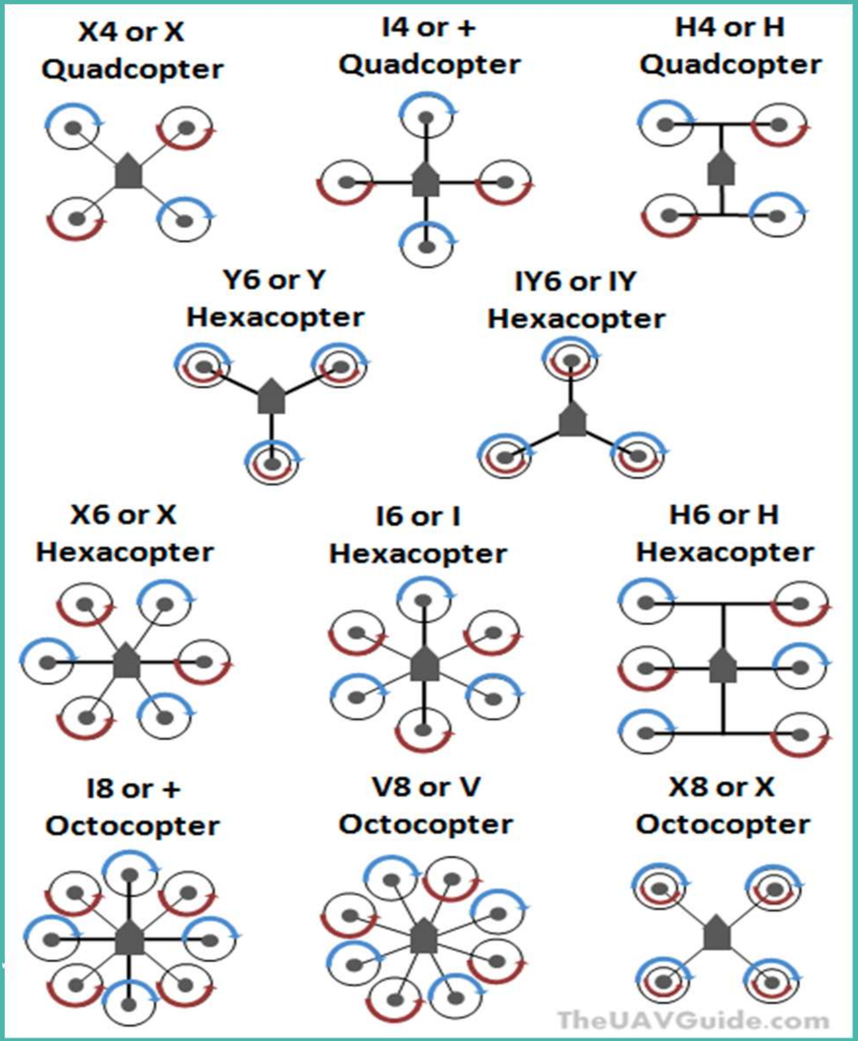
Aerial Robotics

Introduction to Autonomous Drones

Types of Unmanned Aerial Vehicles

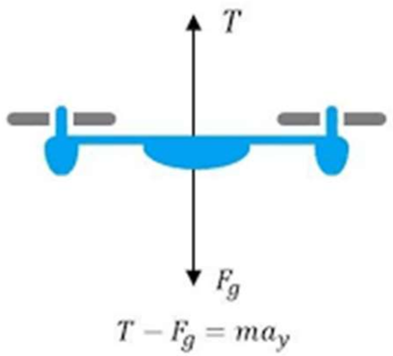
Different Types of Multirotors



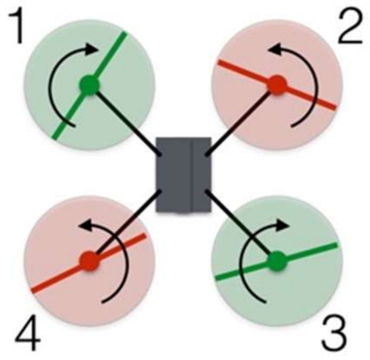
Quadcopters

Flight Basics:

FBD of a Quadcopter



Direction of Rotation of Propellers



Overview of Quadcopter Parts

- The frame
- Motors
- Electronic Speed Control (ESC)
- Flight Control Board
- Radio Transmitter and Receiver
- Propellers
- Battery and Charger

The frame connects all of the other components. For a quadcopter, it's shaped in either an X or a + shape.Usually made out of Carbon Fibre, Aluminium, Fiberglass or 3D printed.

The motors spin the propellers, and provides Thrust. Higher the kV, faster the motor will spin. Kv is often quoted in RPM per volt.

Propellers attached to the motors to provide thrust as a result of aerodynamic lift. More the number of blades more is the thrust, beware it's not directly proportional to the number of blades.

Electric Speed Controls (ESCs) is the component that connect the motors to the battery. They relay a signal to the motors that tells them how fast to spin. "PWM to 3 or 6 phase AC"

The Flight Control Board is the "commander of operations". It uses the information from accelerometer and gyroscopes, which control how fast each motor spins.

The radio transmitter and **receiver** are responsible for the communication to the Quadcopter.

