UAV Design

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Slides Inspired from Dr. Harikumar Kandath's Lecture in "Intro to UAV Design"

Content

Basic Design Concepts

Design of Multirotor UAVs

Design Wheel

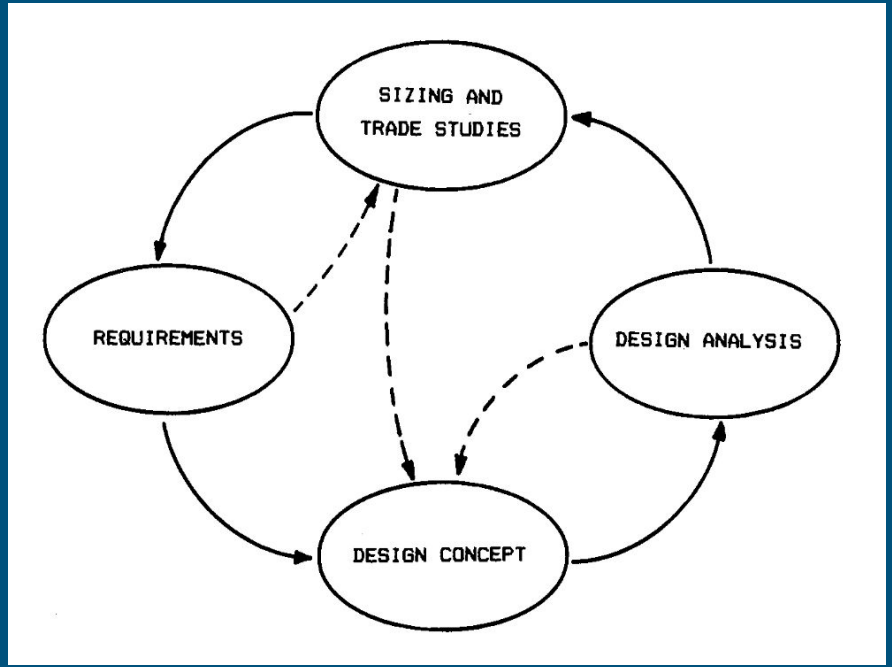


Fig: Design Wheel

Requirement Specifications

Operating velocity

Range : Total distance traversed by a UAV without refuelling/recharging.

Endurance: Total time traversed by a UAV without refuelling/recharging.

Payload: Additional weight that a UAV can carry apart from what essential for flying.

Wind: head, tail and cross.

Altitude

Safety

Maneuverability

Phases of a UAV Flight

Take-off

Climb

Cruise

Loiter

Descent

Landing

Aggressive flight maneuvers (fighter UAV)

UAV Subsystems

Hardware

- Configuration
- Structures
- Propulsion
- Sensors and actuators
- Computer
- Payload
- GCS (Ground Control System)
- Radio and data telemetry

Software

- Navigation (Sensor Interface)
- Guidance/ Motion Planning
- Control System (Actuator Interface)
- Health Monitoring
- Processing of data from payload sensors
- GCS: Data processing and display, mission planner

Requirement Specifications for Quadcopter

Example:

High level user requirement: Video recording for a continuous duration of 20 min. for outdoor applications within 500m from launch position. The operating altitude will be typically 20m from ground level.

Steps :

Conceptual Design -> Preliminary Design -> Detailed Design

Conceptual Design

- CONOPS (concept of operation)
- Requirement specifications
- Market survey
- Sizing and layout
- Component identification
- Analysis and optimization (theory and simulations)

