드론의 제어원리

Professor H.J. Park, Dept. of Mechanical System Design, Seoul National University of Science and Technology.

An Unmanned aerial vehicle (UAV) is a Unmanned Aerial Vehicle. UAVs include both autonomous (means they can do it alone) drones and remotely piloted vehicles (RPVs).

CONTENTS

01 **드론이란 무엇인가?**
드론의 어원, 역사 등을 알아본다.

02 **드론의 분류**
드론의 분류에 대하여 알아본다.

03 **제어원리**
드론의 위치와 자세를 제어하는 원리에 대하여 알아본다.

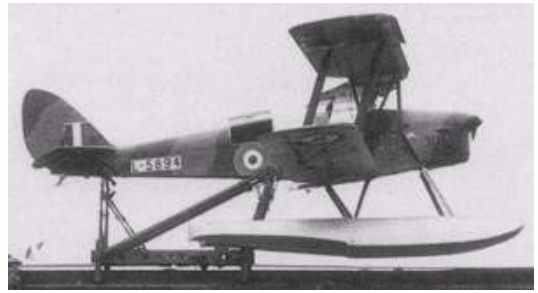
04 **드론용 센서**
IMU 센서의 원리와 센서 융합에 대하여 알아본다.

05 **드론의 구성예**
드론을 구성하는 분품을 살펴본다.

드론이란 무엇인가?

Drone 의 어원

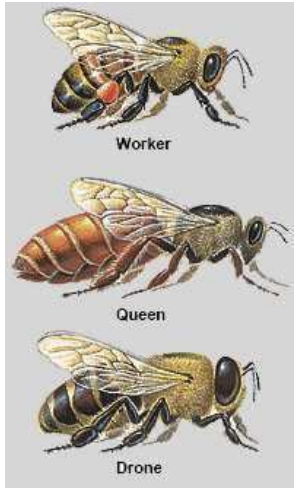
- **정의**:
  - 영어 고어 **Drone** = male bee = lazy people
- 역사
  - 1915: 1차 세계대전 중 무선조종 비행기 개발
  - 1935: 영국해군 DH 82B Queen Bee
  - 1939: Radioplane → Drone



영국 DH 82B "Queen Bee"

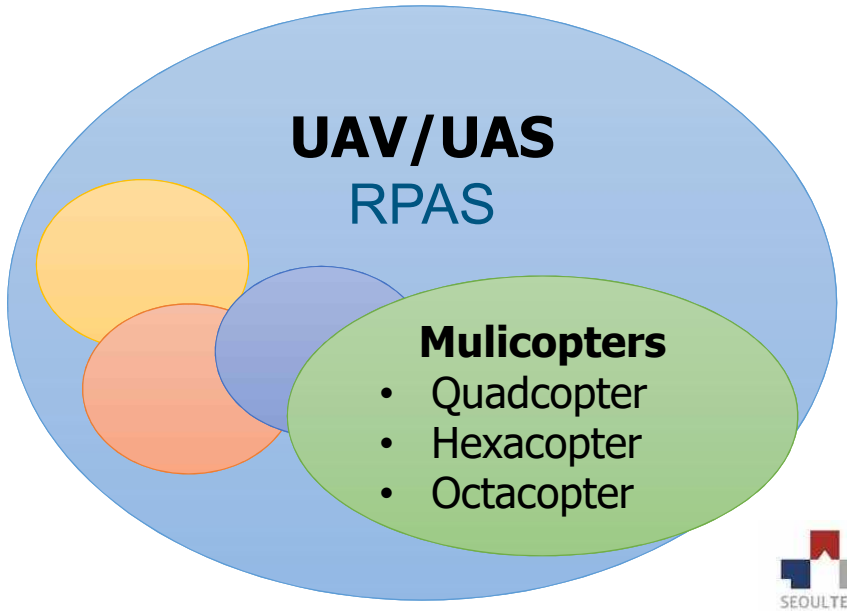
미국 Radioplane - 1939

정찰 및 대공무기의 Target으로 활용됨.



공식명칭

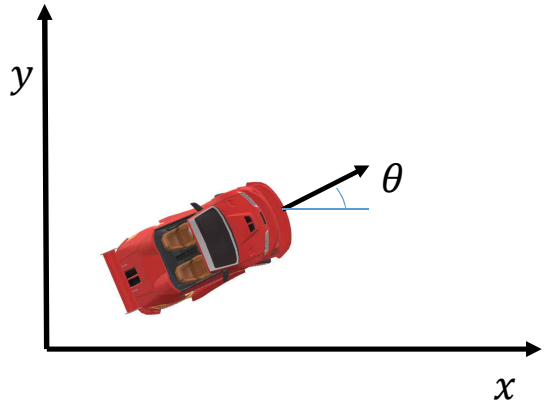
- Official Names
  - Unmanned Aerial Vehicle - UAV
  - Unmanned Aerial System – UAS
  - Remotely Piloted Aircraft Systems - RPAS
  - ***UAS 연방항공국(FAA) 공식이름***

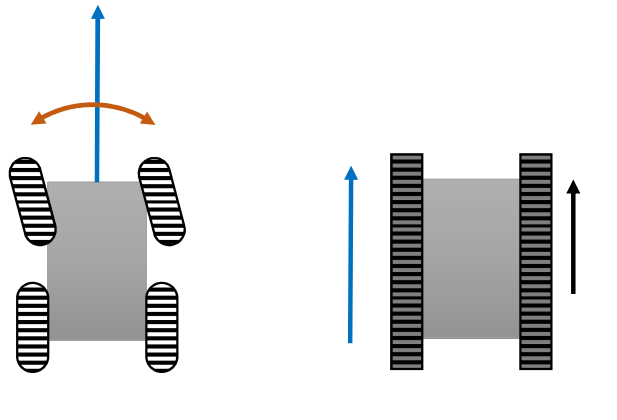


드론의 분류

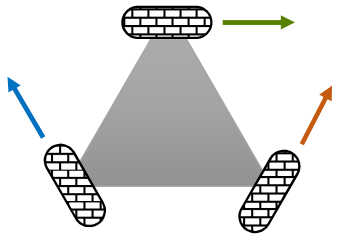
2차원 운동 - 차량, 선박

- 2D상의 차량 상태
  - (x, y, θ) 로 결정
  - 3개의 구동으로 위치/자세를 임의로 결정
    → Holonomic (구동수 = 상태수)
- 상태 결정 방법





