Aerial Robotics: réponses aux questions

Introduction

Given the same weight, what type of small drones (multi-copter, fixed-wing, flapping wing) has the longest endurance?

- Fixed-wing

What are the two types of drone use in agriculture and what is the best customer value for each of them?

- Fixed-wing
  - Inspection
  - Large fields
- Multi-copter
  - Spraying
  - small fields, high value crops, difficult terrain

What are the possible uses of drones in the energy business sector?

- Stationary inspection
- Long range inspection
- Power generation

What type of parcel delivery could be more profitable for drone companies in the short term?

- Pharmaceutical / medical
- Non-perishable consumer goods

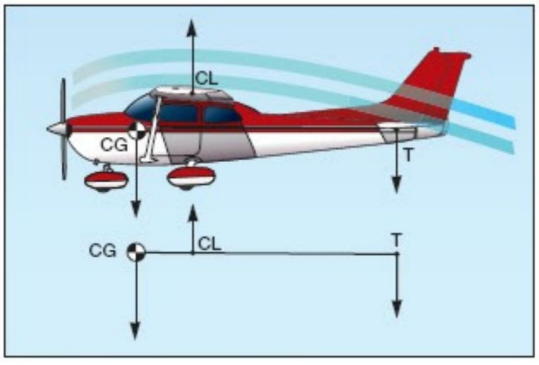
Fixed Wing UAVs

What are the main flight control surfaces in fixed-wing aircrafts?

Ailerons (on the main wings, roll), Elevator (on the tail wings, pitch), Rudder (on the tail, yaw)

What are the main stabilization strategies in fixed-wing aircrafts?

Pitching: Center of gravity at the front wrt. the center of pressure of the main wing



Rolling: Dihedral (angle between the two wings), Keel effect, Weight distribution (C.G. center line)
Yawing: Side surface greater aft of the C.G.

How a delta wing is controlled and stabilized?
Thanks to elevons (for pitch and roll) and vertical stabilizers (yaw)

What are the main contributions to power consumptions in fixed-wing aircrafts?
Profile drag, Parasite drag,

Flapping Wing MAVs

What are the main types of tail designs found in flapping wing MAVs?

- Static
- Tailless
- Active

What are the main types of wings designs found in flapping wing MAVs?

- Flapping
- Clapping
- Morphing

What are the main mechanisms for lift generation in symmetric hovering flight?

- Leading edge vortex
- Rotational forces
- Clap-and-fly motion

What are the main steering strategies in flapping flight MAVs?

- Tail control
- Wing control
    - Roll: tensioning one wing/loosening the other
    - Pitch: tension/loosen both wings during aft part
    - Yaw: wings tightened asymmetrically
- Both control

Multirotor UAVs

What is a NED body frame?
North - Est - Down (corresponding to x, y and z)

What set of conditions corresponds to hovering in a quadcopter?

- Forces must be balanced (F1 + F2 + F3 + F4 + mg = 0)
- Forces must be parallel to gravity (Fi || g)
- All moments must be balanced (M1 + M2 + M3 + M4 = 0)

- Rotor speeds must be balanced ((w1 + w3) - (w2 + w4) = 0)

What set of conditions corresponds to a rotation around the yaw axis in a quadcopter?

- Forces must be balanced (F1 + F2 + F3 + F4 + mg = 0)
- Forces must be parallel to gravity (Fi || g)
- All moments must be balanced (M1 + M2 + M3 + M4 = 0)
- Rotor speeds unbalanced ((w1 + w3) - (w2 + w4) != 0)

How many controllable degrees of freedom has an octocopter?

6 (not sure, maybe only 4)

How the time of flight of multicopters can be increased?

- Weight and drag reduction
- Increase the specific power of the energy source (E/kg)
- Docking station for charging/battery swapping
- Tether for power supply
- Improving efficiency via mechanical redesign
- Energy aware motion planning (see next question)
- Multi-modal operation: switch to rolling/walking

How the power consumption and total thrust evolve at different forward speeds in multicopters?

