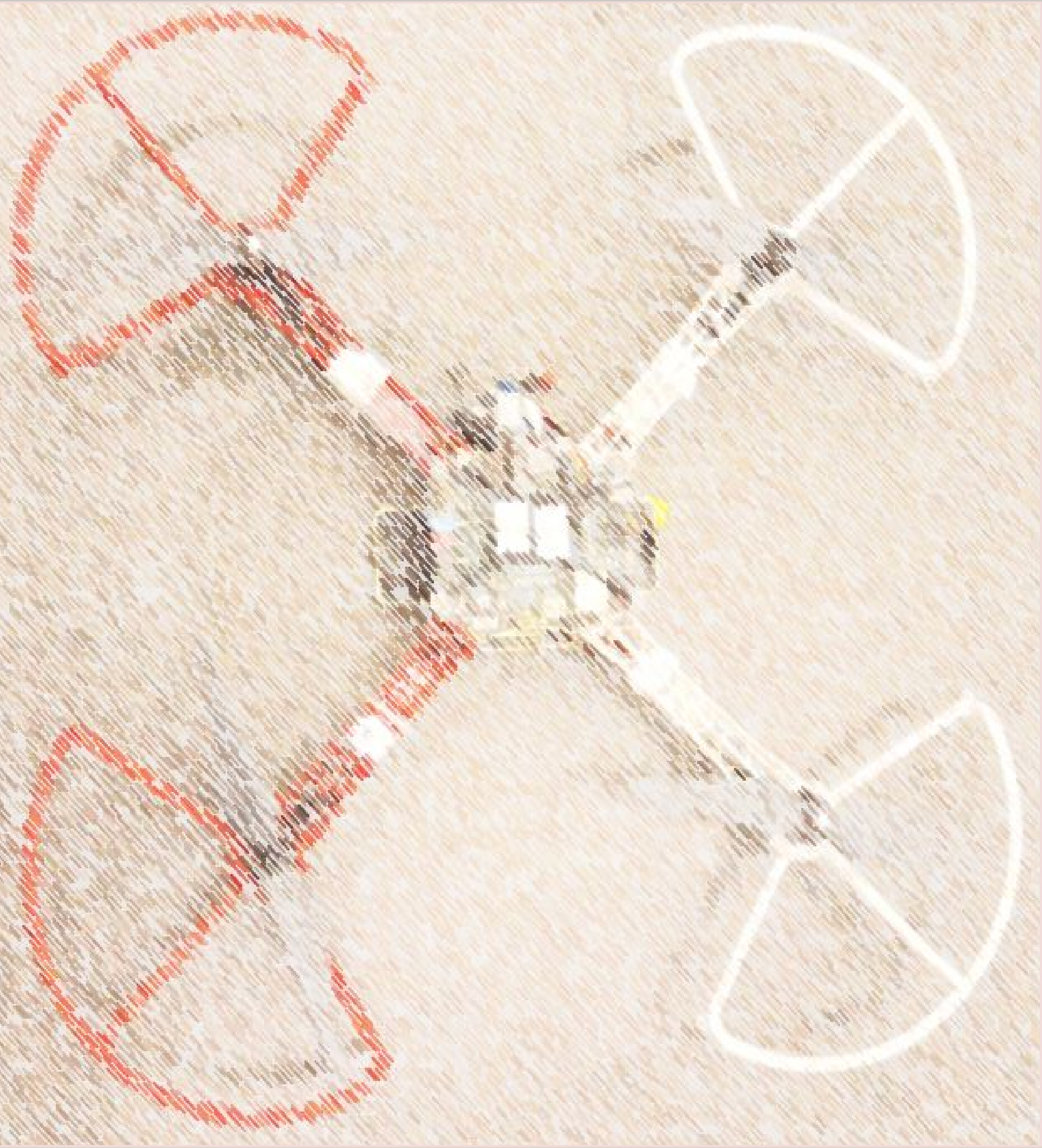


Microprocessor Controlled Aerial Robotics Team (MicroCART)

Dr. Jones and Dr. Elia

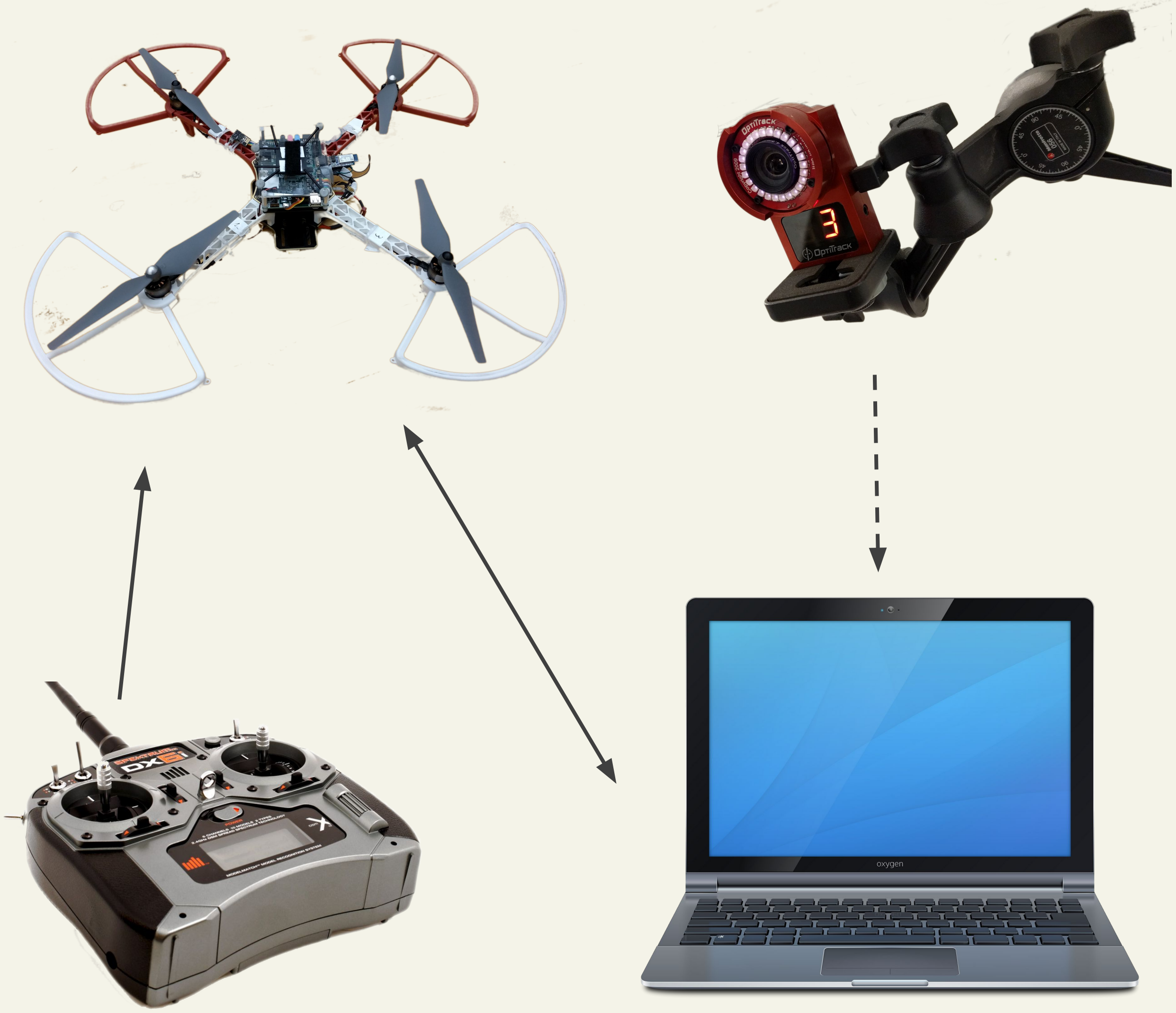
May1716

4 - 27 - 17

Purpose of MicroCART

To develop an aerial robot as a research platform for controls and embedded systems.

