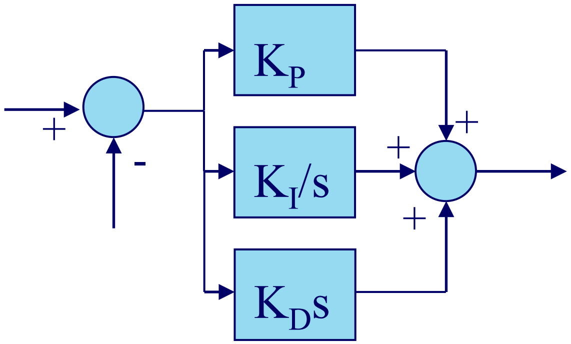
Automatic Control

PID CONTROL APPLICATION - OPEN-SOURCE AUTOPILOT

9. PID Control
How can we apply?

❖ Another formulation of PID Control [1]



$$D(s) = K_p + \frac{K_I}{s} + K_D s = (1 + \bar{K}_D s)(1 + \frac{\bar{K}_I}{s})$$

- PID control = serial connection of PI control and PD control
  - To design PID control, we can design PI and PD control separately.

❖ Another formulation of PID Control [2]

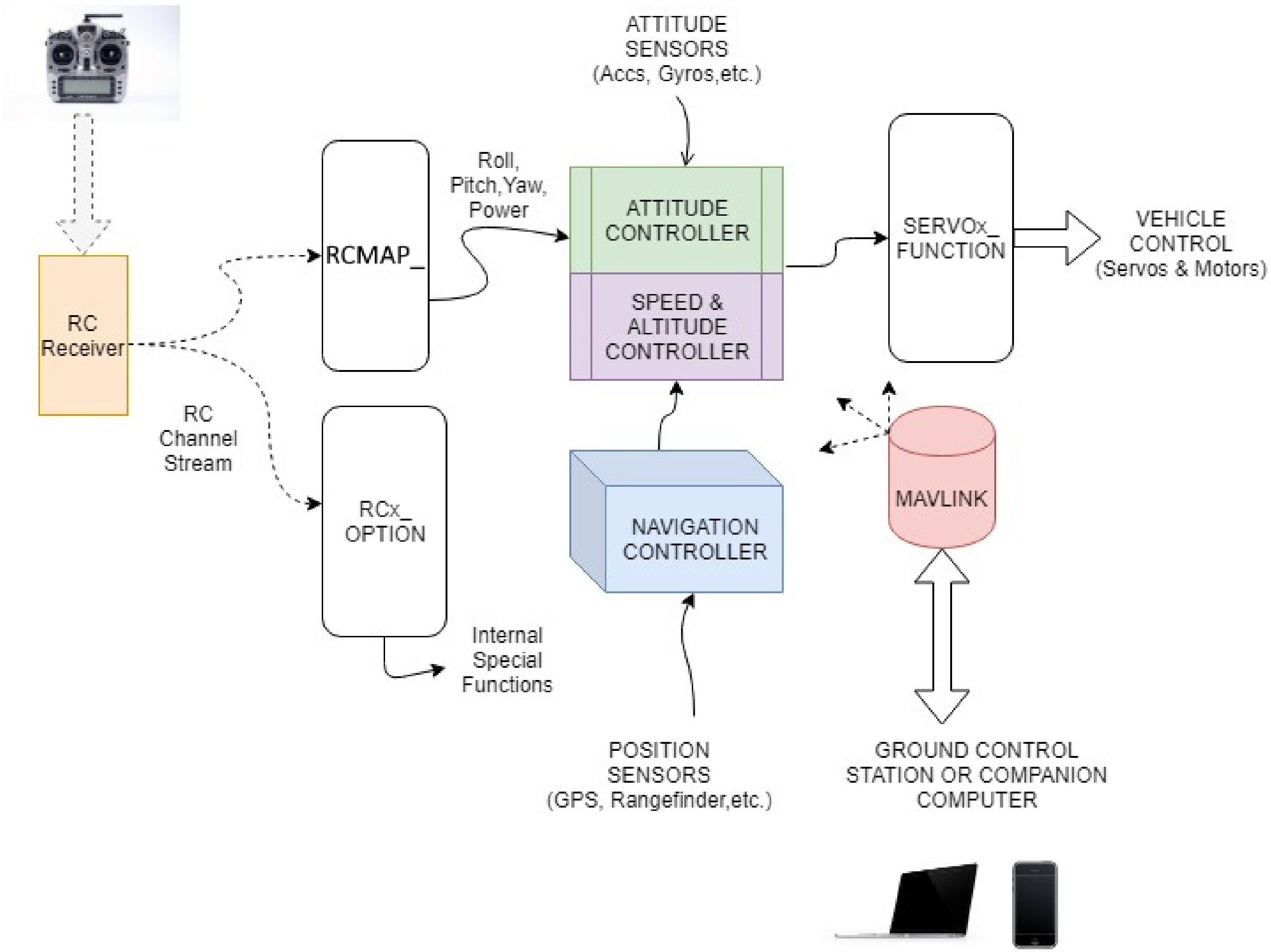
- +: 비례 이득 결정 후, 적분/미분 이득은 이에 대한 비율로 결정 가능