Battery is obviously required as a power source

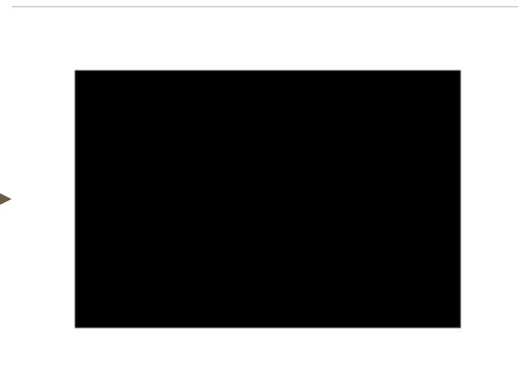
Primary Goal

Build a drone

Sizing

Sizing

- Payload
- Flight Time
- Maneuverability
- Safety



- Thrust Required
- No. of Rotors
- Propeller Size
- Fuel Source (Battery/Fuel)

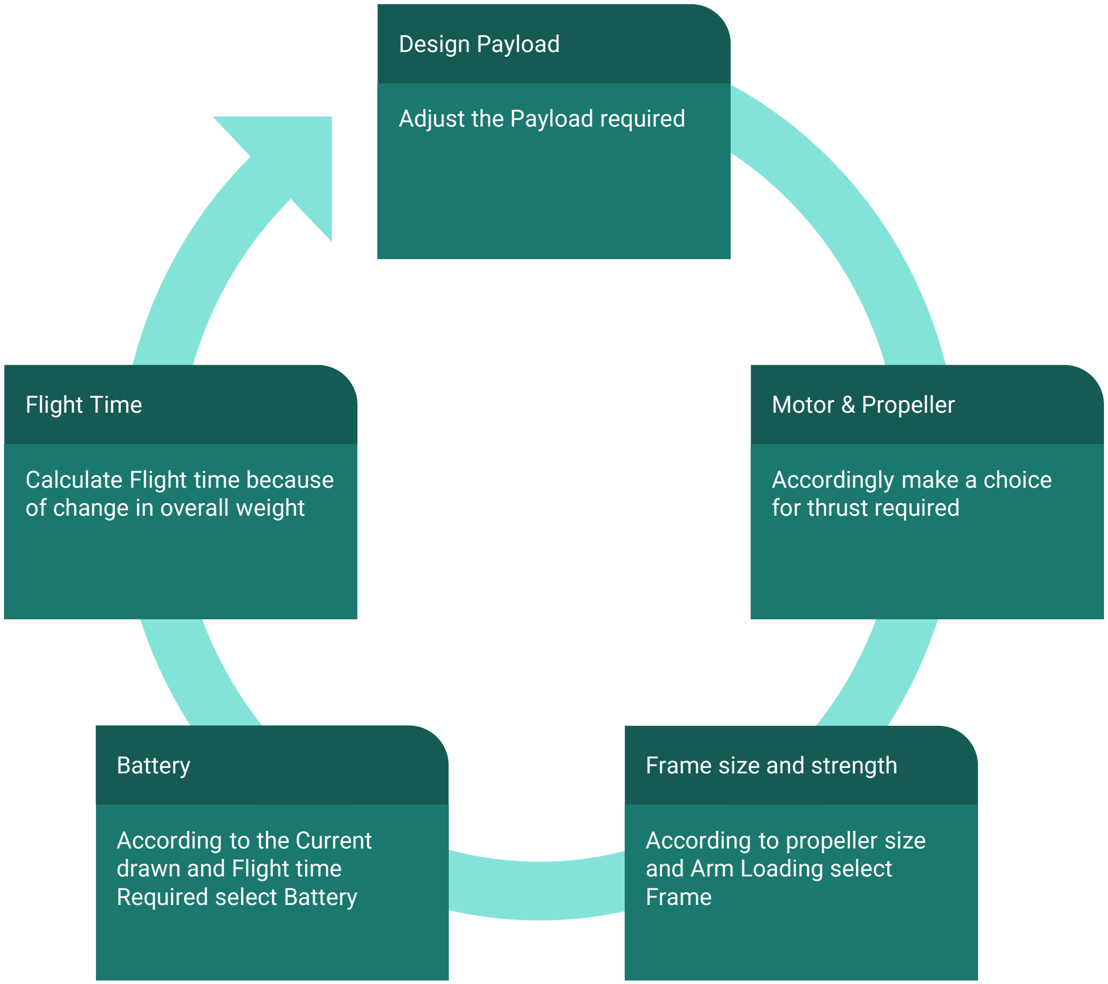
Intuitive Sizing

By using fundamental Laws of Physics:

1) Balancing Thrust and weight
2) Finding suitable Motor Propeller Combination
3) Selecting ESC to support current limits of Motors
4) Looking for battery for suitable Flight time
5) Adjusting the weight again and OOPS lower flight time