CONOPS

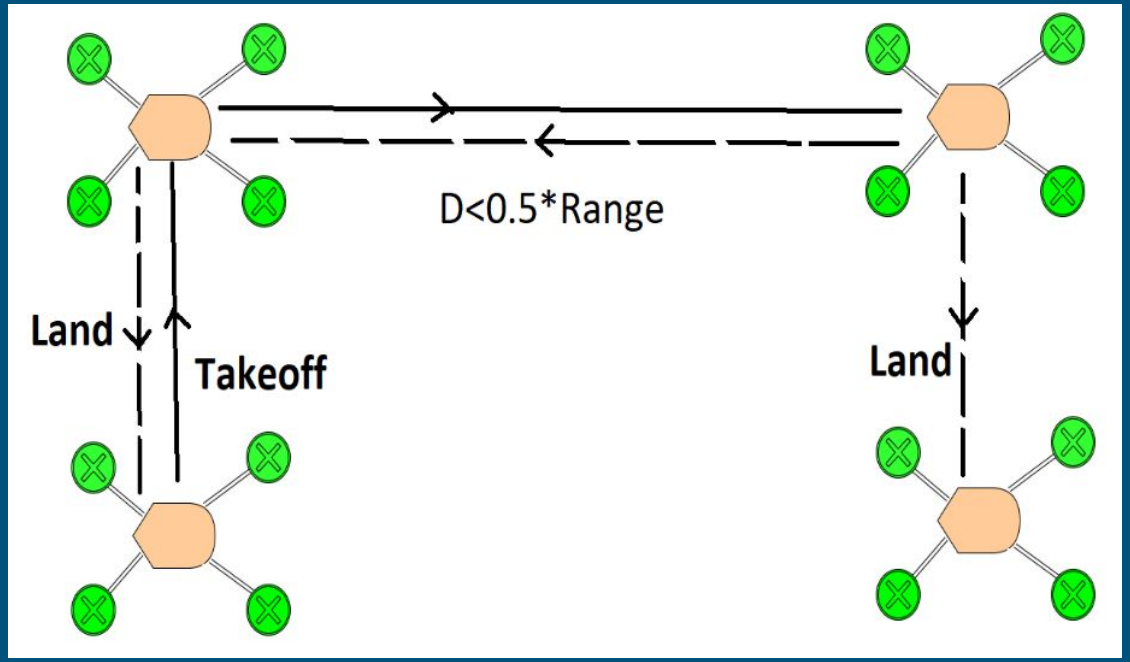


Fig: CONOPS for quadrotor mission

Derived Specifications from User

- Endurance = 30 min
- Range = 1.5 km
- Altitude =20m
- Wind speed = 5m/s (Based on the region)
- Payload = camera

Market Survey - 1

Fig: DJI Mavic 2

- Take-off weight = 0.907 kg
- Size = 0.322×0.242×0.084m (L×W×H)
- Climb and descent rate = 5,3m/s
- Endurance = 31 min
- Range = 18 km
- Cruise speed = 20m/s
- Max. altitude =6000m
- Wind speed = 8m/s
- Payload = CMOS camera with 77° FOV
- Propeller = 8.7 x 4.3 inches

Market Survey -2

- Take-off weight = 2.5 kg
- Size = 1.05×1.05×0.45m (L×W×H)
- Climb rate = 4m/s
- Endurance = 30 min
- Range = 1 km (limited by communication)
- Cruise speed = 11m/s
- Max. altitude =3500m
- Wind speed = 10m/s
- Payload = Kodak 10 MP camera (0.1 kg)

Fig: Skywalker-X41

Estimate from market survey

Market survey

- Take-off weight = 2.5 Kg
- Climb rate = 2m/s
- Payload weight= 0.4 kg
- Cruise speed = 10m/s
- Propeller≈10x5 inches

User

- Endurance = 30 min
- Range = 1.5 km
- Altitude =20m
- Wind speed = 5m/s. (Based on the region)

Major Element of a UAV - Thrust

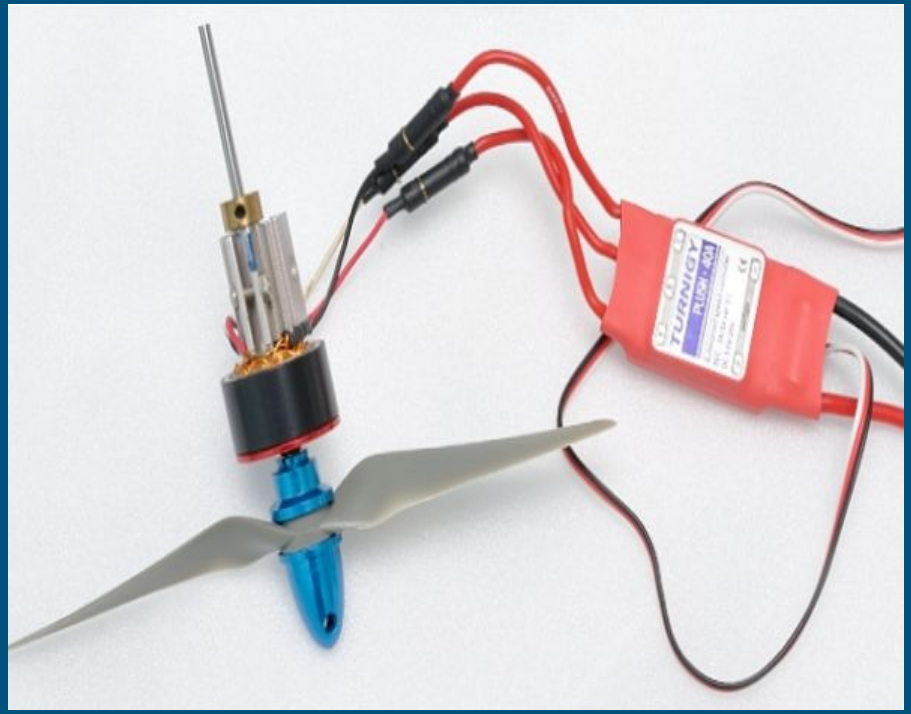
BLDC motor - Propeller Combination controlled by an ESC (Electronic Speed Controller)

