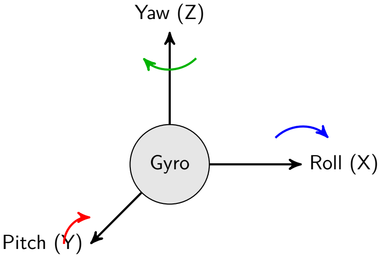
Gyroscope

A gyroscope measures angular velocity - the rate of rotation around an axis

- Unlike the accelerometer (linear motion), the gyroscope measures rotational motion
- Also measures along three axes, corresponding to rotation about each

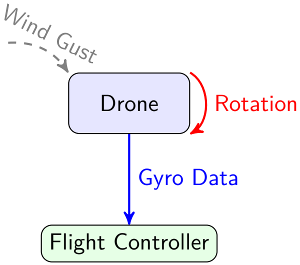
Gyroscope: Relation with Roll, Pitch, Yaw

- Gyroscope's three axes directly correspond to Roll, Pitch, and Yaw (recall Lecture 5 terminology)
- Measures HOW FAST the drone is rotating about each of these axes (rate, not angle)
- This rate data is essential for detecting and correcting unwanted rotation quickly



Gyroscope: Application in Drone

- Primary sensor used for detecting and correcting rapid rotational disturbances (e.g., wind gusts)
- Provides fast-response data critical for real-time stabilization
- Works together with the accelerometer for a complete picture of drone orientation



Accelerometer vs Gyroscope

Accelerometer	**Gyroscope**
Measures linear acceleration	Measures angular velocity
Senses gravity direction/tilt	Senses rotation rate about roll/pitch/yaw

Combined Power

Both are essential and complementary for orientation sensing.

Magnetometer

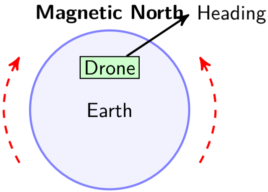
Magnetometer: Definition

Magnetometer

A magnetometer measures the strength and direction of a magnetic field

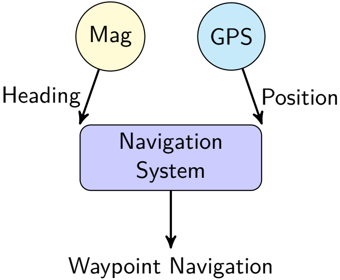
- Functions as a digital compass onboard the drone
- Distinct from accelerometer and gyroscope - it senses direction relative to Earth's magnetic field, not motion

- Senses the Earth's natural magnetic field, which points toward magnetic north
- By comparing the sensed field direction to known magnetic north, the drone can determine its heading
- Can be affected by nearby magnetic interference (e.g., motors, power lines), requiring careful calibration



Magnetometer: Application in Navigation

- Provides heading (compass direction) information to the flight controller
- Essential for yaw stability and accurate navigation, especially for autonomous flight
- Works alongside GPS (covered next lecture) to maintain accurate direction during waypoint navigation (Unit 4 preview)



Summary

Three Sensors Summary Table

Sensor	Measures	Key Application
Accelerometer	Linear acceleration (3-axis)	Tilt detection, stabilization
Gyroscope	Angular velocity (roll/pitch/yaw rate)	Fast rotational correction
Magnetometer	Magnetic field direction	Heading/compass, navigation

Key Takeaways

- Accelerometer measures linear acceleration on 3 axes, used to detect tilt via gravity
- Gyroscope measures angular velocity, directly corresponding to roll/pitch/yaw rotation rates
- Magnetometer measures magnetic field direction, acting as a compass for heading/navigation
- These three sensors provide complementary orientation and heading information to the flight controller

Next Lecture Preview

Lecture 19: Types of Sensors - Part B

- Barometer and GPS
- The Inertial Measurement Unit (IMU)

Questions?

Types of Sensors - Part B (Barometer, GPS) and IMU

Unit 3: Flight Controller and Sensors

Milav Dabgar

GP Palanpur

July 22, 2026

Recap & Agenda

Recap: Sensors Part A

- Accelerometer: linear acceleration, tilt detection
- Gyroscope: angular velocity, roll/pitch/yaw rate
- Magnetometer: magnetic heading for navigation

Today's Agenda

- Barometer
- GPS
- Inertial Measurement Unit (IMU)
- How all 5 sensors + IMU work together

Barometer

Barometer: Definition

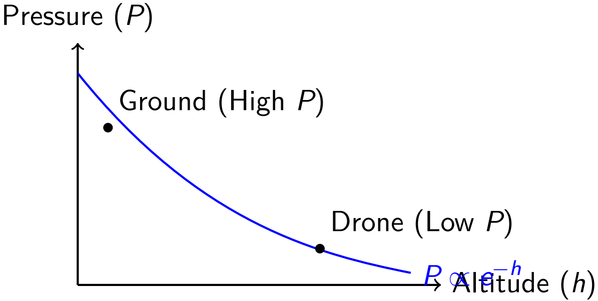
What is a Barometer?

A **barometer** measures atmospheric (air) pressure.

- One of the oldest and simplest sensor types used in aviation
- In drones, it is used specifically to estimate **altitude**, not direction or position

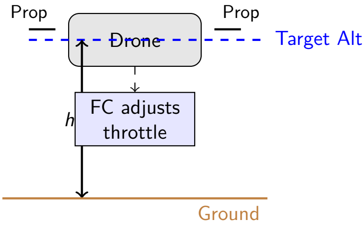
Barometer: Relation Between Pressure and Altitude

- Atmospheric pressure **decreases** predictably as altitude **increases**
- By measuring current pressure and comparing it to a reference (ground-level) pressure, the drone can estimate its height
- This relationship is well-established in atmospheric physics and used across aviation



Barometer: Application in Drone

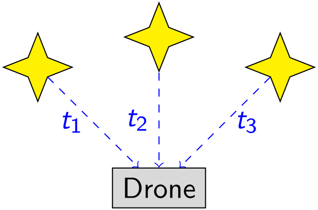
- Provides **altitude hold** capability – the drone can maintain a constant height automatically
- Complements GPS altitude data (GPS altitude is often less precise than barometric altitude)
- Essential for stable hovering and consistent flight height during a mission



Global Positioning System (GPS)

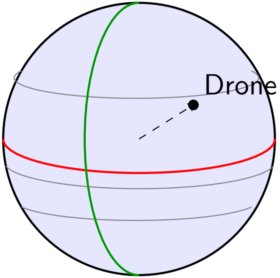
GPS: Working Concept

- **GPS** = Global Positioning System, a satellite-based positioning technology
- The drone's GPS receiver picks up signals from multiple satellites orbiting Earth
- By comparing signal timing from several satellites, the receiver calculates its precise location (basic trilateration idea)
- Requires a clear view of the sky and a minimum number of visible satellites for an accurate 'GPS lock'



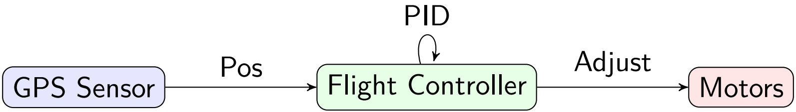
GPS: Key Parameters

- **Latitude**: north-south position on Earth
- **Longitude**: east-west position on Earth
- **Altitude**: height, though barometric altitude (previous slide) is often more precise for short-term flight control



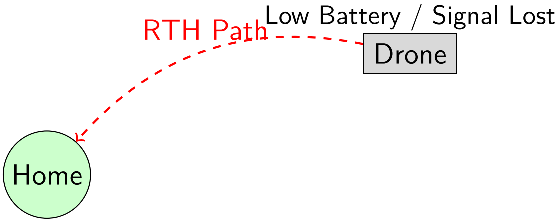
GPS Application: Position Holding

- GPS allows a drone to maintain a fixed horizontal position automatically, even in light wind
- Flight controller continuously compares current GPS position to the desired hold position and makes corrections



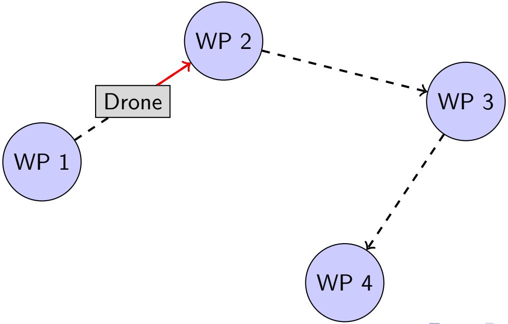
GPS Application: Return to Home (RTH)

- The drone records its GPS takeoff location as the 'home point'
- If signal is lost, battery runs critically low, or the pilot triggers RTH manually, the drone autonomously navigates back to the home point
- A major safety feature enabled directly by GPS positioning



GPS Application: Navigation

- Enables the drone to follow a planned route or fly to specific coordinates
- Forms the technical foundation for waypoint navigation, covered in detail in Unit 4
- Combined with the magnetometer's heading data for accurate directional flight



Barometer vs GPS: Altitude Measurement

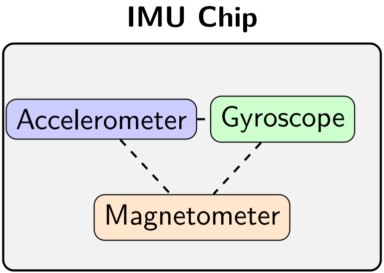
Feature	Barometer	GPS
Measurement Type	Relative altitude via air pressure	Absolute altitude via satellites
Responsiveness	Very responsive, short-term accurate	Less precise short-term
Use Case	Altitude hold, hovering	Global positioning, navigation

Flight controllers often combine both for the most reliable altitude and position estimate.

Inertial Measurement Unit (IMU)

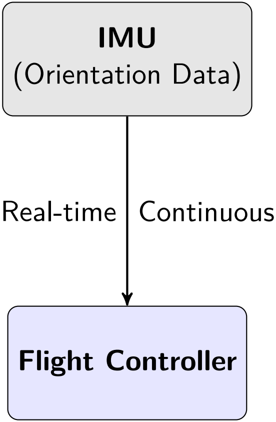
Introducing the IMU

- **IMU** = Inertial Measurement Unit
- A single integrated module that combines the accelerometer and gyroscope (and often the magnetometer) into one package
- Provides comprehensive motion and orientation data from a single sensor unit



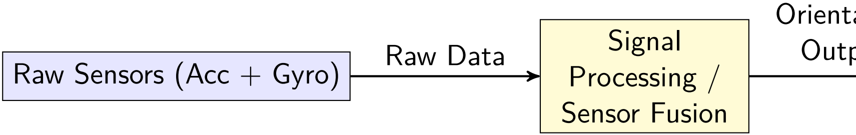
IMU: Function

- Provides real-time orientation data (tilt, rotation rate) to the flight controller
- Central to enabling stabilization and controlled flight, as introduced across this unit
- Nearly every modern flight controller board includes an IMU as a core component



IMU: Working Principle with Block Diagram

- Accelerometer + Gyroscope (+ Magnetometer) sensors → raw sensor data
- Signal conditioning/processing combines and filters the raw data ('sensor fusion')
- Processed orientation data is output continuously to the flight controller



Summary & Next Steps

Key Takeaways

- **Barometer** measures air pressure to estimate altitude, since pressure decreases predictably with height
- **GPS** provides Latitude, Longitude, and Altitude via satellite signals, enabling position holding, return-to-home, and navigation
- **The IMU** combines accelerometer and gyroscope (often with magnetometer) into a single unit providing orientation data
- All 5 sensor types together give the flight controller a complete picture of the drone's state

Next Lecture Preview

20

Lecture 20: Inertial Measurement Unit (IMU) - Deep Dive

A closer look at IMU function and working principle

Questions?

