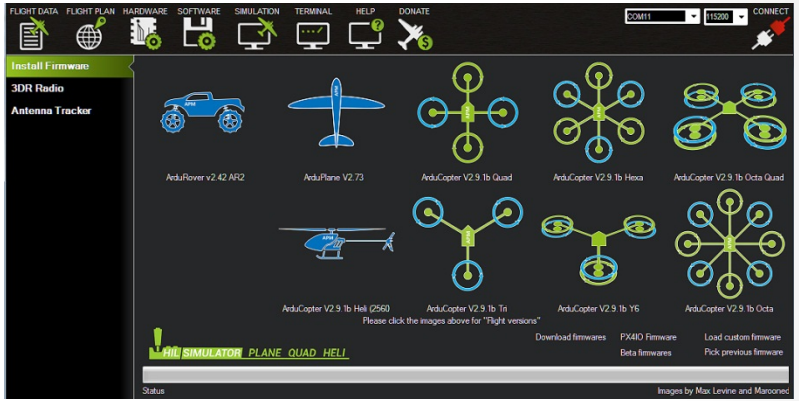

Flying in Tune
ArduCopter
Tuning Basics

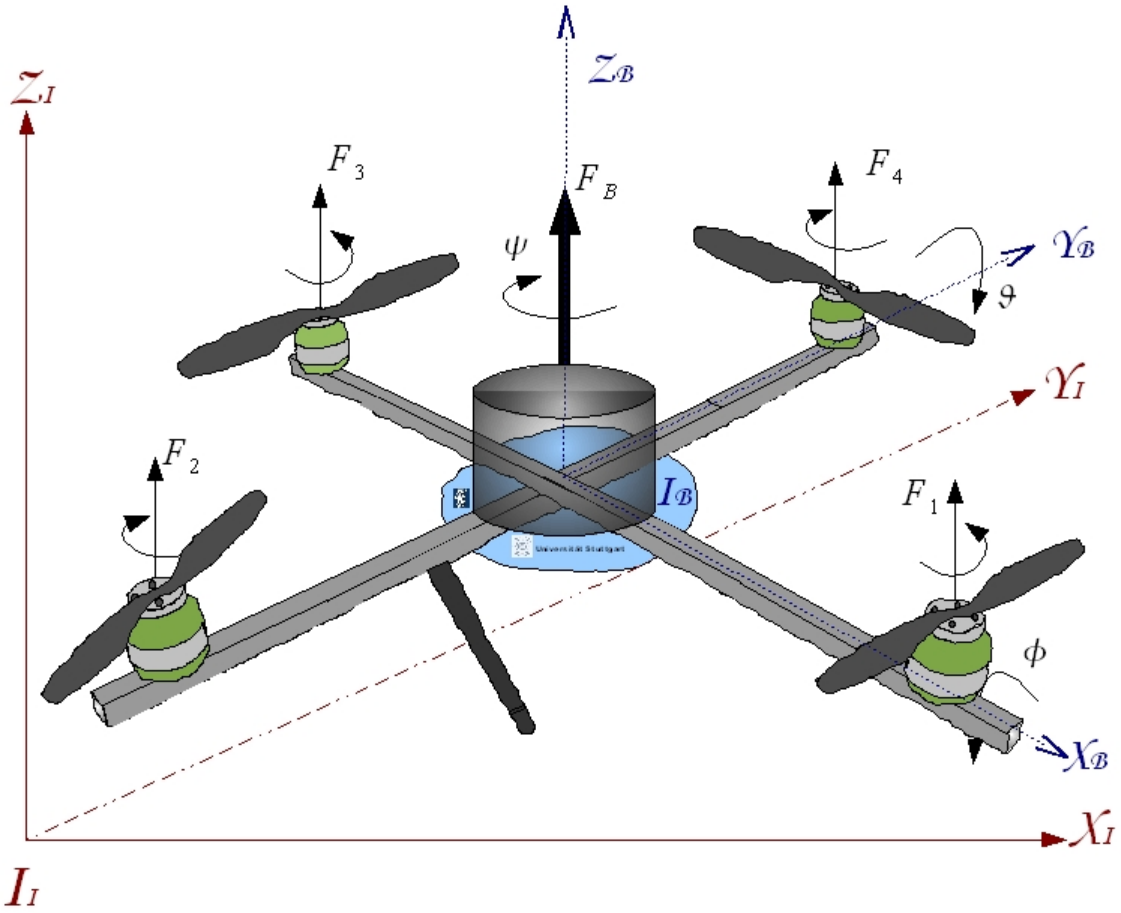
Pre-flight Checklist

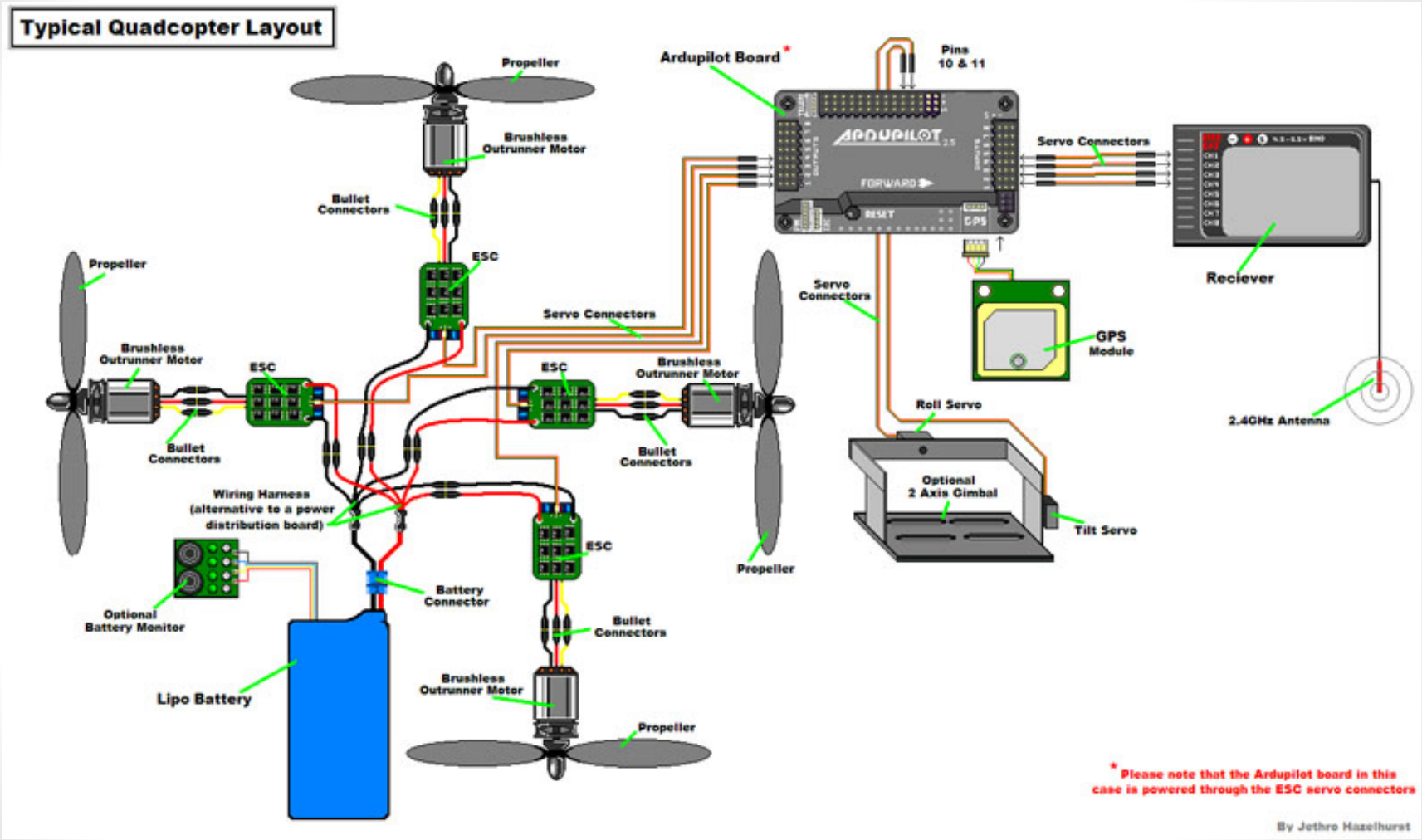
- Hardware
  - Motor / ESC / Frame / Prop combination
    - Use a prop calculator to estimate! [http://ecalc.ch]
  - Vibration Management (e.g. prop balancing)
    - Use a prop balancer to help determine prop balance
    - Isolate IMU sensors from frame vibrations
  - Wire management and other loose structural ends

