University of Pittsburgh Robotics and Automation Society

IARC Symposium, July 31, 2018

Presentation Outline

Mechanical Design

- Mechanical overview
- Roomba Bumper
- Propulsion System

Electrical Systems

- System Overview
- Computers and Microcontrollers
- Safety Switch

State Estimation and Control

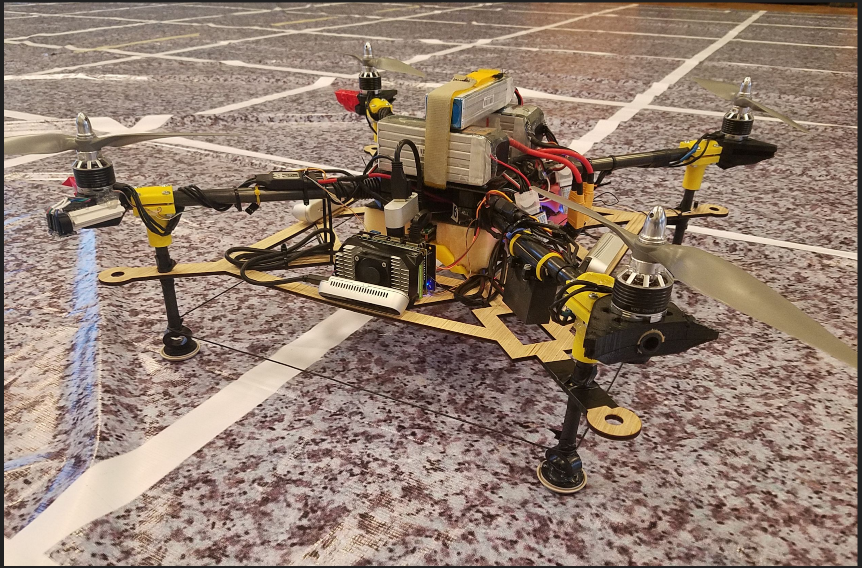
- Motion Control
- Obstacle Detection
- Target Detection
- Position Estimation