Inertial Measurement Unit (IMU) - Deep Dive

Unit 3: Flight Controller and Sensors

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GP Palanpur

July 22, 2026

Recap

Recap: Barometer, GPS, and IMU Introduction

- Barometer: pressure-based altitude; GPS: Latitude/Longitude/Altitude via satellites
- IMU introduced as a combined accelerometer + gyroscope unit

Agenda

Today's Agenda: IMU Deep Dive

- Recap of what an IMU is
- IMU function in detail
- IMU working principle and block diagram
- Sensor fusion concept

3.4 Inertial Measurement Unit (IMU)

What is an IMU? (Recap)

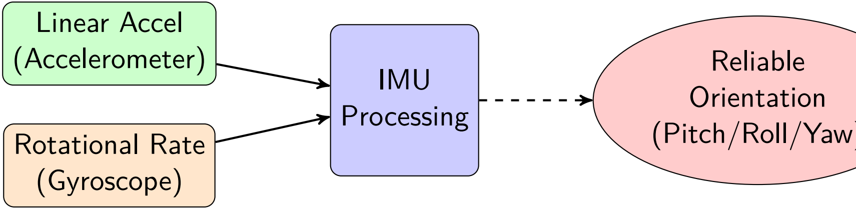
- **IMU** = Inertial Measurement Unit
- Combines **accelerometer** and **gyroscope** (often magnetometer too) into a single integrated module
- Found on virtually every modern flight controller board (recall Lecture 17's board anatomy)

IMU Chip

Accel
+
Gyro
+
Mag

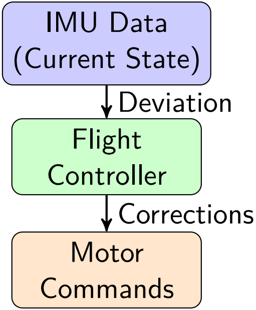
IMU Function: Orientation Sensing

- Provides continuous, real-time data on the drone's orientation: tilt (pitch/roll) and rotation rate (yaw)
- Combines linear acceleration data (from the accelerometer) with rotational rate data (from the gyroscope)
- This combined data is far more reliable than either sensor alone



IMU Function: Enabling Stabilization

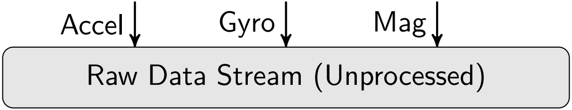
- The flight controller relies on IMU data to detect any deviation from the desired orientation
- Without accurate, fast IMU data, a multirotor cannot maintain stable flight
- This function is the direct foundation for the stabilization concepts covered in Lecture 21



IMU Working Principle: Step 1 - Raw Sensor Data

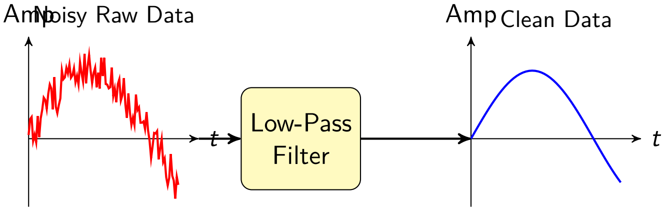
Each sensor outputs raw, individual readings at this stage:

Sensor	Measures	Axes	Output Uni
Accelerometer	Raw linear acceleration	x, y, z	g or m/s^2
Gyroscope	Raw angular velocity	p, q, r	deg/s or rad/
Magnetometer	Magnetic field direction	Hx, Hy, Hz	Gauss or μT



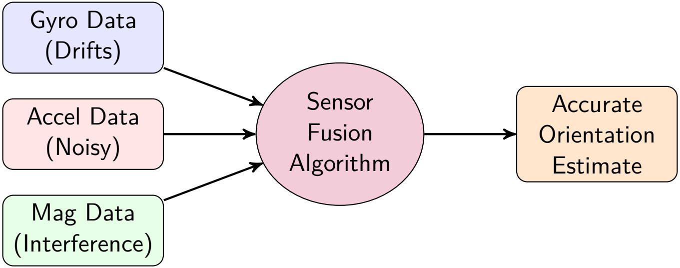
IMU Working Principle: Step 2 - Signal Conditioning

- Raw sensor data often contains noise and small errors
- Signal conditioning filters and cleans this raw data before further processing
- Ensures the data used for flight control is accurate and stable



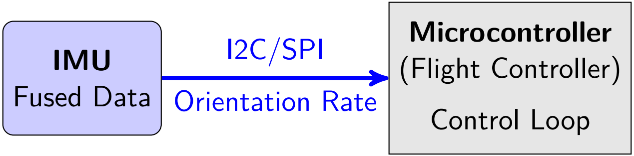
IMU Working Principle: Step 3 - Sensor Fusion

- **Sensor fusion** combines data from multiple sensors into a single, more accurate orientation estimate
- Each sensor has weaknesses (e.g., accelerometer is noisy, gyroscope drifts)
- Fusion algorithms combine strengths while minimizing individual weaknesses

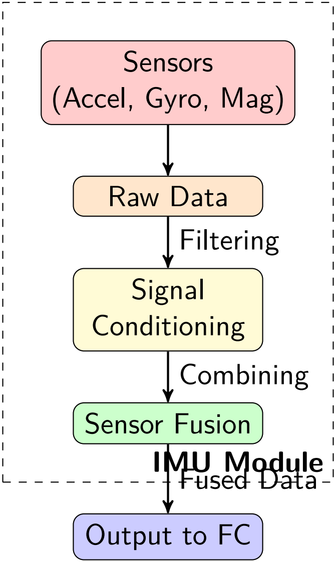


IMU Working Principle: Step 4 - Output to FC

- The final fused orientation data is output continuously to the flight controller's microcontroller
- This is the same 'sensor data' input described in Lecture 16 and 17
- Flight controller uses this data as the basis for all stabilization and control calculations

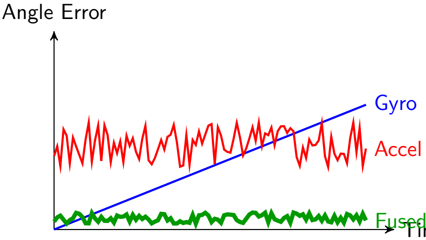


IMU Block Diagram: Complete View



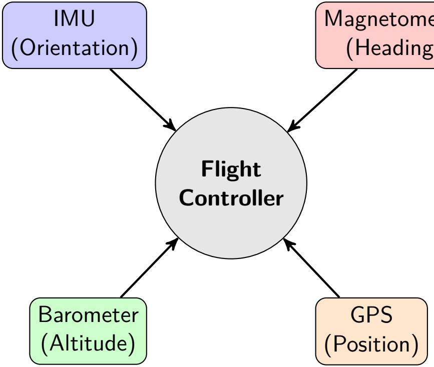
Why Sensor Fusion Matters: An Example

Condition	Characteristic
Accel Only	Accurate for slow tilt, noisy during fast movement
Gyro Only	Very responsive, but drifts over time
Fused IMU	Combines fast response with long-term accuracy



IMU's Place in the Overall Sensor System

- **IMU** (accel + gyro): fast, high-frequency orientation data
- **Magnetometer**: heading/compass reference
- **Barometer**: altitude reference
- **GPS**: absolute position reference
- Flight controller combines all of these for complete flight awareness



Summary

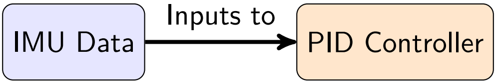
Key Takeaways

- The IMU combines accelerometer and gyroscope (often magnetometer) data into one integrated orientation-sensing unit
- Working principle: raw sensor data $\rightarrow$ signal conditioning $\rightarrow$ sensor fusion $\rightarrow$ output to flight controller
- Sensor fusion combines each sensor's strengths while minimizing individual weaknesses
- IMU output is essential input for the flight controller's stabilization calculations

Next Lecture Preview

Coming Up: Lecture 21

- Stabilization and Basic Flight Control Concepts
- Feedback control and PID control for velocity hold - and a recap of Unit 3



Questions?

Stabilization and Basic Flight Control Concepts

Unit 3: Flight Controller and Sensors

Milav Dabgar

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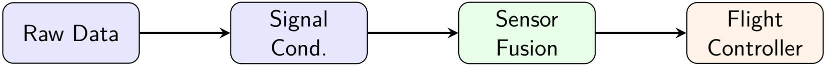
July 22, 2026

Recap & Agenda

Recap: IMU Working Principle

- IMU: raw sensor data $\rightarrow$ signal conditioning $\rightarrow$ sensor fusion $\rightarrow$ output to FC
- Sensor fusion combines strengths of accelerometer and gyroscope



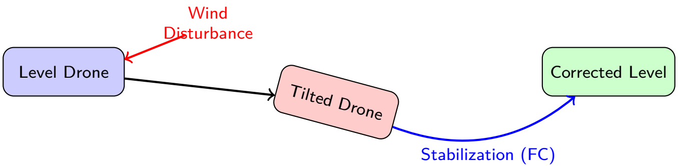
Today's Agenda: Stabilization and Flight Control

- Basic concept of drone stabilization
- Feedback control system diagram
- Example: drone maintaining level position
- PID control concept for velocity hold
- Unit 3 recap

3.5 Stabilization and basic flight control concepts

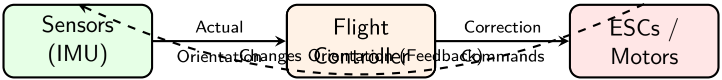
What is Stabilization?

- **Stabilization** = the process of keeping a drone in a desired orientation or position despite disturbances.
- Disturbances include wind gusts, uneven weight distribution, or pilot input changes.
- Without stabilization, a multirotor would be nearly impossible to fly manually.

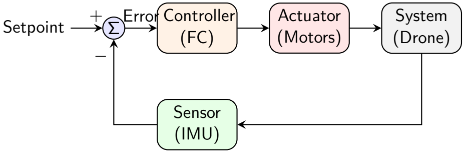


Role of Sensors and Controller

- **Sensors (IMU)** continuously measure the drone's actual orientation.
- **Flight controller** compares actual orientation to desired orientation.
- Any difference triggers a **correction**, sent as adjusted commands to ESCs/motors.



- **Setpoint** is compared with Actual state.
- Difference is **Error**.
- **Controller** computes correction.
- **Actuator** applies correction.
- Loop repeats continuously.

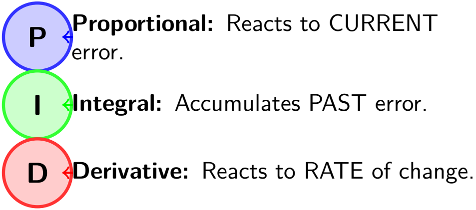


Example: Drone Maintaining Level Position

1. **Setpoint:** Drone should remain perfectly level (0° tilt).
2. **Disturbance:** A wind gust tilts the drone slightly.
3. **Sensor:** IMU detects this tilt as an error.
4. **Controller:** FC calculates correction to level the drone.
5. **Actuator:** FC commands increased speed on motors on lower side.
6. **Continuous Loop:** This entire correction happens continuously.

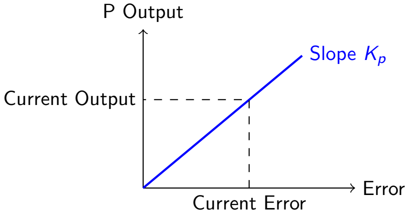
Introducing PID Control

- **PID** = Proportional, Integral, Derivative - widely used algorithm.
- Used by FC to calculate exact correction to apply based on error.
- Each term (P, I, D) contributes differently.