Pre-flight Checklist (cont'd)

- Software (ArduCopter)
  - Configuration
    - **PID control parameters**
    - Flight modes
    - Radio transmitter
  - Calibrate and Verify
    - ESC calibration
    - Radio calibration
    - Accelerometer
    - Compass



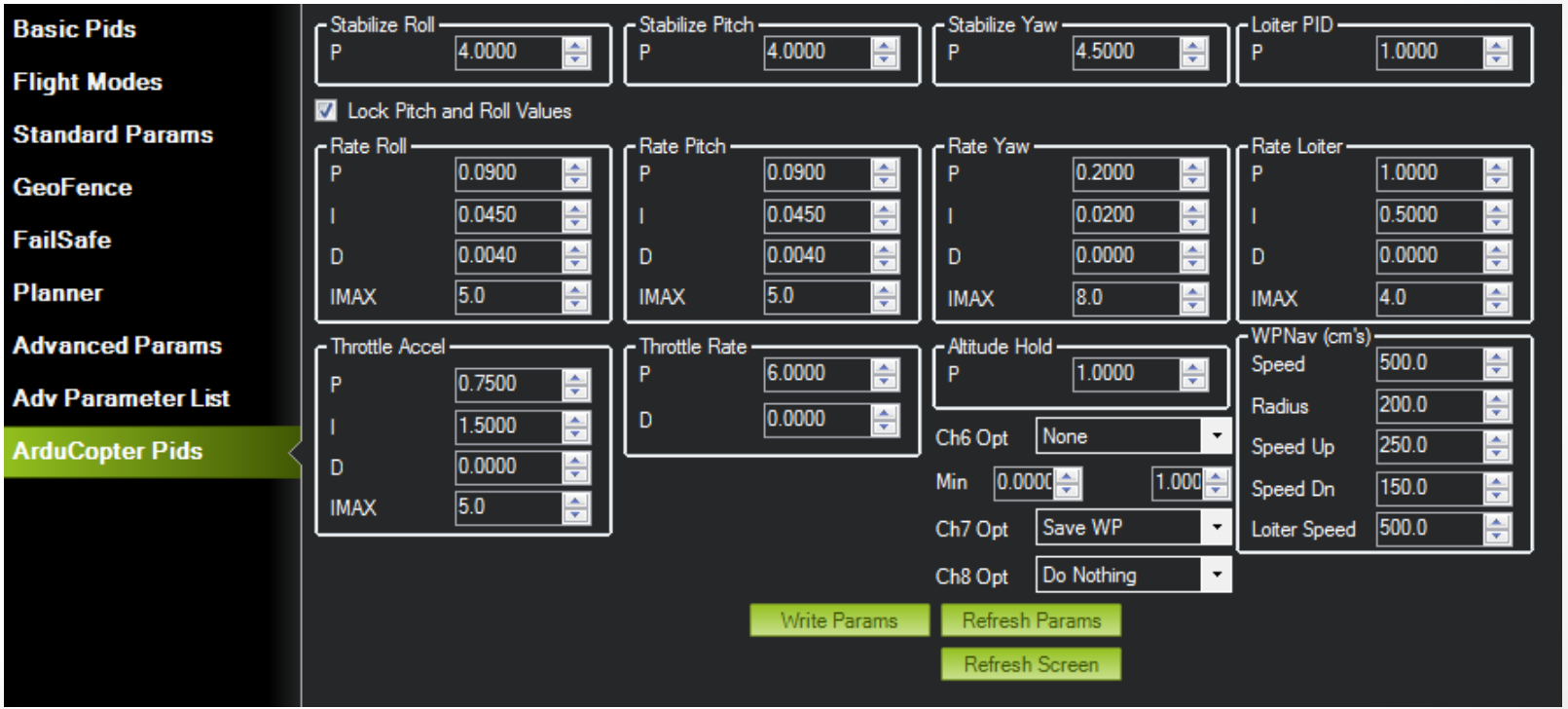

Z_I
Z_B
F_3
F_B
F_4
ψ
Y_B
ϑ
Y_I
F_2
I_B
F_1
ϕ
X_B
X_I
I_I


Typical Quadcopter Layout
Propeller
Brushless Outrunner Motor
Bullet Connectors
ESC
Propeller
Brushless Outrunner Motor
ESC
Bullet Connectors
Servo Connectors
ESC
Brushless Outrunner Motor
Bullet Connectors
Wiring Harness (alternative to a power distribution board)
ESC
Battery Connector
Optional Battery Monitor
Lipo Battery
Bullet Connectors
Brushless Outrunner Motor
Propeller
Propeller
Ardupilot Board *
Pins 10 & 11
ARDUPILOT 2.5
FORWARD
RESET
GPS