non-Holonomic

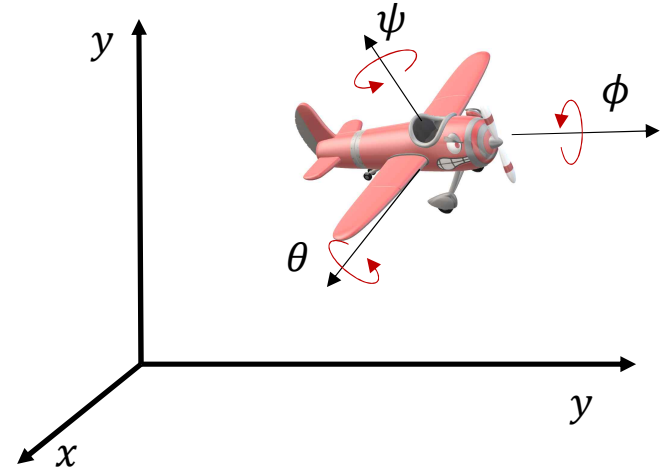


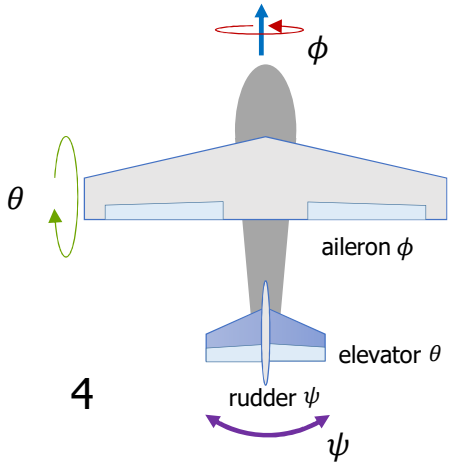
Holonomic

비행체

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

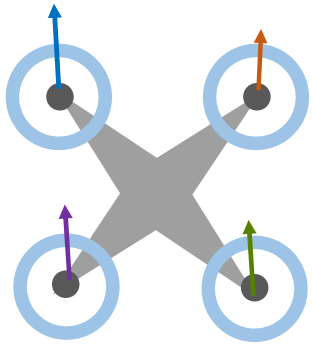
- 공간상의 비행체 상태
  - $(x, y, z, \phi, \theta, \psi)$ 로 결정
  - 6개의 구동으로 6개의 위치/자세를 임의로 결정
    → Holonomic
- 상태 결정 방법