- First decreases as speed increases (additional air flow induced by movement make the propellers more efficient)
- Increases again for higher speeds as drag becomes too important

State estimation

Cheat sheet:

State estimator	Model	Assumed distribution	Computational cost
Kalman filter	Linear	Gaussian	Low
Extended Kalman Filter (EKF)	Locally linear	Gaussian	Low (for analytically-computed Jacobians) Medium (for numerically-computed Jacobians)
Unscented Kalman Filter (UKF)	Nonlinear	Gaussian	Medium

Particle filter	Nonlinear	Non-Gaussian	High

Control

What is the size of the control allocation matrix of an hexacopter with 4 controlled degrees of freedom?
6x4 (number of actuators x number of DOF)

What is the content of each column of the actuator effectiveness matrix?
The force and torque generated by a single actuator [[torque], force]'

Why do we use the pseudo inverse instead of standard matrix inverse to compute the control allocation matrix from the actuator effectiveness matrix?
Because the actuator effectiveness matrix is not necessarily square.

What happens when a rate setpoint [0 0 1] is applied?
The drone starts to yaw at 1 rad/s.

What are the input and output of the rate controller?
Inputs:

- Angular velocity command
- Estimated angular velocity

Output:

- Moment command (motor command)

On which axis is feedforward particularly useful for fixed wing rate control?
Roll.

What happens when an attitude setpoint [0 0 pi/2] is applied?
The drone rotates until roll = 0, pitch = 0 and yaw = pi/2.

What are the input and output of the attitude controller in a cascaded architecture?
Inputs:

- Attitude command
- Estimated attitude

Output:

- Angular velocity command (motor command)

What is the output of the attitude controller in a cascaded architecture?
See above.

How to compute attitude error quaternion from the estimated attitude quaternion and the attitude setpoint quaternion?
$q_e = q_c \otimes \hat{q}^*$

Regulatory and communication issues

What are the weight restriction for sUAS in the USA and in Switzerland?

- USA: up to 25kg
- Switzerland: up to 30kg (without a license), 30 to 120 (with license)

Am I allowed to operate my multicopter everywhere and fly it as high as I want in Switzerland?

- Without license: need direct contact with pilot (VLOS or EVLOS)
- On model airfields and operated by participants in air shows
- below 150m
- In non-restricted areas
- Multicopters on open ground and in populated areas without gathering of more than two dozen people provided (privacy and natural parks respected)

Therefore no, I'm not allowed to fly as high and heavy as I want to.

As of today, do drones command and telemetry links mostly use licensed or unlicensed spectrum portions?

Licensed: C2 link for telemetry and control

- Telemetry:
  - 2.4GHz
  - 433/866/900 MHz
- Control:
  - infrared
  - RF about 40MHz
  - Bluetooth and WiFi
  - RF 2.4GHz
    - DSM2 / DSMX
    - ACCST
    - FASST
- Video streaming:
  - Analog:
    - 2.4GHz / 5.8GHz
  - Digital:
    - 920MHz
    - 2.4GHz
    - 5.7GHz

Soon in 5G who knows.

In the context of UASs, which is the main advantage of 5G with respect to 4G?

- Suited for control and telemetry
- Suited for video streaming

Allows a easier implementation of NVLOS (non-visual line-of-sight). 5G offers for it:

- Lower latency
- Reliability
- **Larger bandwidth**

Navigation

Which component of the acceleration setpoint is converted to roll angle? To pitch angle?

- The thrust in the local frame
- The thrust of the semi-local frame

Why should the thrust setpoint be computed using the estimated attitude instead of the attitude setpoint?

The attitude set point is subject to discrepancies, which can make the thrust setpoint oscillate at every iteration; thus we cannot obtain a stable attitude with a non-estimated attitude and should therefore use an estimated one which reduces the error in a “non-white noisy” way

Why is navigation based on fixed position setpoint inappropriate for fixed wing drones?

- Excessive slowdown near waypoints
    - Fixed-wing drones cannot hover and have to maintain a minimal speed in order to stay in the air
- No straight path in windy conditions

What type of segment compose a Dubins path?

Arcs of a minimal radius and straight lines.

In which case can we construct a RLR Dubins path?

Right rotation - Left rotation - Right rotation, forms the shortest curve that:

- joins a starting point to a terminal point B with the desired tangents at each endpoint
- Does not exceed the given curvature
- Points A and B are not too close from each other

Two circles of the A point and the B point respectively are tangent to each other.