$$T = c_t \rho n^2 D^4$$

c = coefficient of thrust, ρ = density of air (kg/m^3),
n = propeller RPS (rotation per second), D = propeller diameter (m)

Ideally, Quadrotor hovers at 50-60% of the max Thrust value.

$4\ T_{max} = 2\ mg$ $\qquad$ $T_{max} = 12.5\ N$



Motor and Battery Rating

Propeller Efficiency = (60-70%)

Assuming 65 % propeller efficiency, motor needs to deliver 190 watts of power.

Motor efficiency, η_m(75-85) %. Motor input power M_{pin},

$M_{pin} = P_{inmax}/\eta_m$

Battery output power B_{pout}

B_{pout}=Voltage x Current

Lithium-Polymer battery, 4S (4*4.2=16.8 Volts), need to deliver 14 Ampere maximum current.

Components Required

- GPS
- Accelerometer
- Gyroscope
- Magnetometer
- Altimeter
- Propeller
- BLDC Motor + ESC
- Battery
- Payload - camera
- Autopilot hardware
- Remote control receiver and data telemetry

Position

GPS- Global Positioning System (satellite)Signal frequency L_1= 1575.42 MHz,L_2= 1227.60 MHz.Accuracy within a few meters (expressed in CEP (circular error probability)

Orientation and Angular velocities

IMU - Inertial Measurement Unit

Combination of Accelerometers, Gyroscopes, and sometimes Magnetometers

IMU- MPU 9150 (InvenSense)
Acceleration =±4g
Gyroscope =±500 deg/s
Magnetometer =±2 Gauss
Data rate = 1 KHz

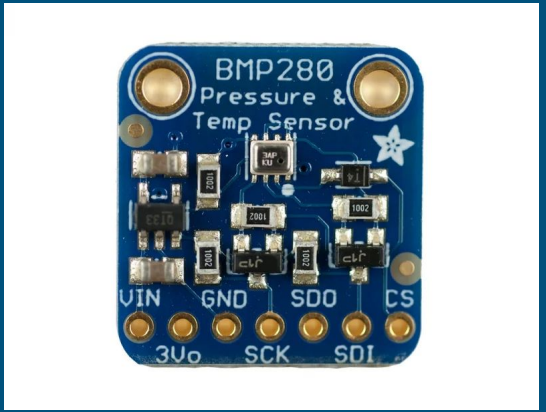
Height

Altimeter

BMP280, range 30000 Pa to 110000 Pa

Sea level pressure = 101325 Pa (1 Pa= $1N/m_2$)

At 30 m, pressure=101001 Pa. Max 6.6 Km from sea level



Upward Thrust

Propeller of Calculated Diameter

Requirement:T_h= 6.15Natn= 100 RPS

APC-11x5 inches,T_h= 6.7N
(UIUC propeller database)

Battery

Requirement: 14 A for 4S (4x4.2=16.8V) Orange 8000mAh, 4S, 35C

Camera + Gimbal

Max. 120 fps (1280px720p), max. 2880px2160p (24 fps video), still photo max. 4608x3456,α_d= 45°

Stabilizing camera from the oscillations of the UAV

Flight Controller

Ardupilot Pixhawk / PX4

On board flight controller with different modes and PID. Easily tunable and has a lot of different functionalities.