$$D(s) = K_p + \frac{K_I}{s} + K_D s = K_p(1 + \frac{1}{T_i s} + T_d s)$$

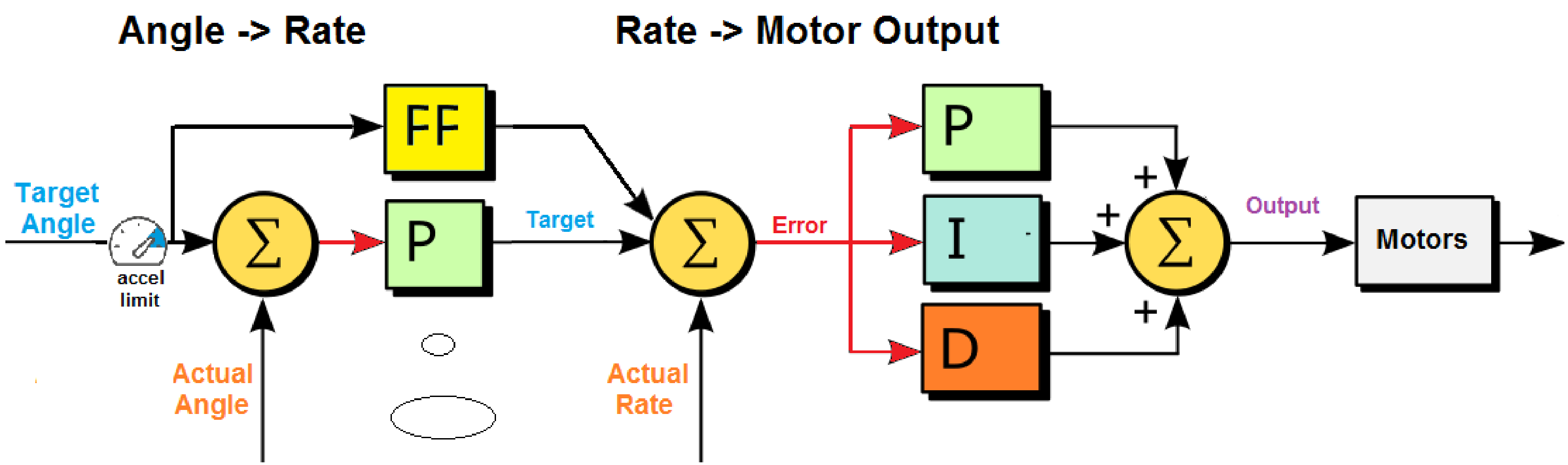
$$\text{where } T_i = \frac{K_p}{K_I} \ \& \ T_d = \frac{K_D}{K_p}$$

9. PID Control
How can we apply?

- **Example: Open-source autopilot SW "Ardupilot"**
  - Simple Overview of ArduPilot Operation
    - https://ardupilot.org/copter/docs/common-basic-operation.html



- **Example: Open-source autopilot SW "Ardupilot"**
  - https://ardupilot.org/copter/docs/tuning.html



A block diagram of multicopter attitude control

9. PID Control
How can we apply?

❖ **Example: Open-source autopilot SW "Ardupilot"**

- https://ardupilot.org/copter/docs/tuning.html
- 멀티콥터형 VTOL: 각 축의 K_P에 대한 K_D와 K_I의 상대적 비율 확인!

9. PID Control

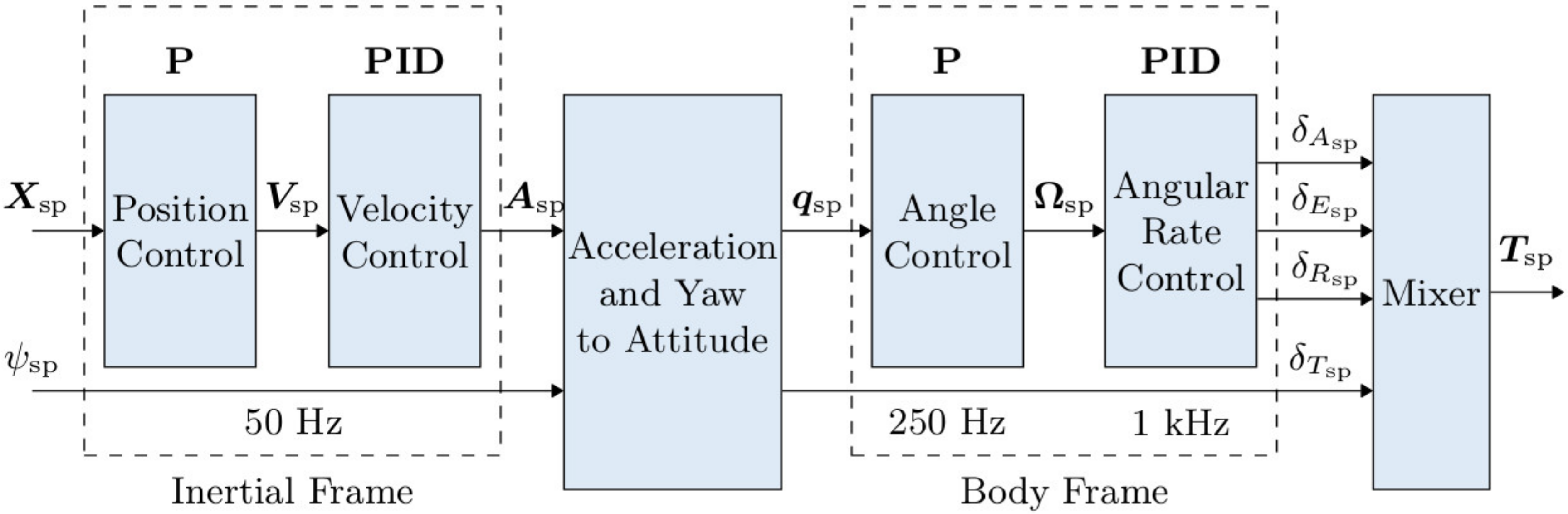
How can we apply?