Testing

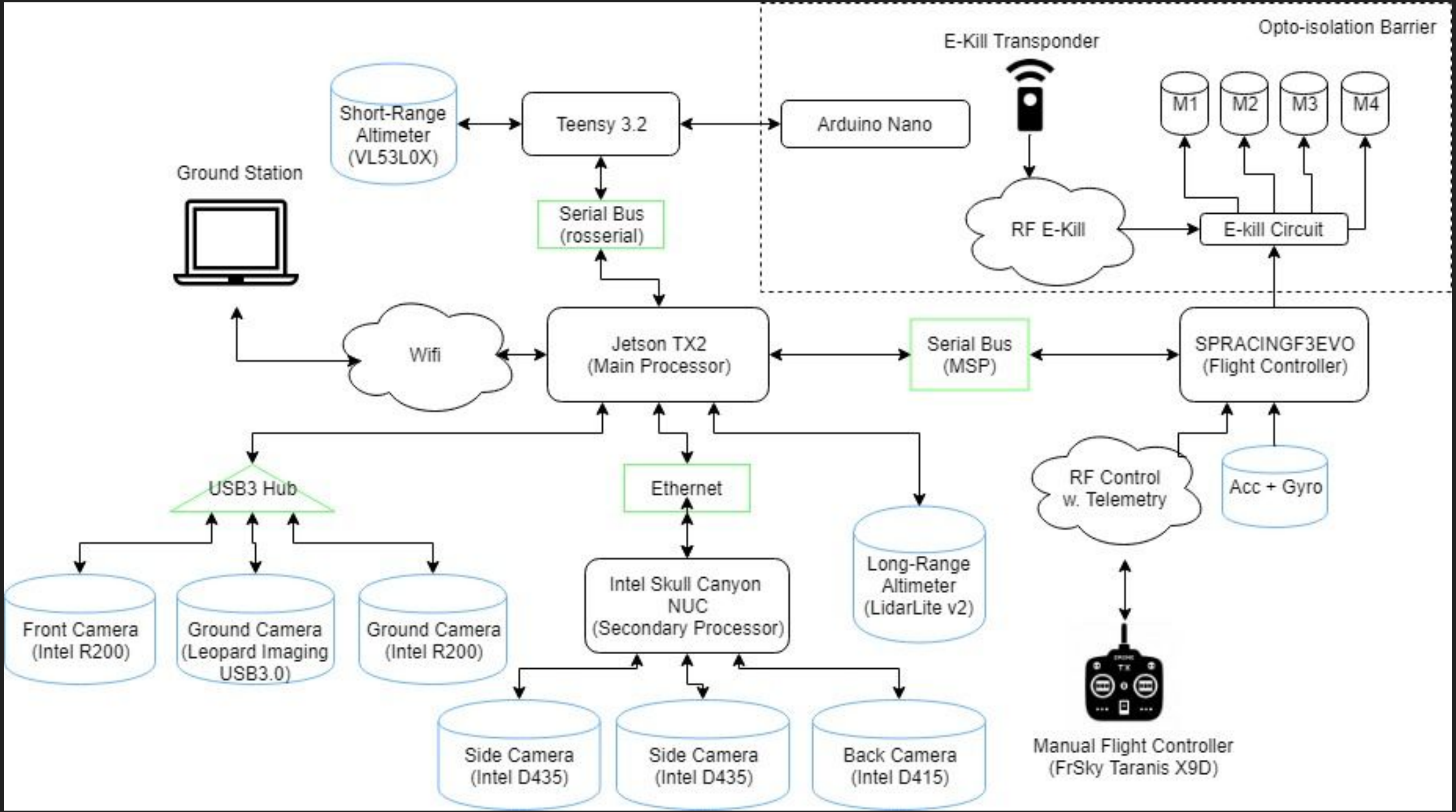
- Integration Testing
- Half Scale Arena

Mechanical Design

- Focus on durability and extensibility
- Laser cut plywood roomba bumper
  - Lightweight and strong
- Carbon fiber center frame
- Quick Facts
  - 4.5kg (10lbs)
  - 7 minute flight time
  - 1.2 meters across
  - 12x6 APC props
  - 25.2V, 10.4 Ah motor battery
  - 2 kW average power usage