Processor

- 32-bit ARM Cortex M4 core with FPU (floating point unit)
- 168 Mhz/256 KB RAM/2 MB Flash
- 32-bit fail-safe co-processor

Sensors

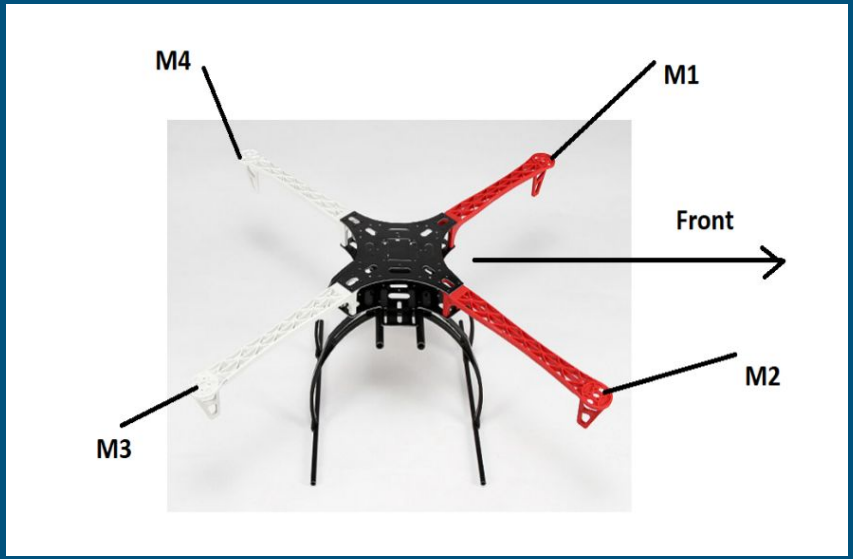
- MPU6000 as main accel and gyro
- ST Micro 16-bit gyroscope
- ST Micro 14-bit accelerometer/ (magnetometer)
- MEAS barometer

Telemetry

Radio Receiver and Transmitter

Body

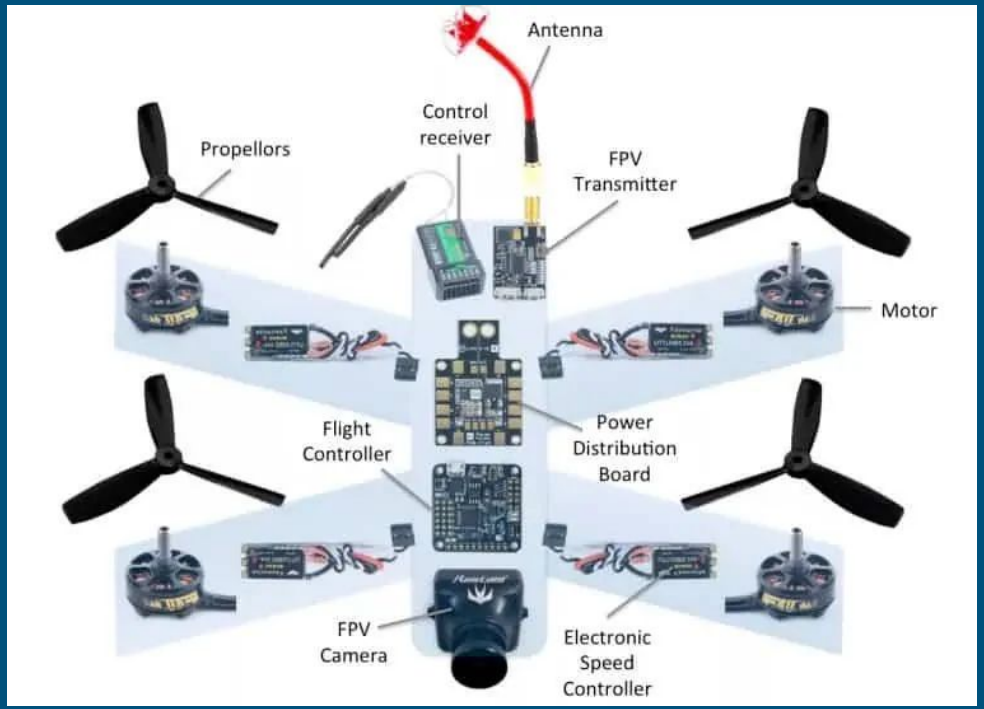
Materials used: Carbon fiber, Nylon, glass fiber



Weight Estimation

Component	**Weight** (grams)
GPS	12
Autopilot	38
RC receiver	9
Data Telemetry	67
Propeller	4x40=160
Motor	4x112=448
ESC	4x15=60
Battery	720
Camera	64
Gimbal	400
Structure	600+200=800
Total	**2778**

Final Assembly



THANK YOU!