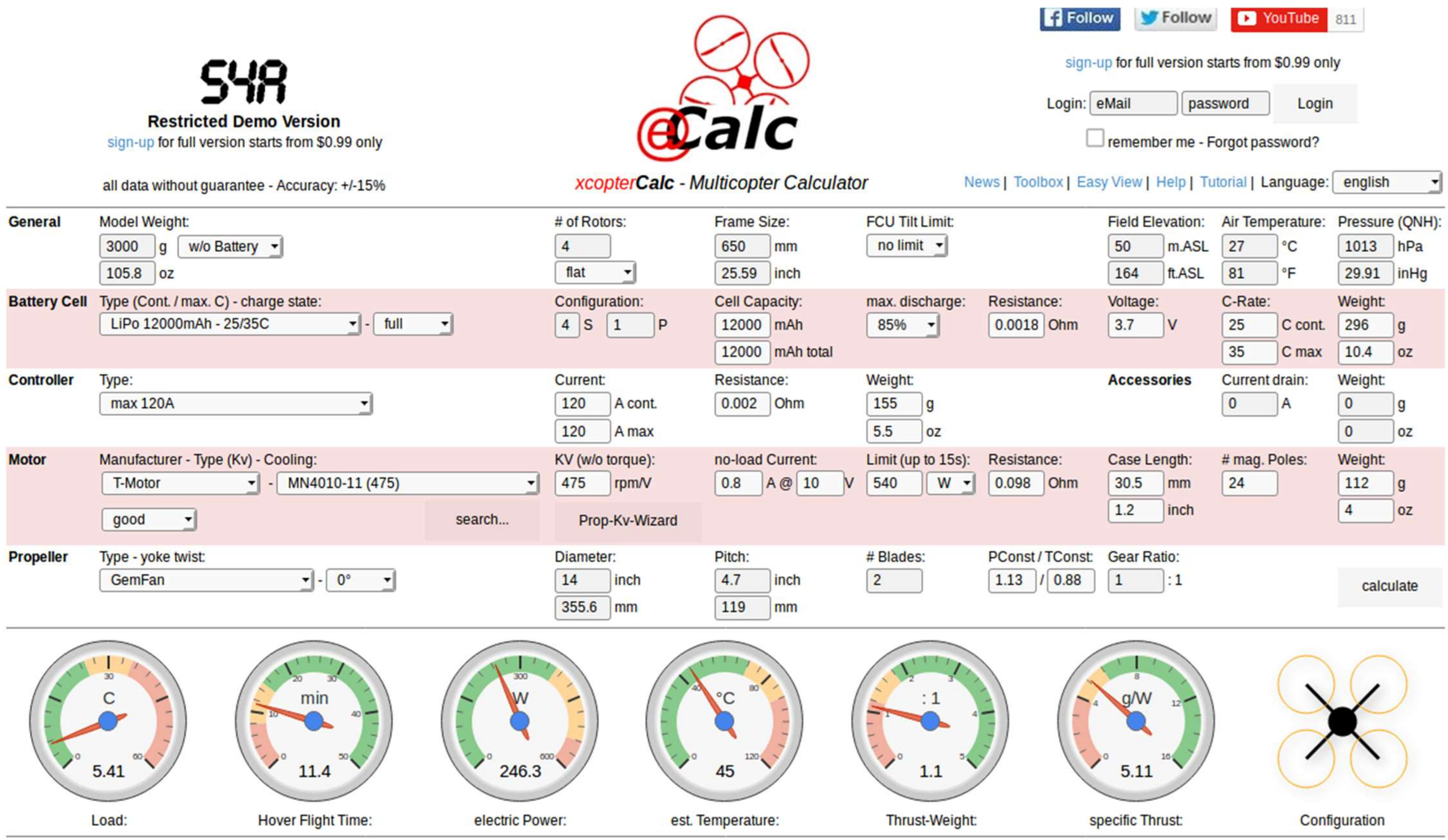
Becomes an iterative process!!

Sizing



Design Payload
Adjust the Payload required
Motor & Propeller
Accordingly make a choice for thrust required
Frame size and strength
According to propeller size and Arm Loading select Frame
Battery
According to the Current drawn and Flight time Required select Battery
Flight Time
Calculate Flight time because of change in overall weight

Or Use Sizing resources


S4R
Restricted Demo Version
sign-up for full version starts from $0.99 only
all data without guarantee - Accuracy: +/-15%
eCalc
xcopterCalc - Multicopter Calculator
Follow
Follow
YouTube 811
sign-up for full version starts from $0.99 only
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General
Model Weight: 3000 g w/o Battery 105.8 oz
# of Rotors: 4 flat
Frame Size: 650 mm 25.59 inch
FCU Tilt Limit: no limit
Field Elevation: 50 m.ASL 164 ft.ASL
Air Temperature: 27 °C 81 °F
Pressure (QNH): 1013 hPa 29.91 inHg
Battery Cell
Type (Cont. / max. C) - charge state: LiPo 12000mAh - 25/35C - full
Configuration: 4 S 1 P
Cell Capacity: 12000 mAh 12000 mAh total
max. discharge: 85%
Resistance: 0.0018 Ohm
Voltage: 3.7 V
C-Rate: 25 C cont. 35 C max
Weight: 296 g 10.4 oz
Controller
Type: max 120A
Current: 120 A cont. 120 A max
Resistance: 0.002 Ohm
Weight: 155 g 5.5 oz
Accessories
Current drain: 0 A
Weight: 0 g 0 oz
Motor
Manufacturer - Type (Kv) - Cooling: T-Motor - MN4010-11 (475) good
search...
KV (w/o torque): 475 rpm/V
Prop-Kv-Wizard
no-load Current: 0.8 A @ 10 V
Limit (up to 15s): 540 W
Resistance: 0.098 Ohm
Case Length: 30.5 mm 1.2 inch
mag. Poles: 24
Weight: 112 g 4 oz
Propeller
Type - yoke twist: GemFan - 0°
Diameter: 14 inch 355.6 mm
Pitch: 4.7 inch 119 mm
Blades: 2
PConst / TConst: 1.13 / 0.88
Gear Ratio: 1 : 1
calculate
C 5.41
Load:
min 11.4
Hover Flight Time:
W 246.3
electric Power:
°C 45
est. Temperature:
: 1 1.1
Thrust-Weight:
g/W 5.11
specific Thrust:
Configuration