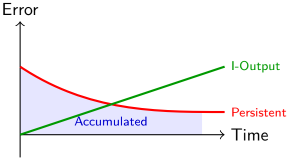
PID: The Proportional (P) Term

- P term produces a correction proportional to CURRENT error.
- Larger error → larger immediate correction.
- Provides primary, immediate response.
- Acting alone, can leave a steady-state error.



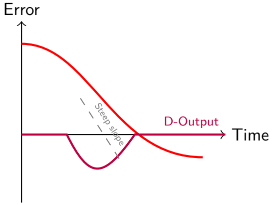
PID: The Integral (I) Term

- I term accumulates error over time.
- Corrects small, persistent error (steady-state).
- Helps system reach exact setpoint over time.



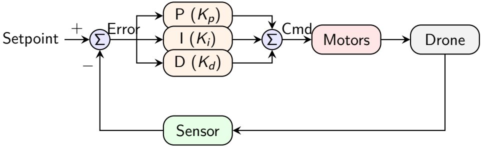
PID: The Derivative (D) Term

- D term reacts to RATE OF CHANGE.
- Predicts and dampens overshoot.
- Improves stability by smoothing out response.



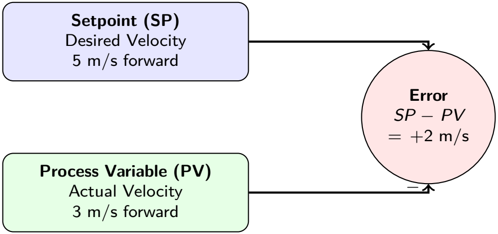
PID Block Diagram for Velocity Hold Control

- Error passed through P, I, D in parallel.
- P + I + D summed for final command.
- Sent to motors.
- Measured again (feedback).



Velocity Hold Example: Setpoint and Process Variable

- **Setpoint:** desired constant velocity pilot requested.
- **Process Variable (PV):** drone's actual current velocity.
- **Error** = Setpoint minus Process Variable



Velocity Hold Example: Role of P, I, D

P (Proportional): Drone is at 3 m/s, target 5 m/s. Error +2 m/s. P instantly increases motor power proportional to gap.

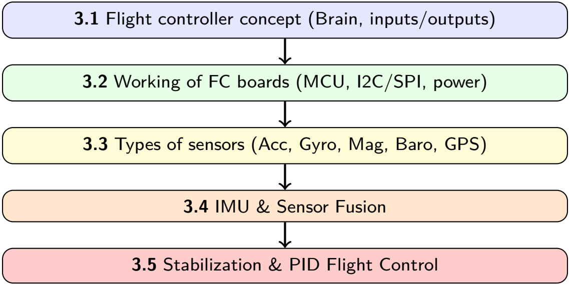
I (Integral): Suppose headwind keeps drone at 4.5 m/s. Error remains +0.5 m/s. I accumulates this, gradually increasing power until 5 m/s is reached.

D (Derivative): As drone accelerates from 3 to 5 m/s, error decreases quickly. D senses fast rate of change and reduces power to prevent overshoot.

Final Command = P + I + D: Continuously adjusts motors to smoothly reach and perfectly hold 5 m/s.

Unit 3 Summary

Unit 3 Recap: The Big Picture



Unit 3 Key Concepts Consolidated

Sensors & IMU

- 5 types provide unique data.
- IMU fuses several into one reliable output.

Flight Controller

- The "Brain" combining inputs.
- Commands motors via ESCs.

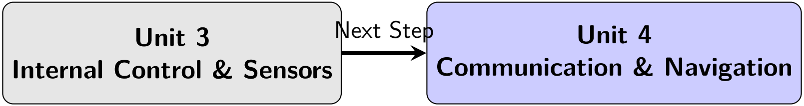
Stabilization & PID

- **Loop:** Setpoint vs Measured $\rightarrow$ Error $\rightarrow$ Correction.
- **PID:** Proportional, Integral, Derivative.
- Standard method for precise corrections.

Next Lecture

Next Lecture Preview: Unit 4 Begins

- **Lecture 22:** Basics of Drone Communication.
- Moving from "how the drone controls itself" (Unit 3) to "how the drone communicates" (Unit 4).



Questions?

Lecture 4.1: Basics of Drone Communication

Unit 4: Communication and Navigation Systems

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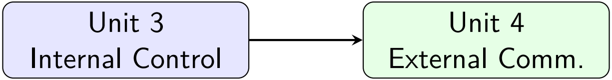
July 22, 2026

Recap

Recap: Unit 3 Summary

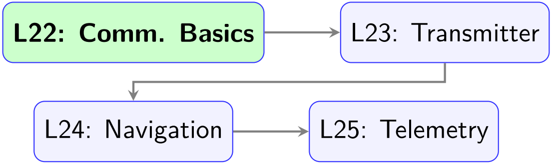
- Unit 3 covered flight controllers, sensors, IMU, and PID-based stabilization
- We now move from internal control to external communication with the drone



Agenda

Unit 4 Overview & Today's Agenda

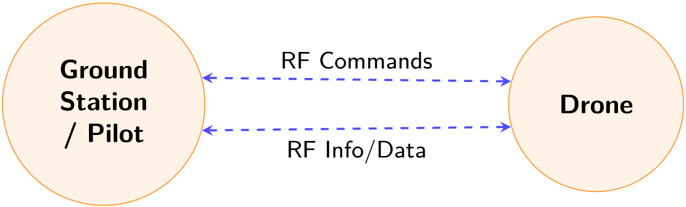
- Unit 4: Communication and Navigation Systems (5 lectures)
- Today: Basics of Drone Communication
- Definition, need, and types of communication (control vs data)



4.1 Basics of Drone Communication

Definition of Communication in Drones

- Communication in drones refers to the exchange of signals between the pilot/ground station and the drone
- Includes both sending commands to the drone and receiving information back from it
- Relies on radio frequency (RF) wireless links, since there is no physical connection to the drone in flight



Need of Communication System

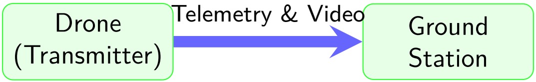
- Without communication, the pilot cannot send control commands (throttle, pitch, roll, yaw - recall Lecture 5)
- Without communication, the ground station cannot receive telemetry, video, or sensor data from the drone
- Communication ensures safety - loss of link must trigger failsafe behaviors (e.g., return-to-home, recall Lecture 19)
- Essential for real-time monitoring and mission execution

Types of Communication: Control Communication

- Control communication: signals sent FROM the pilot/transmitter TO the drone
- Carries commands such as throttle, pitch, roll, yaw, and flight mode switches
- Must be fast and reliable, since delays directly affect flight responsiveness and safety

Types of Communication: Data Communication

- Data communication: signals sent FROM the drone TO the ground station
- Carries telemetry data (battery status, GPS position, altitude - preview of Lecture 25), video/camera feed, and sensor readings
- Enables the pilot/operator to monitor the drone's status and mission progress in real time



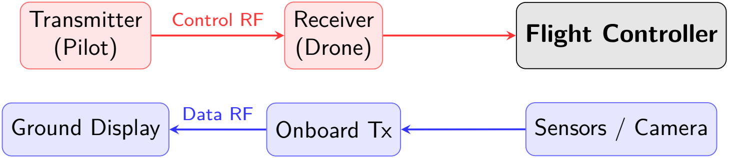
Control vs Data Communication: Side by Side

- Most drones operate both types of communication simultaneously

Control Communication	**Data Communication**
Pilot → Drone	Drone → Ground Station
Carries flight commands (pitch, roll, throttle, yaw)	Carries telemetry, video, and sensor data
Must be extremely low-latency	Enables real-time monitoring
Essential for drone maneuvering	Essential for awareness and missions

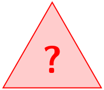
Two-Way Communication in a Drone System

- Control link: transmitter → receiver → flight controller (recall Lecture 9's architecture)
- Data link: sensors/camera → onboard transmitter → ground station display
- Together these form a complete two-way communication system



Why Reliable Communication Matters

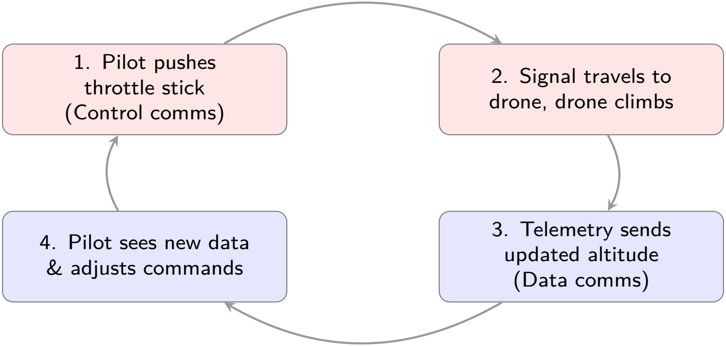
- Loss of control link can cause loss of drone control - a serious safety risk
- Loss of data link means the pilot loses situational awareness of the drone's status
- Failsafe features (recall GPS return-to-home from Lecture 19) depend on reliable, monitored communication



Broken Link Risk:
No Commands + No Telemetry = Failsafe Activation

Example: A Complete Communication Cycle

- Communication forms a continuous feedback loop during flight



Summary

Key Takeaways

- Communication in drones is the exchange of wireless signals between the pilot/ground station and the drone
- It is essential for sending commands, receiving status data, and enabling safety failsafes
- Control communication flows from pilot to drone (commands); data communication flows from drone to ground (telemetry/video)
- Reliable two-way communication is fundamental to safe drone operation

Next Lecture Preview

Next Lecture Preview

- Lecture 23: Radio Transmitter and Receiver
- The physical hardware that implements control communication

Focus shifts to hardware:
Transmitter Sticks, Switches, and Receivers

Questions

Any Questions?

Thank You!

Any questions?

Radio Transmitter and Receiver

Unit 4: Communication and Navigation Systems

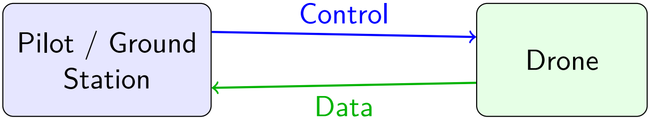
Milav Dabgar

GP Palanpur

July 22, 2026

Recap: Basics of Drone Communication

- **Control communication**: pilot → drone (commands)
- **Data communication**: drone → ground (telemetry/video)



Radio Transmitter and Receiver

Today's Agenda: Transmitter and Receiver

- Definition of transmitter
- Parts of the transmitter (control sticks, switches)
- Function of each control
- Definition and working of the receiver
- Connection with the flight controller

Definition of Transmitter

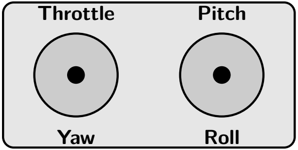
Transmitter

The handheld device the pilot uses to send control commands to the drone.