System Overview



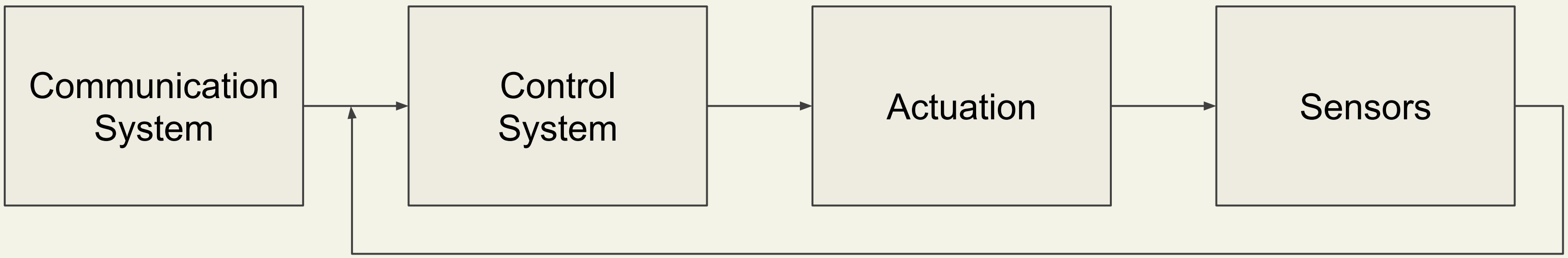
Goals and Deliverables

- Improved Flight Ability
  - Autonomous Flight
    - Controller designed from mathematical model
    - User-specified waypoints
  - Outdoor flight
- Modular Research Platform Features
  - Customizable controls structure
  - Flexibility in client types (GUI or CLI)
- Increased Robustness of System
  - Continuous Integration and Dedicated Hardware Tests
  - Communication reliability and throughput

Increased Flight Ability: Mathematical Model

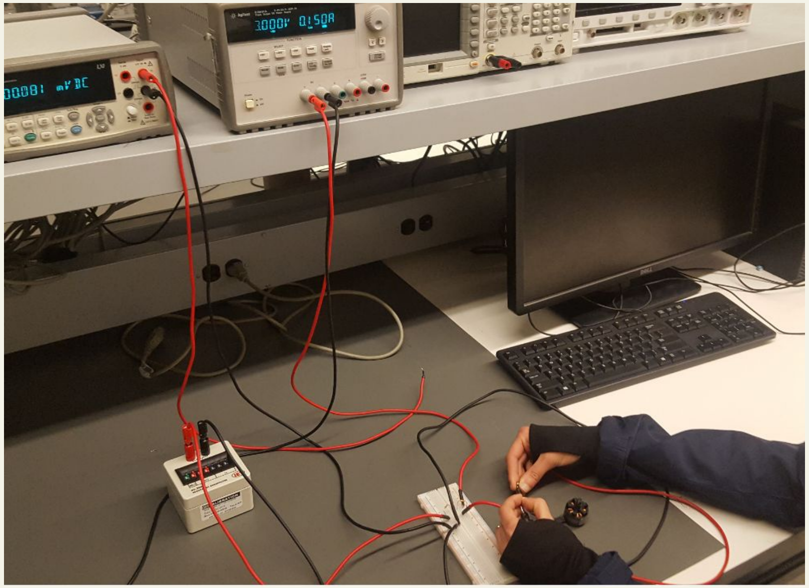
- Previously had no model of current system
  - Advantages:
    - Faster control structure development
      - Allows teams to find stabilizing controllers quickly
      - Different control structures can be simulated before being applied
    - Possibility for more advanced control in the future
      - Model based controllers can be explored