Flight Modes

Modes	Altitude Control	Position Control	Gps Reqd	
Acro	Manual	Manual	N	RC Flight mode
Stabilize	Manual	Self Levelling	N	Holding steady level
Alt Hold	Auto	Self Levelling	N	Maintaining altitude
Loiter	Auto	Self Levelling (Holds Position)	Y	Holding position w/ GPS
Auto	Auto	Auto	Y	Pre-Loaded waypoint mission
Guided	Auto	Auto	Y	Single coordinate waypoints
Land	Auto	Auto	Y	Auto Landing w/ GPS or beacon
RTL	Auto	Auto	Y	Auto return to original take-off Location

Electrical Layout

Flight Controllers

Readily available in market:

Open source:

- Pixhawk
- Naze

Commercial:

- DJI N3
- DJI A3

For Racing drones:

- Omnibus F4

Need of building a controller on our own:

- Depending on different requirements
- Building a modular design

For which we need to have a grasp on:

- Control theory and different control algorithm
- State estimation using various sensors

Types of Control systems

Open Loop Control

- Needs calibration

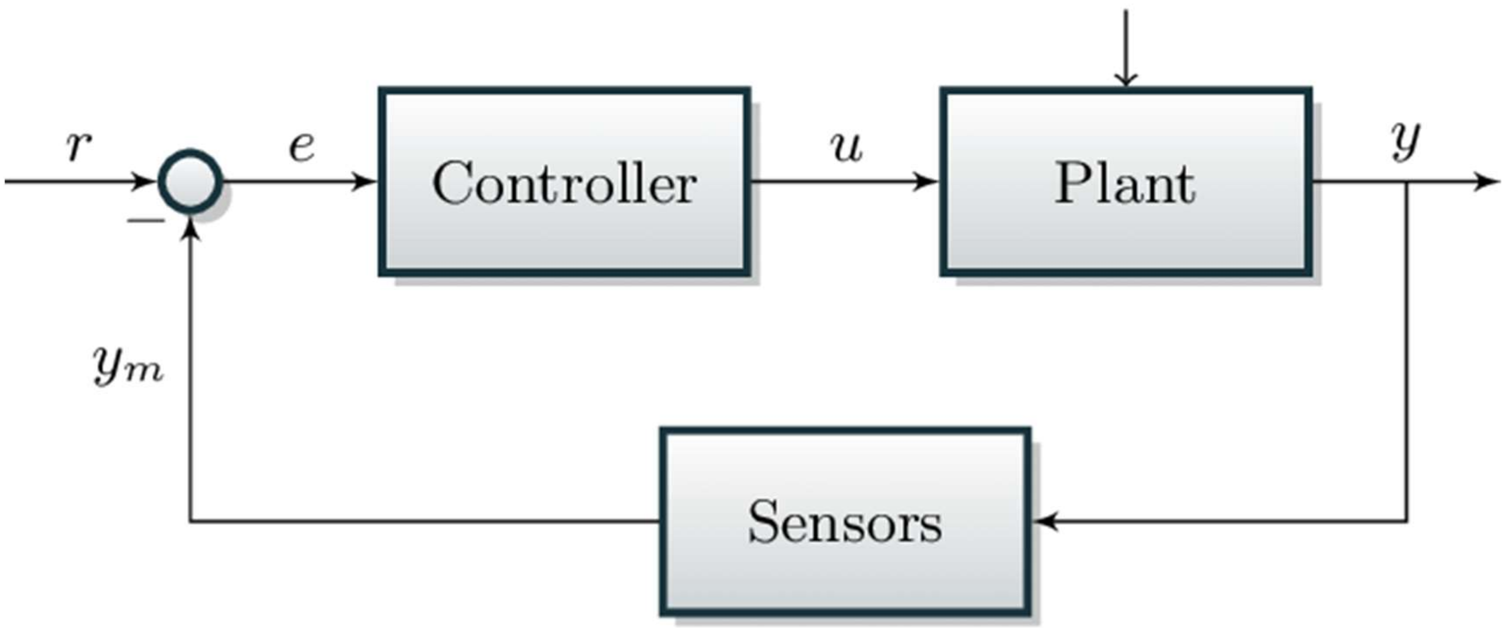
Closed Loop Feedback Control

- Takes real time measurements and changes control input accordingly
- Can stabilize unstable systems without calibration