- Converts the pilot's physical stick/switch movements into radio frequency (RF) signals
- Implements the control communication described in Lecture 22

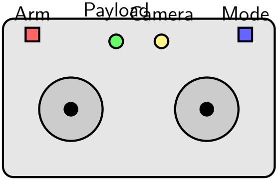
Basic Parts of the Transmitter: Control Sticks

- Transmitters have two main control sticks (gimbals)
- **Left stick** typically controls **throttle and yaw** (in the common 'Mode 2' convention)
- **Right stick** typically controls **pitch and roll**
- Each stick moves in two directions, giving four total control inputs



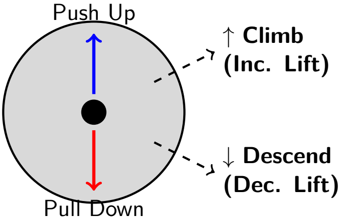
Basic Parts of the Transmitter: Switches

- Transmitters include multiple switches and dials in addition to the main sticks
- Used for flight mode selection, arming/disarming the drone, and other auxiliary functions
- Some switches control payload functions like camera trigger or gimbal tilt (recall Lecture 15's payload)

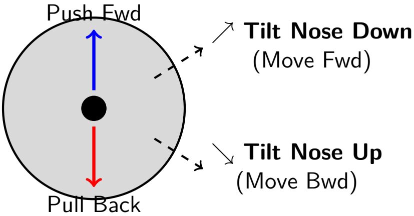


Function of Each Control: Throttle

- Throttle stick controls overall motor power (recall Lecture 5's terminology)
- **Pushing up** increases power/lift, causing the drone to **climb**
- **Pulling down** decreases power/lift, causing the drone to **descend**

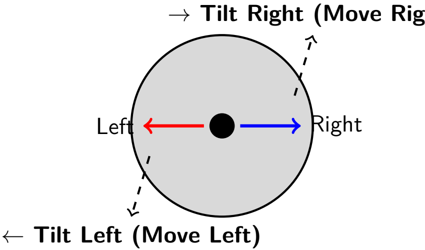


- Pitch stick controls the forward/backward tilt of the drone (recall Lecture 5)
- **Pushing forward** tilts the nose down, moving the drone **forward**
- **Pulling back** tilts the nose up, moving the drone **backward**

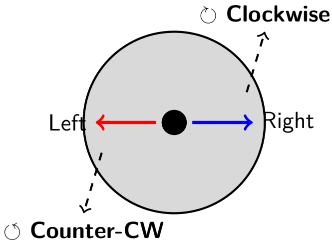


Function of Each Control: Roll

- Roll stick controls the left/right tilt of the drone (recall Lecture 5)
- **Moving right** tilts the drone right, moving it sideways to the **right**
- **Moving left** tilts the drone left, moving it sideways to the **left**



- Yaw stick controls the rotation of the drone about its vertical axis
- **Moving right** rotates the drone's heading **clockwise**
- **Moving left** rotates the drone's heading **counter-clockwise**
- Recall from Lecture 13 that yaw is achieved by unbalancing CW/CCW motor speeds

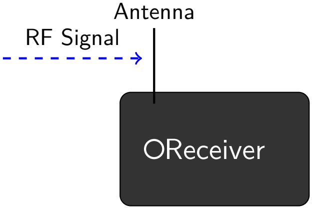


Definition of Receiver

Receiver

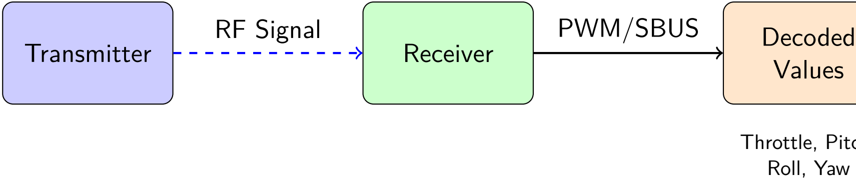
The small onboard device mounted on the drone that receives signals from the transmitter.

- Works as the counterpart to the transmitter, completing the control communication link
- Physically small and lightweight, mounted inside the drone frame



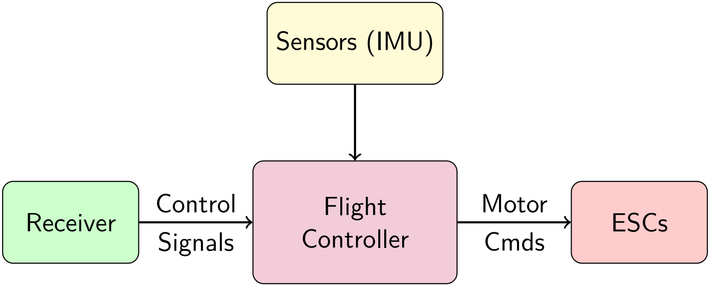
Working of the Receiver

- Receives the RF signal broadcast by the transmitter
- Decodes the signal back into individual control values (throttle, pitch, roll, yaw, switch states)
- Passes these decoded values on to the flight controller for processing



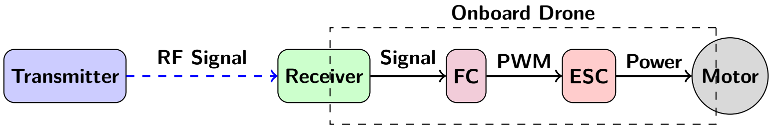
Connection with Flight Controller

- Receiver output is wired directly to the flight controller's input (recall Lecture 16's 'receiver signals' input)
- This is exactly the 'receiver signals' input shown in the block diagram from Lecture 16
- Flight controller combines this pilot input with sensor data to compute motor commands



Complete Control Signal Path

- Pilot moves sticks/switches on Transmitter
- Transmitter converts movement to RF signal, broadcasts wirelessly
- Receiver (onboard drone) picks up and decodes the signal
- Receiver sends decoded values to the Flight Controller
- Flight Controller processes and sends commands to ESCs → Motors



Summary & Next Lecture

Key Takeaways

- The transmitter is the handheld device sending pilot commands via control sticks and switches
- Throttle, Pitch, Roll, and Yaw each map to specific stick movements and specific flight behaviors
- The receiver is the onboard device that receives and decodes transmitter signals
- The receiver connects directly to the flight controller, delivering the pilot's commands as its input

Next Lecture Preview

- Lecture 24: Channels in Drone Communication and Frequency Bands
- How many channels are needed, and which radio frequencies are used

Next Time: Channels & Frequencies
2.4 GHz, 5.8 GHz, etc.

Questions?

Channels in Drone Communication and Frequency Bands

Unit 4: Communication and Navigation Systems

Milav Dabgar

GP Palanpur

July 22, 2026

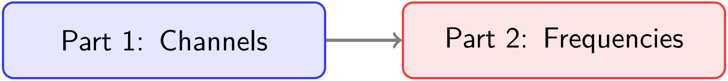
Recap: Transmitter and Receiver

Recap: Transmitter and Receiver

- Transmitter converts stick/switch movement into RF signals
- Receiver decodes signals and connects to the flight controller

Today's Agenda

- Part 1: Channels in Drone Communication (definition, minimum required, additional channels)
- Part 2: Communication Frequency Bands (frequency concept, 2.4GHz/5.8GHz, range vs frequency)



Part 1: Channels in Drone Communication

Part 1: What is a Channel?

- A channel is one independent control signal path carrying one specific piece of information
- Each stick or switch movement on the transmitter (recall Lecture 23) is typically assigned its own channel
- The number of channels a transmitter/receiver supports determines how many independent controls it can carry

Minimum Channels Required: The Core 4

- A minimum of 4 channels is required for basic flight
- Channel 1: Throttle | Channel 2: Pitch
- Channel 3: Roll | Channel 4: Yaw
- These correspond directly to the four core stick controls covered in Lecture 23

Ch 1: Throttle

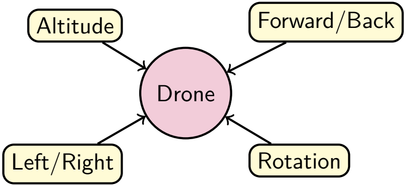
Ch 2: Pitch

Ch 3: Roll

Ch 4: Yaw

Why These 4 Channels Are the Minimum

- Throttle, Pitch, Roll, and Yaw together provide complete control over a drone's motion in 3D space
- Without any one of these four, the pilot loses a fundamental degree of control
- Any drone capable of full manual flight must support at least these 4 channels

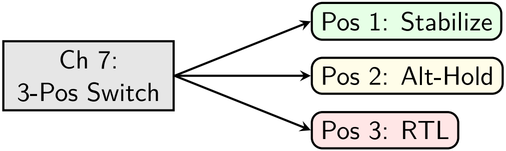


Additional Channels: Camera Control

- Beyond the core 4, additional channels can control camera functions
- Examples: gimbal tilt angle, photo capture trigger, video record start/stop
- Requires transmitters with more than 4 channels (e.g., 6, 8, or 16-channel transmitters)

Additional Channels: Flight Modes

- Additional channels are also commonly used for flight mode switching
- Flight modes can include manual, stabilize, altitude-hold, or return-to-home
- Modern transmitters often have many auxiliary channels available for such functions



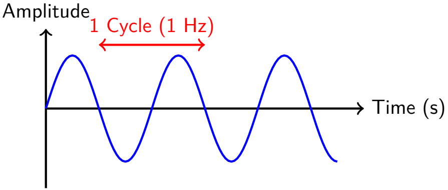
Channels Summary

Channel Type	Examples
Core (minimum 4)	Throttle, Pitch, Roll, Yaw
Additional	Camera trigger, gimbal tilt, flight mode switch

Part 2: Communication Frequency Bands

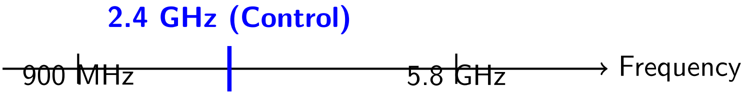
Part 2: Basic Concept of Frequency

- Frequency = the rate of oscillation of a radio wave, measured in Hertz (Hz)
- Radio signals used for drone communication travel as electromagnetic waves at specific frequencies
- Different frequency bands are allocated for different types of communication to avoid interference



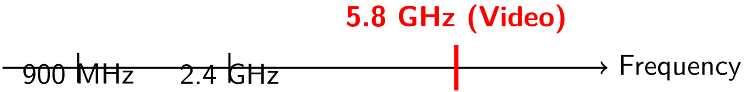
Common Frequency Bands Used: 2.4 GHz

- 2.4 GHz is the most common frequency band used for drone control communication
- Offers a good balance of range and reliability
- Widely available worldwide and used by many wireless devices (Wi-Fi, Bluetooth, etc.)



Common Frequency Bands Used: 5.8 GHz

- 5.8 GHz is another common band, often used for video transmission from the drone's camera
- Provides higher data bandwidth, suitable for carrying video signals
- Generally offers shorter range compared to 2.4 GHz

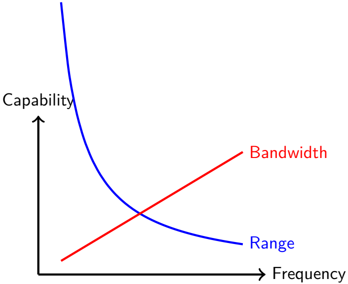


Using Both Bands Together

- Many drones use 2.4 GHz for control communication (pilot commands)
- The same drone may use 5.8 GHz for data communication (video feed)
- Using separate bands for control and video reduces interference between the two critical signal types

Range vs Frequency: The Basic Trade-off

- Lower frequency signals generally travel further and penetrate obstacles better
- Higher frequency signals generally carry more data but have shorter range
- This is why 2.4 GHz (lower) is preferred for long-range control, while 5.8 GHz (higher) suits high-bandwidth video over shorter range



Summary

Key Takeaways

- A channel carries one specific piece of control information; a minimum of 4 channels (Throttle, Pitch, Roll, Yaw) is required for flight
- Additional channels enable camera control and flight mode switching
- Common drone frequency bands are 2.4 GHz (control) and 5.8 GHz (often video)
- Lower frequency generally means longer range; higher frequency generally means more data capacity but shorter range

Next Lecture Preview

- Lecture 25: Telemetry Systems and Ground Control Stations
- How drone status data is transmitted and monitored on the ground

Any Questions?