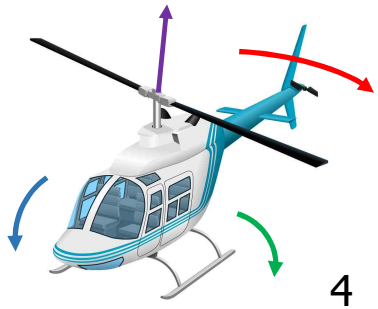


4

non-Holonomic



4

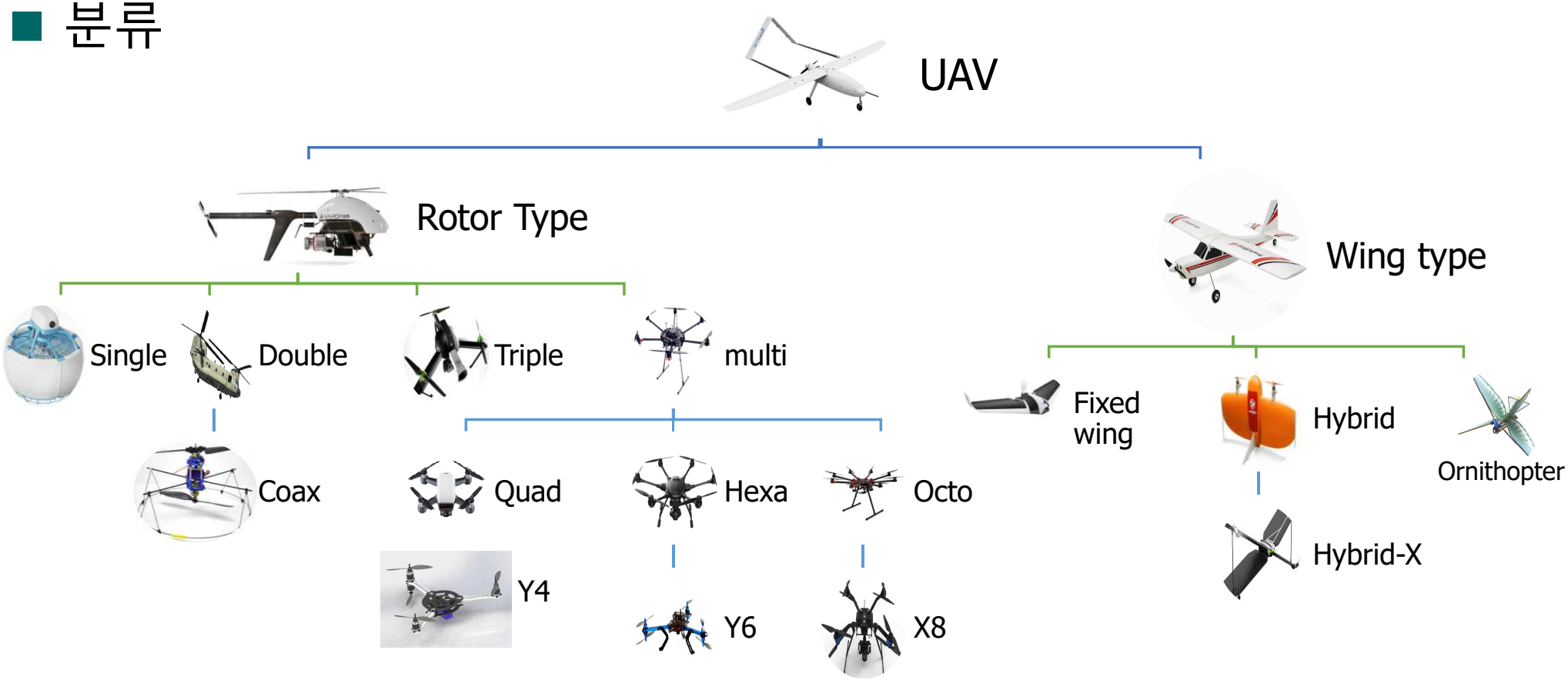


4

드론의 종류

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

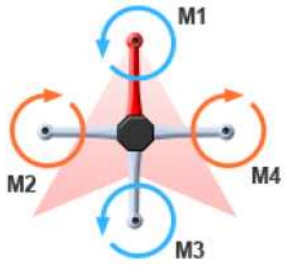
분류



SEOULTECH

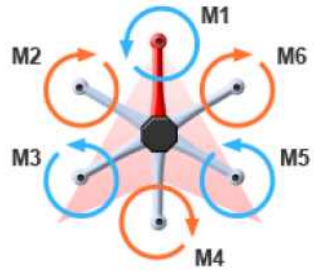
공식 Multi-copter

- 로터의 수는 주로 짝수개
  - 회전 반작용 상쇄에 유리

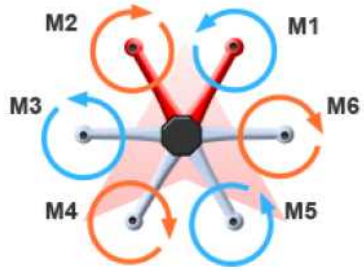


Quad-rotor I

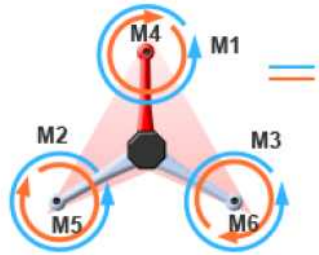
Quad-rotor X



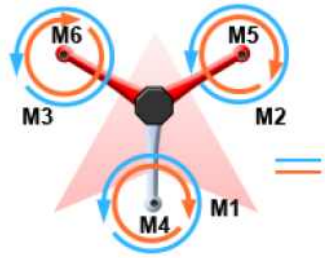
Hexa-rotor I



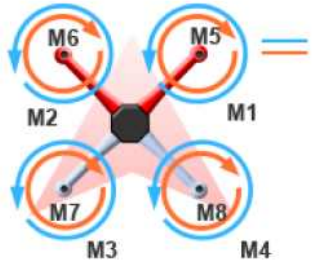
Hexa-rotor V



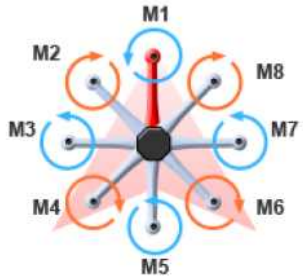
Hexa-rotor IY



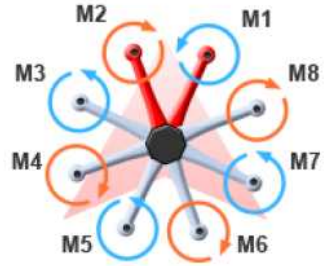
Hexa-rotor Y



Octo-rotor X



Octo-rotor I



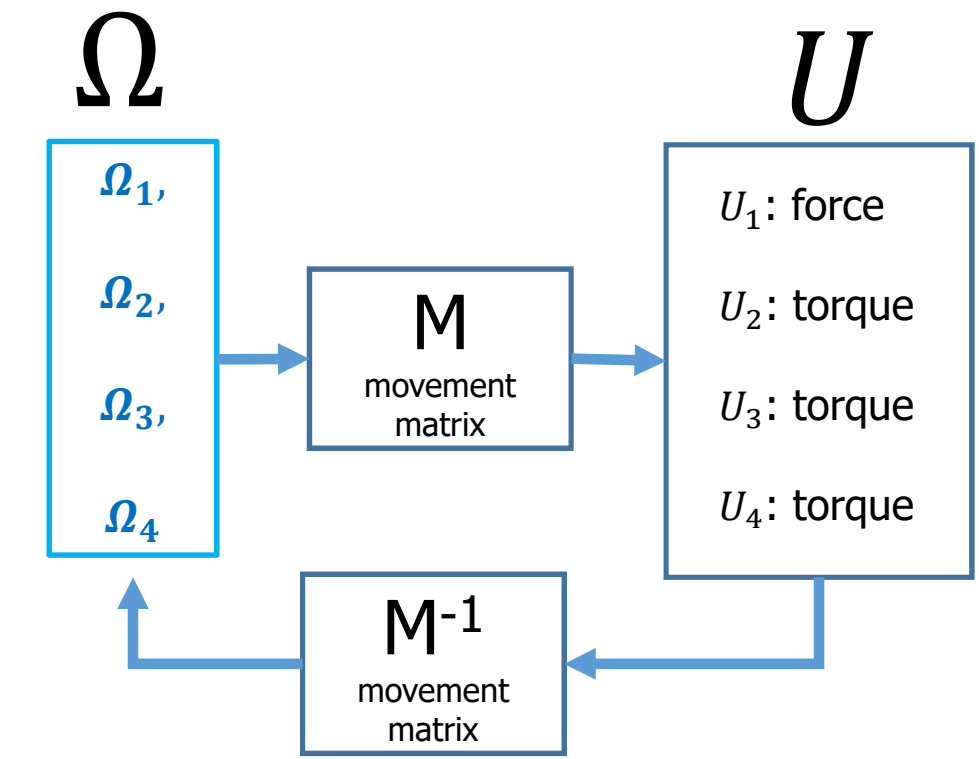
Octo-rotor V

제어원리

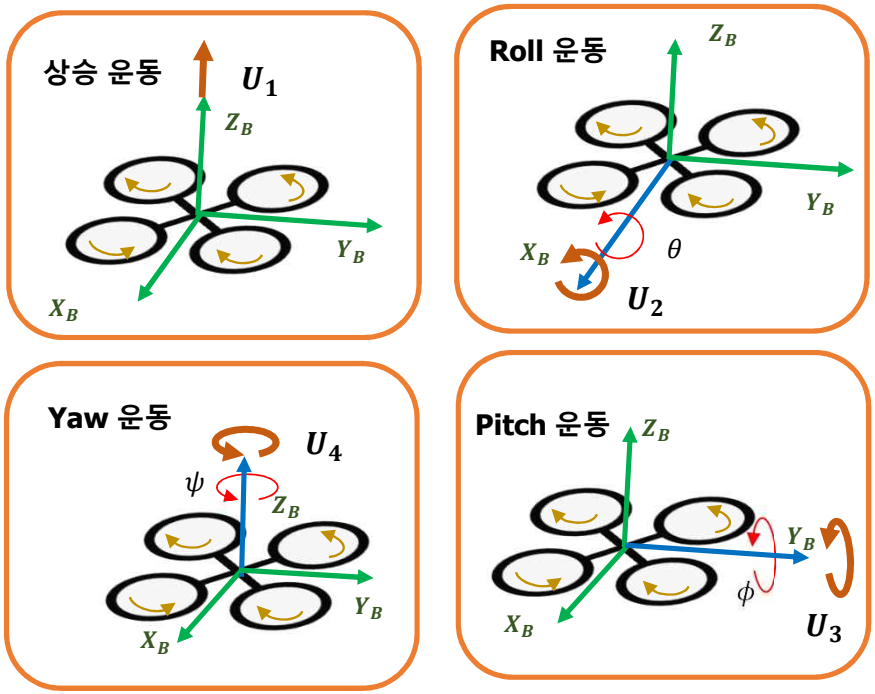
Quadrotor 제어방식

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

- 4개의 프로펠러 회전속도 ➔ 4개의 작용력 ➔ 4개의 운동



Prof. HJ Park



4개의 운동

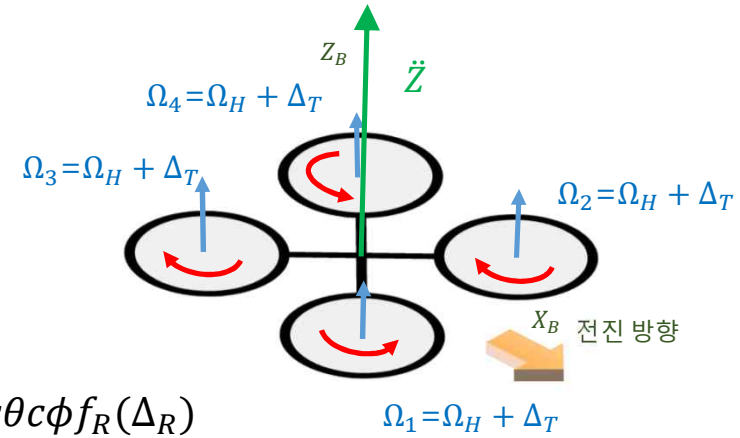
Quadrotor 제어방식

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

■ U_1 **Throttle** 제어: Z_B방향의 가속 $\ddot{Z}$

- 기본 Hovering+Δ_T
  - $\Omega_1 = \Omega_H + \Delta_T$:
  - $\Omega_2 = \Omega_H + \Delta_T$:
  - $\Omega_3 = \Omega_H + \Delta_T$:
  - $\Omega_4 = \Omega_H + \Delta_T$:

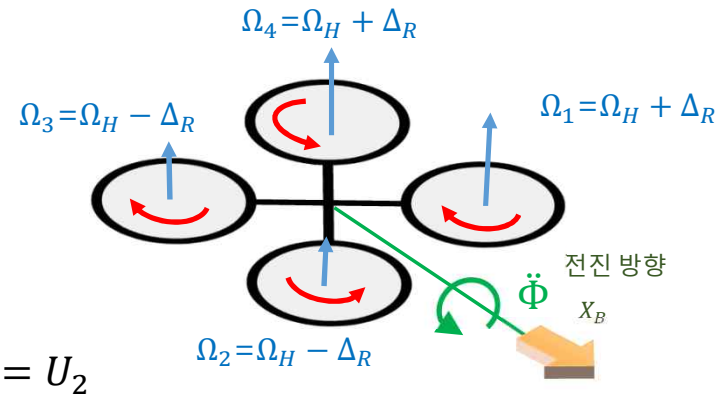
  where Ω_H: speed required for hovering
- $\sum_i \Omega_i = 4(\Omega_H + \Delta_T)$



$$m\ddot{Z} = -m\,g + c\theta c\phi f_R(\Delta_R)$$
$$= -m\,g + c\theta c\phi U_1$$