Feedforward Loop Control

- Any known disturbances can be removed before they even appear, by generating it in software

Closed Loop Feedback Control



General PID Controller

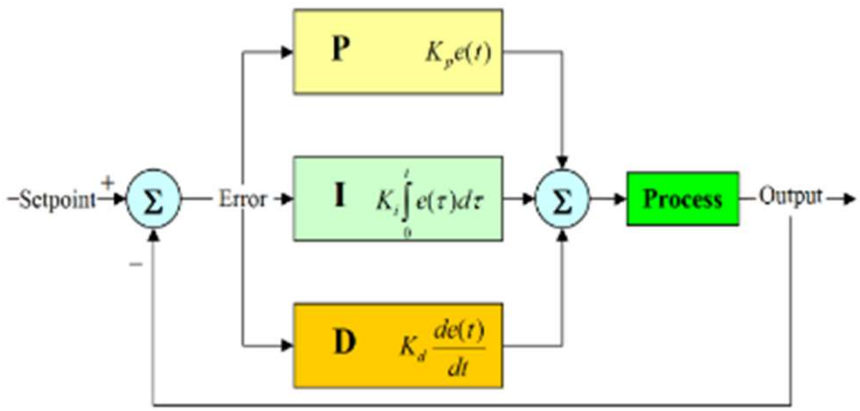


Fig 4: General structure of PID controller.

Linear Feedback Control

PID is the most popular example,

P Gain

- P gain determines **how hard the flight controller works to correct error** and achieve the desired flight path
- Generally speaking, higher P gain means **sharper control** while low P gain means softer control.

I Gain

- I term determines how hard the FC works to **hold the drone's attitude against external forces**, such as wind and off-centered CG.
- When I gain gets too high, your quadcopter will be overly constrained by this, and start to feel **stiff and unresponsive**.

D Gain

- D gain works as a **damper and reduces the over-correcting and overshoots** caused by P term. Like a shock absorber stops the suspension from being bouncy, adding D gain can "**soften**" and **counteract the oscillations** caused by excessive P gain, as well as minimizing propwash oscillations.
- Increasing D gain can improve these problems, however, an excessive D value can introduce vibration in your quadcopter because it amplifies the noise in the system. Eventually this will lead to motor overheat and quad oscillation.

Control Block Diagram for Position Control

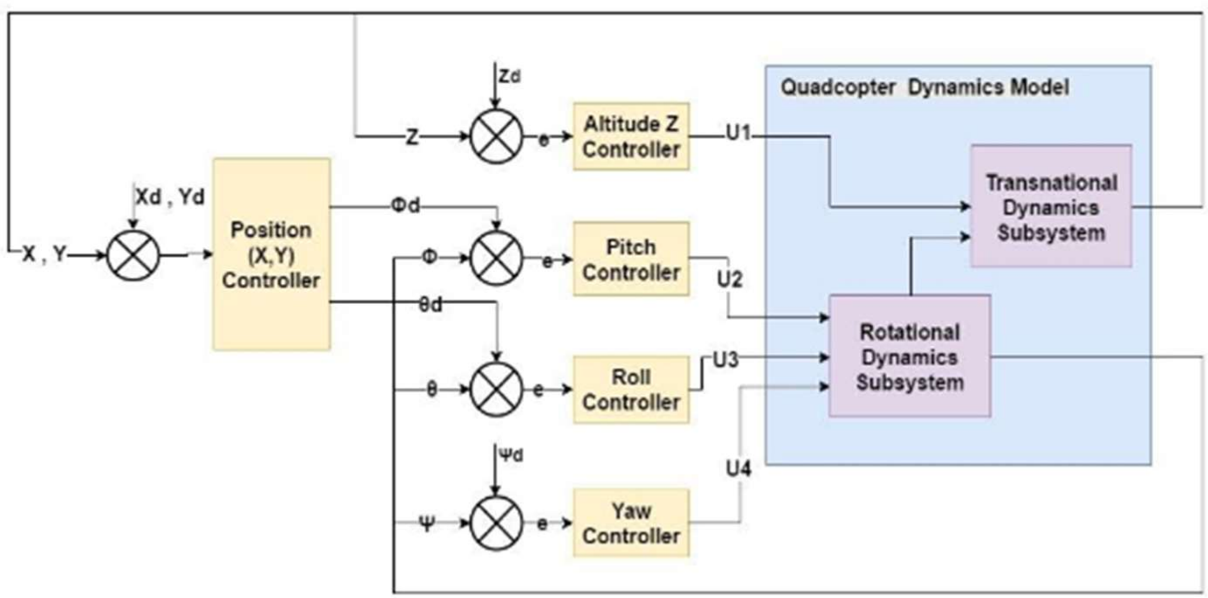
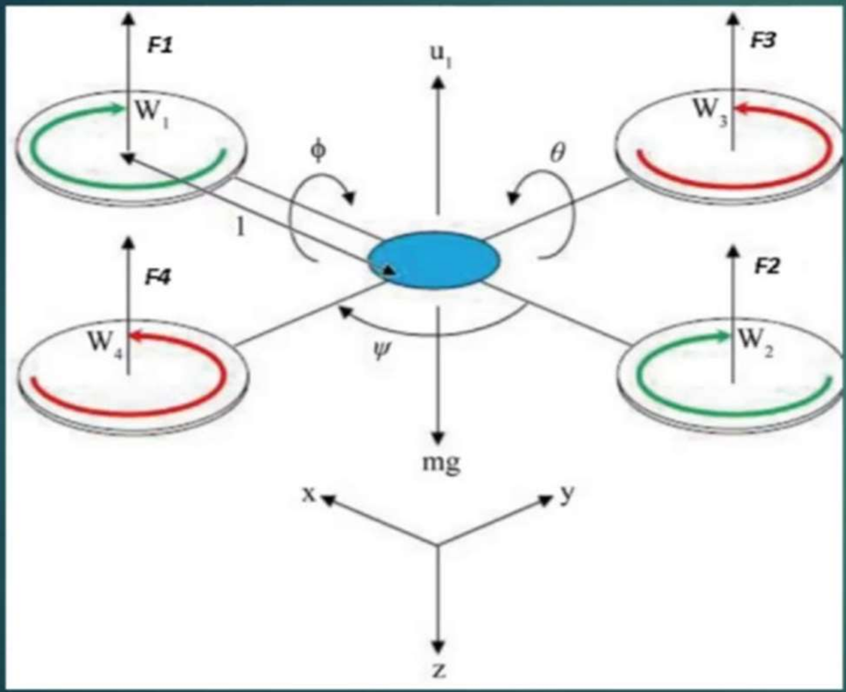