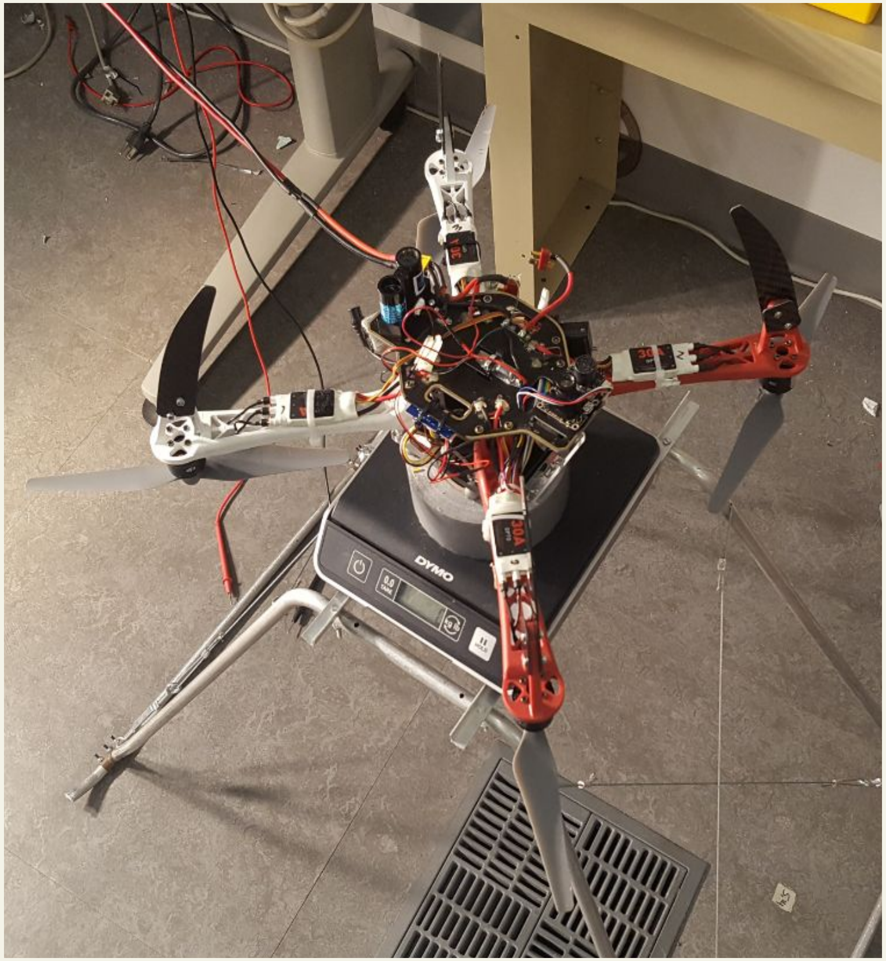
Quadcopter Model High Level Structure



Increased Flight Ability: Creating the Model

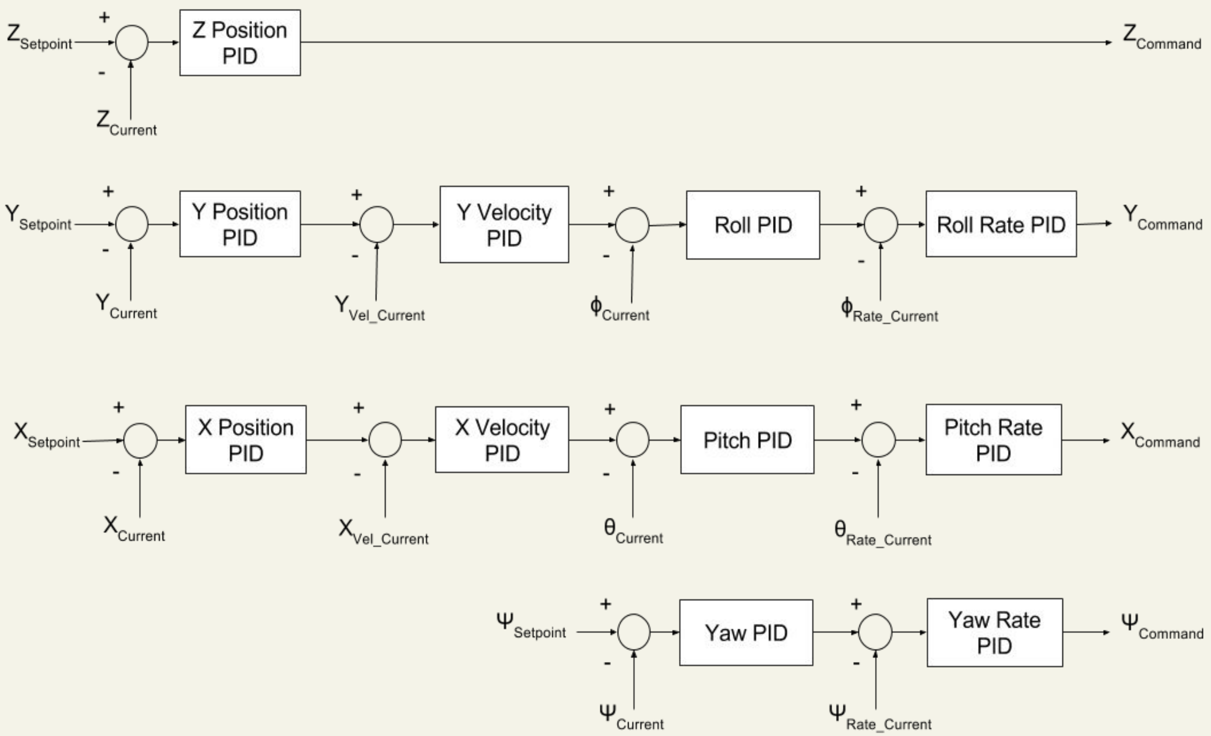
- System Identification
- Parameters Measured:
  - Moments of inertia
  - Thrust and drag constants
  - Sensor noise characteristics
  - Motor resistance





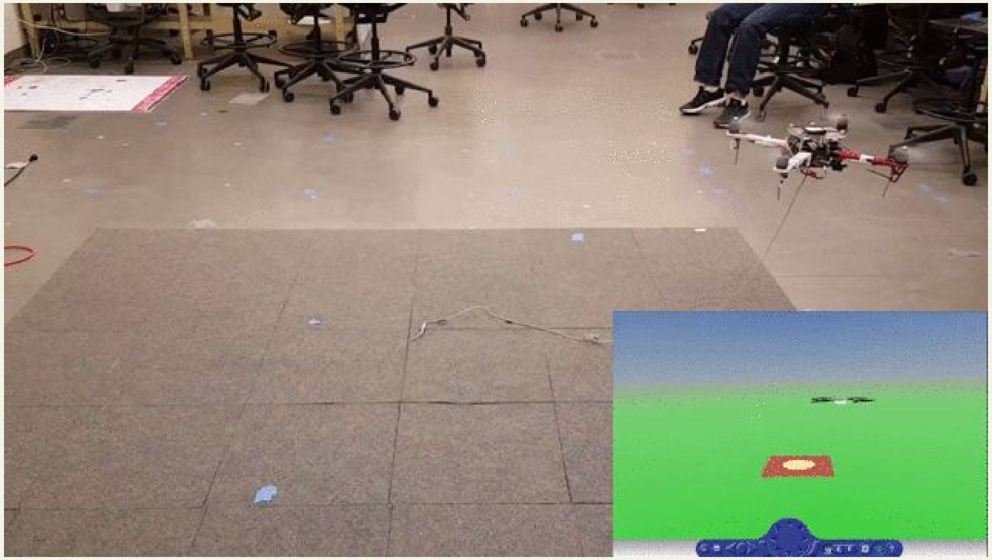
Increased Flight Ability: Control Structure

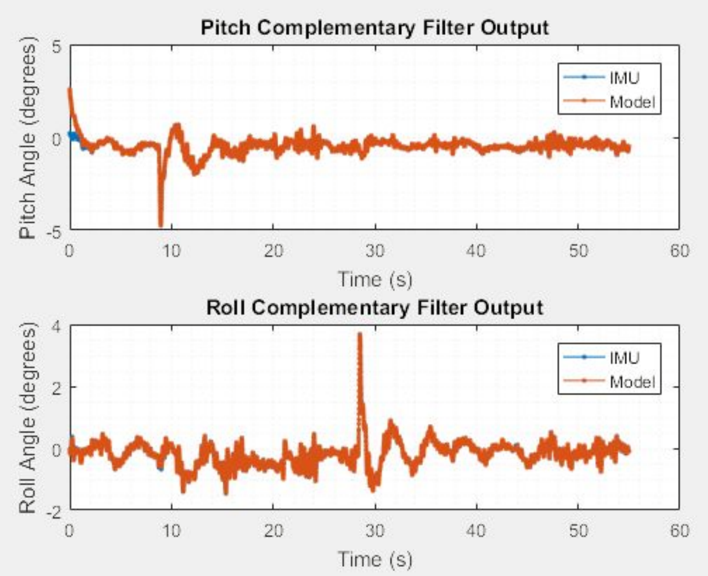
- 4 movement options
  - Height
  - Longitudinal
  - Lateral
  - Yaw
- Nested PID Structure
- Position and Velocity Control
- Euler angle and rate control

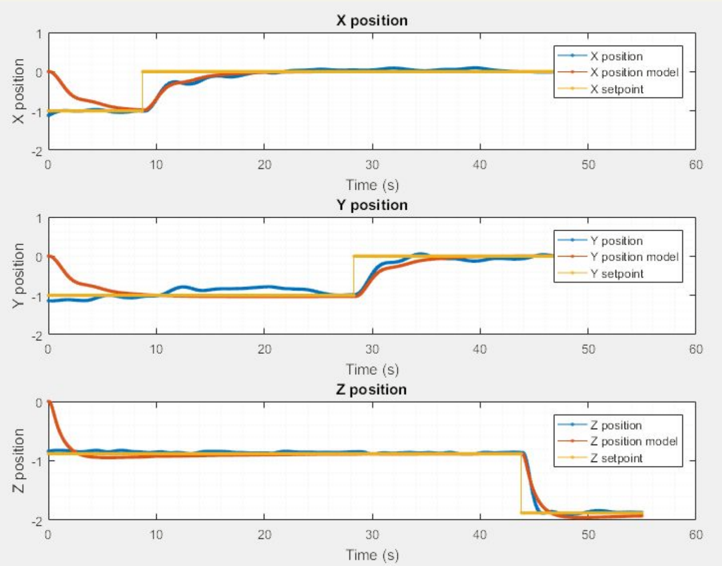


Current Model Developments

- Logging Analysis
- Setpoint Testing
  - Current model accurately reflects movement from real quadcopter