❖ **Example: Open-source autopilot SW "Ardupilot"**

- https://ardupilot.org/plane/docs/tuning-quickstart.html
- 고정익 (Plane): 각 축의 K_P에 대한 K_D와 K_I의 상대적 비율 확인!

❖ Example: Open-source autopilot SW “PX4”

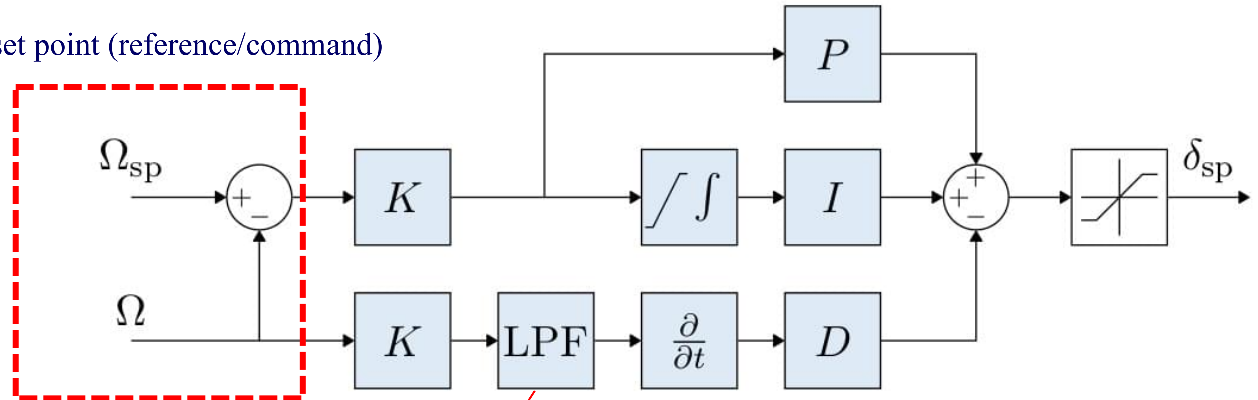
- Multicopter Control Architecture
  - https://docs.px4.io/main/en/flight_stack/controller_diagrams.html



9. PID Control
How can we apply?

- **Example: Open-source autopilot SW "PX4"**
  - Multicopter Angular Rate Controller
    - https://docs.px4.io/main/en/flight_stack/controller_diagrams.html

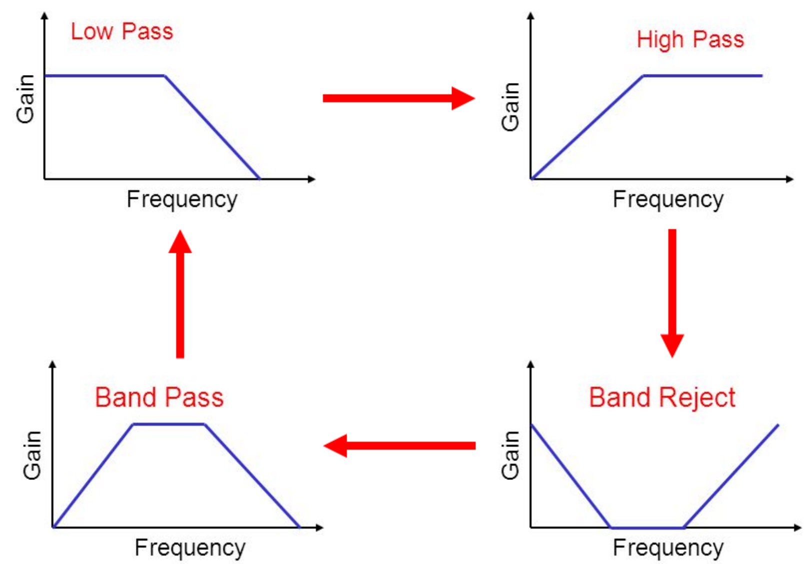
*sp: set point (reference/command)



Why doesn't D-control use error?