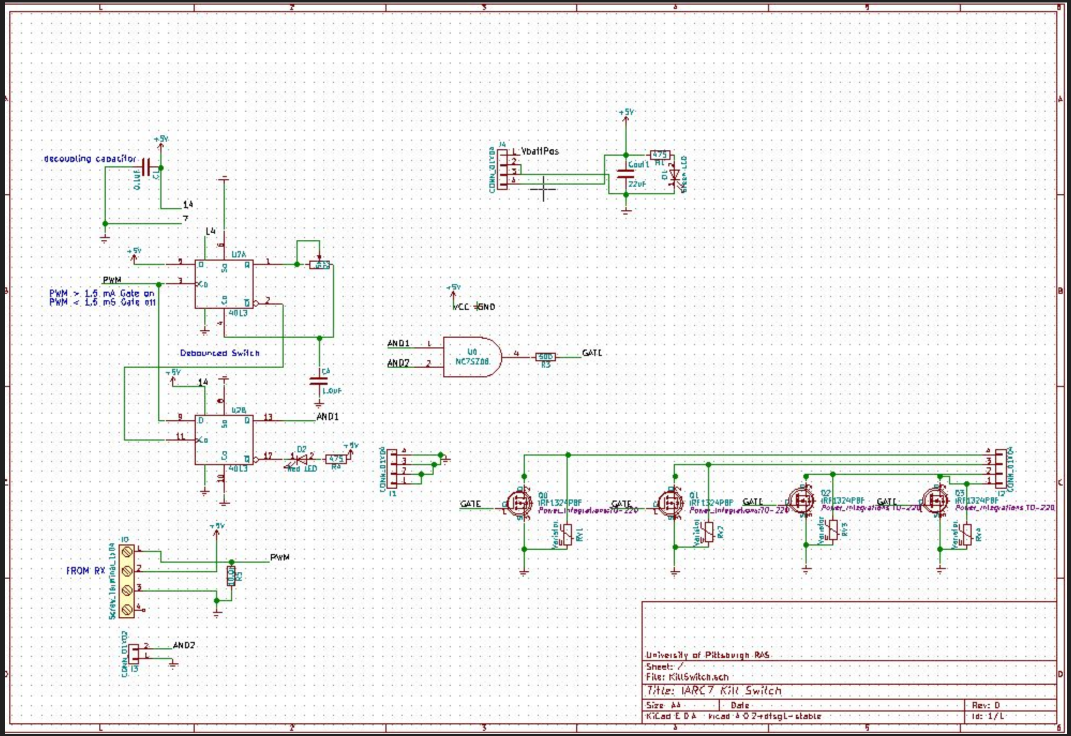


Electronic Systems: System Overview



Electronic Systems: Safety Switch

- One-Shot PWM to DC converter
- Capable of 120A peak, 80A continuous without significant heat rise
  - Low Rds-on ensures minimal power waste
- Simple design and construction provides robust operation and no failures to date



State Estimation and Control: Overview

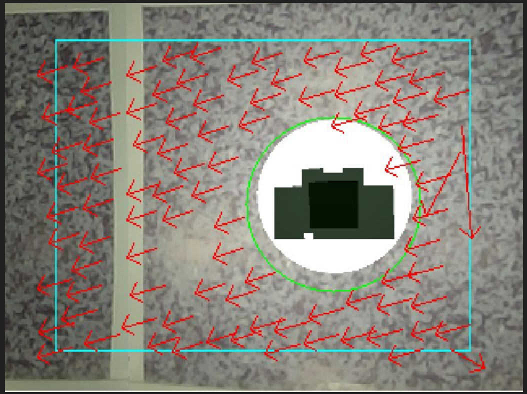
Core Software Components

- Motion Planner and Trajectory Control
- Obstacle Detector and Kalman Filter
- Target Detector and Kalman Filter
- Position Estimation
- Safety Monitor
- Localization Extended Kalman Filter

State Estimation and Control: Position Estimation

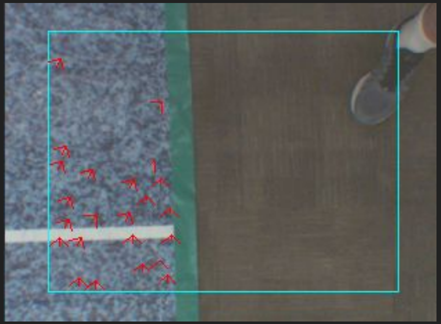
Optical Flow:

- Custom optical flow implementation
- Statistical filter monitors flow health
- Ignores vectors on ground targets



Arena Detection:

- Texture classification using SVM
- 41 filters including color and derivatives
- Linear SVM finds boundary line



