Spring Final Review

RAVEN

Rover and Air Visual Environment Navigation

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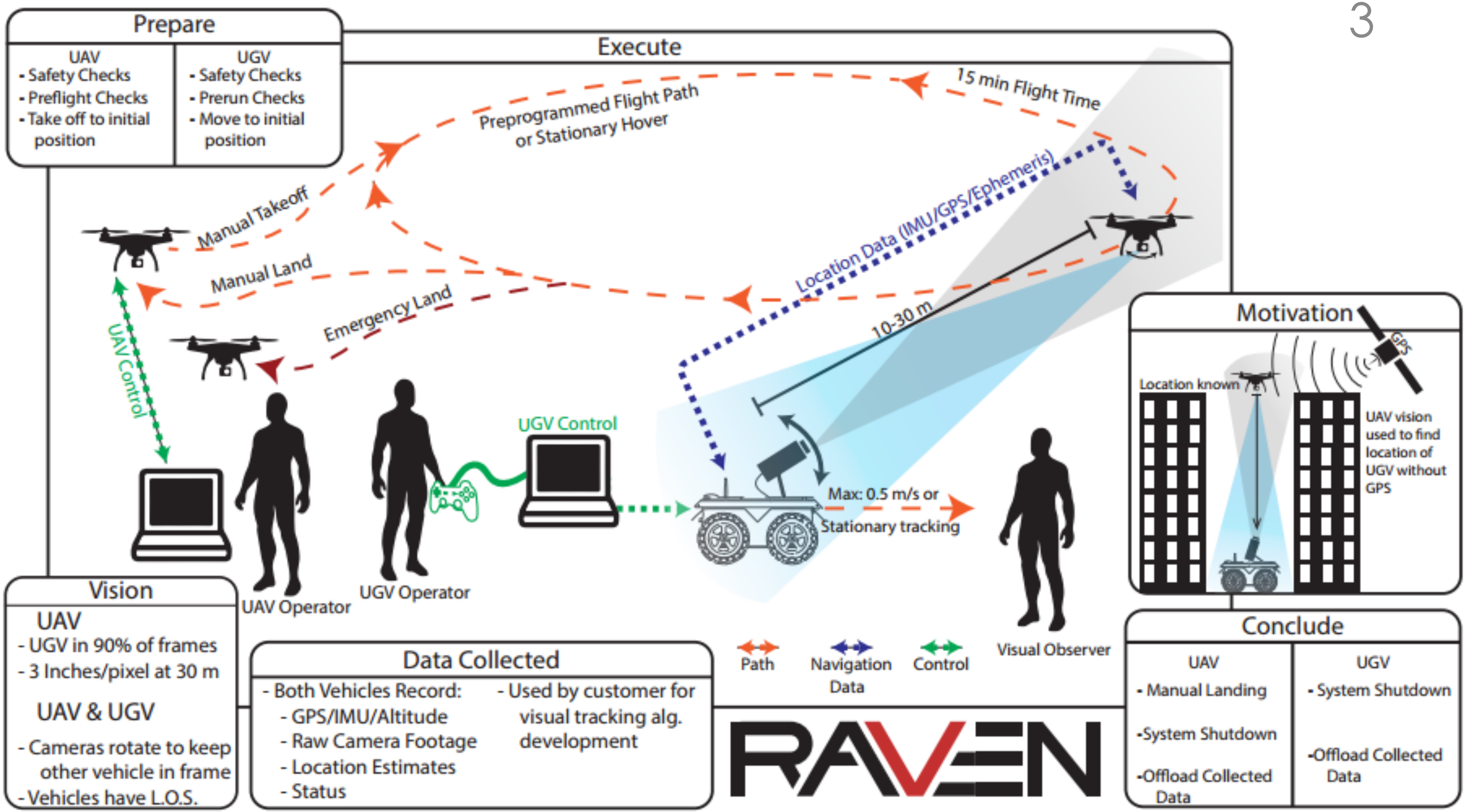
Project Purpose and Objectives

Mission Statement: RAVEN will develop a testbed that will collect image, position, and sensor data to be used by the customer for the verification of customer developed cooperative localization algorithms.

- Provide the customer with an **UAV and UGV** pair **testbed**
- Record **image, position, and sensor** data
- **Deliver** recorded information, including **collected GPS data,** and UAV/UGV pair to customer

Concept of Operations



Levels of Success

<u>Significant Level 3 Objectives:</u>

- Vision: A moving UAV shall track the UGV at 10-30 m and be **in 90 % of frames**. A stationary UGV shall track the UAV at 10-30 m and be in **90 % of frames.** Acquire target **in less than 3 seconds**.
- Captured Data: Store battery life estimate, package temperature, control input data, GPS/ephemeris data, IMU data, magnetometer data, and barometer data all in **ROS bags** w/ 20 GB storage margin.
- Controls: UAV will have **emergency land** switch. Control station displays map overlay of UAV/UGV positions as well as battery status, flight timer, and storage capacity.
- Comms: Vehicles **shall share GPS data**, visual tracking, and state data with the control stations.
- Electronics/Software: Vehicles shall have **15 min tracking endurance**.
- Management: Project cost shall remain **under budget**.

Levels of Success: Vision

<table>
<tr><th>Level 1</th><th>Level 2</th><th>Level 3 (Design Target)</th></tr>
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UAV shall track (keep in frame) UGV at range of 10-30 m.
Visual system extrinsics and intrinsics must be identified.
Image resolution must be less than or equal to 3 in/pixel at maximum range of 30 m.
Neither vehicle is moving.

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Level 1
AND UGV shall track UAV at maximum range of 30 m.
AND UAV shall identify target in 90% of captured frames within range.
INSTEAD only UAV shall be moving.