→ Next page

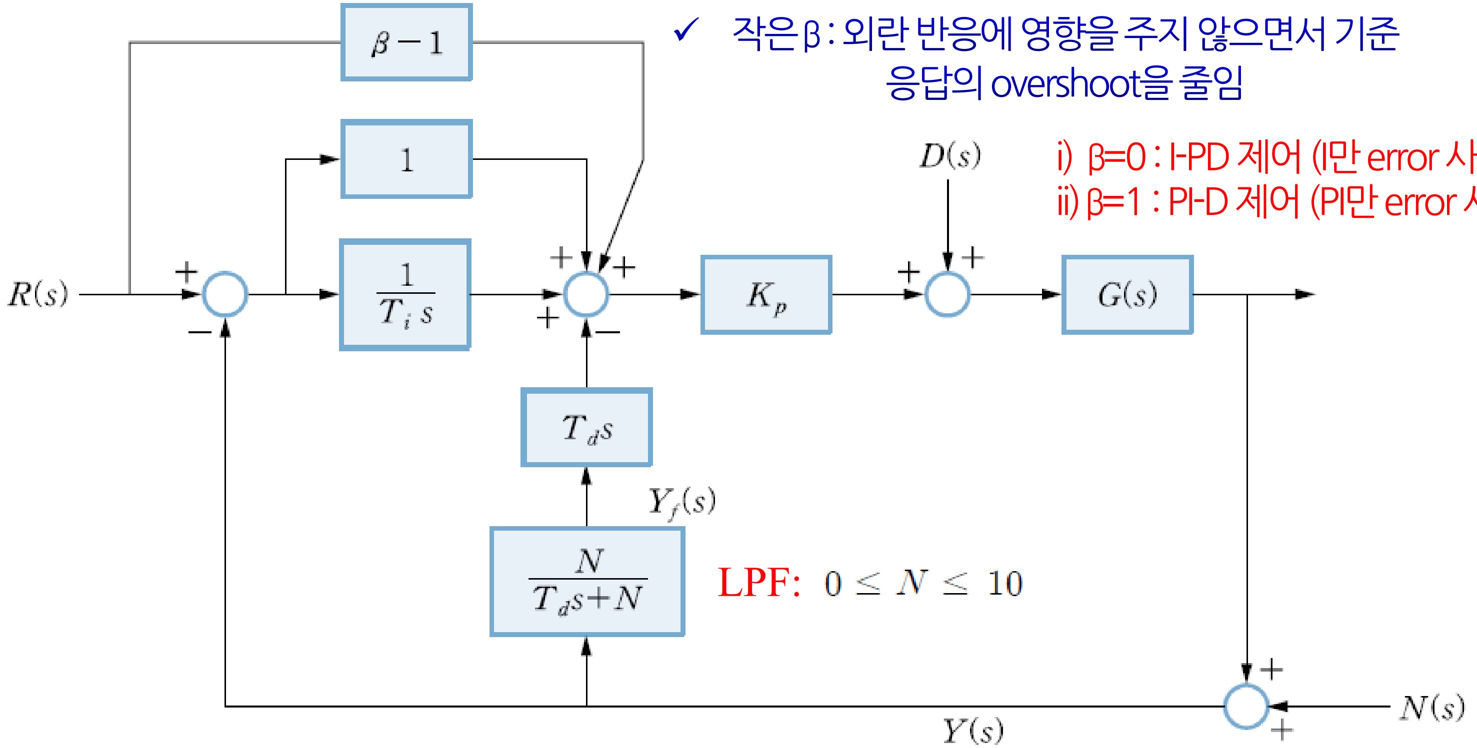
Why here?
(Low Pass Filter)



9. PID Control
How can we apply?

❖ **Example: Open-source autopilot SW “PX4”**

- Multicopter Angular Rate Controller
- **PI-D control: 피드백 신호에만 미분 동작 수행 (PID 제어기 변형)**
  - **기준 신호에 대해 미분 X → 미분 폭주 회피**



✓ 작은β : 외란 반응에 영향을 주지 않으면서 기준 응답의 overshoot을 줄임

i) β=0 : I-PD 제어 (I만 error 사용)
ii) β=1 : PI-D 제어 (PI만 error 사용)