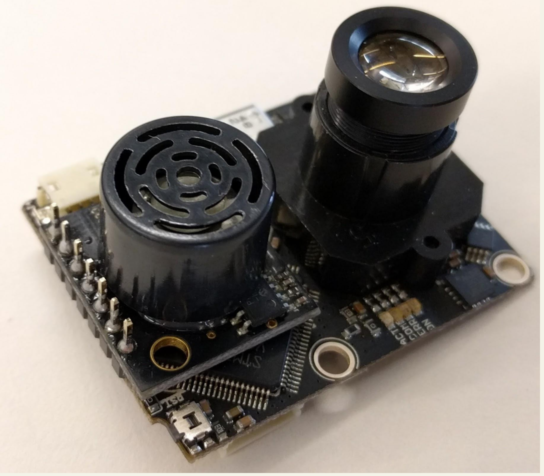




Increased Flight Abilities: Flying Outside

- Flying Outside:
  - LiDAR sensor for distance from ground
    - 1cm resolution
    - Sensor fusion algorithm combines LiDAR and accelerometer data
  - Optical Flow sensor
    - Takes high-speed images of the ground and computes pixel flow
    - Quad computes ground velocities and integrates to estimate position

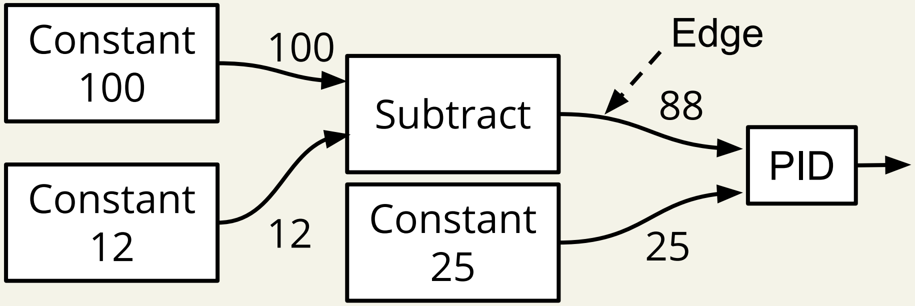
LiDAR Sensor

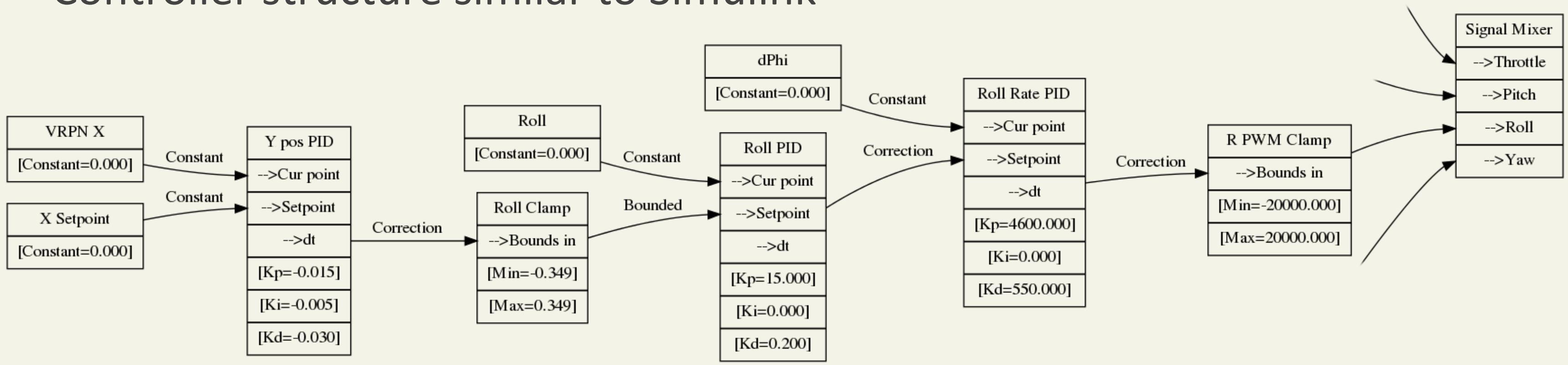


Optical Flow Sensor

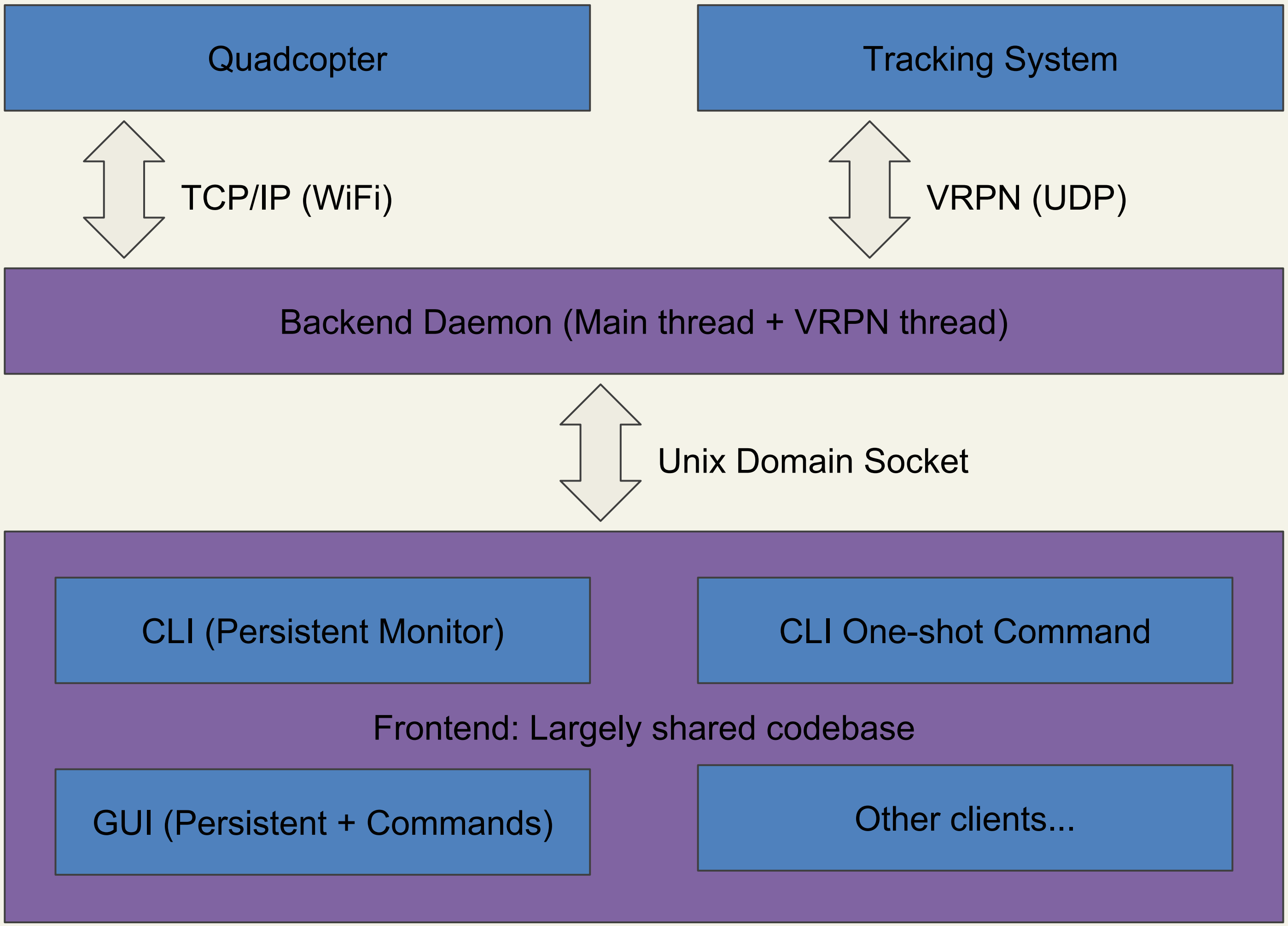
Modular System: Customizable Control Structure

- Structure controller as a directed graph
  - Nodes are discrete functions
  - Calculated values are passed along edges to inputs of other nodes
- Benefits
  - Blocks can be developed and tested independently of the quadcopter system
  - Allows changing controller at runtime
  - Controller structure similar to Simulink