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Level 2
AND both UAV and UGV shall record if target is in frame.
INSTEAD UGV shall also be moving while not tracking.
AND UGV shall identify target in 90% of captured frames within range, while UAV is in flight.
AND shall not lose target for more than 3 seconds

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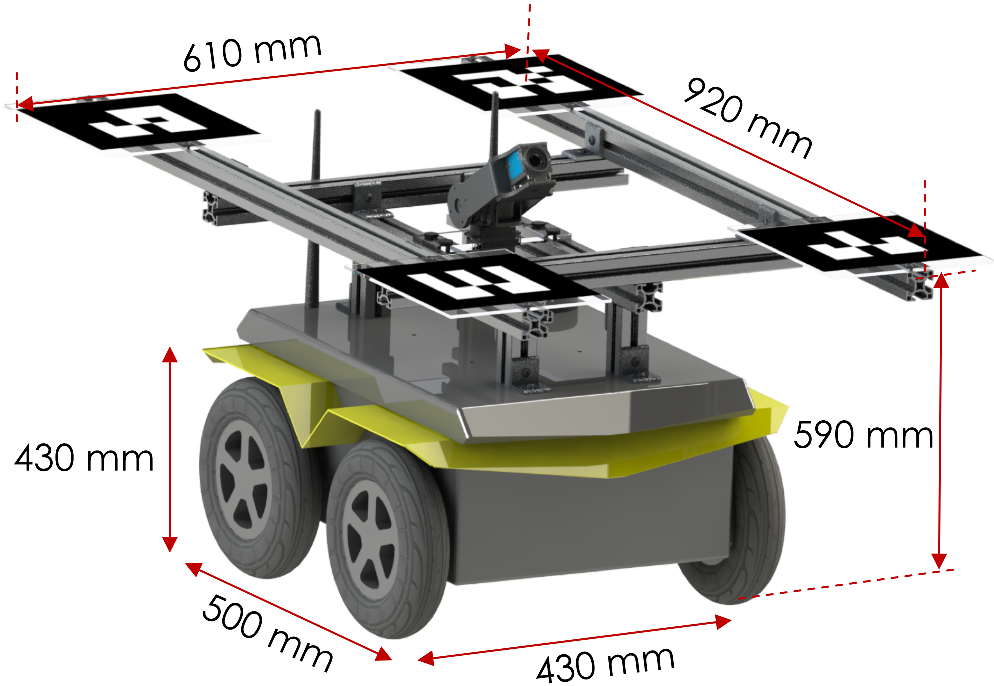
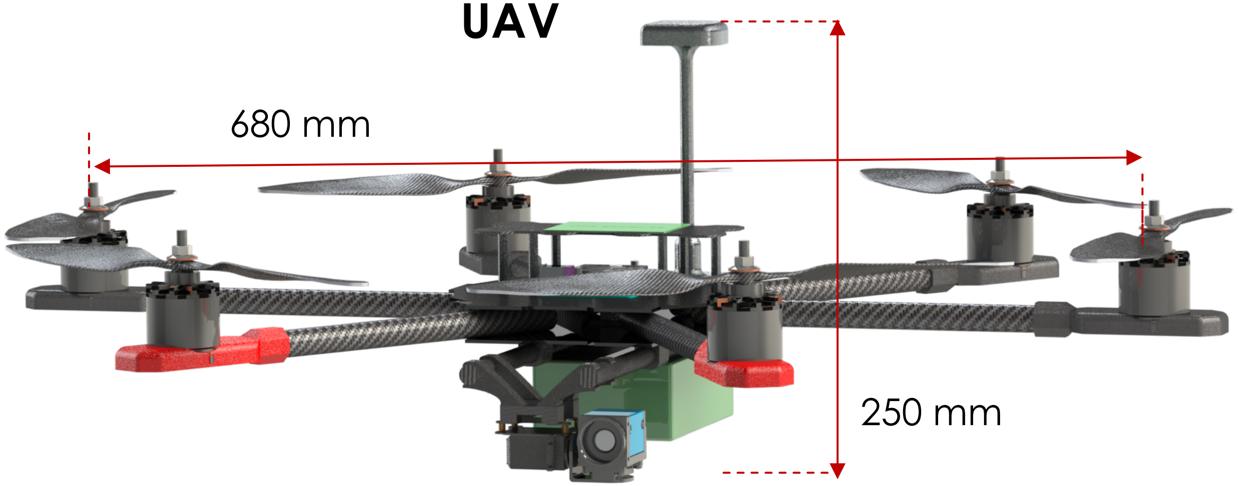
Design Description