Telemetry Systems and Ground Control Stations

Drone Technology - Unit 4: Communication and Navigation Systems

Milav Dabgar

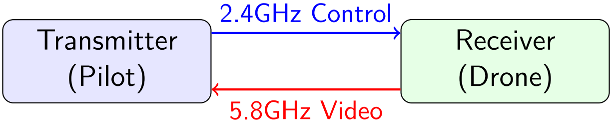
GP Palanpur

July 22, 2026

Introduction

Recap: Channels and Frequency Bands

- Minimum 4 channels required: Throttle, Pitch, Roll, Yaw
- Common bands: 2.4GHz (control), 5.8GHz (often video)



Today's Agenda

Part 1

Telemetry Systems

- Definition
- Purpose
- Application

Part 2

Ground Control Stations

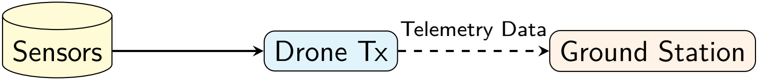
- Definition
- Types
- Functions
- Mobile App Examples

Telemetry Systems

Telemetry

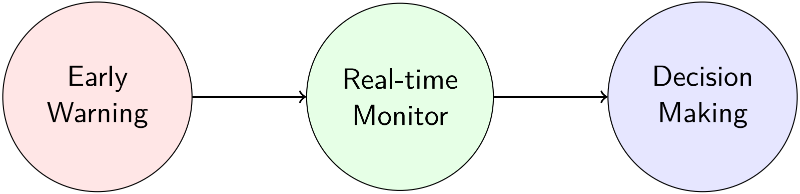
The transmission of measured data from the drone to the ground station in real time.

- This is the practical implementation of the 'data communication' concept from Lecture 22.
- Includes measurements like battery voltage, GPS position, altitude, speed, and signal strength.



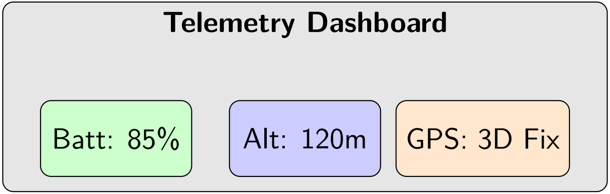
Purpose of Telemetry

- Allows the pilot/operator to monitor the drone's real-time status during flight.
- Provides early warning of issues (e.g., low battery, weak signal) before they become critical.
- Enables informed decision-making during the mission (e.g., when to trigger return-to-home, recall Lecture 19).



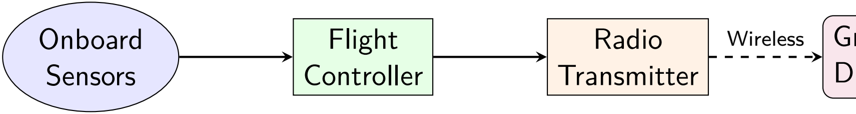
Application of Telemetry

- **Real-time flight monitoring**: battery level, altitude, speed, GPS coordinates displayed live.
- **Data logging**: telemetry history can be recorded and reviewed after flight for analysis.
- **Safety alerts**: automatic warnings when parameters (e.g., battery) cross critical thresholds.



Telemetry Data Flow Recap

- Onboard sensors (battery monitor, GPS, barometer, etc.) continuously measure drone status.
- Data is transmitted wirelessly to the ground station.
- Ground station software displays the data to the pilot/operator in real time.



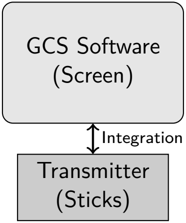
Ground Control Stations

Part 2: Definition of Ground Control Station (GCS)

Ground Control Station (GCS)

The software/hardware system on the ground used to monitor and control a drone.

- Displays telemetry data (from Part 1) and provides tools for mission planning and control.
- Works together with the transmitter (recall Lecture 23) as the pilot's complete ground-side toolkit.



Types of GCS: Mobile-Based

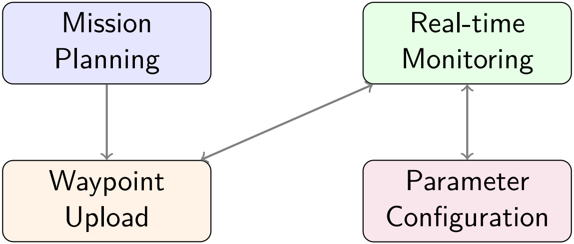
- Runs as an app on a smartphone or tablet.
- Lightweight, portable, and convenient for consumer and light commercial use.
- Common for smaller drones and everyday operations.

Types of GCS: Laptop-Based

- Runs as dedicated software on a laptop or computer.
- Typically offers more advanced features: detailed mission planning, data logging, and analysis tools.
- Common for professional, industrial, and research drone operations.

Functions of a Ground Control Station

- Mission planning: defining flight paths and waypoints (preview of Lecture 26)
- Real-time monitoring: displaying live telemetry data
- Waypoint upload: sending planned routes to the drone's flight controller
- Parameter configuration: adjusting flight controller settings before or during flight

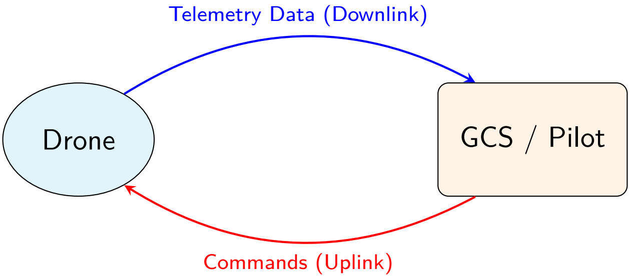


Mobile App Examples

- **DJI Fly / DJI GO**: popular consumer mobile GCS apps for DJI drones.
- **QGroundControl**: open-source GCS app compatible with PX4/ArduPilot flight controllers (recall Lecture 16).
- **Litchi**: popular third-party mobile app offering advanced mission planning features.

GCS and Telemetry Working Together

- Drone continuously sends telemetry data (Part 1) over the communication link.
- GCS (mobile or laptop-based) receives and displays this telemetry in real time.
- Pilot uses the GCS display to make informed decisions and issue mission commands.



Summary

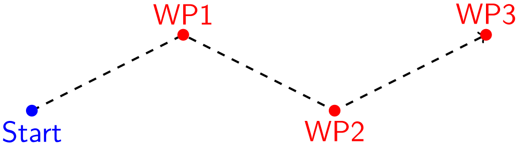
Key Takeaways

- Telemetry is the real-time transmission of drone status data (battery, GPS, altitude, speed) to the ground.
- Telemetry's purpose is real-time monitoring, early warning, and mission decision support.
- A Ground Control Station (GCS) is the system used to monitor and control the drone, available as mobile-based or laptop-based.
- GCS functions include mission planning, real-time monitoring, waypoint upload, and parameter configuration.

Next Lecture Preview

Lecture 26: Waypoint Navigation Concept

How pre-programmed GPS points enable autonomous flight paths - and a recap of Unit 4.



Questions?

4.7 Waypoint Navigation Concept

Unit 4: Communication and Navigation Systems

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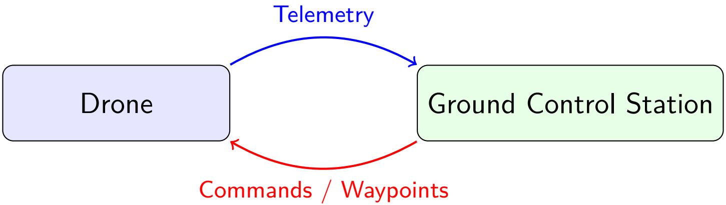
July 22, 2026

Recap

Recap: Telemetry and GCS

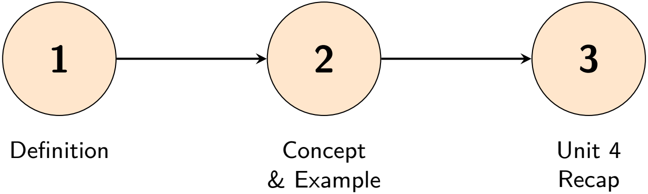
- Telemetry: real-time status data from drone to ground
- GCS: mobile/laptop system for monitoring, mission planning, waypoint upload



Agenda

Today's Agenda: Waypoint Navigation

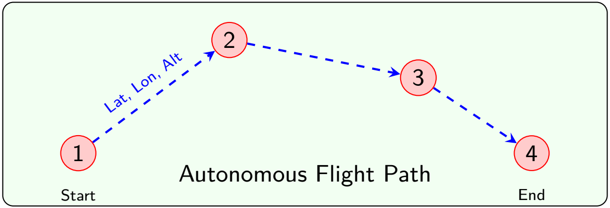
- Definition of waypoint navigation
- Concept with a practical example
- Unit 4 recap



Definition of Waypoint Navigation

Definition of Waypoint Navigation

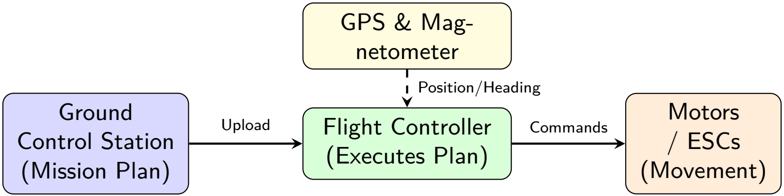
- Waypoint navigation is the ability of a drone to autonomously fly to a series of pre-programmed GPS points
- Each waypoint specifies a location (Latitude, Longitude, recall Lecture 19) and often an altitude and speed
- The drone follows the sequence of waypoints automatically, without continuous manual control



How Waypoint Navigation Works

How Waypoint Navigation Works

- Waypoints are planned and uploaded using a Ground Control Station (recall Lecture 25's mission planning function)
- The flight controller (recall Unit 3) uses GPS data to navigate from waypoint to waypoint automatically
- The magnetometer (recall Lecture 18) helps maintain accurate heading between waypoints

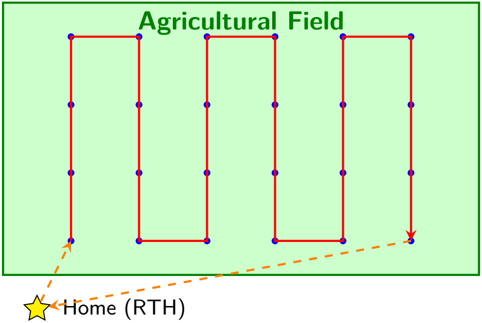


Concept with Example

Concept with Example: Agricultural Field Mapping

- A farmer wants to map crop health across a large field (recall Lecture 8's agriculture monitoring application)
- Using a GCS, the operator marks a grid pattern of waypoints covering the entire field
- The drone autonomously flies from waypoint to waypoint, capturing images or sensor data at each point
- Once all waypoints are completed, the drone can automatically return to home (recall Lecture 19's RTH)

Agricultural Field Mapping (Visual)



Benefits and Safety

Benefits of Waypoint Navigation

- ✓ Enables consistent, repeatable flight paths for surveying and mapping missions
- ✓ Reduces pilot workload during long or complex missions
- ✓ Improves accuracy and coverage compared to fully manual flight