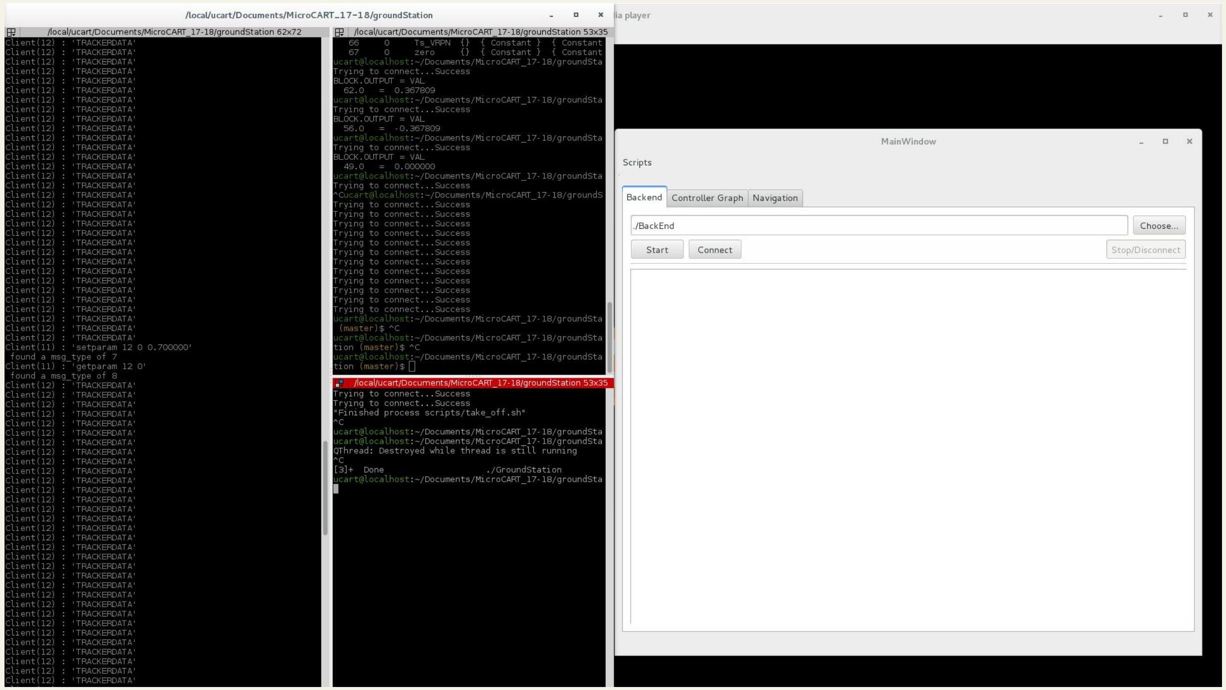




Modular System: Ground Station Architecture

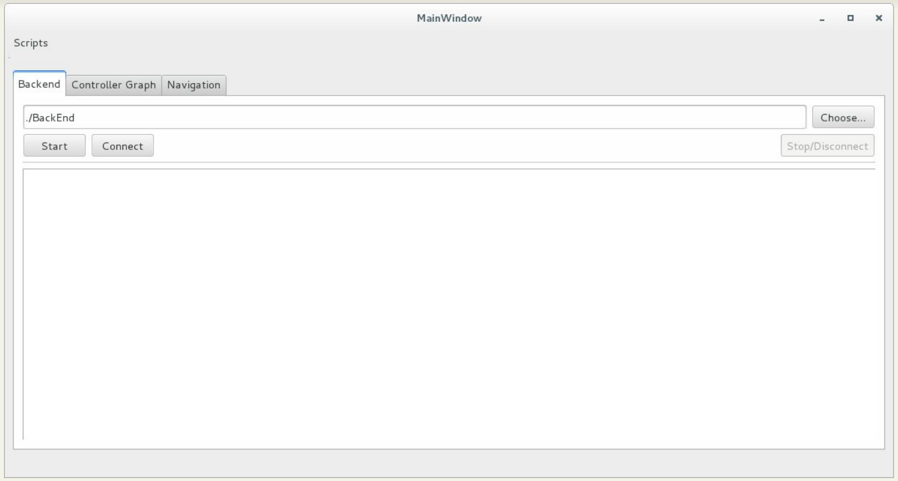


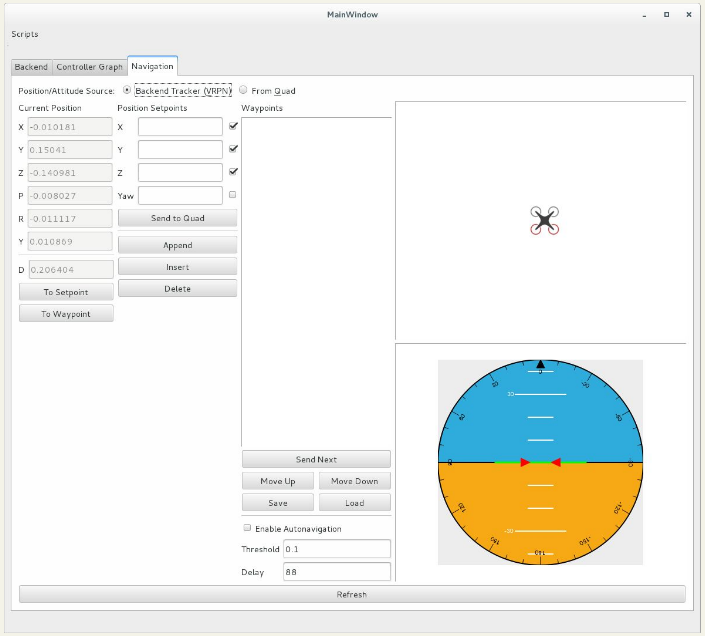
Ground Station Modular Structure

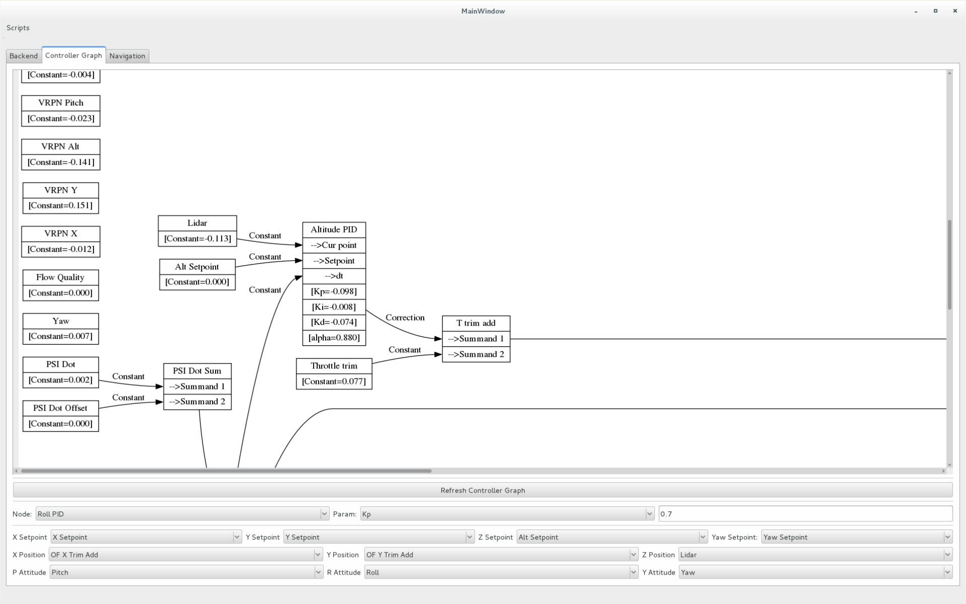


- Backend Daemon
  - Manages quad connection, tracking system
  - Services requests from frontend
- Decoupled Command Line Interface (CLI)
  - getoutput, getparam, getsource
  - setparam, setsource, getnodes
- Intuitive Graphical User Interface (GUI)
  - Same features as CLI
  - More information at-a-glance