Baseline Design

UGV

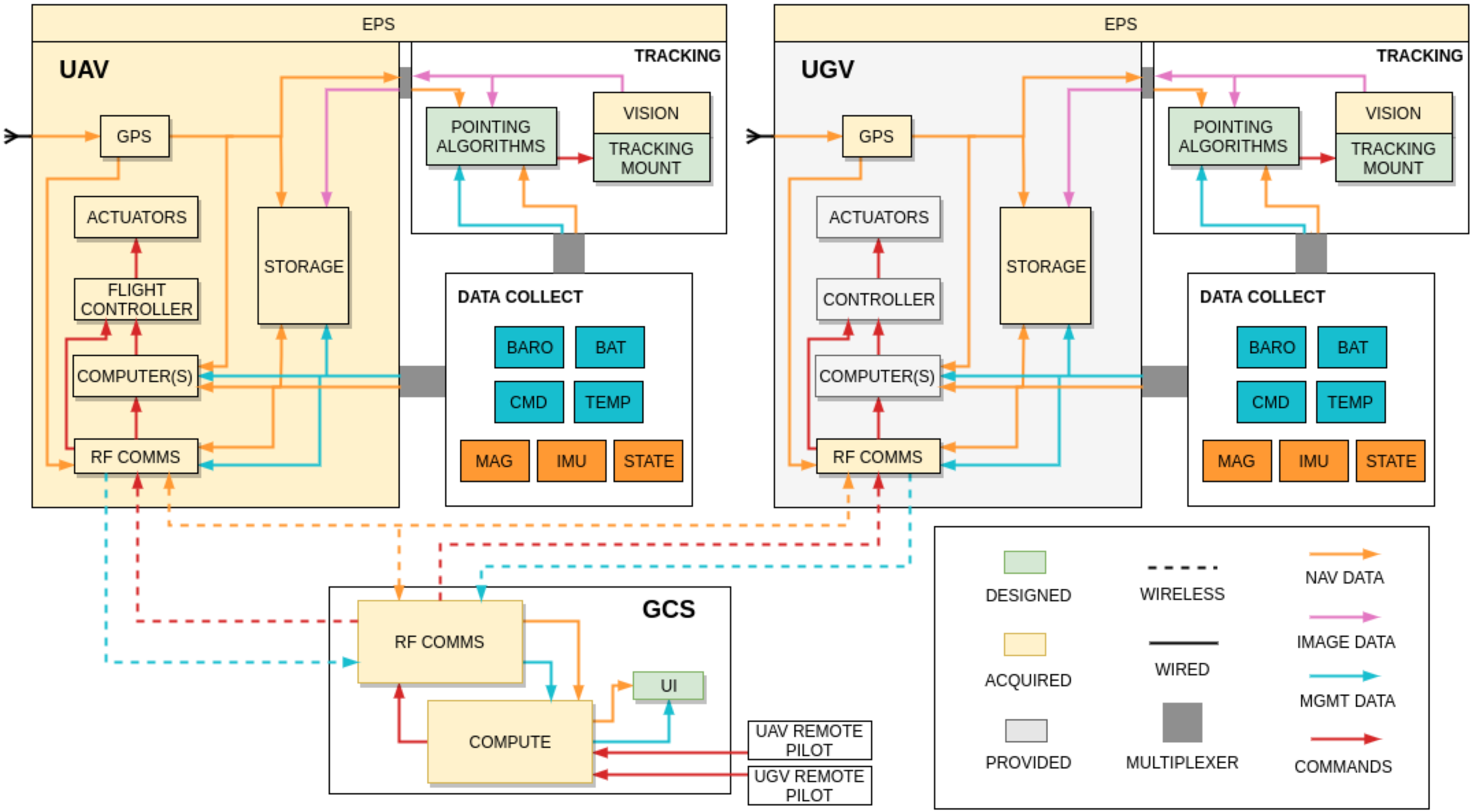


UAV



Ground Control Station

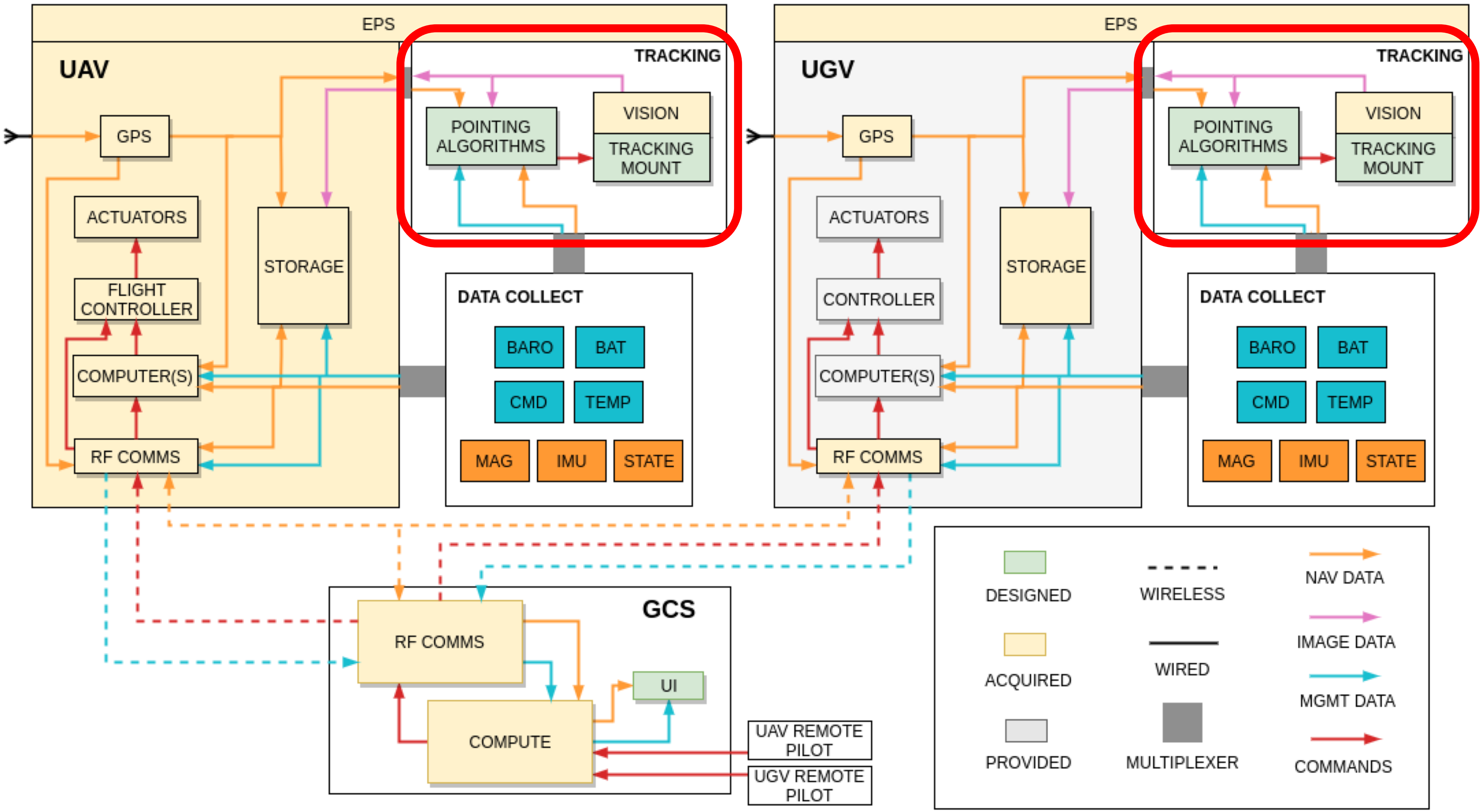
System Level Functional Block Diagram



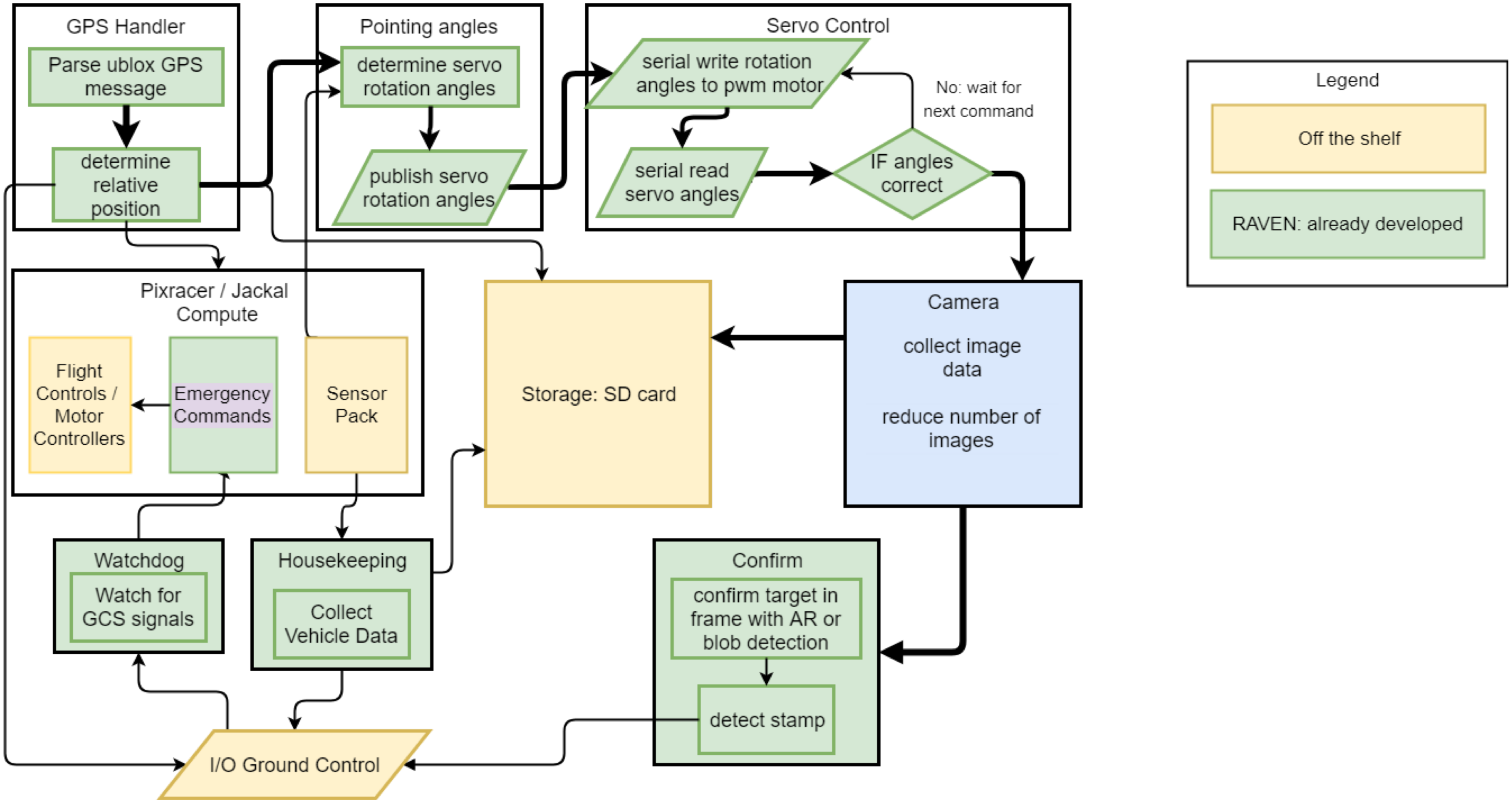
Critical Project Elements: Overview

Tracking	Communications	Integration
▶ Determination of target vehicle location by opposing vehicle ▶ Acquisition of target vehicle within camera frame ▶ Confirm that the target vehicle is in frame	▶ Record and store commands sent to vehicles ▶ Record and store data sent between vehicles and ground stations	▶ Platform and payload integration ▶ Hardware compatibility ▶ Software architecture