■ U_2 **Roll 제어**: X_B방향의 회전가속 $\ddot{\Phi}$

- $\Omega_1 = \Omega_H + \Delta_R$:
- $\Omega_2 = \Omega_H - \Delta_R$:
- $\Omega_3 = \Omega_H - \Delta_R$:
- $\Omega_4 = \Omega_H + \Delta_R$:
- $\sum_i \Omega_i = 4\Omega_H$



$$I_{xx}\ddot{\Phi} = 4\ell f_R(\Delta_R) = U_2$$

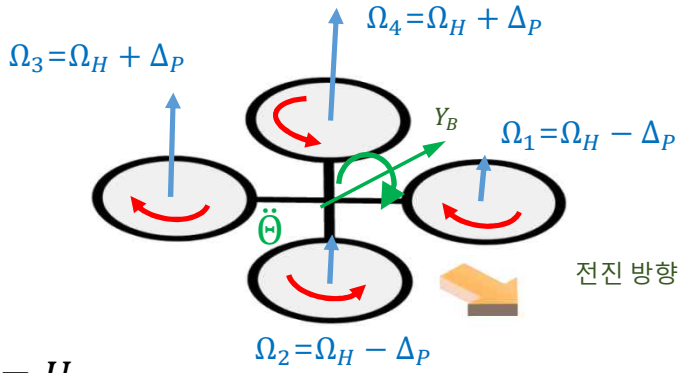
SEOULTECH

Quadrotor 제어방식

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

■ U_3 Pitch 제어: Y_B방향의 회전가속 $\ddot{\Theta}$

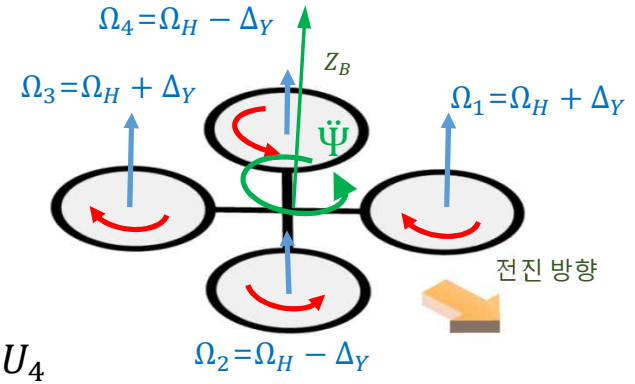
- 기본 Hovering+Δ_P
  - $\Omega_1 = \Omega_H - \Delta_P$:
  - $\Omega_2 = \Omega_H - \Delta_P$:
  - $\Omega_3 = \Omega_H + \Delta_P$:
  - $\Omega_4 = \Omega_H + \Delta_P$:
- $\sum_i \Omega_i = 4\Omega_H$



$$I_{yy}\ddot{\Theta} = 4\ell f_P(\Delta_P) = U_3$$

■ U_4 Yaw 제어: Z_B방향의 회전가속 $\ddot{\Psi}$

- $\Omega_1 = \Omega_H + \Delta_Y$:
- $\Omega_2 = \Omega_H - \Delta_Y$:
- $\Omega_3 = \Omega_H + \Delta_Y$:
- $\Omega_4 = \Omega_H - \Delta_Y$:
- $\sum_i \Omega_i = 4\Omega_H$



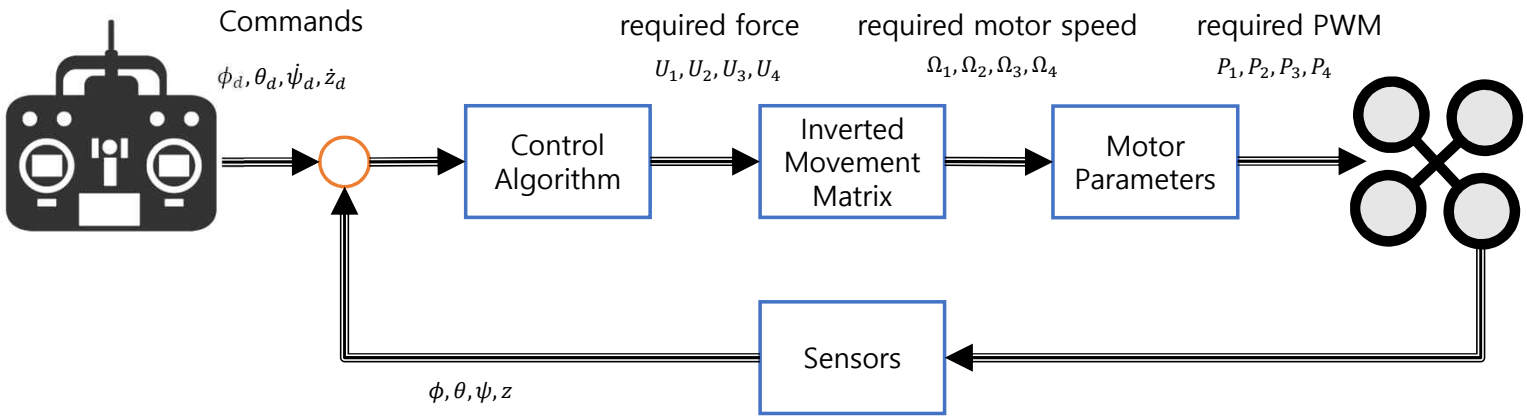
$$I_{zz}\ddot{\Psi} = 4f_Y(\Delta_Y) = U_4$$