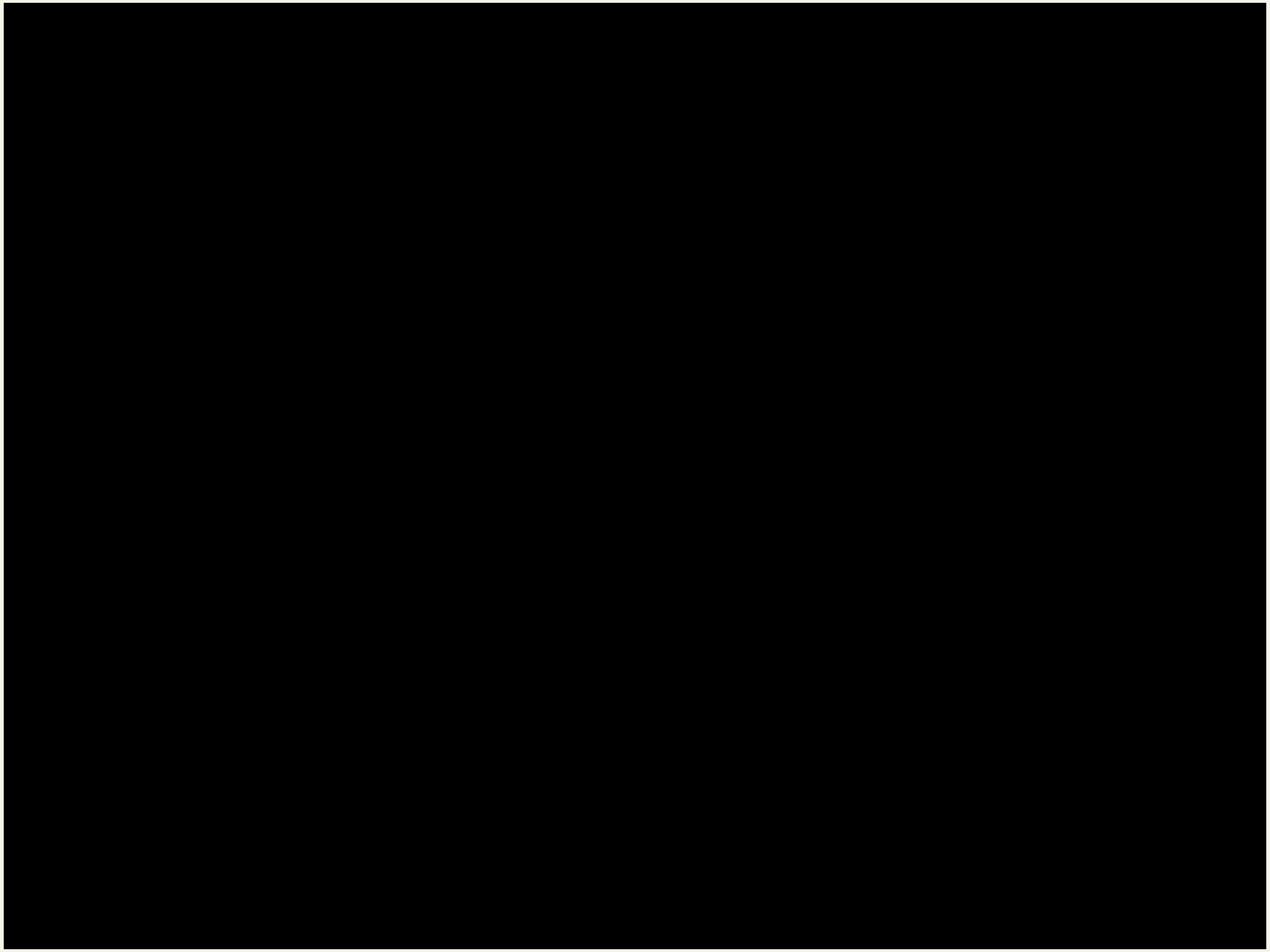
Ground Station GUI





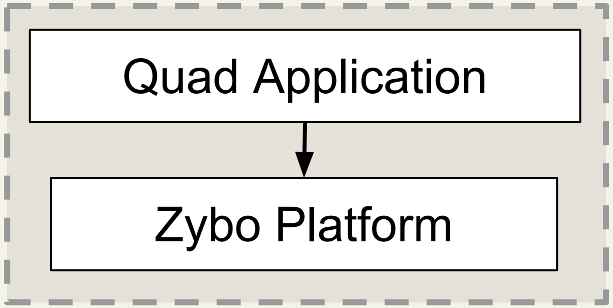


Ground Station GUI



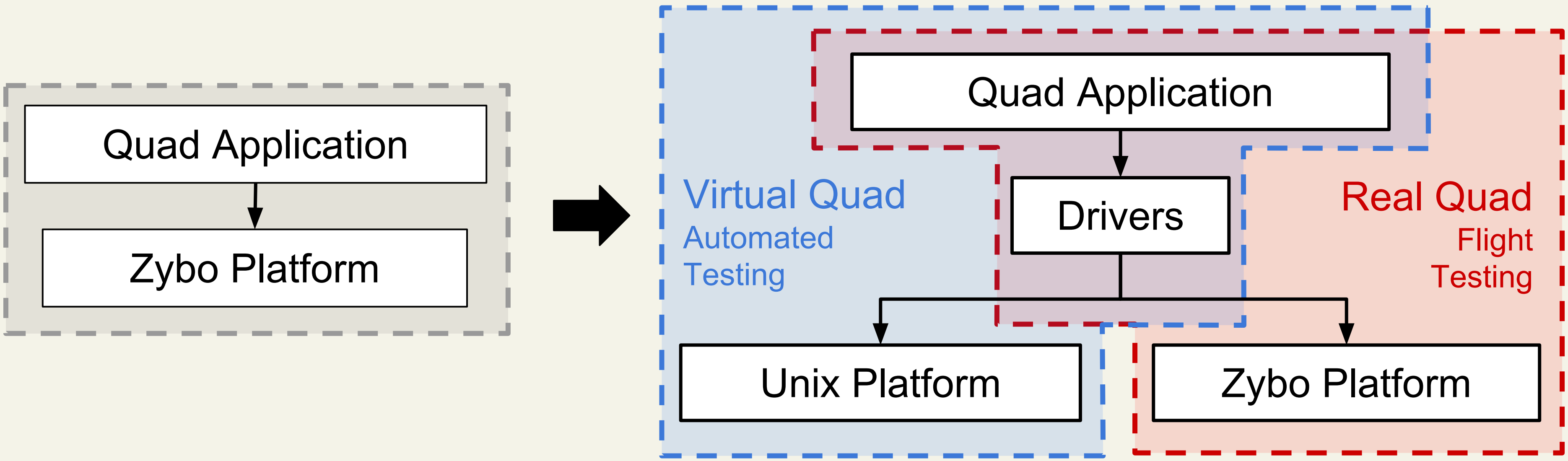
Robustness: Improved Testing Strategy

- Problem
  - Previous teams relied on end user tests to verify embedded software
    - But end-to-end tests are expensive in terms of man hours
  - Lack of testing flexibility was due to quadcopter software design
    - Tight coupling between the application and Zybo platform
    - Cannot compile for laptops or continuous integration environment



Robustness: Improved Testing Strategy

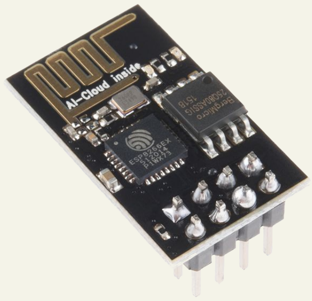
- Solution
  - Re-design software architecture to use interface-like drivers in order to target specific platforms.