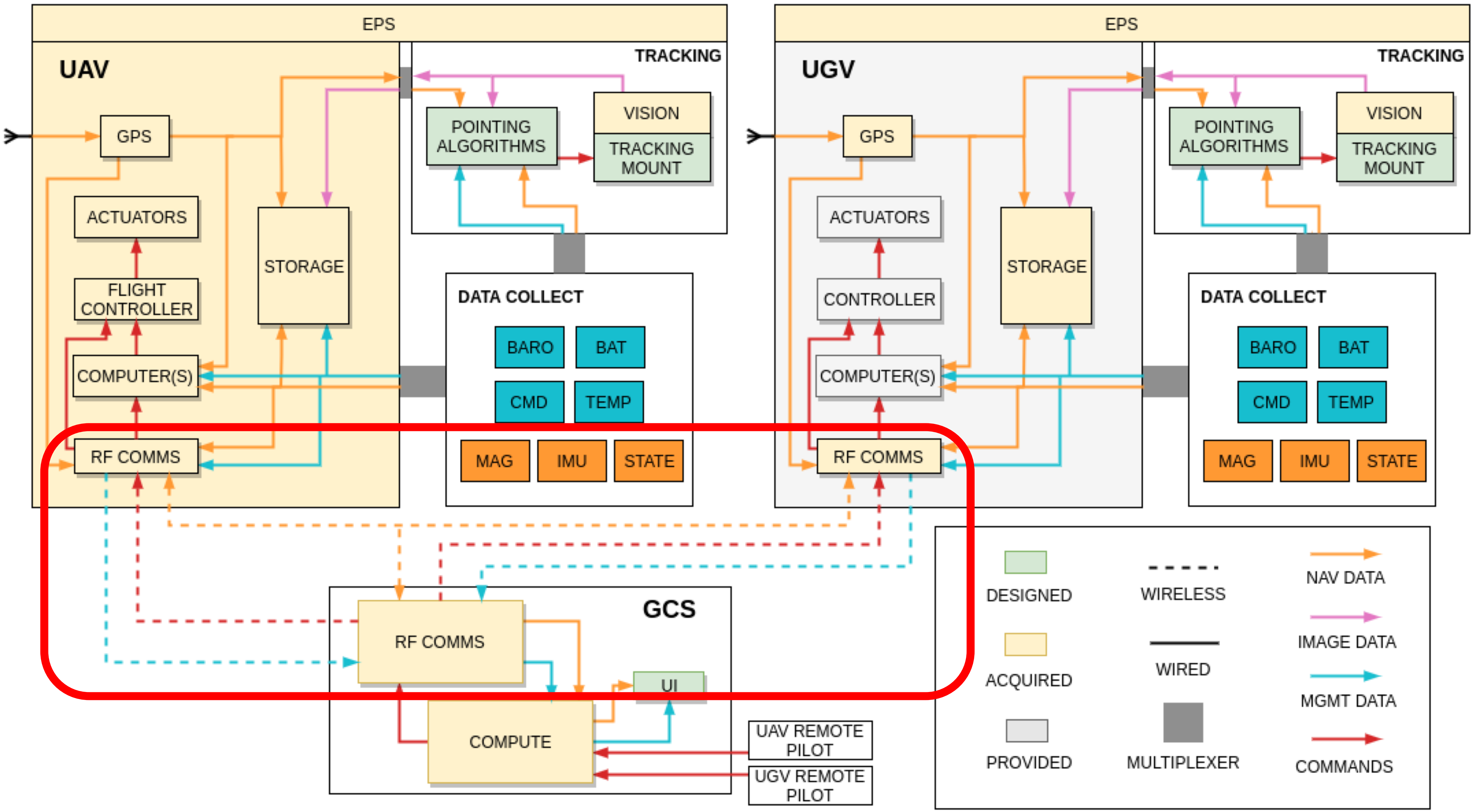
Critical Project Element: Tracking



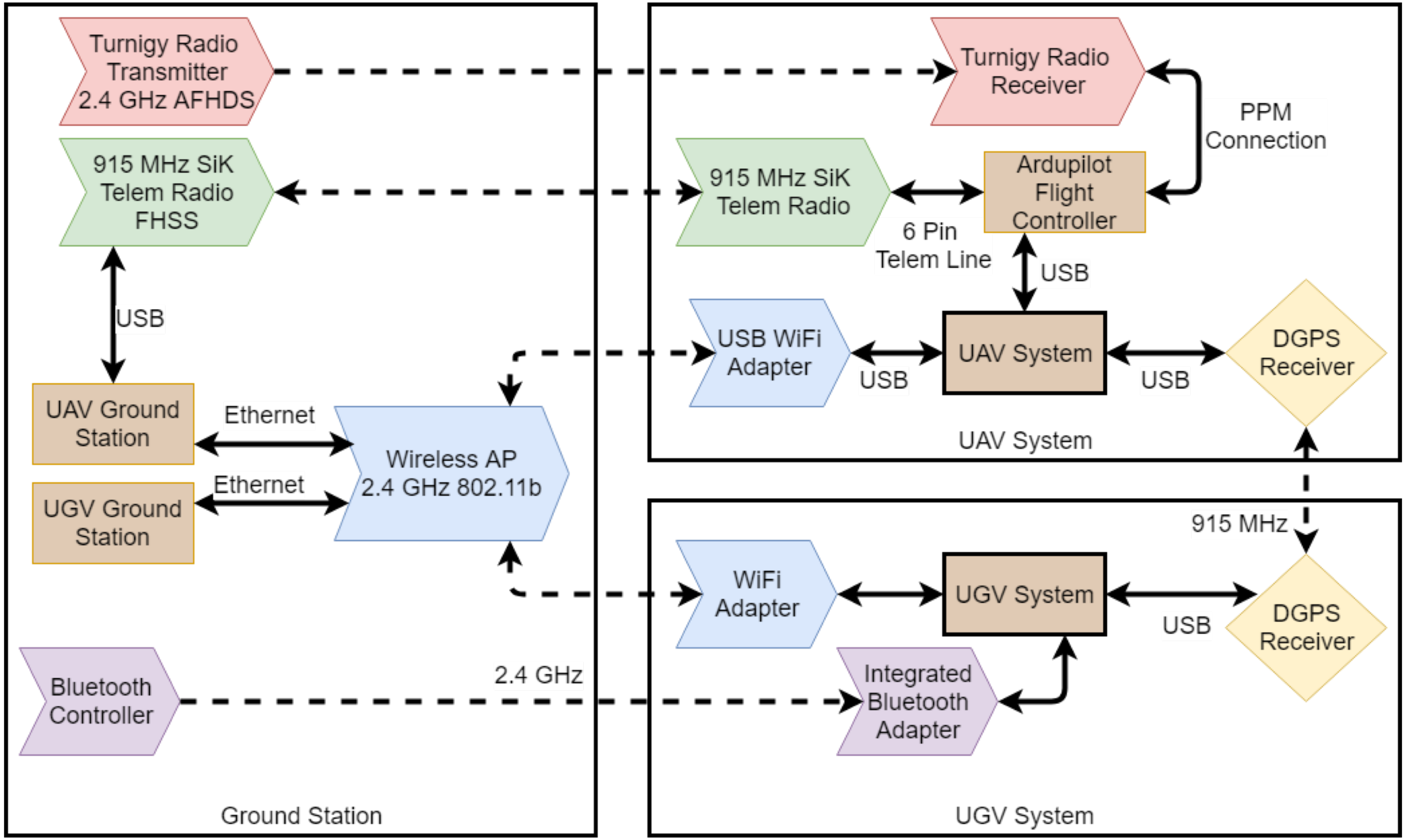
Vehicle Tracking Software



Critical Project Element: Communications