SEOULTECH

Quadrotor 제어시스템

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

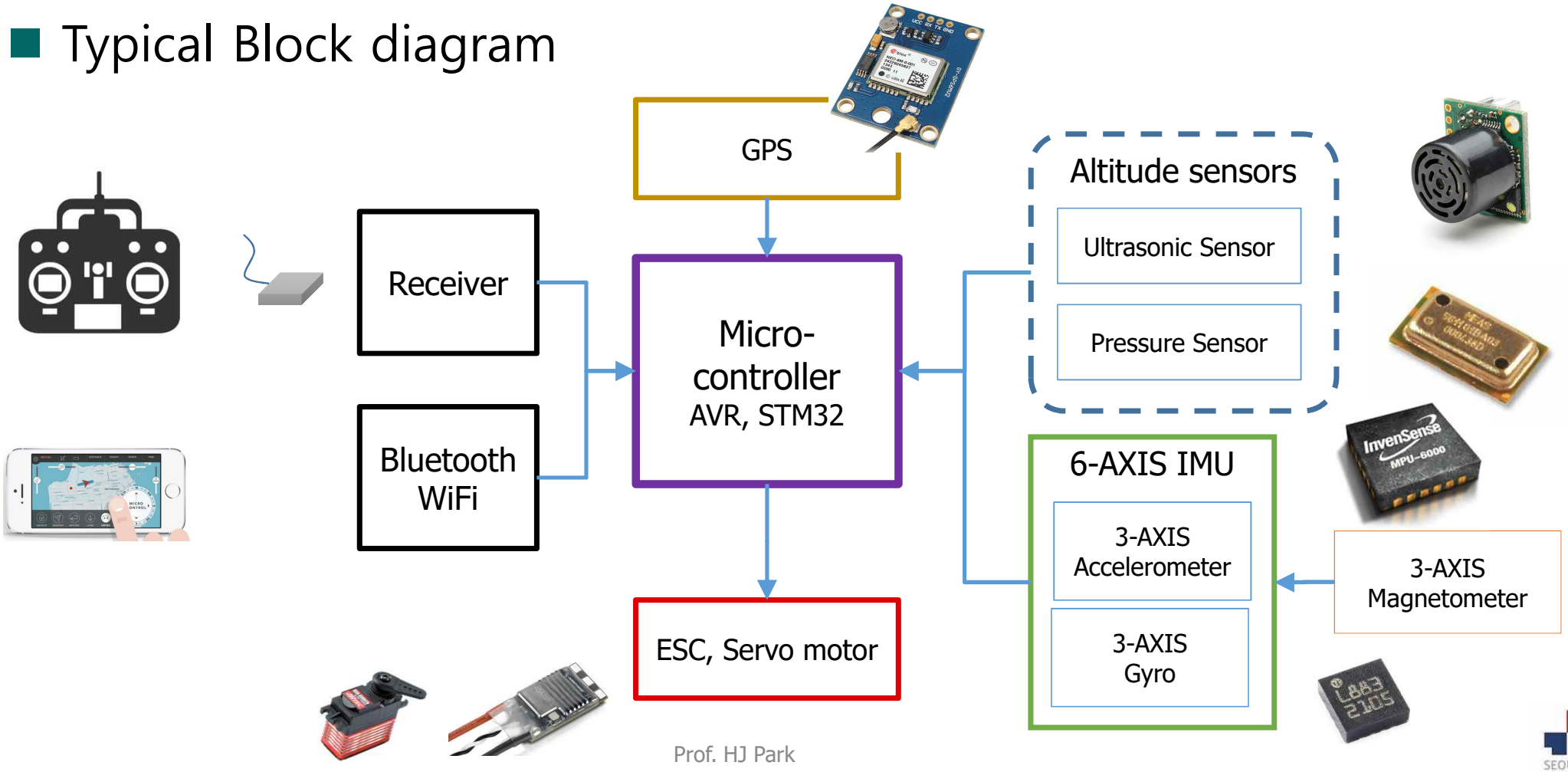
Overall control system diagram



Quadrotor 제어시스템

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

Typical Block diagram



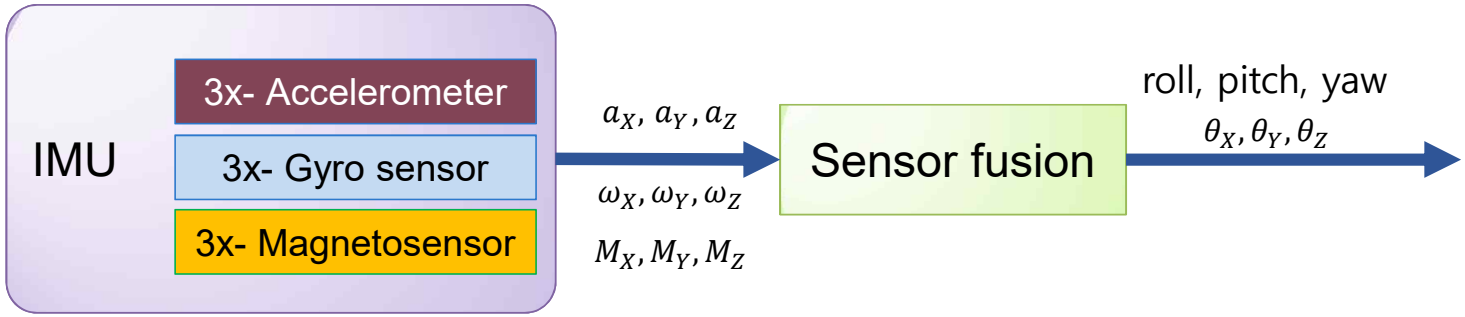
SEOULTECH

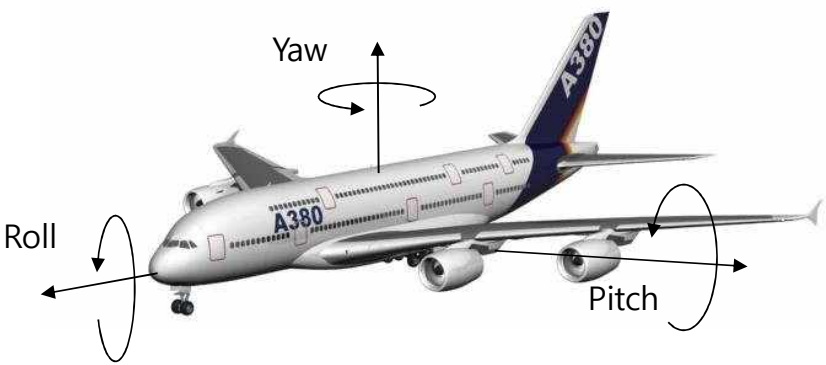
드론용 센서

센서융합 (Fusion)

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

IMU 센서의 Fusion



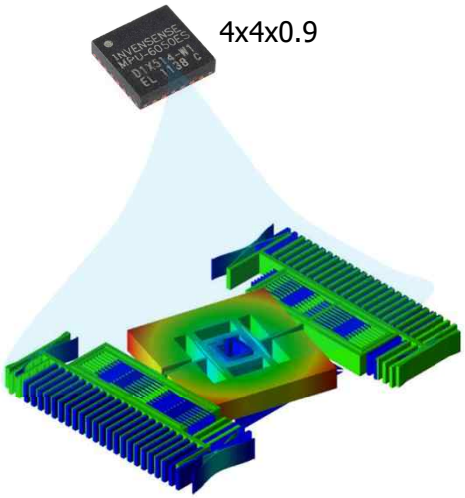


MEMS IMU 센서

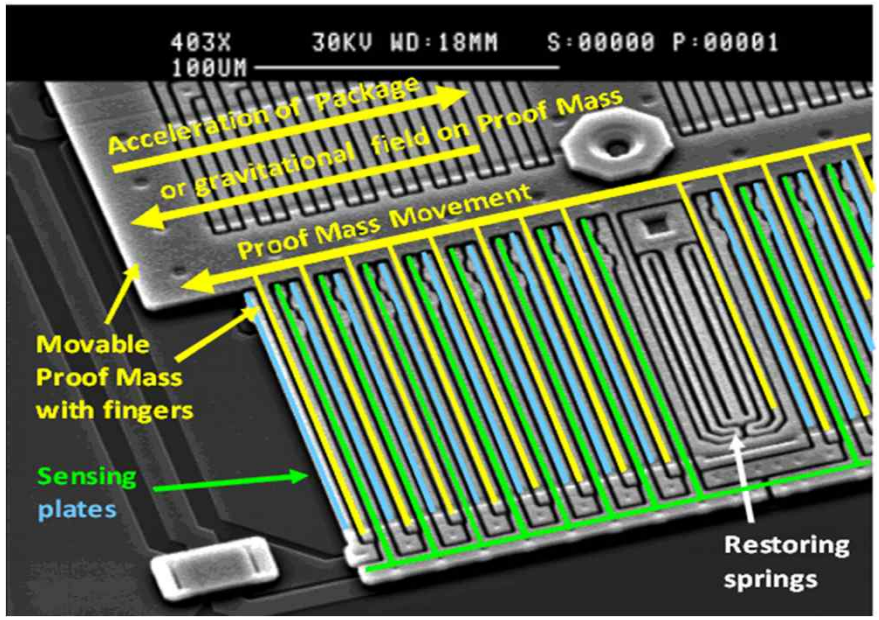
Dept. of Mechanical System Design, Seoul National University of Science and Technology.