LPF: $0 \le N \le 10$

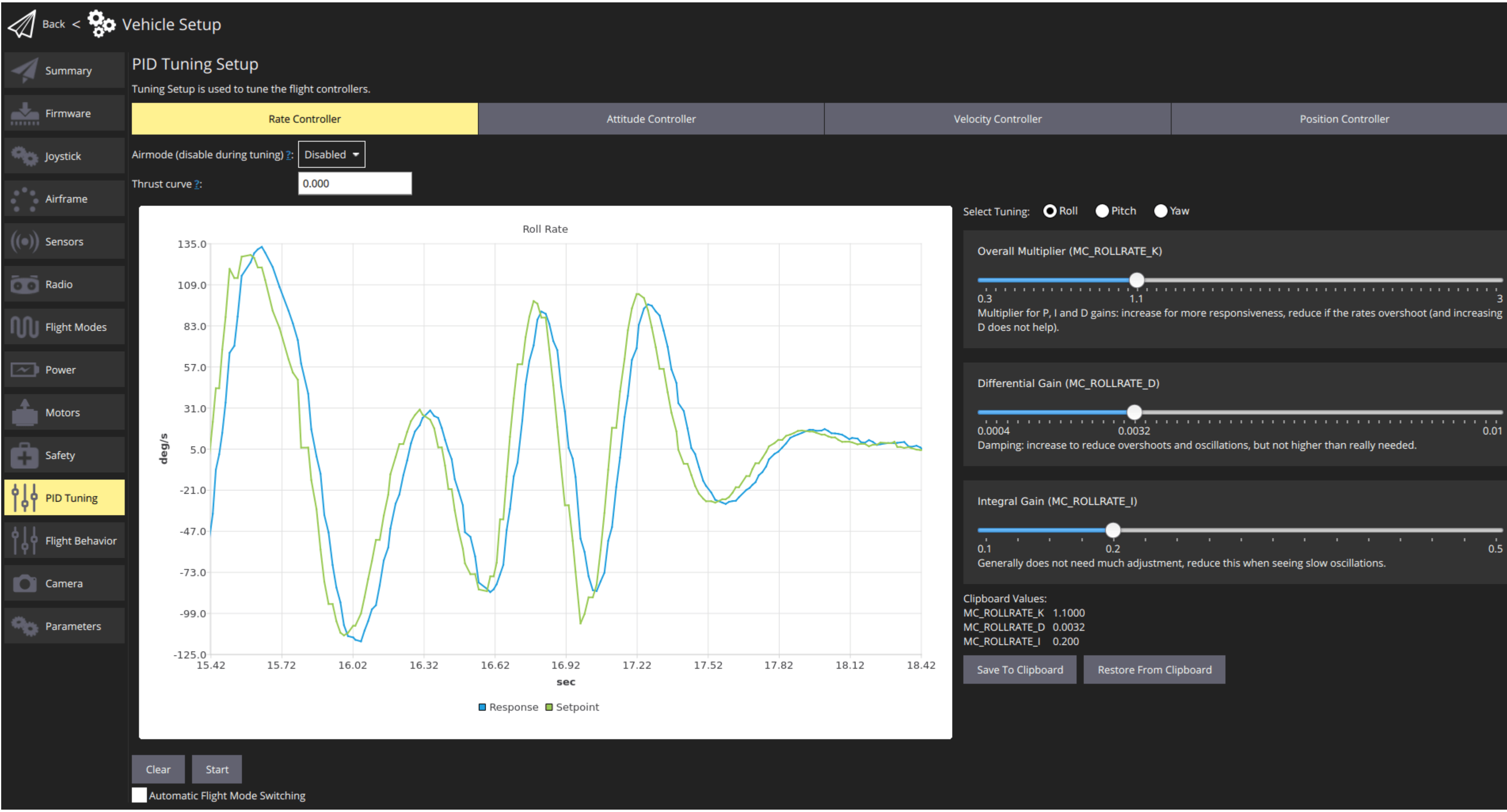
[그림 6-45] PI-D 제어

$$u(t) = K_p\left[\beta r(t) - y(t) + \frac{1}{T_i}\int e(t)dt - T_d\frac{d}{dt}y_f(t)\right]$$

9. PID Control
How can we apply?

❖ Example: Open-source autopilot SW "PX4"

- https://docs.px4.io/main/ko/config_mc/pid_tuning_guide_multicopter_basic.html
- 멀티콥터형 VTOL: K_P에 대한 K_D와 K_I의 상대적 비율/최대치 확인!



9. PID Control
How can we apply?

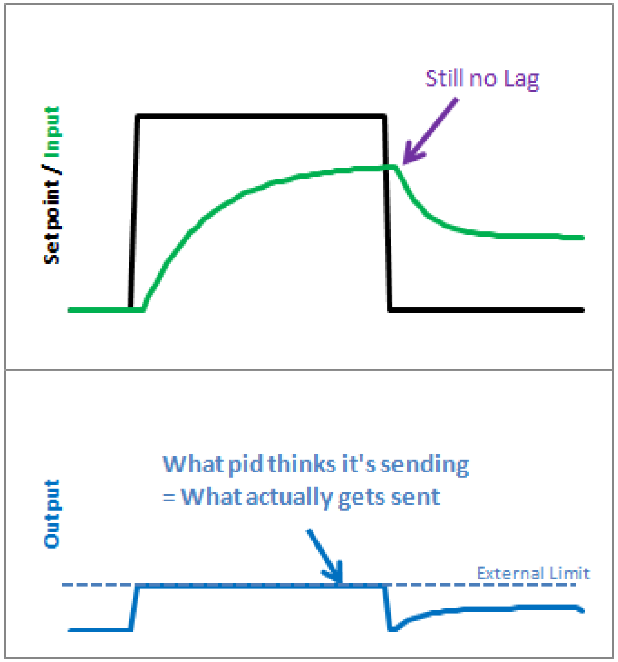
❖ Example: Open-source autopilot SW "PX4"