Servo Connectors
Reciever
Servo Connectors
GPS Module
Roll Servo
Optional 2 Axis Gimbal
Tilt Servo
2.4GHz Antenna
* Please note that the Ardupilot board in this case is powered through the ESC servo connectors
By Jethro Hazelhurst

Control Needed Everywhere!

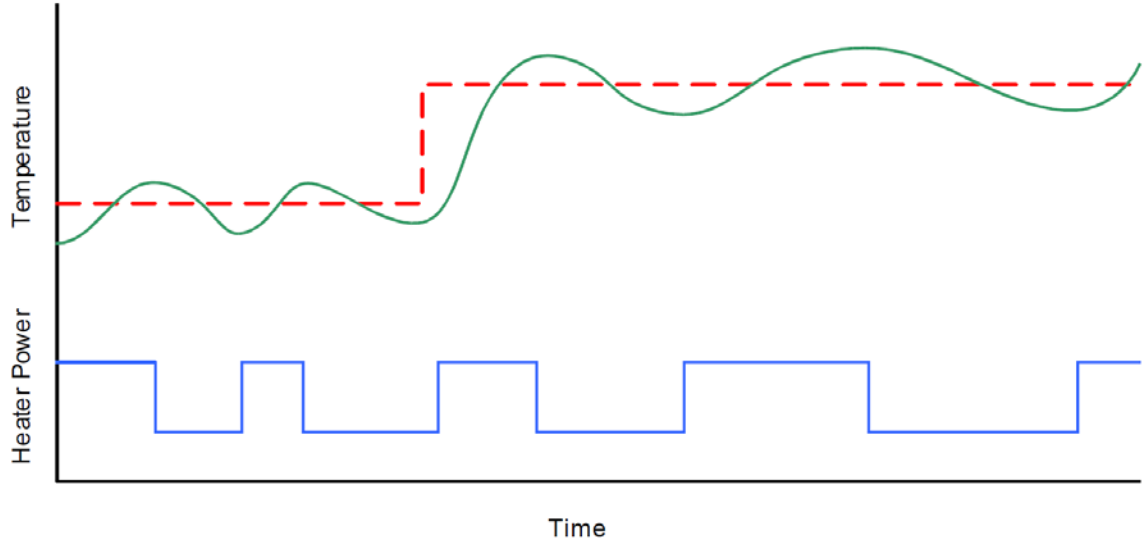
- Control rotation rate needed to correct for errors in angle (Stabilize - STB_RLL, STB_YAW, STB_PIT)
- Control thrust used to correct for errors in rotation rate (Rate - RATE_RLL, RATE_YAW, RATE_PIT)
- Control throttle used to correct for errors in vertical acceleration (Throttle Rate - THR_RATE)
- Control acceleration used to correct for errors in altitude (THR_ALT)
- Control rate of rotation used to correct for errors in actual rotation vs. user input in acro mode (ACRO_RP)
- … and several more controls