Fused with IMU measurements in Extended Kalman Filter

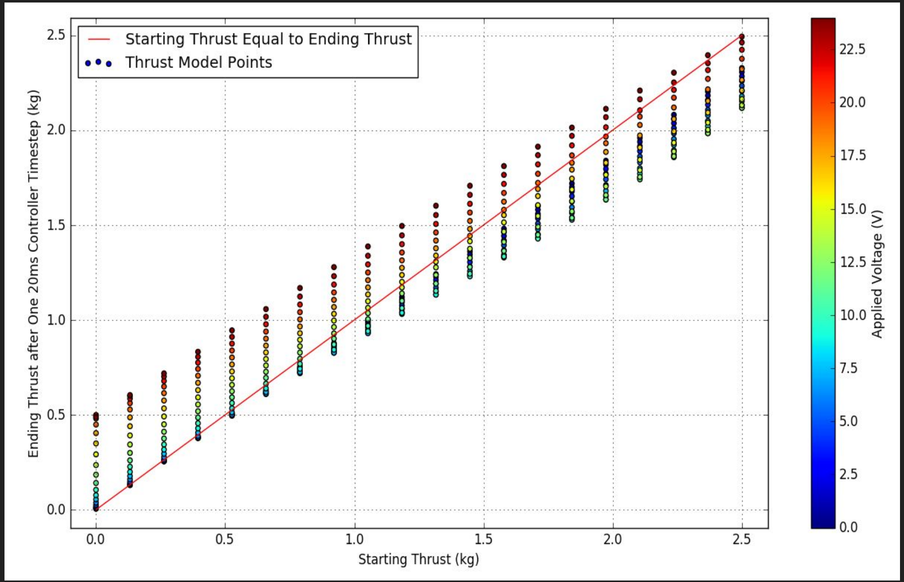
State Estimation and Control: Motion Control

Motion Planner:

- Architecture for motion primitives
- Support for search based planner

Trajectory Controller:

- PID on velocity with feedforward
- Nonlinear, dynamic thrust model
  - Reduces rotor lag by 40ms
  - Increases thrust slew rate by 4 times
- Applies acceleration setpoints
  - Not supported by current flight controllers
  - Significantly decreases control lag



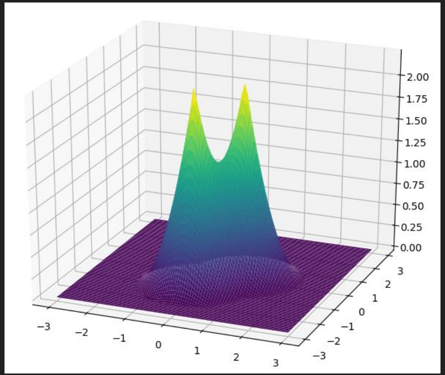
Software: Obstacle Detection and Avoidance

Detection

- Based on depth images received from Intel's R and D series Realsense cameras
- DBSCAN clustering to find individual obstacles

Avoidance

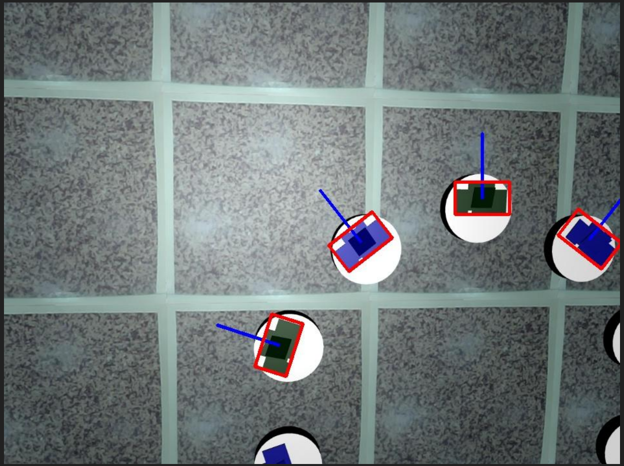
- Potential field to prohibit velocities which would bring the drone too close to any obstacle



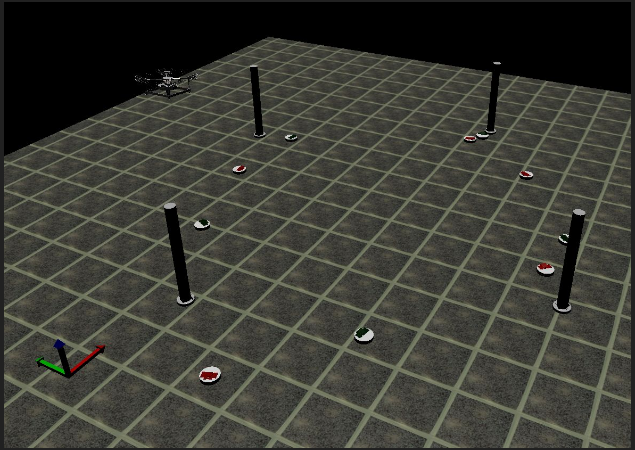
Software: Target Detection

- Bottom camera detector
  - Classical computer vision techniques
  - HSV normalization and threshold, morphology operations