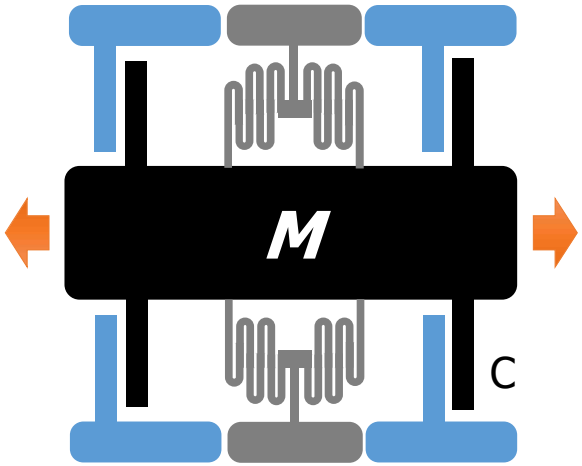
가속도 측정센서

- mass-spring-capacitance sensor



MEMS IMU





출처:
http://www.freescale.com/files/sensors/doc/app_note/**A**N3461.pdf

SEOULTECH

MEMS IMU 센서

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

- MEMS IMU 센서의 원리
- 물체가 직선운동을 시키고 회전을 시키면 **Coriolis force**가 발생
  - $\boldsymbol{F_c} = -2m\boldsymbol{\Omega} \times \boldsymbol{v}$
  - $\boldsymbol{F_c}$: Coriolis force vector, $\boldsymbol{\Omega}$: rotation vector, $\boldsymbol{v}$: linear velocity vector
- $\boldsymbol{F_c}$ 에 의한 변위를 capacitive 센서로 측정

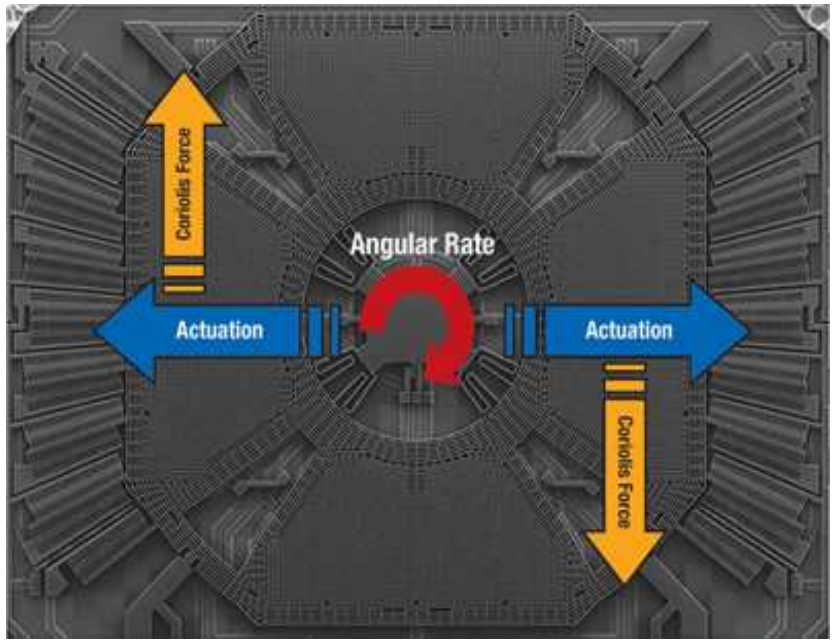


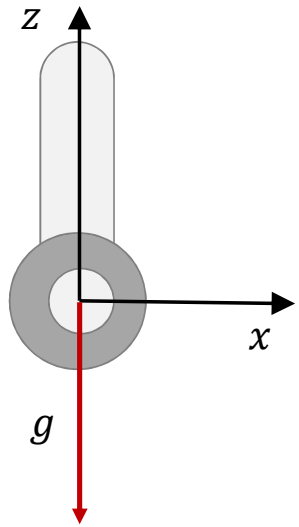
Image credit:
http://www.digikey.com/us/en/techzone/sensors/resources/articles/MEMS-Accelerometers.html

SEOULTECH

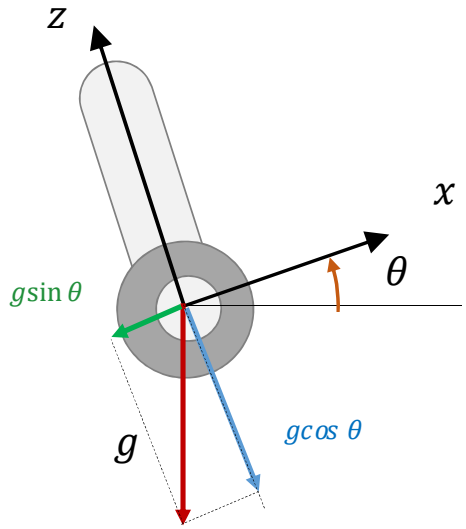
각도측정의 원리 - Accelerometer

- 가속도 센서를 이용한 pitch θ
  - $\theta = 0$ 인 경우 $a_z = -g$, $a_x = 0$
  - $\theta > 0$ 인 경우 $a_z = -g\cos\theta$, $a_x = -g\sin\theta$
  - $\therefore \quad \theta = \tan^{-1}\frac{a_x}{a_z}$

- 문제점
  - 잡음에 취약하다.
  - 운동 가속도에도 영향을 받는다.



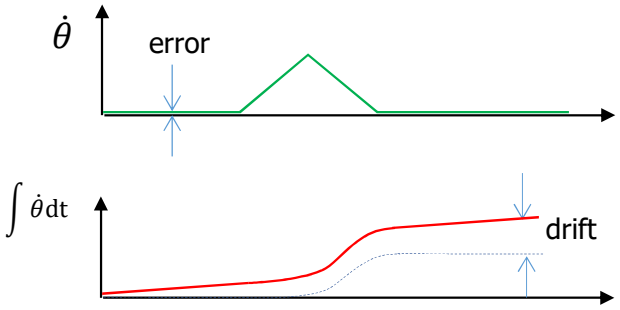
1) $\theta = 0$

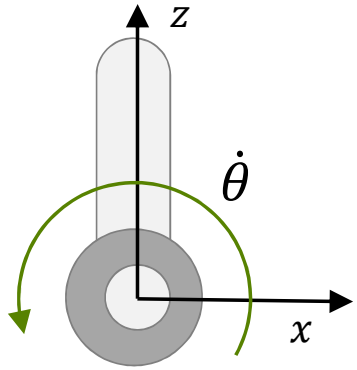


2) $\theta > 0$

각도측정의 원리-Gyro

- Gyro 센서를 이용한 pitch θ
  - gyro 센서는 근본적으로 각속도를 측정하는 센서
  - θ 를 구하려면 각속도 $\dot{\theta}$를 적분
  - 문제점: Drift 현상
    - 작은 오차 적분에 의하여