Fig 5: Block diagram of the complete quadcopter control

Forces and Moments on Quadcopter



$$F_i = K_f \times \omega_i^2$$

$$M_i = K_m \times \omega_i^2$$

$$M_y = (F_1 - F_2) \times L$$

$$M_x = (F_3 - F_4) \times L$$

$$Weight = mg$$

Equations of Motion

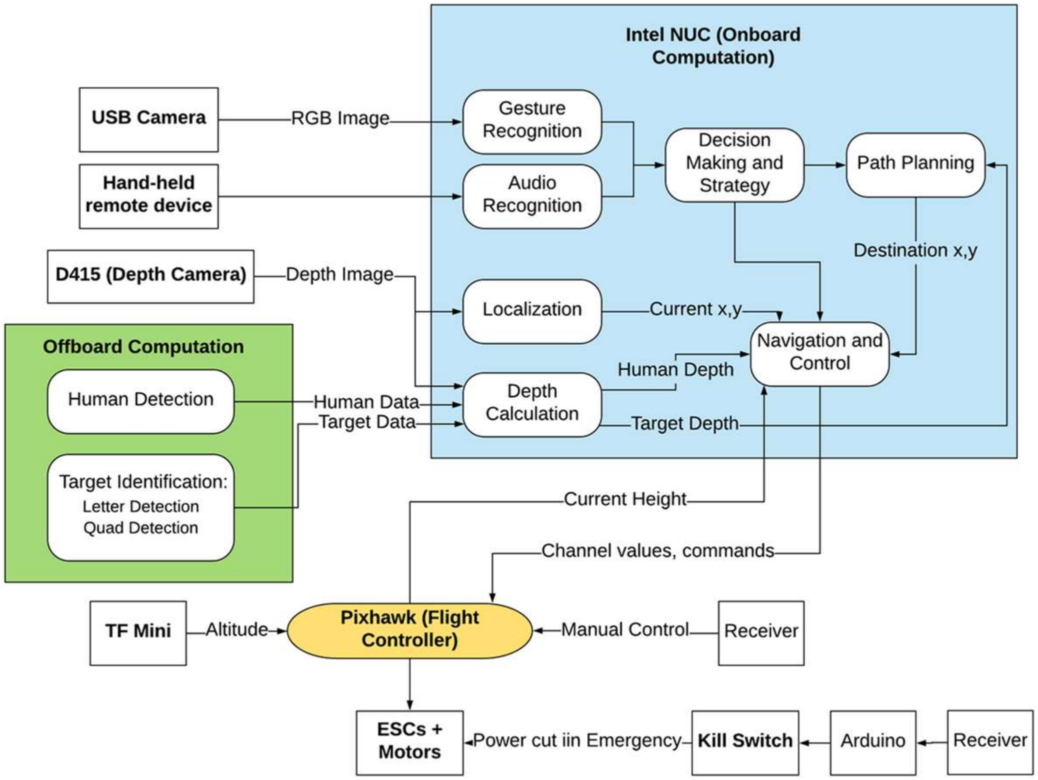
$$
\begin{aligned}
\dot{u} &= -g\sin(\theta) + rv - qw \\
\dot{v} &= g\sin(\phi)\cos(\theta) - ru + pw \\
\dot{w} &= \tfrac{1}{m}(-F_z) + g\cos(\phi)\cos(\theta) + qu - pv \\
\dot{p} &= \tfrac{1}{I_{xx}}(L + (I_{yy} - I_{zz})qr) \\
\dot{q} &= \tfrac{1}{I_{yy}}(M + (I_{zz} - I_{xx})pr) \\
\dot{r} &= \tfrac{1}{I_{zz}}(N + (I_{xx} - I_{yy})pq) \\
\dot{\phi} &= p + (q\sin\phi + r\cos\phi)\tan\theta \\
\dot{\theta} &= q\cos\phi - r\sin\phi \\
\dot{\psi} &= (q\sin\phi + r\cos\phi)\sec\theta \\
\dot{x}^E &= c_\theta c_\psi u^b + (-c_\phi s_\psi + s_\phi s_\theta c_\psi)v^b + (s_\phi s_\psi + c_\phi s_\theta c_\psi)w^b \\
\dot{y}^E &= c_\theta s_\psi u^b + (c_\phi c_\psi + s_\phi s_\theta s_\psi)v^b + (-s_\phi c_\psi + c_\phi s_\theta s_\psi)w^b \\
\dot{h}^E &= -1 * (-s_\theta u^b + s_\phi c_\theta v^b + c_\phi c_\theta w^b)
\end{aligned}
$$