- Side camera detector
  - CNN based on modified Tiny YOLO architecture



Testing: Integration



Simulation:

- Uses the MORSE simulator
- Physics, textures, most sensors
- Virtual Roombas

Crazyflie:

- Full software stack run on laptop
- Introduces stochastic variation
- Used primarily for testing controls

Testing: Quarter Scale Arena

Accomplished Behaviours:

- Stable Trajectory Control
- Arena Boundary Detection
- Search-based trajectory planning for jerk limits
- Target Interaction (Hit and Block)
- Obstacle Avoidance

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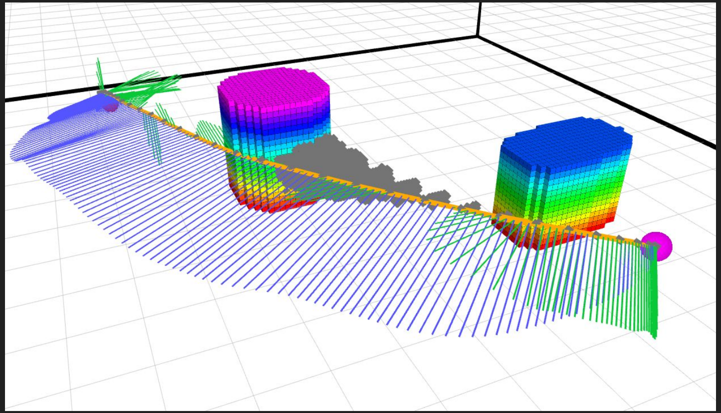
Software: Motion Planning

- Planning for various tasks accomplished by a heuristic search based planner
- Accounts for both obstacles within the arena and the dynamic constraints of the drone
- Uses anytime search with bounded sub-optimality to achieve real-time performance



Software: Localization

Vertical

- Long-range lidar
- Short-range lidar
- Accelerometer

Horizontal

- Accelerometer
- Sparse Optical Flow (OpenCV Lucas-Kanade)

Orientation

- IMU onboard flight controller, fused with Mahony filter
- Grid orientation fused with complementary filter

Fusion

- 15DOF Extended Kalman Filter (robot_localization)
- Complementary filters fusing velocities