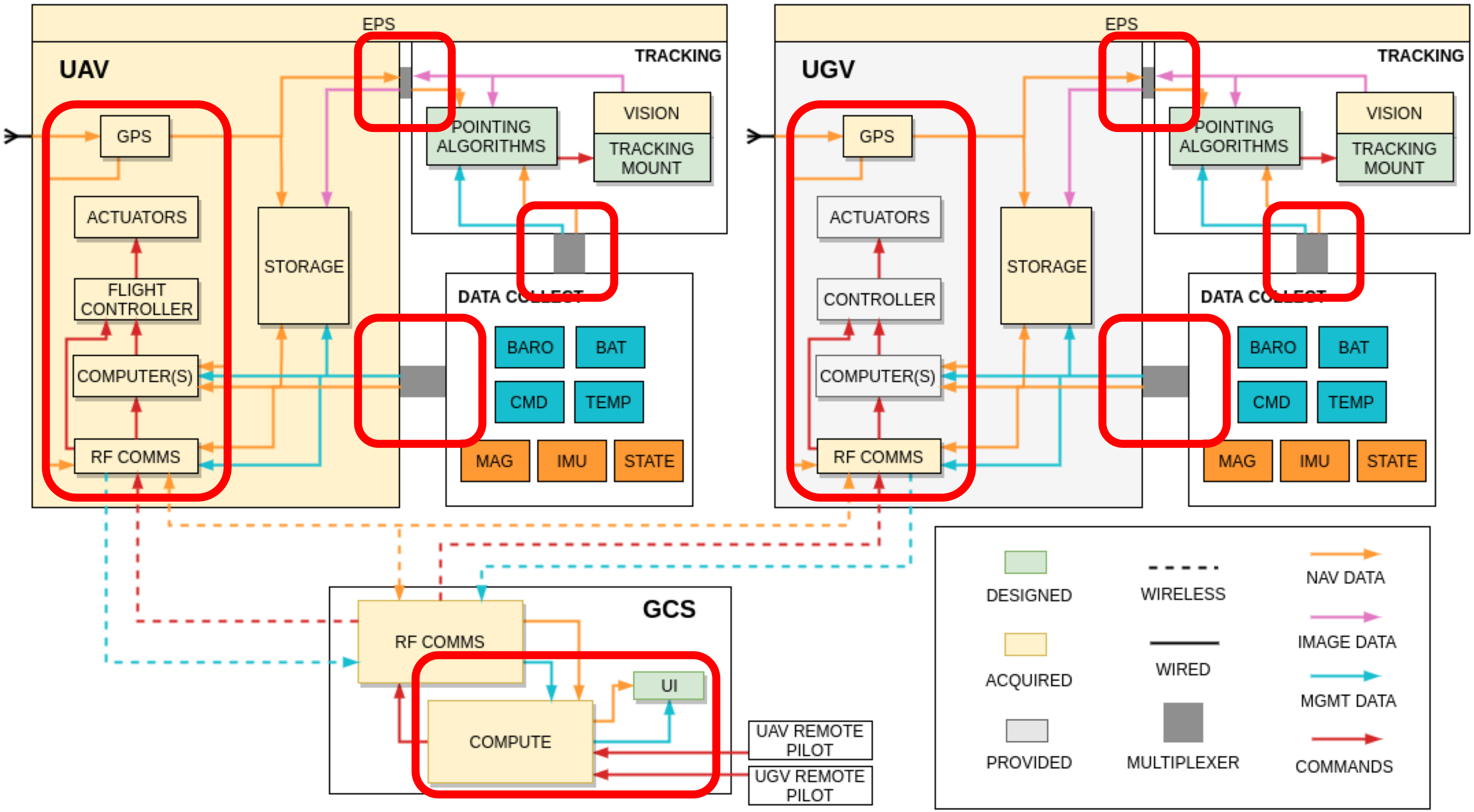
Communications Overview



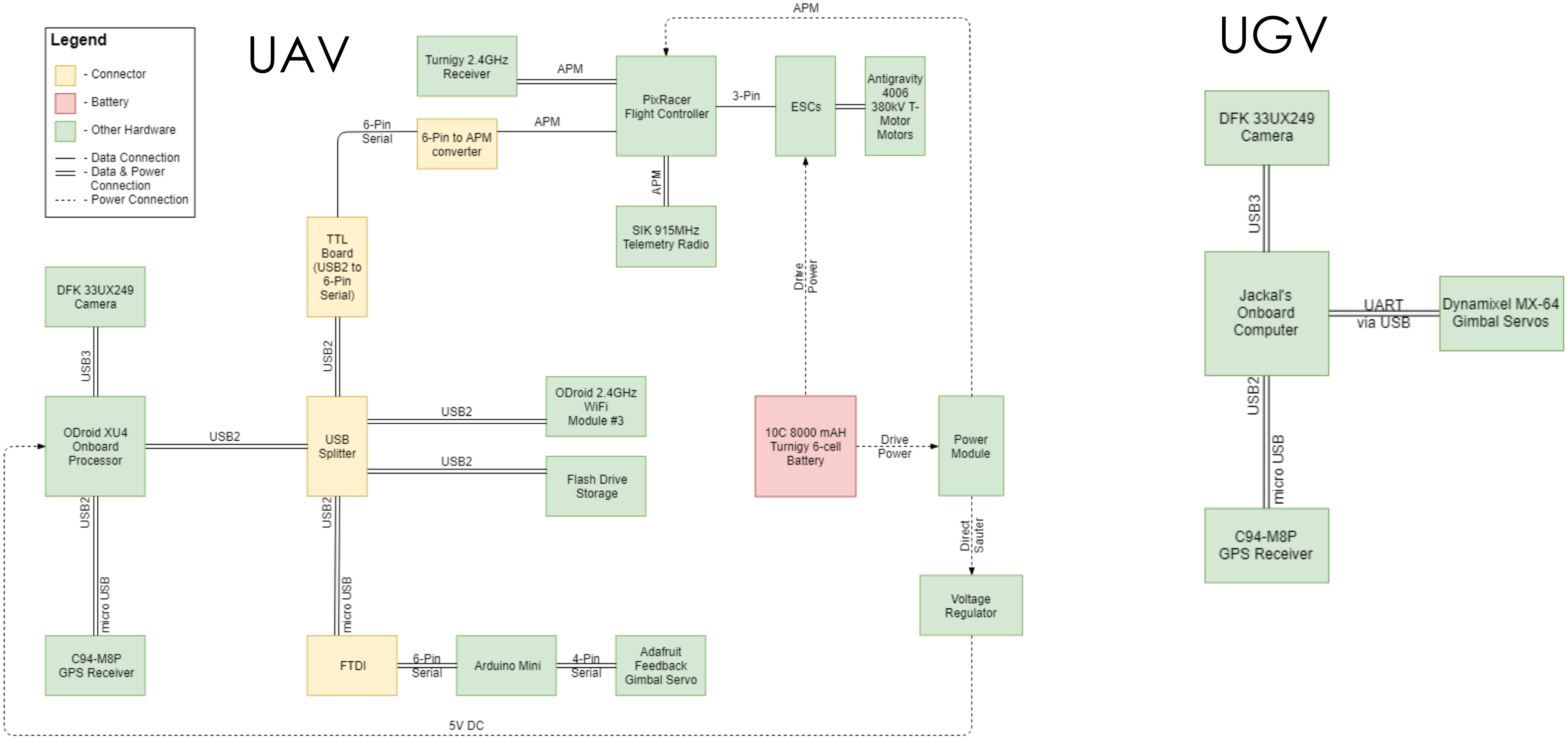
Item	Network Rate
Preview Image	500 kb/s
GPS Data	19.2 kb/s
Nav Data	35 kb/s
Total Rate	<1mb/s
Network Cap.	11 mb/s