Control Parameters



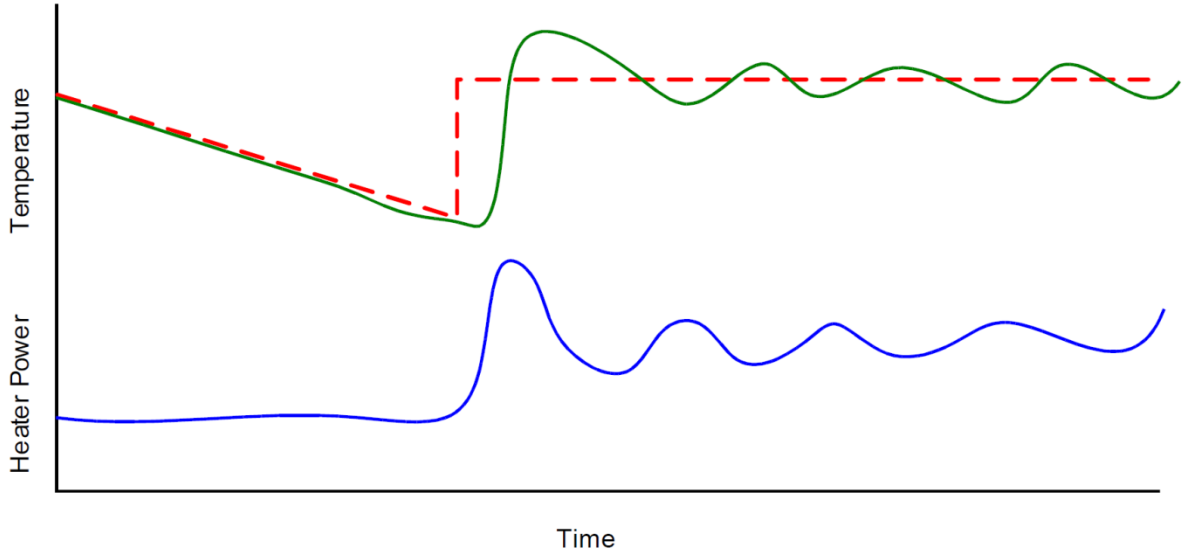
SV: Set Value: User input via temperature knob
PV: Process Value: Temperature