Making it Autonomous

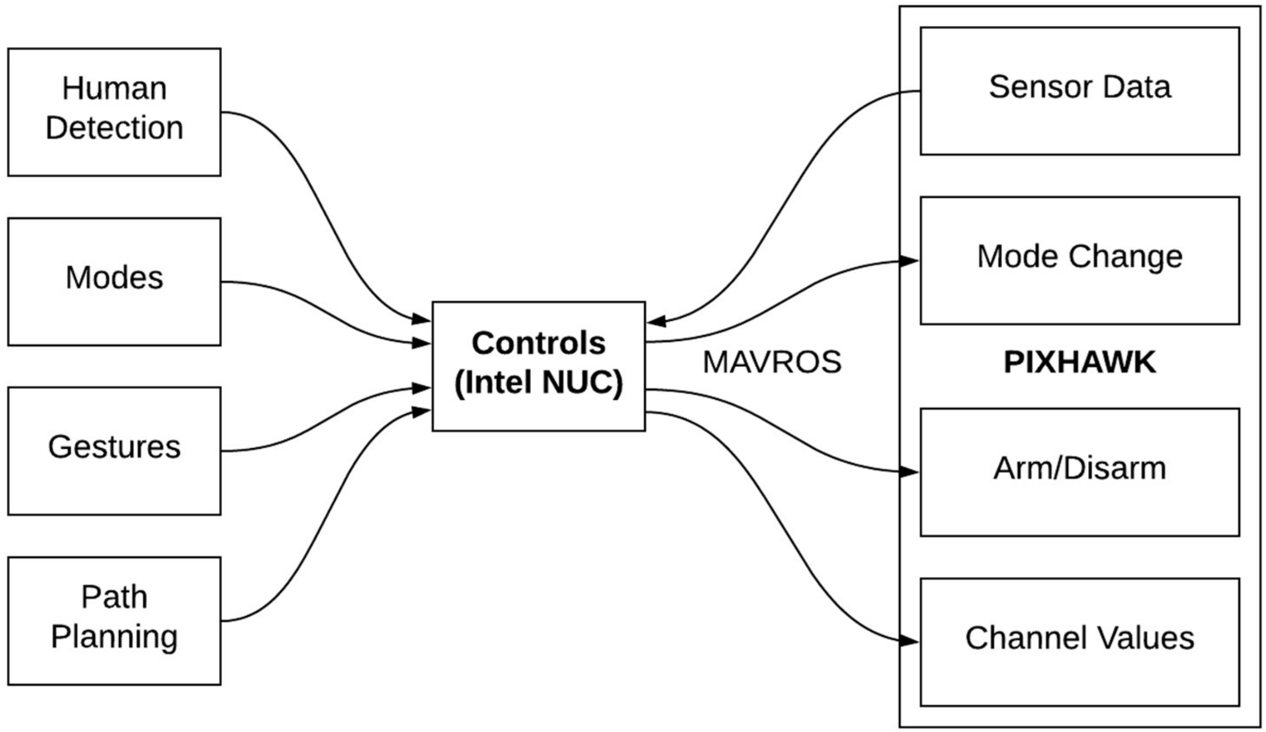
Overview

- STRATEGY
- VEHICLE DESIGN
- SYSTEM ARCHITECTURE
- COMMUNICATION
- LOCALIZATION
- HUMAN TRACKING
- TARGET IDENTIFICATION
- PATH PLANNING
- MAN/MACHINE INTERFACE
- SAFETY

System Architecture



Controls Architecture



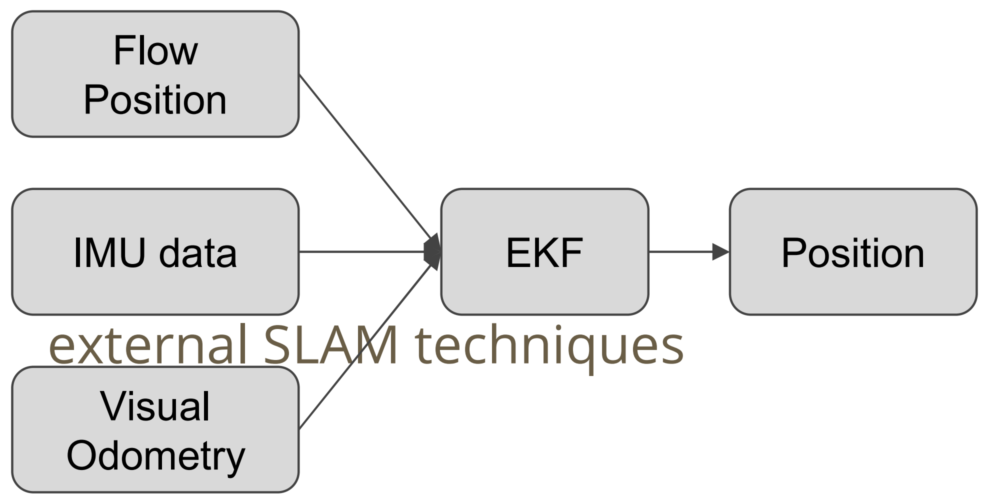
Localisation

Need :