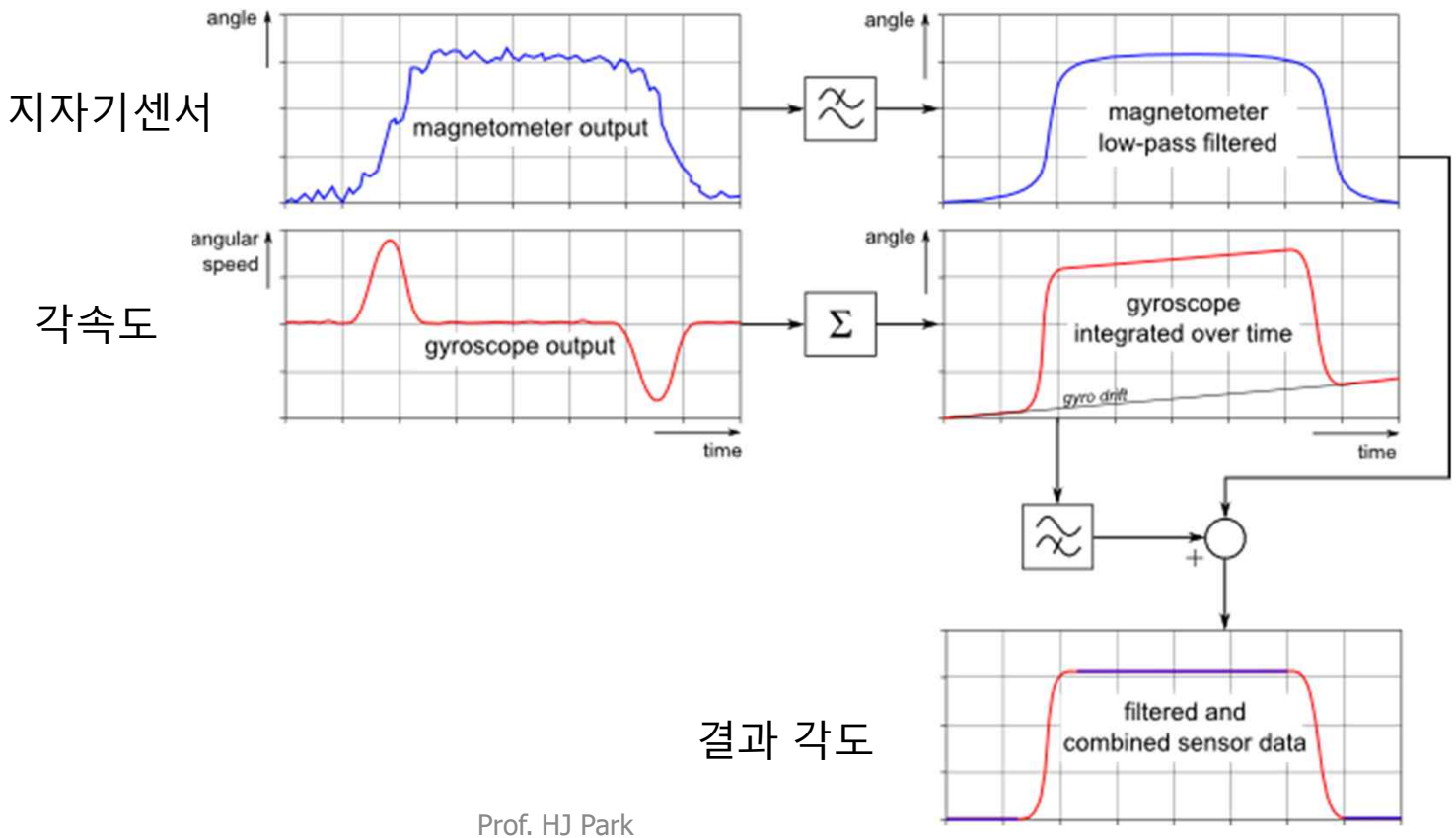


$$\theta = \int_0^t \dot{\theta} d\tau$$

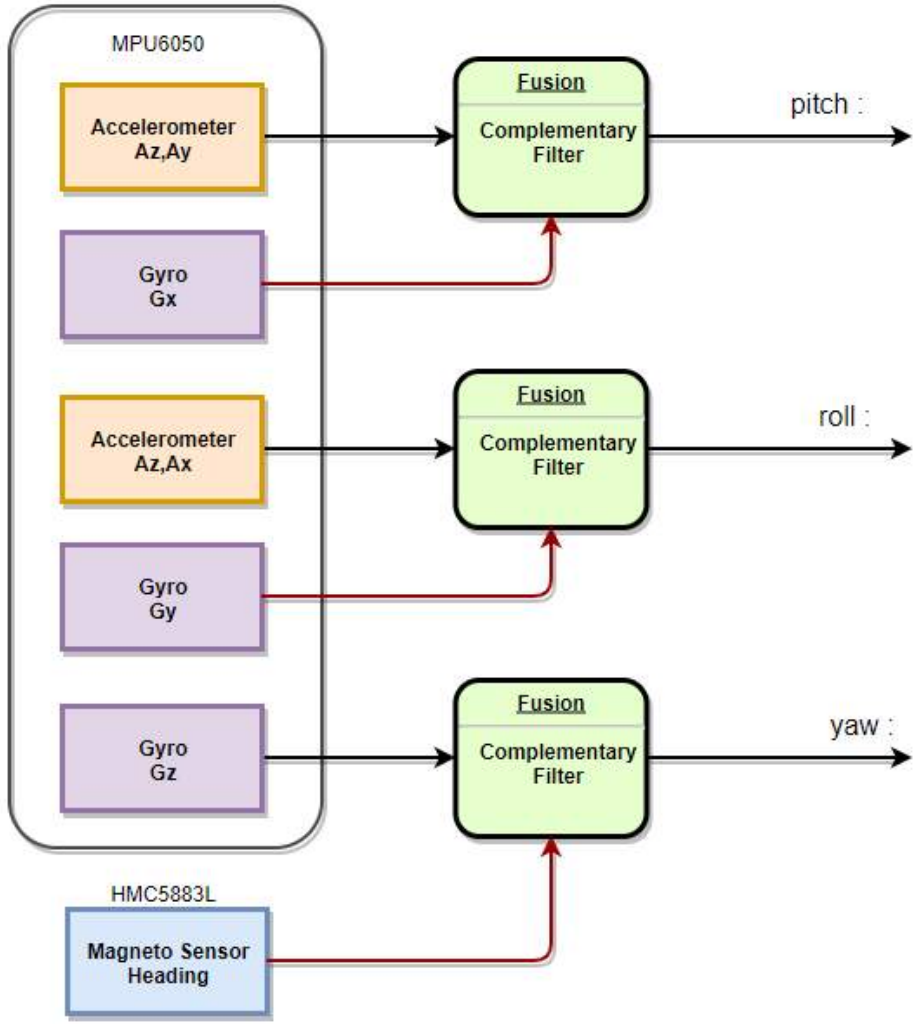
센서융합 (Fusion)

Dept. of Mechanical System Design, Seoul National University of Science and Technology.