- https://docs.px4.io/main/ko/config_mc/pid_tuning_guide_multicopter_basic.html

The PID values can be adjusted as follows:

- P (proportional) or K gain:
  - increase this for more responsiveness
  - reduce if the response is overshooting and/or oscillating (up to a certain point increasing the D gain also helps).
- D (derivative) gain:
  - this can be increased to dampen overshoots and oscillations
  - increase this only as much as needed, as it amplifies noise (and can lead to hot motors)
- I (integral) gain:
  - used to reduce steady-state error
  - if too low, the response might never reach the setpoint (e.g. in wind)
  - if too high, slow oscillations can occur

https://images.app.goo.gl/RHjKcJDWGgi4hKBp7



Automatic Control

ANTI-WINDUP CONTROL (적분 누적 방지법)

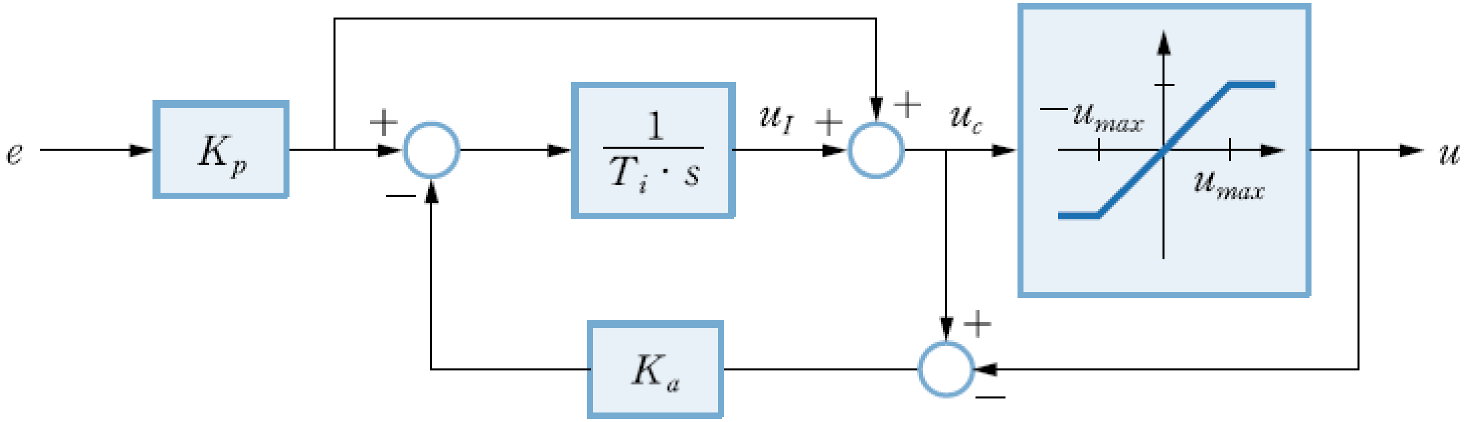
9. PID Control
Integrator Anti-windup (적분 누적 방지)

❖ 적분제어의 문제점

- 대부분의 시스템에서 구동기의 입력값에 한계 존재
- 계속되는 적분 과정으로 한계값 이상의 입력이 요구
  - 입력 포화 → 적분 제어 중지 → 과도응답이 느려지는 현상 발생

❖ 적분 누적 방지 원리

- 제어 신호와 구동기 신호의 차이를 피드백 하여 제어 → 적분 누적 방지



[그림 6-41] 적분 누적 방지를 위한 제어기

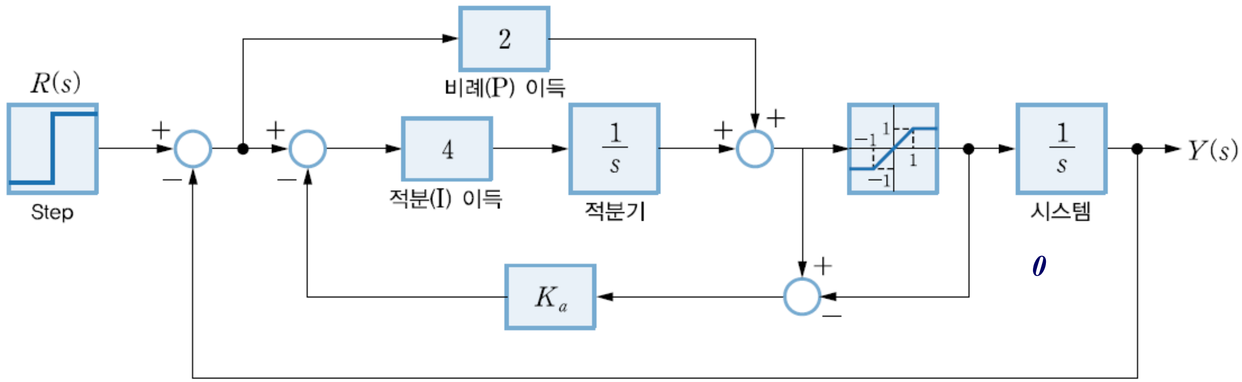
$$u_c = -\frac{K_a}{s\,T_i}(u_c - u) + \left(1 + \frac{1}{s\,T_i}\right)K_p e$$