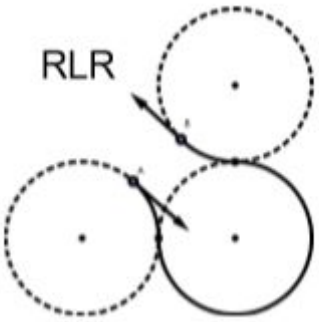


Figure 2: schematic of a RLR Dubin’s path

What happens when centrifugal acceleration is not taken into account in the formulation of a circle following vector field?
The drone diverges from the trajectory and tends to form a bigger and bigger circle.

Perception and Swarming

What kind of camera is used in motion capture systems?
Infrared camera. High acquisition rate (~300 fps) but relatively low resolution (1664x1088)

What is the precision of a motion capture system?
It depends on the number of cameras used.

What is the main technique used by insects for flying?
Visual motion (also called optic flow (OF))

How insects land precisely on an object?
The insect can compute the distance it is from the ground by measuring the time needed to observe the ground beneath it by longitudinally visually sweeping it:

$$d\theta/dt = \omega = V * sin\theta/r$$

By knowing its speed V, it can then compute its distance from the object r.

How can you simulate a flock of birds?
Using Reynolds flocking rules:

- Cohesion: "steer to move toward the average position of local flockmates"
- Separation: "steer to avoid crowding local flockmates"
- Alignment: "steer towards the average heading of local flockmates"

Hardware Components and Integration

How does the amount of current drawn from a Li-Po battery (expressed in C) affects its discharge behavior?
Discharge curve determined by the amount of current (expressed in “C”) drawn from the battery.
At higher discharge rates (high discharge currents), the temperature rises significantly and further increasing the discharge rate poses overheating risks.

What are the main differences between electric motors and internal combustion engines?
Electric motors:

- Clean and quiet
- Reliable and easy to maintain
- Limited weight to power ratio due to energy source

Combustion engines:

- High power to weight ratio
- Vibration (saturation of attitude control)

- Noisy and dirty
- Not suited for fast change of speed (problem in controlling quadcopters)

What is the effect of changing the blade pitch in propellers?
Changes by how far (in retard units inches) the propeller will move through the air per single rotation of the engine.
Fine pitch gives high propeller efficiency per propeller advance ratio (used for takeoff), coarse gives high propeller advance ratio per propeller efficiency (used for cruise flight).

What control protocol is used for servomotors?
Controlled by sending electrical pulse of variable width (PWM) through the control wire. The PWM signal sent to the motor determines position of the shaft, and based on the duration of the pulse sent via the control wire, the rotor will turn to the desired position.

What is a pitot tube?
Sensor used to measure airspeed. Pitot tube directed into the direction of motion and difference between stagnation pressure (static + dynamic pressure) and the static pressure reveals airspeed:

$$(p_s + \rho V^2/2) = p_t$$
$$V = \sqrt{2(p_t - p_s)/\rho}$$

Difference of pressure is measured by a pressure transducer.

What is the working principle of an electrostatic autopilot?
Voltage differences between insulated sensors located on the wing tip of an aircraft when it banks in the Earth's atmospheric field. Those differences are converted into feedback signals to provide a vertical reference for the autopilot.

What are the main communication protocols between remote controller receivers and autopilots?
It is required, for safety, to ensure the possibility to put the vehicle back into manual mode.
PWM: pulse width modulation
- Used by ESC's and servos
- analog
- Each channel has its own single wire (up to 16 channels)
- Value of each channel is represented as a 1 ms to 2 ms "ON" signal and its repeat/update every 20 milliseconds (→ control frequency up to 50Hz).

PPM - Pulse Position Modulation:
- Analog
- A channels communicate through a single wire
- Think of PPM as several PWM signals "lined up back to back". Same signalling is used as PWM (1-2 ms pulses) but each channel is sent successively, then it loops back to channel 1 after a delay.

Serial protocols:
- Serial receiver is digital lossless protocol with 3 wires (signal, power, ground) for multiple channels.

- SBUS is an inverted UART communication signal
- Bidirectional and also supports telemetry
- Requires a serial port on the flight controller.