상보 (Complementary) 필터



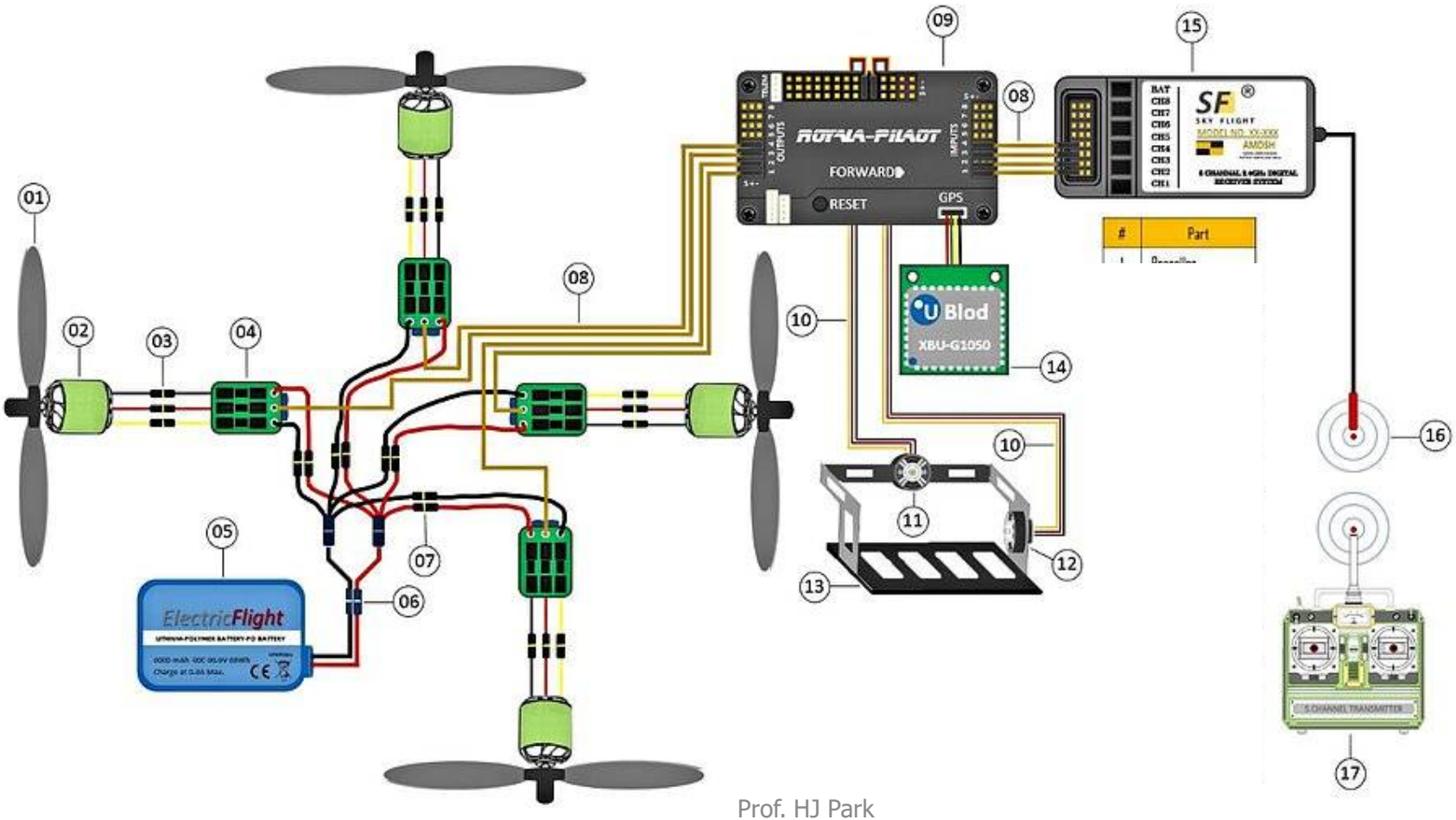
Sensor fusion



드론의 구성

Ardupilot Components

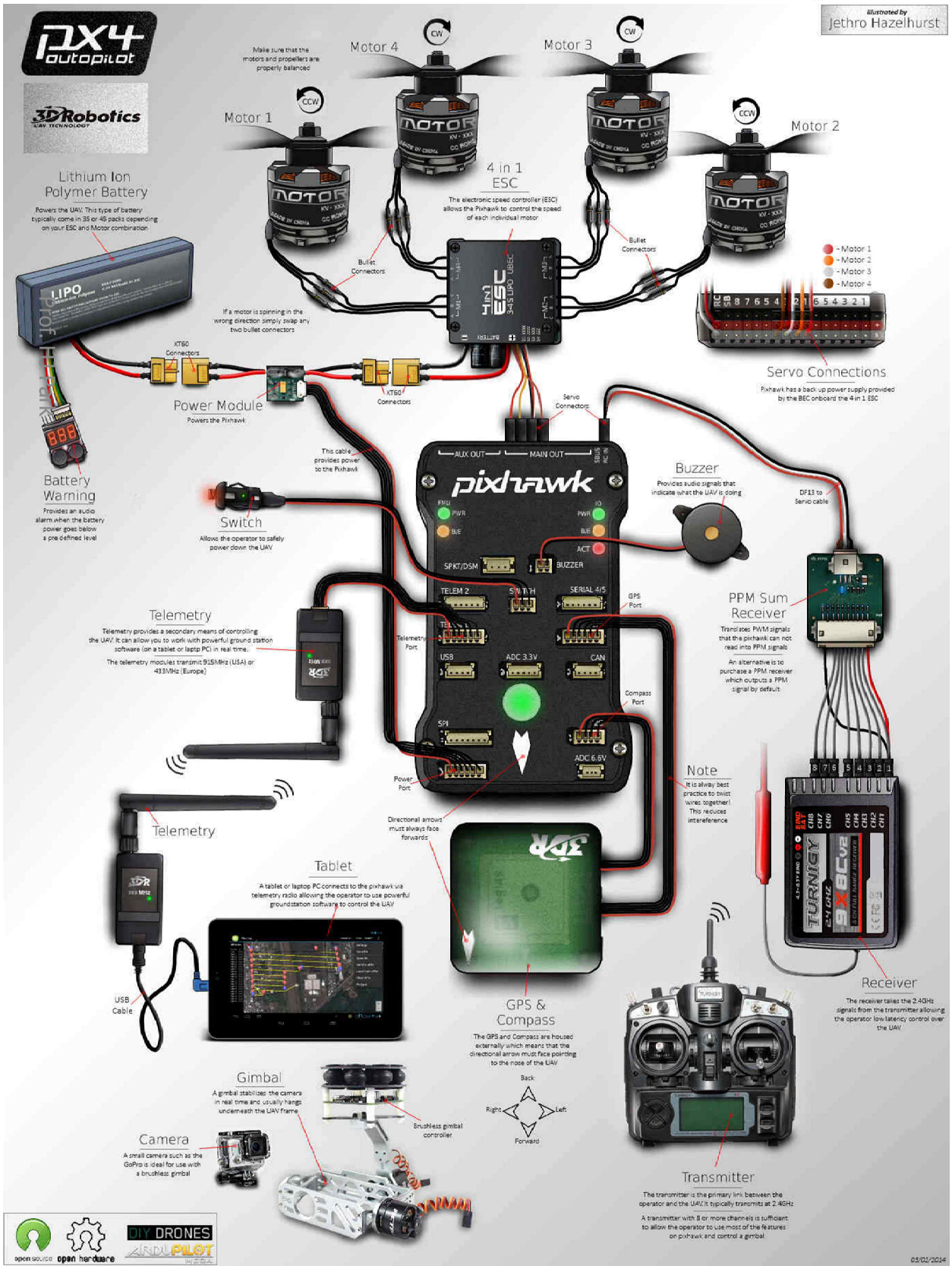
Dept. of Mechanical System Design, Seoul National University of Science and Technology.



1	Propeller
2	BLDC motor
3	Connectors
4	ESC
5	Li-Po battery
6	Power Distributor
7	
8	Servo connector
9	Flight Controller
10	Gimbal Connector
11	Gimbal - Roll
12	Gimbal - Pitch
13	Gimbal
14	GPS
15	RC receiver
16	2.4GHz Antenna
17	RC Transmitter

PX4

Dept. of Mechanical System Design, Seoul



THANK YOU

An Unmanned aerial vehicle (UAV) is a Unmanned Aerial Vehicle. UAVs include both autonomous (means they can do it alone) drones and remotely piloted vehicles (RPVs).