- For knowing relative position of all quadcopters from entry gate
- Feedback to path planning

Challenges :

- GPS denied environment
- Cannot use Beacons, external SLAM techniques



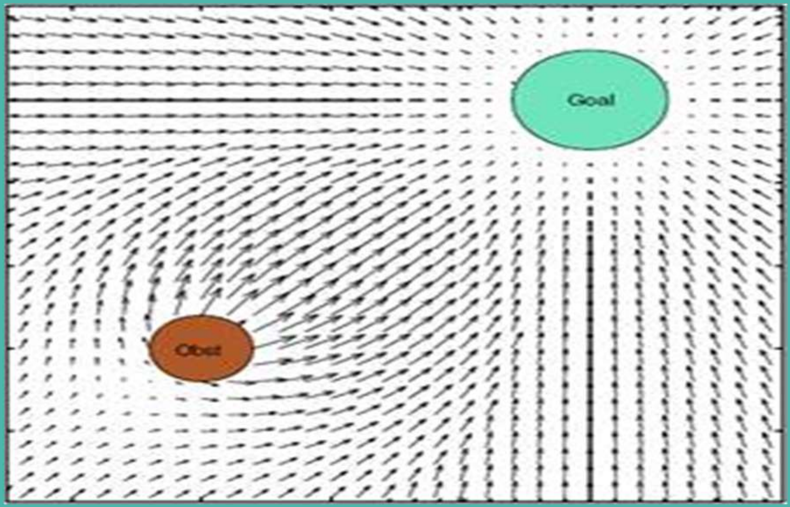
Path Planning

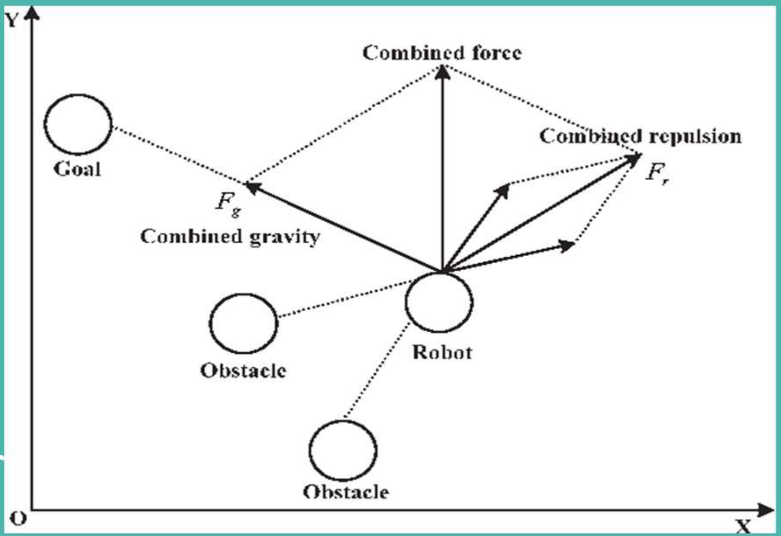
Artificial Potential Fields - Real-time Path Planning Method:

- Goal - constant attractive potential field
- Obstacle - repulsive inverse distance decaying potential field
- Robot moves along net direction of potential field

Advantages:

- Low computational cost
- High operational speed
- Satisfactory results with low obstacle number





Dynamics of Quadcopter

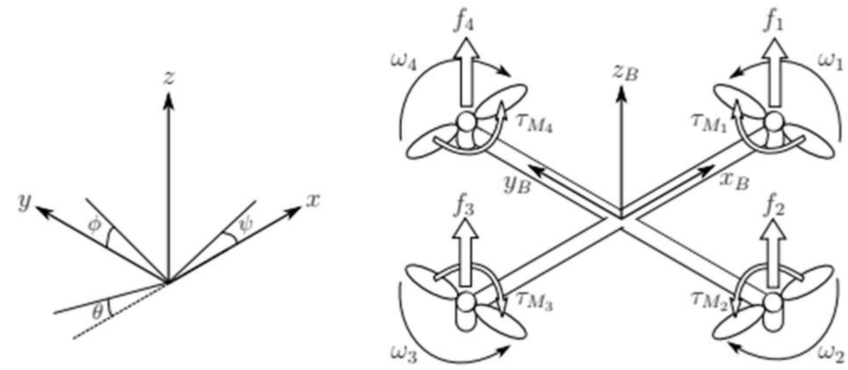


Figure 1: The inertial and body frames of a quadcopter