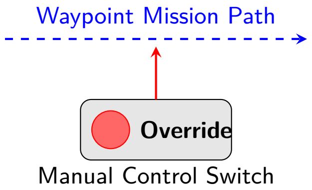
Repeatable
Consistent Paths

Lower Workload
Less Pilot Stress

High Accuracy
Better Coverage

Waypoint Navigation and Safety

- Pre-planned waypoints reduce the chance of pilot error during complex missions
- Most systems allow the pilot to override and take manual control at any time
- Waypoint missions typically still respect no-fly zones and safety limits (preview of Unit 5)

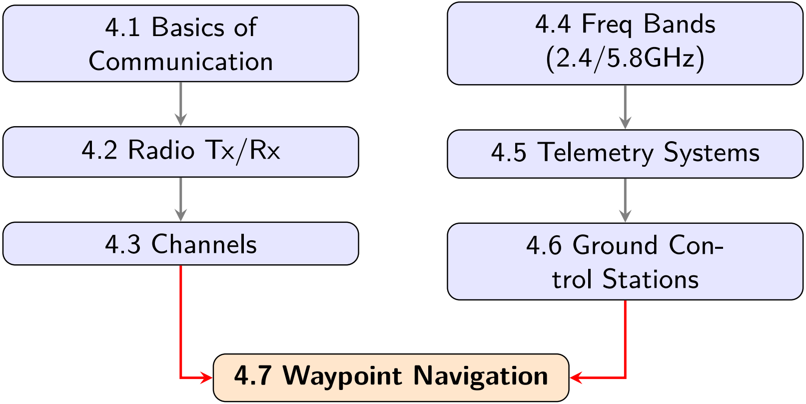


Unit 4 Recap

Unit 4 Recap: The Big Picture

Topic	Description
4.1	Basics of drone communication (control vs data)
4.2	Radio transmitter and receiver
4.3	Channels in drone communication
4.4	Communication frequency bands (2.4GHz, 5.8GHz)
4.5	Telemetry systems
4.6	Ground control stations
4.7	Waypoint navigation concept

Unit 4 Topic Map

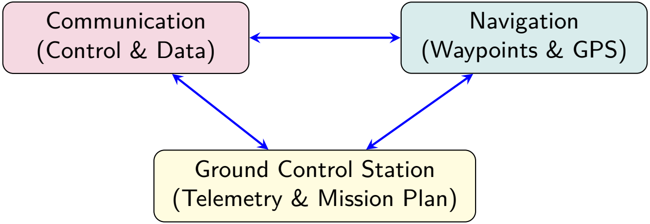


Summary

Unit 4 Key Concepts Consolidated

- Drone communication has two types: control (pilot to drone) and data (drone to ground)
- Transmitter/receiver hardware and channels/frequency bands implement this communication
- Telemetry and Ground Control Stations let the pilot monitor and manage the drone from the ground
- Waypoint navigation combines GPS, the flight controller, and GCS mission planning for autonomous flight paths

Consolidated Summary (Visual)



Preview

Next Lecture Preview: Unit 5 Begins

- Lecture 27: Drone Safety Guidelines and Pre-flight Checklist
- Moving to the final unit: Drone Safety and Regulations

Questions?

Questions?

Drone Safety Guidelines and Pre-Flight Checklist

Unit 5: Drone Safety and Regulations

Milav Dabgar

GP Palanpur

July 22, 2026

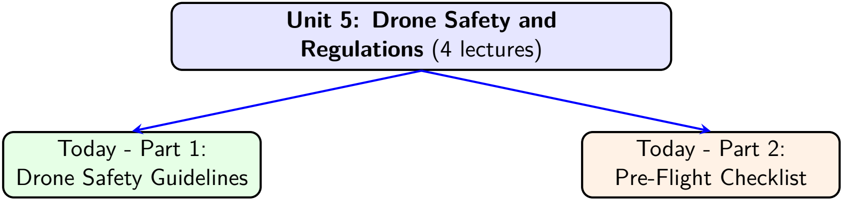
Recap

Recap: Unit 4 Summary

- Unit 4 covered communication (control/data), transmitter/receiver, channels/frequency, telemetry/GCS, and waypoint navigation
- We now move to the final unit: Drone Safety and Regulations

Agenda

Unit 5 Overview & Today's Agenda



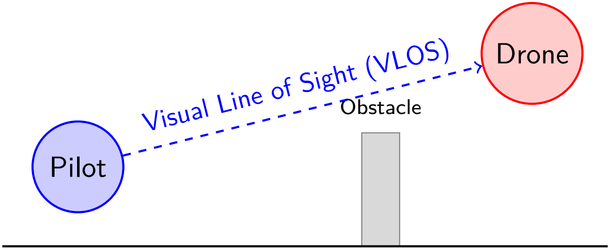
5.1 Drone Safety Guidelines

Part 1: Why Safety Guidelines Matter

- Drones carry real risks: collisions, crashes, injury, and property damage if operated carelessly
- Recall Lecture 7's limitations - weather sensitivity, payload/range constraints, and regulatory concerns all tie into safety
- Following safety guidelines protects people, property, and the drone itself

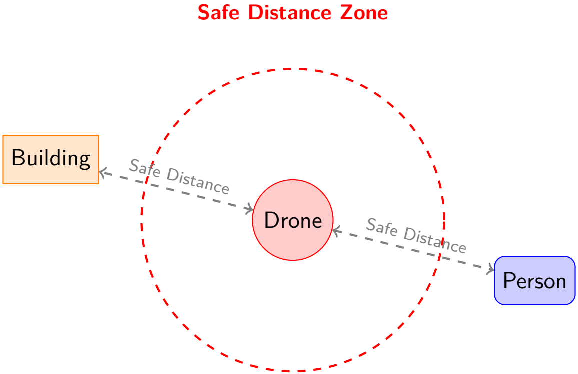
Drone Safety Guidelines: Visual Line of Sight (VLOS)

- Always maintain visual line of sight (VLOS) with the drone during flight
- Enables the pilot to react quickly to obstacles or unexpected situations
- A fundamental safety principle followed across most drone regulations worldwide



Drone Safety Guidelines: People and Property

- Never fly directly over crowds or large gatherings of people
- Maintain a safe distance from people, vehicles, and buildings not involved in the operation
- Reduces risk of injury or damage in case of a technical failure or crash



Drone Safety Guidelines: Airspace and Weather

- Respect no-fly zones and restricted airspace (detailed further in Lecture 30)
- Check weather conditions before flight - avoid flying in strong wind, rain, or storms (recall Lecture 7's weather limitation)
- Follow all applicable local regulations before every flight (previewed further in Lectures 29-30)

Drone Safety Guidelines: Equipment Practices

- Use propeller guards for beginners or when flying near people
- Regularly maintain and inspect the aircraft (frame, motors, propellers - recall Unit 2)
- Keep firmware and flight controller software up to date

Part 1 Summary: Key Safety Guidelines

1. Maintain Visual Line of Sight (VLOS)	2. Avoid flying over crowds; keep safe distance
3. Respect no-fly zones & check weather	4. Use guards and maintain equipment

5.2 Pre-Flight Checklist

Part 2: Purpose of a Pre-Flight Checklist

- A pre-flight checklist is a systematic set of checks performed before every flight
- Ensures the drone and its systems are in safe, working condition before takeoff
- Helps catch potential problems early, before they become in-flight failures (preview of Lecture 28)

Pre-Flight Checklist: Power and Battery

- Check battery charge level for both the drone and the transmitter (recall Lecture 14's Li-Po safety)
- Inspect battery for any physical damage or swelling before use
- Ensure battery is securely mounted

Pre-Flight Checklist: Frame and Propellers

- Inspect propellers for cracks, chips, or damage (recall Lecture 13)
- Confirm propellers are securely attached in the correct CW/CCW positions
- Inspect the frame and motors (recall Unit 2) for visible damage or looseness

Pre-Flight Checklist: GPS, Sensors, and Home Point

- Confirm GPS lock is achieved before flight (recall Lecture 19)
- Calibrate compass/sensors if required (recall Lecture 18's magnetometer)
- Verify the home point is correctly set for return-to-home functionality (recall Lecture 19)

Pre-Flight Checklist: Environment and Communication

- Check weather conditions: wind speed, rain, visibility
- Verify communication link/signal strength between transmitter and receiver (recall Unit 4)
- Confirm the flight area is clear of obstacles and unauthorized people

Pre-Flight Checklist: Payload

- Verify camera, gimbal, or other payload equipment (recall Lecture 15) is securely mounted
- Confirm payload equipment is powered on and functioning correctly before takeoff

Complete Pre-Flight Checklist Summary

Check Category	Example Items
Power/Battery	Charge level, physical condition, secure mounting
Frame/Propellers	Damage inspection, secure attachment
GPS/Sensors	GPS lock, compass calibration, home point set
Environment/Comms	Weather, signal strength, clear area
Payload	Secure mounting, powered and functioning

Summary

Key Takeaways

- Safety guidelines include maintaining VLOS, avoiding crowds, respecting no-fly zones, and checking weather
- A pre-flight checklist systematically verifies battery, frame/propellers, GPS/sensors, environment/communication, and payload
- Following these practices consistently prevents most common in-flight problems
- Safety is a continuous responsibility, not a one-time consideration

Next Lecture Preview

- Lecture 28: Common Drone Failures/Troubleshooting and Airspace Awareness
- What can go wrong in flight, and how to fly safely within airspace rules

Questions?

Common Drone Failures/Troubleshooting and Airspace Awareness

Drone Technology (DI05000081) - Unit 5

Milav Dabgar

GP Palanpur

July 22, 2026

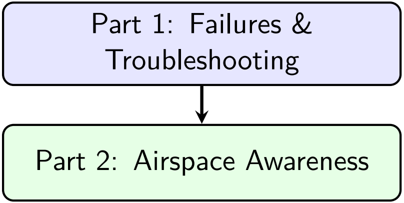
Recap

Recap: Safety Guidelines and Pre-Flight Checklist

- Safety guidelines: VLOS, avoid crowds, respect no-fly zones, check weather
- Pre-flight checklist: battery, frame/propellers, GPS/sensors, communication, payload

Today's Agenda

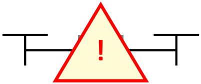
- Part 1: Common Drone Failures and Troubleshooting
- Part 2: Airspace Awareness (Safe Flying Practices)



Common Drone Failures and Troubleshooting

Part 1: Why Failures Happen

- Even with careful pre-flight checks (recall Lecture 27), failures can still occur during flight
- Understanding common failure modes helps pilots respond quickly and safely
- Most failures fall into a few recognizable categories

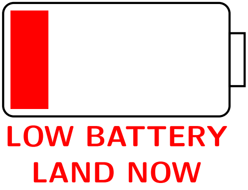


Common Failure: GPS Signal Loss

- GPS signal loss can cause the drone to lose position-hold capability (recall Lecture 19)
- Risk: potential 'fly-away' if the drone drifts uncontrolled
- Troubleshooting/mitigation: switch to manual control, or rely on return-to-home once signal is regained

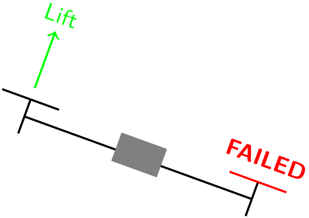
Common Failure: Battery Issues

- Low battery voltage can cause reduced power, erratic behavior, or sudden loss of lift
- Recall Lecture 14's Li-Po safety - damaged or improperly charged batteries are a common failure source
- Troubleshooting/mitigation: land immediately when a low-battery warning appears; never ignore battery alerts