Electronic Systems: Computers and Microcontrollers

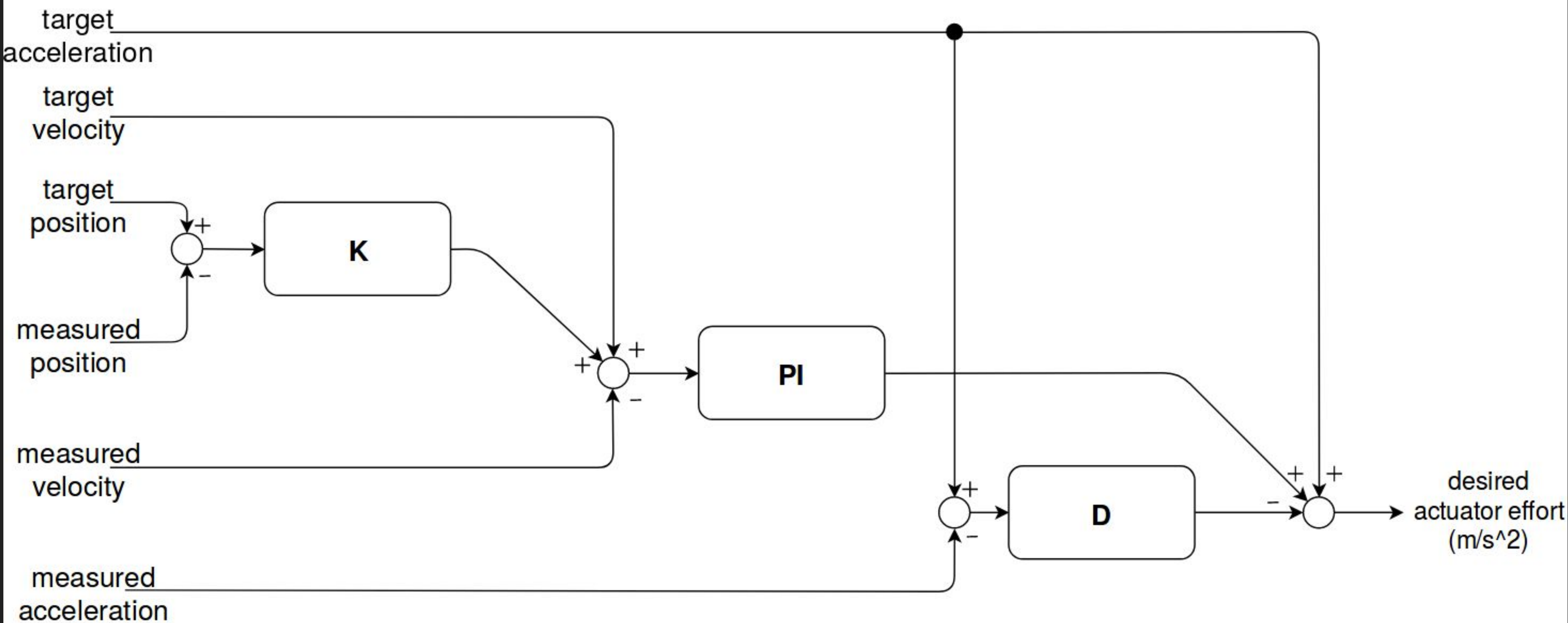
Main computers:

- NVIDIA Jetson TX2
  - Onboard GPU for low latency roomba identification and optical flow
  - CPU used for state estimation, motion planning, and controls
- Intel NUC (i7-6770HQ)
  - High USB bandwidth used to connect 4 Intel Realsense depth cameras
  - Processes point clouds
  - Estimates obstacle positions

Supporting microcontrollers:

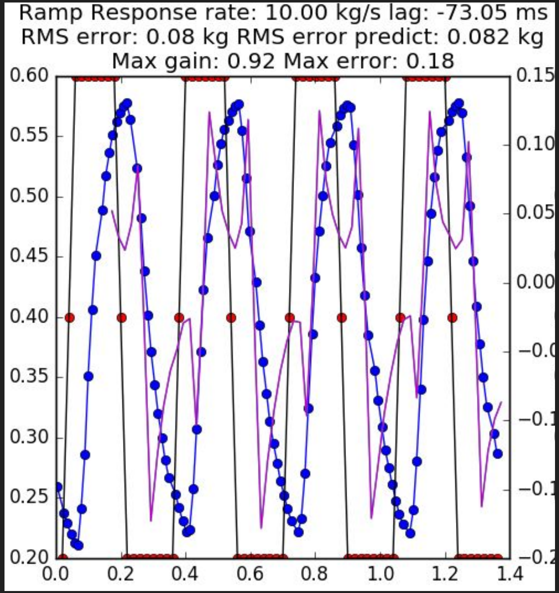
- Seriously Pro Racing F3 EVO
  - Cortex M3 Flight Controller board with integrated IMU
- Teensy 3.2
  - Relays Lidar range finder readings
- Arduino Nano
  - Relays battery voltage over opto-isolated serial link

Motion Control: Height Holding



State Estimation and Control: Motion Control

Static Model



Nonlinear Dynamic Model