Bang-Bang Control



Advantage: Easy
Disadvantage: Jerky control, poor performance

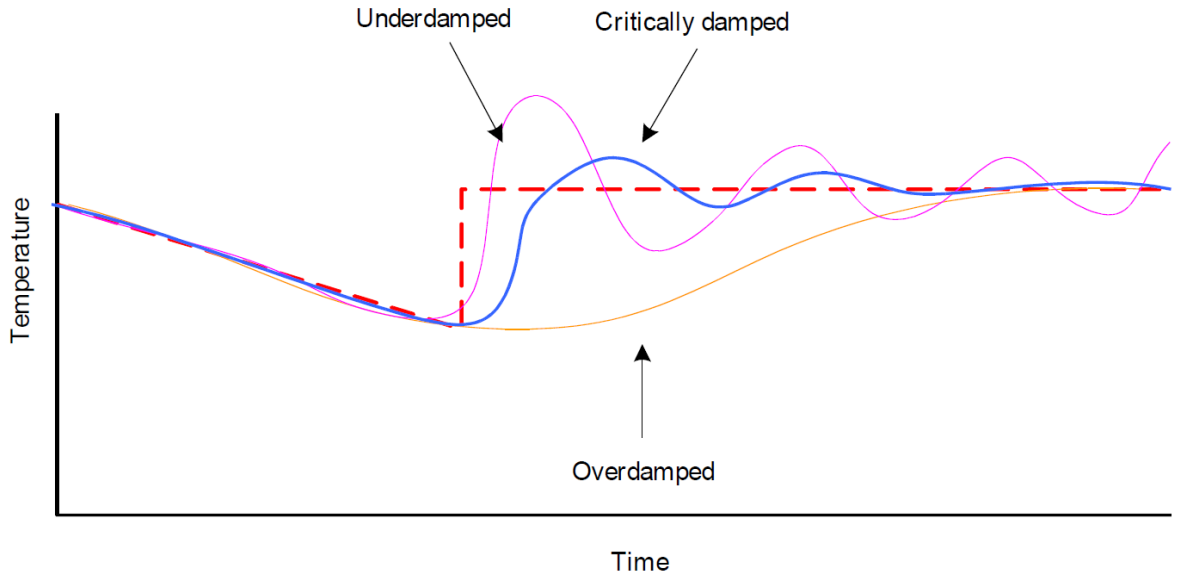
Proportional Control



$$F = -Px$$

where x is error

Proportional + Derivative Control



$$F = -Px - D\ddot{x}$$

PID Control

add an integrative term to compensate for **droop**

$$F = -Px - D\ddot{x} - I\int x\,dt$$

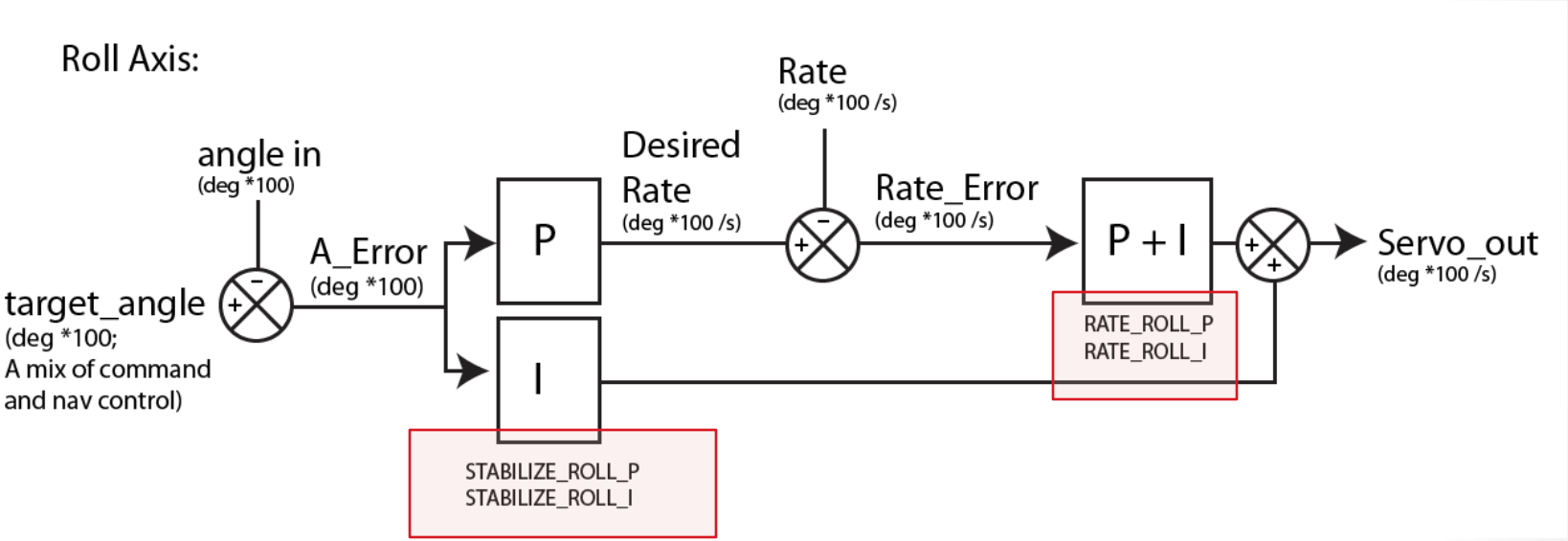
PID Summary

- You need to balance or *tune* the P, I, and D constants to optimum values to get the desired control response.
  - P value (most important!)
    - Too little = insensitive, but laggy
    - Too much = overshoots, oscillates
  - D value
    - Too little = unstable, twitchy
    - Too much = settles slowly, like molasses, can amplify error
  - I value
    - Too little = offset error
    - Too much = overshoots, oscillates.