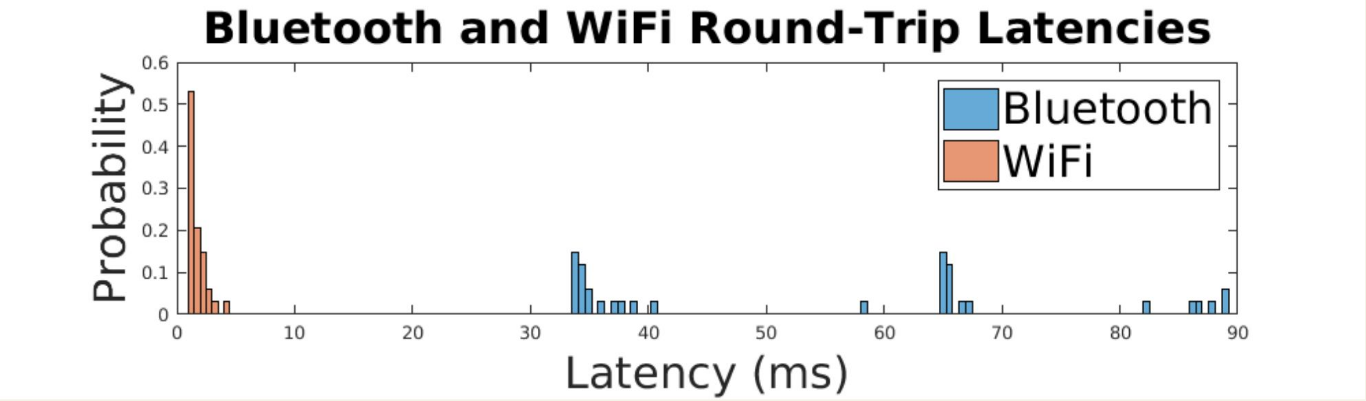


- New Testing Strategy
  - **Unit Tests** - Automated on **Continuous Integration**
  - **Functional Tests** using the Virtual Quad - Automated on **Continuous Integration**
  - **Dedicated Hardware Tests** - Testing each driver manually on the quad
  - **End-to-end Tests** - Flying the quad

Robustness: Decreased Latency

- Past issues with autonomy
  - Suspected cause: high latencies
    - Between base station to quadcopter
    - Using Bluetooth
      - 50 milliseconds on average
  - Solution to Decrease latency
    - Communicate via WiFi embedded system
    - Decreased average round-trip latency to 3ms average
    - Increased transmission reliability





Conclusions

Thank You

Questions?

- Team Members
  - Eric Middleton (CprE)
  - Brendan Bartels (EE)
  - Kris Burney (CprE)
  - Andy Snawerdt (EE)
  - Jake Drahos (CprE)
  - Joe Bush (CprE)
  - Tara Mina (EE)
  - David Wehr (CprE)
- Faculty Advisors
  - Dr. Jones
  - Dr. Elia

References

Bluetooth vs Wi-Fi. (n.d.). Retrieved November 19, 2016, from http://www.diffen.com/difference/Bluetooth_vs_Wifi

Cavallo, A., A. Cirillo, P. Cirillo, G. De Maria, P. Falco, C. Natale, and S. Pirozzi. Experimental Comparison of Sensor Fusion Algorithms for Attitude Estimation. Thesis. Second University of Nepales, 2014. Aversa: ScienceDirect, 2016. Print.

Ogata, Katsuhiko. Modern Control Engineering. 5th ed. Englewood Cliffs, NJ: Prentice-Hall, 1970. Print.

"Products." DJI Store. DJI, 2016. Web. 12 Oct. 2016. <http://store.dji.com/>.

"Research UAV – Drones / UAS for Research & Development." Ascending Technologies. N.p., 5 Nov. 2016. Web. 04 Dec. 2016. <http://www.asctec.de/en/asctec-research-uav/>.

Rich, Matthew. Model Development, System Identification, and Control of a Quadcopter Helicopter. Thesis. Iowa State University, 2012. Ames: Graduate Theses and Dissertations, 2012. Web.

Zynq-7000 All Programmable SoC Overview. DS190 (v1.10). Xilinx. September 27, 2016

Budget Plan

Item	Source	Cost
New Groundstation Computer	Provided by Client	$1400
Frame Kit - DJI Flamewheel F450	Provided by Client	$190
Optical Flow Sensor	Provided by Client	$100
Work Lights	Provided by Client	$70
Tent	Provided by Client	$100
LiDAR	Provided by Client	$150
WiFi Module	Provided by Client	$40
Miscellaneous	Provided by Client	$50
Total Cost for This Year:	**-**	**$2100**

System Identification

Symbol	Nominal Value	Units	Brief Description
m_q	0.986	*kg*	Quadrotor mass
m_b	0.204	*kg*	Battery mass
m	1.19	*kg*	Quadrotor + battery mass
g	9.81	m/s^2	Acceleration of gravity
J_{xx}	0.0218	kgm^2	Quadrotor + battery moment of inertia around b_x
J_{yy}	0.0277	kgm^2	Quadrotor + battery moment of inertia around b_y
J_{zz}	0.0332	kgm^2	Quadrotor + battery moment of inertia around b_z
J_{req}	4.201210-5	kgm^2	Rotor + motor m.o.i. around motor axis of rotation
K_T	8.155810-6	*kgmrad2*	Rotor thrust constant
K_d	1.747310-7	*kgm2rad2*	Rotor drag constant

System Identification (cont.)

Symbol	Nominal Value	Units	Brief Description
$\|rhx\|$	0.016	*m*	x-axis distance from center of mass to a rotor hub
$\|rhy\|$	0.016	*m*	y-axis distance from center of mass to a rotor hub
$\|rhz\|$	0.003	*m*	z-axis distance from center of mass to a rotor hub
R_m	0.2308	*Ω*	Motor resistance
K_Q	96.3422	*ANm*	Motor torque constant
K_V	96.3422	radVs	Motor back-emf constant
i_f	0.511	*A*	Motor internal friction current
P	0.47	*(none)*	ESC turn-on duty cycle command
P	0.40	*(none)*	Minimum Zybo output duty cycle command
P_T	0.80	*(none)*	Maximum Zybo output duty cycle command
$\|rhx\|$	0.016	*m*	x-axis distance from center of mass to a rotor hub
$\|rhy\|$	0.016	*m*	y-axis distance from center of mass to a rotor hub