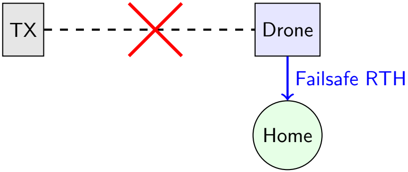
Common Failure: Motor/ESC Failure

- A failed motor or ESC (recall Lectures 11-12) can cause loss of lift on one side, leading to instability or crash
- Often caused by physical damage, overheating, or manufacturing defects
- Troubleshooting/mitigation: thorough pre-flight inspection (recall Lecture 27) helps catch damage before flight



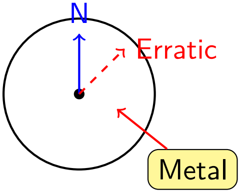
Common Failure: Loss of Radio Signal

- Loss of communication link (recall Unit 4) leaves the drone without control input
- Most flight controllers have a programmed 'failsafe' behavior (e.g., auto return-to-home or auto-land)
- Troubleshooting/mitigation: configure and verify failsafe settings before every flight



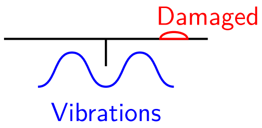
Common Failure: Sensor Malfunction

- Compass/magnetometer interference (recall Lecture 18) can cause incorrect heading readings and erratic flight
- Often caused by nearby metal objects, magnets, or electronics during calibration
- Troubleshooting/mitigation: calibrate sensors in an open area, away from magnetic interference



Common Failure: Propeller Damage/Imbalance

- Damaged or imbalanced propellers (recall Lecture 13) cause excessive vibration
- Vibration can degrade sensor accuracy (recall IMU sensitivity, Lecture 20) and reduce flight stability
- Troubleshooting/mitigation: regularly inspect and replace damaged propellers



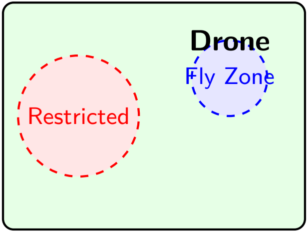
Part 1 Summary: Failures and Troubleshooting

Failure Type	Basic Mitigation
GPS signal loss	Switch to manual control / await RTH
Battery issues	Land immediately on low-battery warning
Motor/ESC failure	Thorough pre-flight inspection
Radio signal loss	Configure and verify failsafe settings
Sensor malfunction	Calibrate away from interference
Propeller damage	Regular inspection and replacement

Airspace Awareness (Safe Flying Practices)

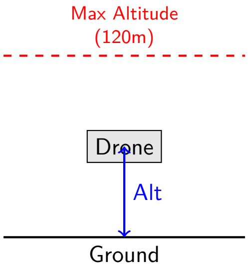
Part 2: What is Airspace Awareness?

- Airspace awareness means understanding where a drone is legally and safely permitted to fly
- Involves knowing altitude limits, restricted zones, and nearby air traffic considerations
- A foundational concept that will be expanded with specific zone types in Lecture 30



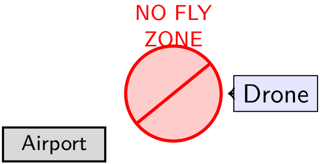
Safe Flying Practices: Altitude Limits

- Most civilian regulations impose a max altitude limit (commonly 120m / 400ft)
- Staying within limits reduces conflict with manned aircraft
- Altitude can be monitored using barometer and GPS sensors (recall Lecture 19)



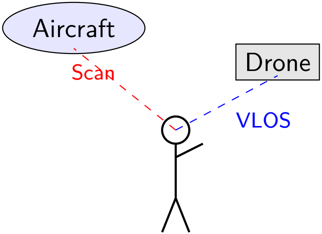
Safe Flying Practices: Avoiding Restricted Areas

- Avoid flying near airports, military installations, and other sensitive/restricted locations
- These areas carry heightened risk of interfering with manned aircraft or critical operations
- Full detail on zone classification (Red/Yellow/Green) is covered in Lecture 30



Safe Flying Practices: General Awareness

- Maintain visual line of sight and awareness of surrounding air traffic (recall Lecture 27)
- Check for any temporary flight restrictions before flying in a new area
- Be aware of local weather patterns that could affect nearby manned aircraft operations too



Summary

Key Takeaways

- Common drone failures include GPS loss, battery issues, motor/ESC failure, radio loss, sensor malfunction, and propeller damage
- Most failures can be mitigated through careful pre-flight inspection and configured failsafe behaviors
- Airspace awareness means understanding altitude limits and restricted areas before flying
- Safe flying practices build directly on the VLOS and safety guidelines from Lecture 27

Next Lecture Preview

Lecture 29: Drone Regulations in India

- Drone Regulations in India and the Role of DGCA
- Understanding the formal regulatory framework governing drone operations

Questions?

Drone Regulations in India and Role of DGCA

Unit 5: Drone Safety and Regulations

Milav Dabgar

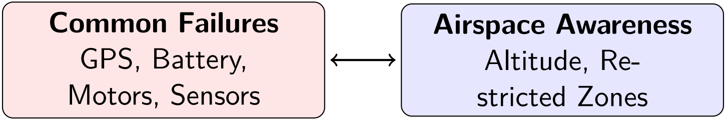
GP Palanpur

July 22, 2026

Recap

Recap: Failures and Airspace Awareness

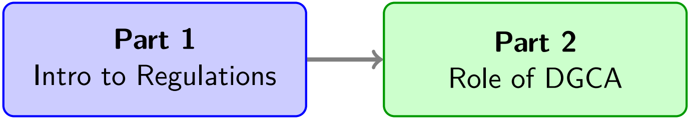
- Common failures: GPS loss, battery issues, motor/ESC failure, radio loss, sensor issues
- Airspace awareness: altitude limits, restricted areas



Today's Agenda

Today's Agenda

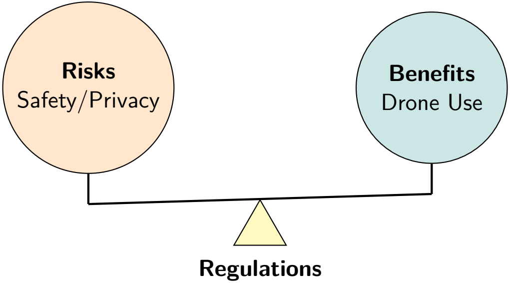
- Part 1: Introduction to Drone Regulations in India
- Part 2: Role of the DGCA



Part 1: Introduction to Drone Regulations in India

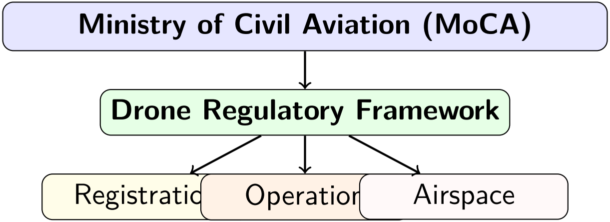
Part 1: Why Drone Regulations Are Needed

- Recall Lecture 7's limitations - safety, privacy, and airspace risks require formal regulation
- Ensures safe integration of drones into shared airspace with manned aircraft
- Protects public safety, security, and privacy while enabling beneficial drone use



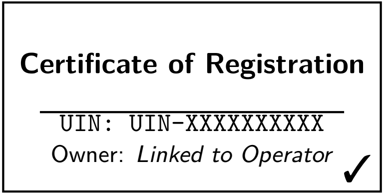
Introduction to Drone Regulations in India

- India's drone regulatory framework is issued by the Ministry of Civil Aviation
- Establishes rules for drone registration, operation, and airspace access
- Uses the size/weight classification introduced in Lecture 4 (Nano, Micro, Small, Medium, Large) as a basis for rules



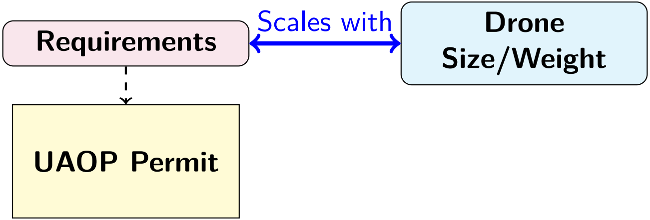
Key Regulatory Concepts: Registration

- Most drones (above the smallest Nano category) require registration
- Each registered drone typically receives a Unique Identification Number (UIN)
- Registration links a drone to its owner/operator for accountability



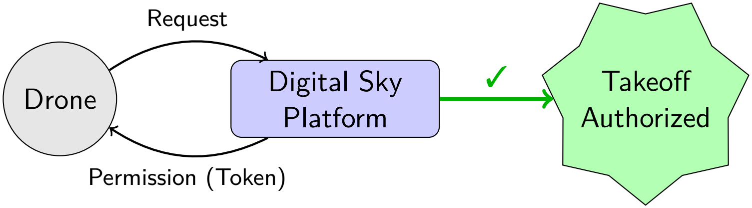
Key Regulatory Concepts: Operator Permits

- Certain categories of drone operation require an Unmanned Aircraft Operator Permit (UAOP)
- Operators may need to demonstrate competency or meet specific requirements depending on drone category
- Requirements generally scale with drone size/weight and intended use



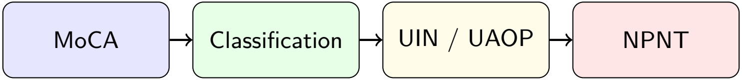
Key Regulatory Concepts: No Permission No Takeoff (NPNT)

- NPNT is a core safety principle: a drone cannot take off without prior digital permission
- Permission is checked and granted through the Digital Sky platform (detailed in Lecture 30)
- Ensures every flight is authorized and traceable within the regulatory system



Part 1 Summary: India's Regulatory Framework

- Regulations are issued by the Ministry of Civil Aviation
- Based on drone size/weight classification (recall Lecture 4)
- Requires registration (UIN) and, for some categories, an operator permit (UAOP)
- Enforces the No Permission No Takeoff (NPNT) principle



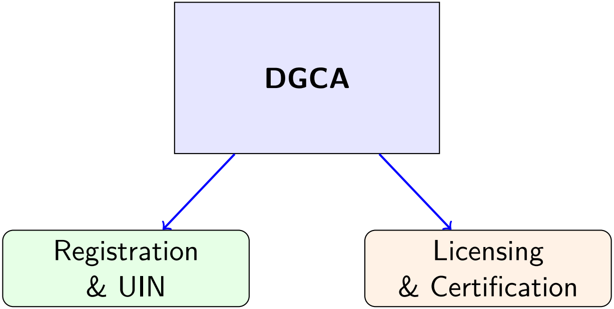
Part 2: Role of the DGCA

Part 2: Introducing the DGCA

- DGCA = Directorate General of Civil Aviation
- The regulatory authority responsible for civil aviation in India, including drones
- Operates under the Ministry of Civil Aviation

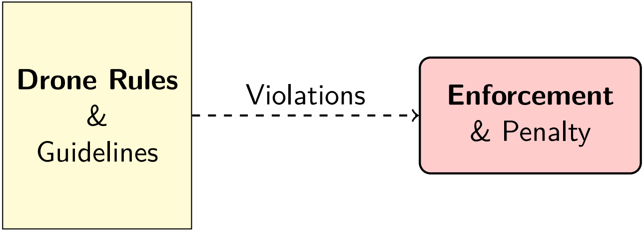
Role of DGCA: Drone Registration and Licensing

- Oversees the drone registration process and issuance of Unique Identification Numbers (UIN)
- Manages remote pilot licensing/certification for operators who require it
- Sets qualification requirements for different categories of drone operation