PID Tuning Procedure

- Set I and D to zero
- P is the king!
  - Increase P until system just begins to oscillate, back off until it stops oscillating.
- Add a teeny tiny bit of I to correct for offset if required
  - Usually more relevant for steady state error in yaw or altitude hold
- Maybe add some D if required. Some controllers avoid D altogether because it is sensitive to measurement noise.
  - Might be relevant if you want to increase P

ArduCopter: Cascading PIDs



Getting started tips

- **SAFETY FIRST** – Experimental aircraft are dangerous!
  - Use goggles, maybe even a motorcycle helmet
  - Do all the pre-flight checks, calibrations, etc. Important!

- **Start tuning in Stabilize mode.** This should be your default mode and its control parameters are used in all other modes.

- **Start from the defaults.** If you don't know them you can find the default values on the ArduCopter wiki.

- It's possible to use CH6 knob to tune, but avoid it. "Tweak and verify" is more reliable.

Rate and Stabilize Parameters

1. RATE P - Angular Rate Control P
   - Input: Desired copter rate; Output: motor speed
   - This changes the most between copter designs.
   - Copters with big power to weight ratio (i.e. overpowered craft) requires less P.
   - Adjust this to the highest value possible without “fast oscillation”
2. STABILIZE P - Stabilize Control P
   - Input: Desired angle and user-input angle; Output: Desired copter rate
   - Controls the “aggressiveness” of stabilization to correct for angle error AND user input.
   - Defaults are usually good, but you might want to make this more aggressive or less aggressive to your user input.
   - Rookie mistake – using too low P here because the aircraft is “too sensitive”. Solution: get used to the sensitivity, or modify the sensitivity on the user interface side (the remote control)

Throttle and Altitude Parameters

3. THR_RATE – Throttle Rate P
   - Input: Desired vertical acceleration; Output: Throttle amount
   - In Alt Hold or Loiter, this controls how much throttle is used to achieve a given acceleration.
   - Start with P, tweak until it stays perfectly at an altitude (even better if you can test with a better sensor like sonar)
4. THR_ALT – Altitude Hold P
   - Input: Desired altitude; Output: Desired vertical acceleration
   - This controls how much acceleration is used to achieve a set altitude.
   - Defaults usually good here, but you can tweak this to get more aggressiveness.

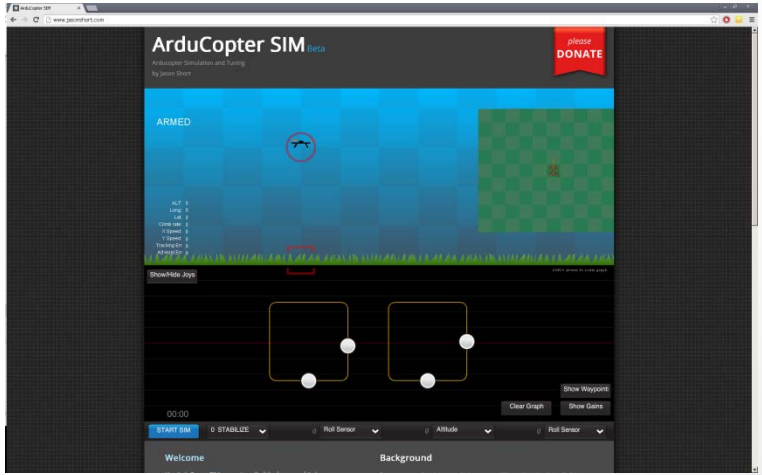
Loiter Parameters

5. LOITER_LAT, LOITER_LON – Loiter rate controller
   - Input: Error in speed; Output: Desired lean angle
   - If not moving into a position, increase or check GPS
   - If oscillating around a position, decrease
6. HLD_LAT, HLD_LON – Loiter speed controller
   - Input: Error in lat/lon position; Output: Desired speed
   - Defaults should be good, but you can increase if you want it to be more aggressive.

More Parameters and Practice

- See ArduPilot Tuning Guide:
  - http://copter.ardupilot.com/wiki/tuning/

- Practice PID tuning (Quick ArduCopter Simulator):
  - http://www.jasonshort.com/



Pro Tips

- Tuning is an art, but also a science.
  - Be organized and methodical.
  - Make hypotheses, and then iteratively increase / decrease your parameters to test them. Do NOT just wildly guess.

- Tune in pairs.
  - Another person can manage Mission Planner while you carefully pilot the aircraft. You can even change parameters mid-air!