[참고] 한수희 외, 실감나게 배우는 제어공학, 한빛아카데미

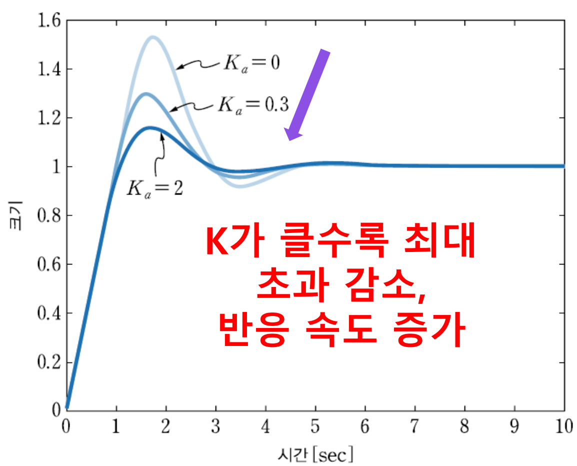
Integrator Anti-windup (적분 누적 방지)

❖ 예제

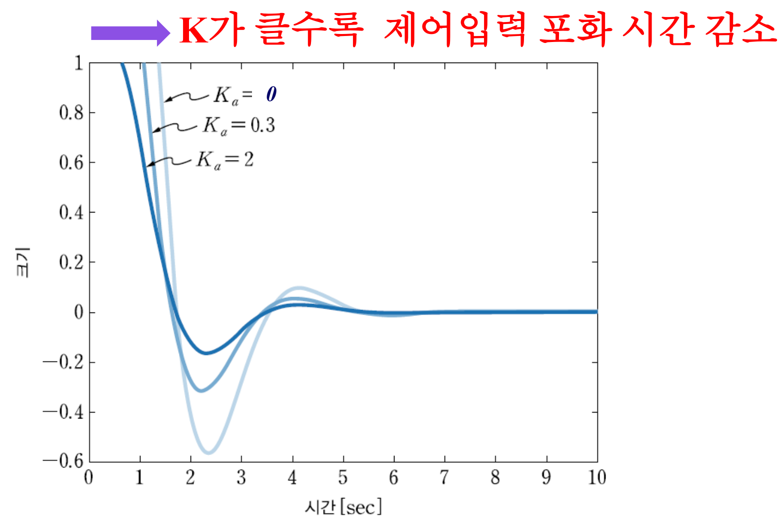
- 적분기 시스템에 대하여 anti-windup을 위한 피드백을 설계하시오.