Item	Storage Rate
Camera	17 mB/s
Other	2.87 mB/s
Total Rate	19 mbB/s
Card Cap	90 mb/s

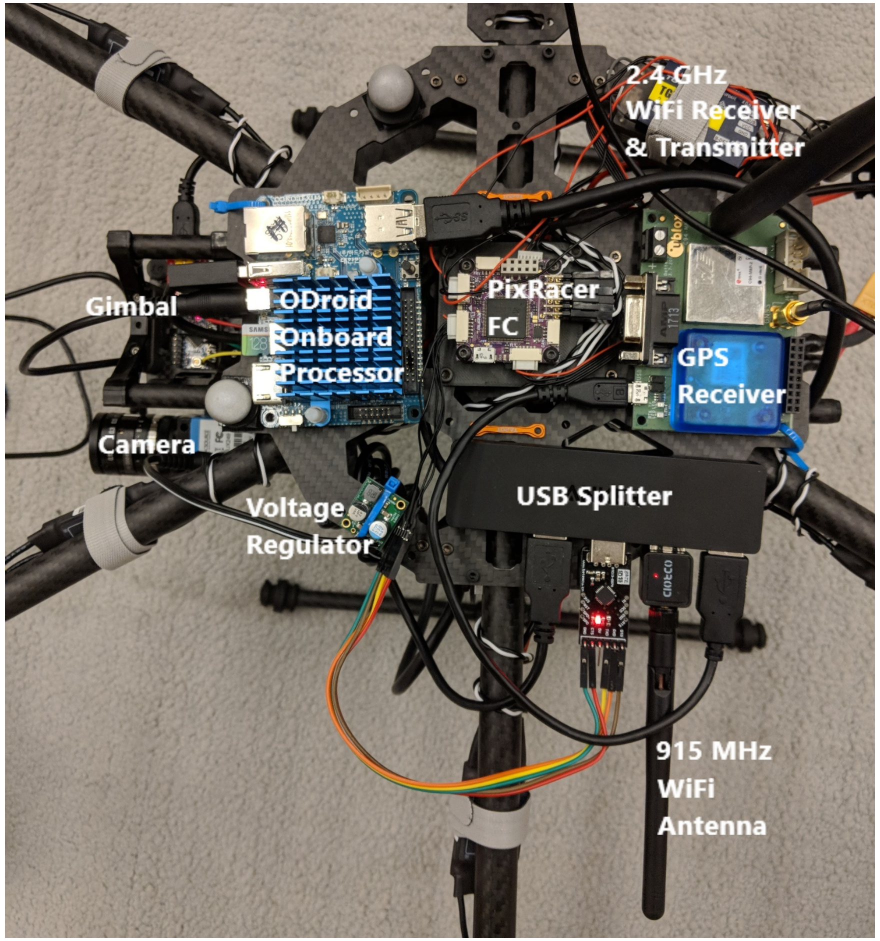
Critical Project Element: Integration

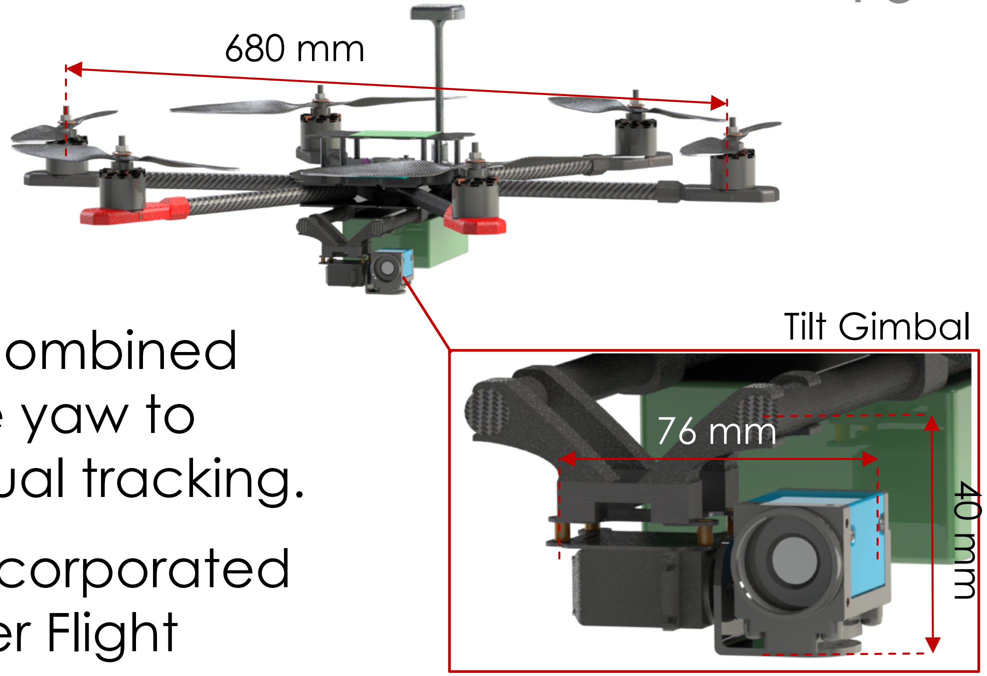


Vehicle Electronics Wiring

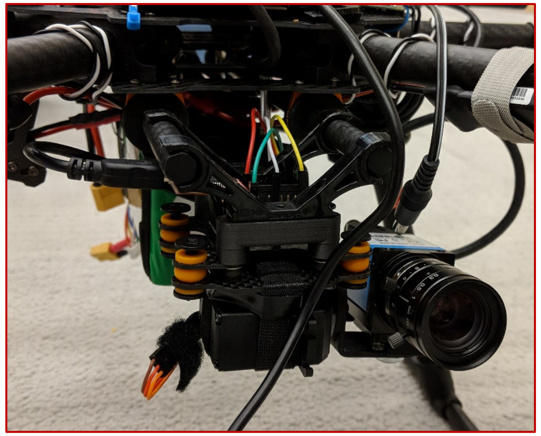