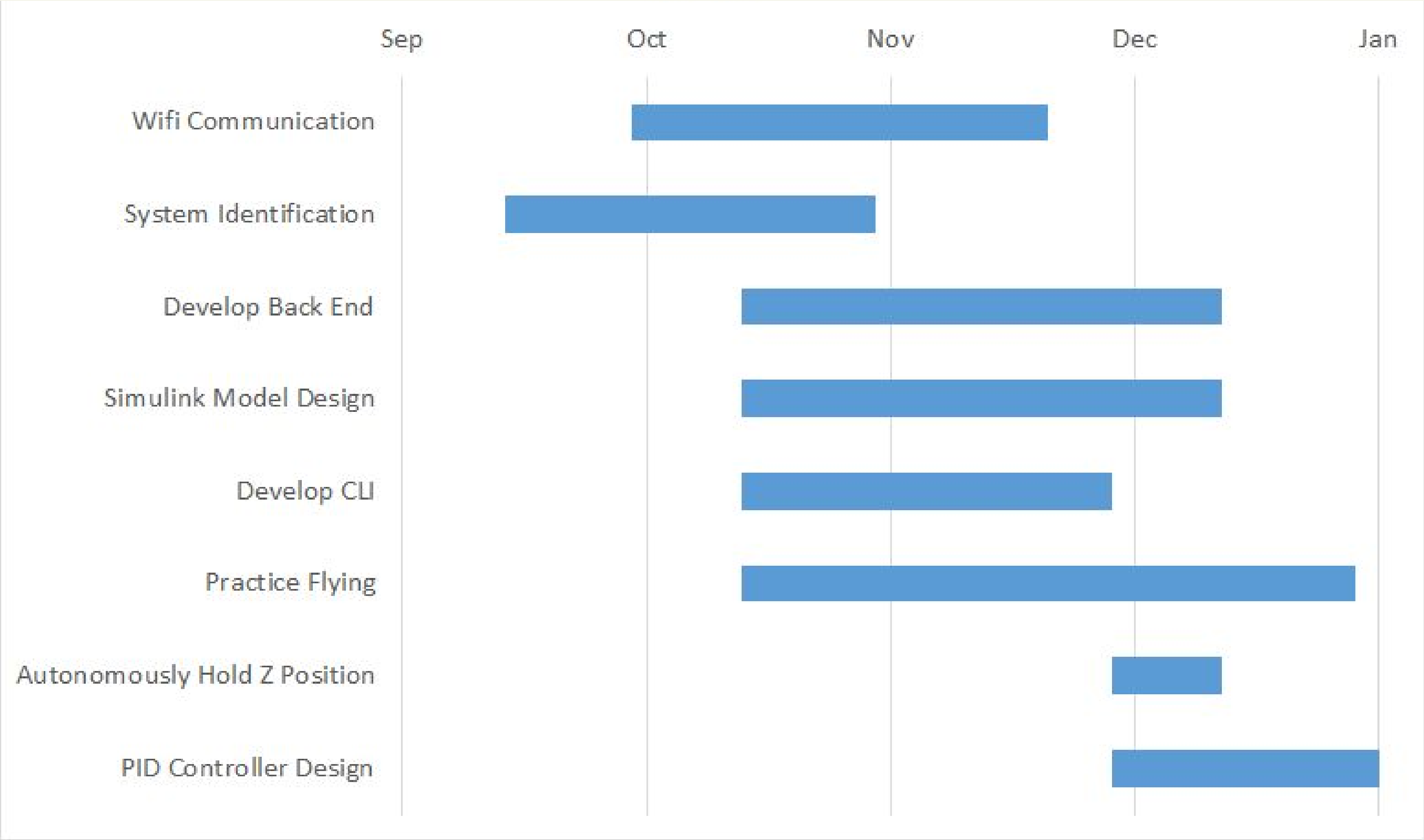
General Safety Practices

- Tether in Flight
- Awareness of Surroundings
  - Respectful of others in lab
  - Observant of obstacles
- Charge batteries in LiPo-safe charging sacks
- Practice Flying Small Quadcopters

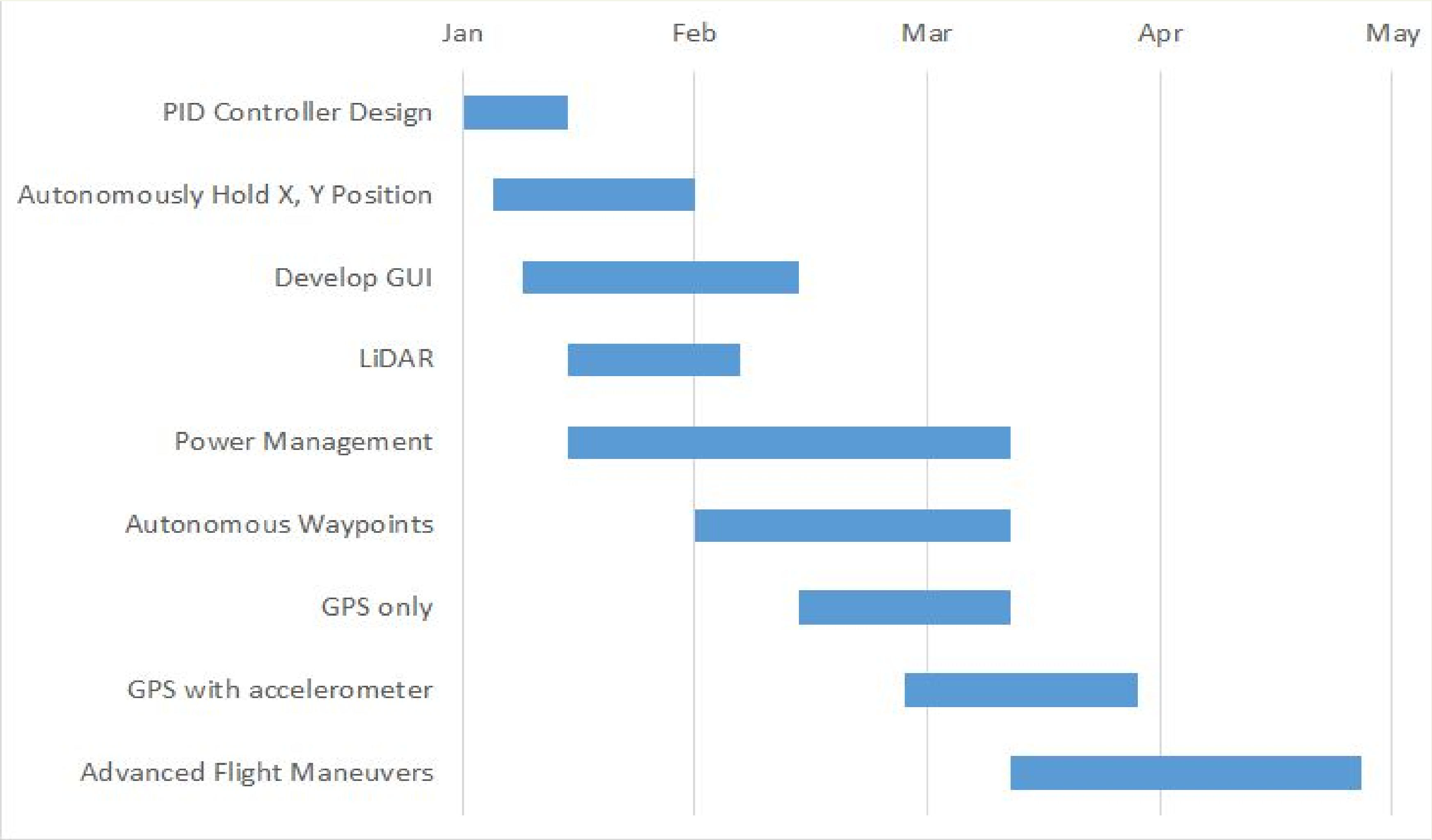
Stages of Testing Software Changes

- Stage 1: Test without Motor Power
  - Can verify that communication & lights work as expected
- Stage 2: Test without Propellers
  - Able to verify that motor velocities are as roughly as expected
- Stage 3: Test with Short Tether
  - Can verify that quadcopter tries to stabilize, and won't fly away
  - Prevents from flipping
  - Emergency: One person holds down quadcopter, another unplugs battery
- Stage 4: Regular Flight Testing
  - Always tethered when in flight

Overall Progress: Fall Semester Timeline



Our Plans: Spring Semester Timeline



Driver Interface Layer