[그림 6-42] 적분 누적 방지를 위한 적분기



[그림 6-43] 계단 응답에 나타난 적분 누적 방지 효과



[그림 6-44] 제어 입력에 나타난 적분 누적 방지 효과

[참고] 한수희 외, 실감나게 배우는 제어공학, 한빛아카데미

❖ [IFAC] Newsletter - April 2024

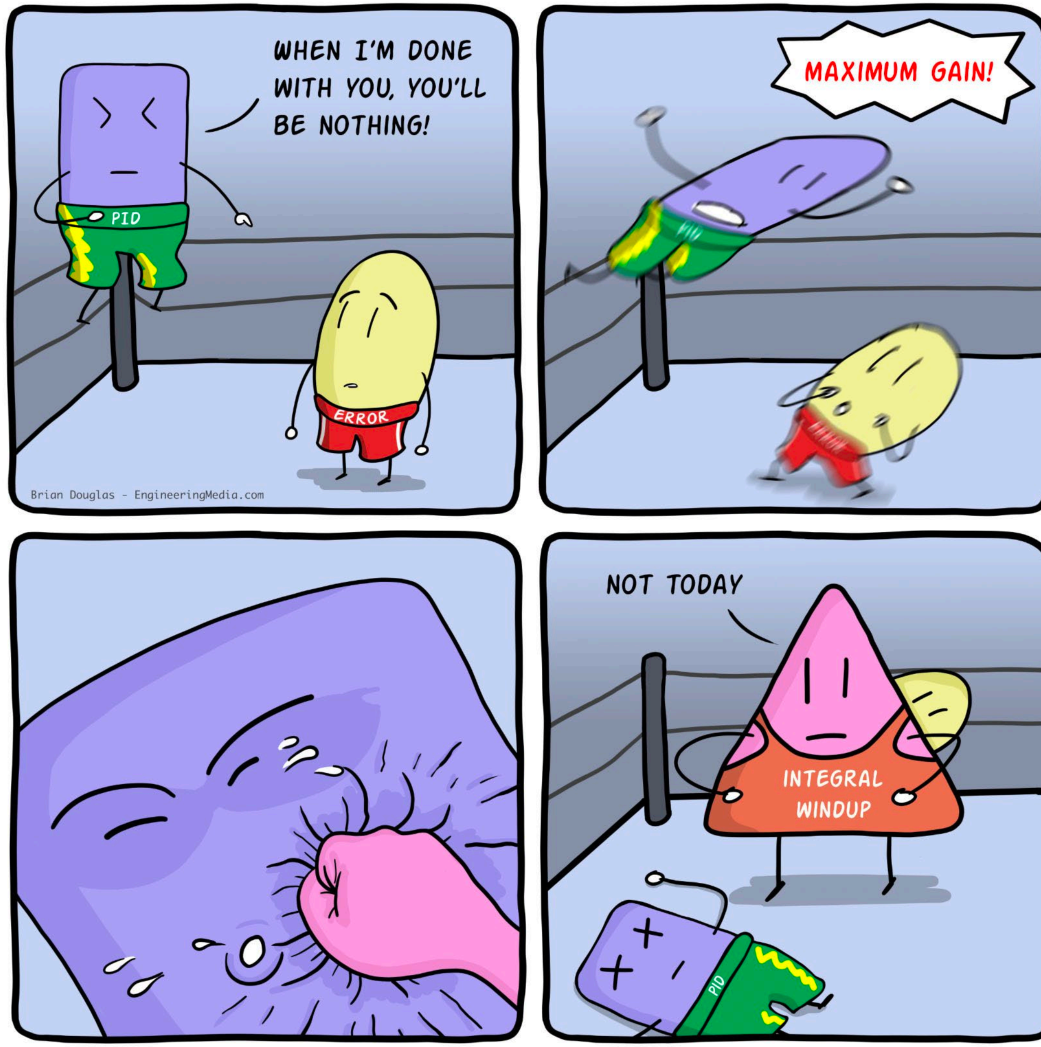
Fabulous Control Cartoon

We are pleased to share the second control cartoon in 2024.

It reminds us ***not to underestimate windup*** in PID control. ;-)

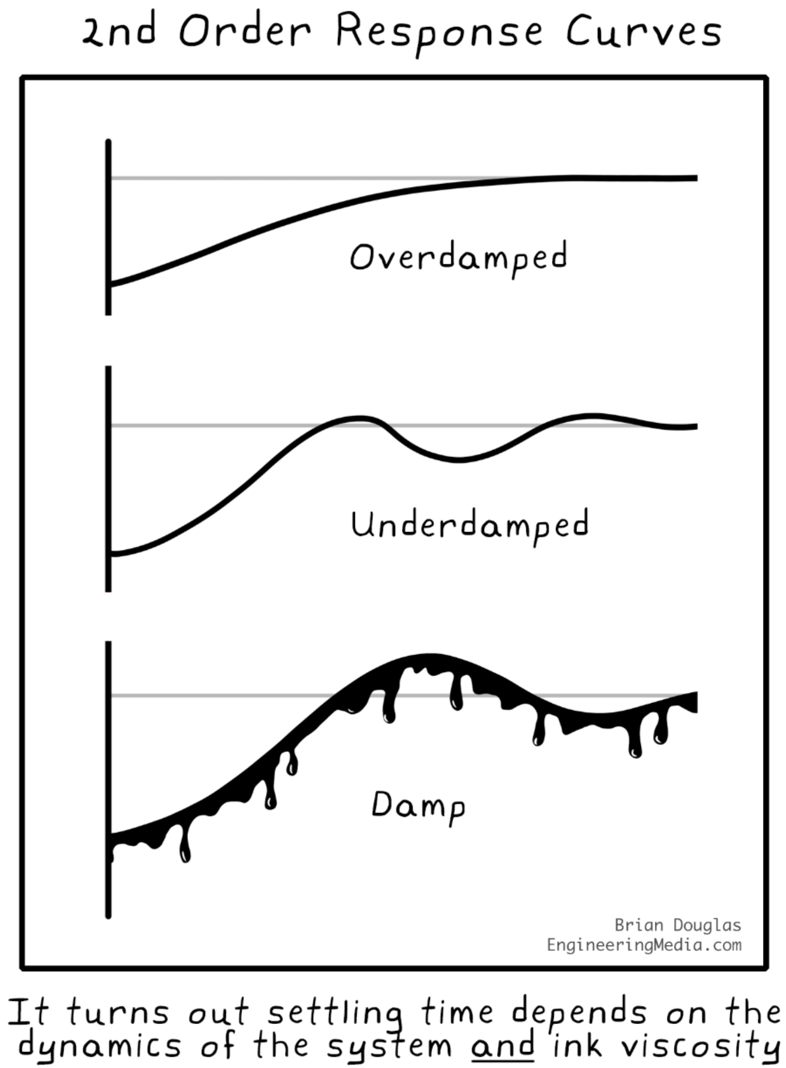
Many thanks to Brian Douglas for preparing the cartoon and for supporting its distribution by IFAC.

https://www.ifac-control.org/publications/cartoons



Integrator Anti-windup (적분 누적 방지)

❖ **Another my favorite cartoon**



❖ PID control application - open-source autopilot

- Another formulation of PID control
- Intro to PID gain setup & tuning for open-source autopilot SW (Ardupilot/PX4)

❖ Integrator Anti-windup

- 구동기는 항상 제한 범위가 있다!
  - → 구동기 제한 시 **적분기에 대한 입력** 줄여주자!

Thank You !

Automatic Control