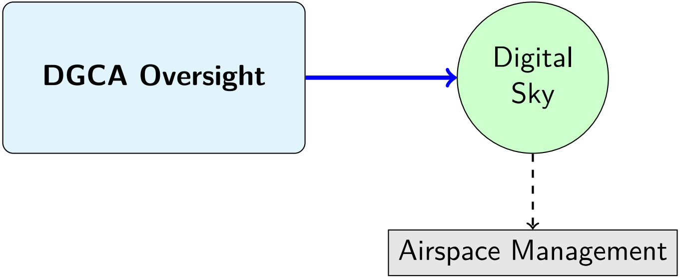
Role of DGCA: Rules and Enforcement

- Issues and enforces the Drone Rules governing civilian drone operations
- Publishes guidelines and circulars updating operational requirements
- Has authority to take action against unauthorized or unsafe drone operations



Role of DGCA: Airspace Clearance and Digital Sky Oversight

- Defines airspace clearance requirements for drone operations
- Oversees the Digital Sky platform (detailed in Lecture 30), which manages permissions and airspace mapping
- Coordinates with other aviation authorities to maintain safe, shared airspace



DGCA's Overall Role Summary

Responsibility	Description
Registration	Issues UIN for registered drones
Licensing	Manages remote pilot certification
Rule-making	Issues and updates Drone Rules
Enforcement	Acts against unsafe/unauthorized operations
Digital Sky oversight	Manages the digital permission platform

Summary

Key Takeaways

- India's drone regulations are issued by the Ministry of Civil Aviation, based on drone size/weight classification
- Key elements include registration (UIN), operator permits (UAOP), and the No Permission No Takeoff (NPNT) principle
- The DGCA is the regulatory authority responsible for registration, licensing, rule enforcement, and Digital Sky oversight
- These regulations formalize the safety concepts introduced across Lectures 27-28

Next Lecture Preview

Coming Up: Lecture 30

- No-Fly Zones and the Digital Sky Platform
- The final lecture of the course, including a complete course recap

Questions?

No-Fly Zones and Digital Sky Platform (Course Conclusion)

Unit 5: Drone Safety and Regulations

Milav Dabgar

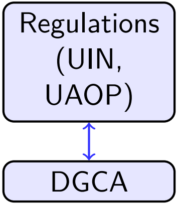
GP Palanpur

July 22, 2026

Recap

Recap: Indian Drone Regulations and DGCA

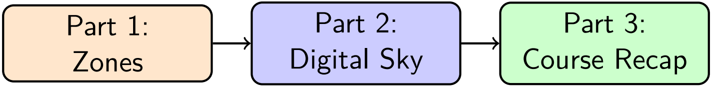
- Regulations: registration (UIN), operator permits (UAOP), NPNT principle
- DGCA: India's civil aviation regulatory authority



Agenda

Today's Agenda: Final Lecture of the Course

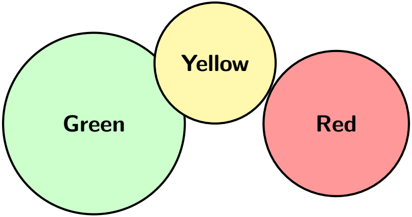
- Part 1: No-Fly Zones and Restricted Areas (Red/Yellow/Green Zone)
- Part 2: Digital Sky Platform Overview
- Part 3: Full Course Recap (all 5 units)



No-Fly Zones and Restricted Areas

Part 1: Why Zone Classification Matters

- Recall Lecture 28's airspace awareness - not all airspace is equally safe or legal for drone flight
- India's regulatory framework (recall Lecture 29) classifies airspace into color-coded zones
- This classification tells an operator exactly where they can, cannot, or conditionally can fly



Red Zone

- Red Zone: flying is NOT permitted without special permission
- Typically includes areas near international borders, military/strategic installations, and airports
- Represents the highest level of airspace restriction for drone operators

RESTRICTED
✗

Yellow Zone

- Yellow Zone: controlled airspace requiring permission from Air Traffic Control (ATC) before flying
- Typically includes areas near airports or other controlled airspace regions, but less restrictive than Red Zone
- Operators must obtain clearance through the Digital Sky platform (Part 2) before takeoff

Green Zone

- Green Zone: automatic permission granted (up to a specified height) - the safest zone for drone flying
- No additional ATC clearance is typically required within Green Zone limits
- Most everyday civilian drone flying is expected to occur within Green Zones

PERMITTED

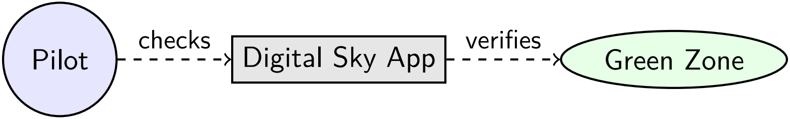
Auto-Clearance ✓

Red, Yellow, Green Zones: Summary Comparison

Zone Color	Status	Rule
Red Zone	✗ Restricted	Flying **not permitted** without special permission
Yellow Zone	? Controlled	Permission required from **ATC** before flying
Green Zone	✓ Permitted	**Automatic permission** up to a certain height

Checking Zone Status Before Flight

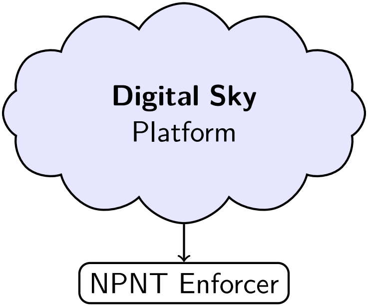
- Before any flight, an operator should check which zone their intended flight area falls into
- This directly supports Lecture 27's pre-flight checklist and Lecture 28's airspace awareness practices
- Zone information is available digitally through the Digital Sky platform



Digital Sky Platform Overview

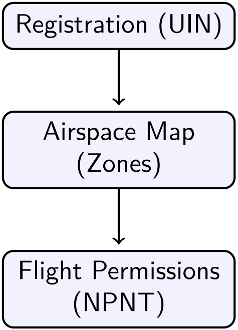
Part 2: Introducing the Digital Sky Platform

- Digital Sky is the online platform developed to manage drone regulation and airspace access in India
- Overseen by the DGCA (recall Lecture 29)
- Serves as the digital backbone implementing the NPNT principle introduced in Lecture 29



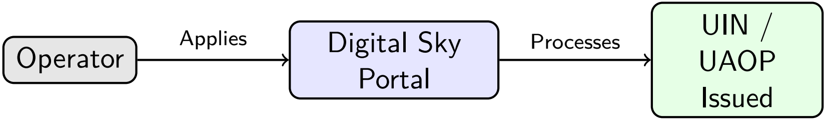
Digital Sky Platform: Key Functions

- Drone registration: operators register their drones and receive a UIN through this platform
- Airspace map: displays Red, Yellow, and Green zones (Part 1)
- Permission requests: operators request and receive digital flight permission (implementing NPNT)



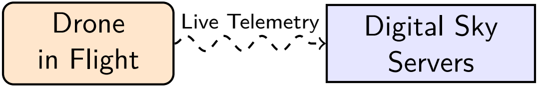
Digital Sky Platform: UIN and UAOP Applications

- Operators can apply for a Unique Identification Number (UIN) through the platform
- Operators requiring an Unmanned Aircraft Operator Permit (UAOP) can also apply digitally
- Reduces paperwork and centralizes the regulatory process into one digital system



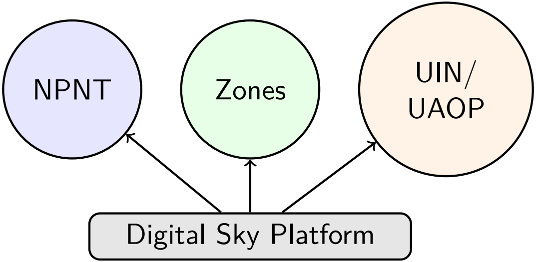
Digital Sky Platform: Real-Time Tracking

- Supports tracking of authorized drone flights within the regulated system
- Helps ensure only permitted flights are conducted, supporting the safety goals discussed throughout Unit 5
- Represents the modern, technology-driven approach to managing the rapidly growing drone ecosystem



Part 2 Summary: Digital Sky Platform

- Digital Sky is the DGCA-overseen platform implementing India's drone regulatory system
- Functions: registration, airspace zone mapping, digital permission requests (NPNT), and flight tracking
- Central digital tool connecting every regulatory concept covered in Lectures 29-30



Course Conclusion & Recap

Unit 5 Recap: The Big Picture

- 5.1 Safety guidelines
- 5.2 Pre-flight checklist
- 5.3 Common failures & troubleshooting
- 5.4 Airspace awareness
- 5.5 Drone regulations
- 5.6 Role of DGCA
- 5.7 No-fly zones (Red/Yellow/Green)
- 5.8 Digital Sky platform

Unit 5: Drone Safety
and Regulations
(Connecting Rules to Safe Flight)

FULL COURSE RECAP: Unit 1

- Unit 1 - Introduction to Drone Technology
- Defined UAV, UAS, and Drone; traced drone history
- Covered classification (size/weight, type, altitude, structure), terminology (Pitch/Roll/Yaw/Throttle/Altitude), and forces (Lift/Drag/Thrust/Gravity)
- Covered advantages, limitations, and 7 major application areas

UAV, Forces, Terminology, Applications

FULL COURSE RECAP: Unit 2

- Unit 2 - Drone Components and Architecture
- Covered the basic architecture block diagram
- Covered frame/materials, BLDC motors, ESC, propellers, power system (Li-Po battery), and payload systems

Motors, ESCs, Batter-
ies, Props, Payloads

FULL COURSE RECAP: Unit 3

- Unit 3 - Flight Controller and Sensors
- Covered the flight controller concept and working of FC boards
- Covered 5 sensor types (accelerometer, gyroscope, magnetometer, barometer, GPS) and the IMU
- Covered stabilization concepts and PID control for velocity hold

Flight Controller,
IMU, PID Tuning

FULL COURSE RECAP: Unit 4

- Unit 4 - Communication and Navigation Systems
- Covered control vs data communication, transmitter/receiver hardware
- Covered channels, frequency bands (2.4GHz/5.8GHz), telemetry, ground control stations
- Covered waypoint navigation for autonomous flight paths

Telemetry, Rx/Tx,
Waypoints, GCS

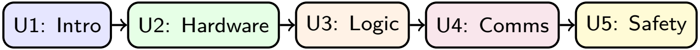
FULL COURSE RECAP: Unit 5

- Unit 5 - Drone Safety and Regulations
- Covered safety guidelines and the pre-flight checklist
- Covered common failures/troubleshooting and airspace awareness
- Covered India's drone regulations, DGCA's role, no-fly zones, and the Digital Sky platform

Safety, DGCA,
NPNT, No-Fly Zones

The Complete Drone Technology Picture

- From definitions (Unit 1) to physical components (Unit 2) to intelligent control (Unit 3) to communication/navigation (Unit 4) to safe, legal operation (Unit 5)
- Each unit built directly on the concepts of the previous one
- Together, these 5 units form a complete foundation for understanding, building, and safely operating drones



Course Key Takeaways

- A drone (UAV/UAS) is defined by its lack of onboard pilot, its components, and its systems working together
- Flight depends on a continuous sensor-feedback-control loop managed by the flight controller
- Communication and navigation systems enable both manual piloting and autonomous mission execution
- Safe, legal, and responsible operation requires following safety guidelines and India's regulatory framework

Hardware + Software + Rules
= **Safe Drone Ecosystem**

Congratulations and Course Closing

- You have completed all 30 lectures of Drone Technology (DI05000081)
- You now understand drone fundamentals, components, flight control, communication, and safe/legal operation
- This foundation prepares you for further study, hands-on practice, and careers in the growing drone industry

Course Completed!

Thank You!

Any Questions?