UAV Payload



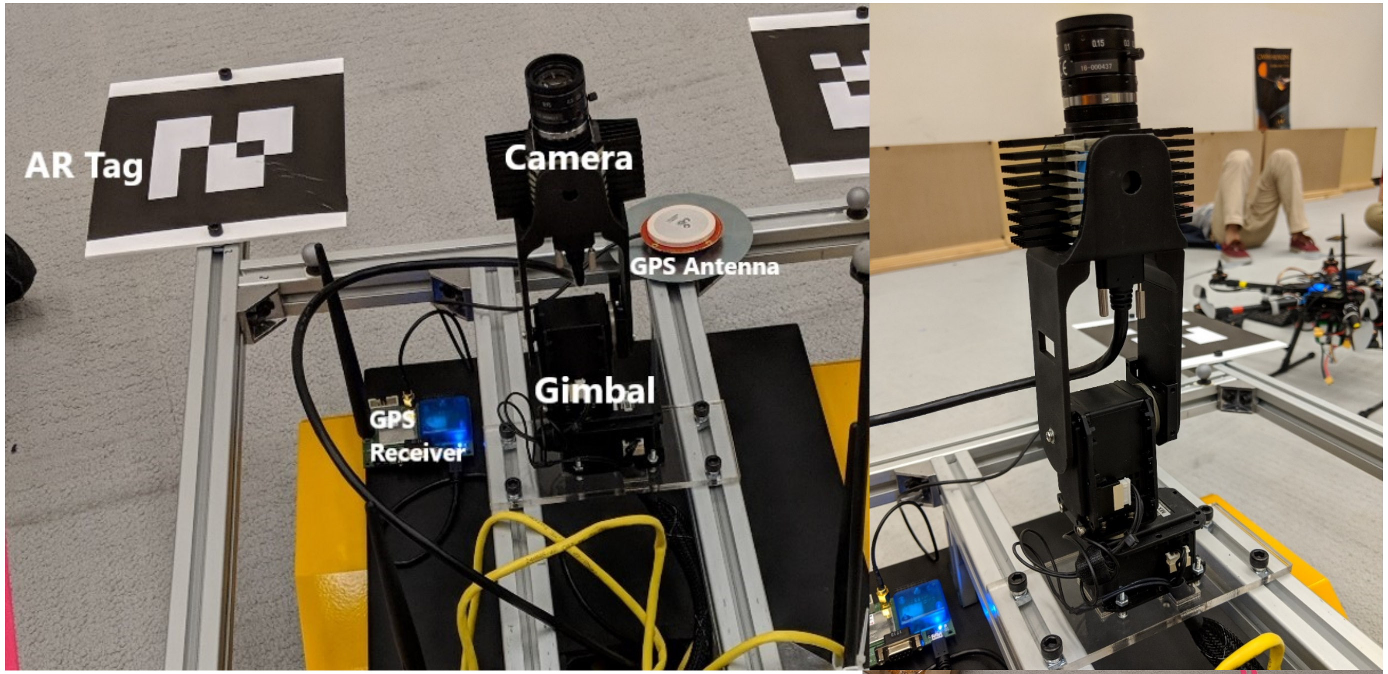


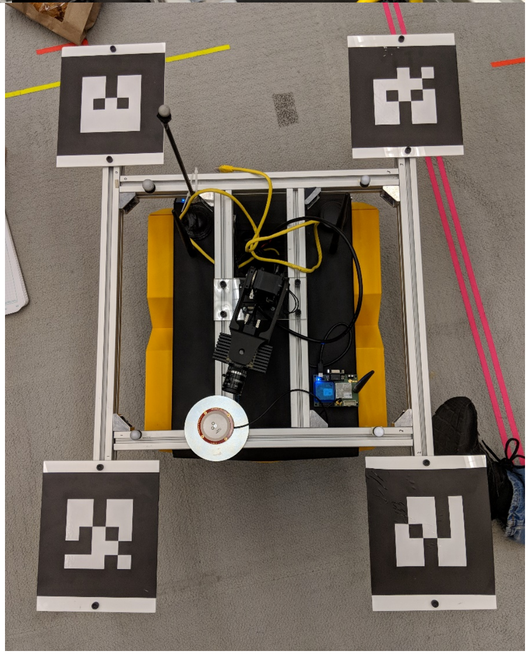
- Tilt gimbal combined with vehicle yaw to achieve visual tracking.
- IMU data incorporated into PixRacer Flight Controller
- GPS
- Communication via wireless channels

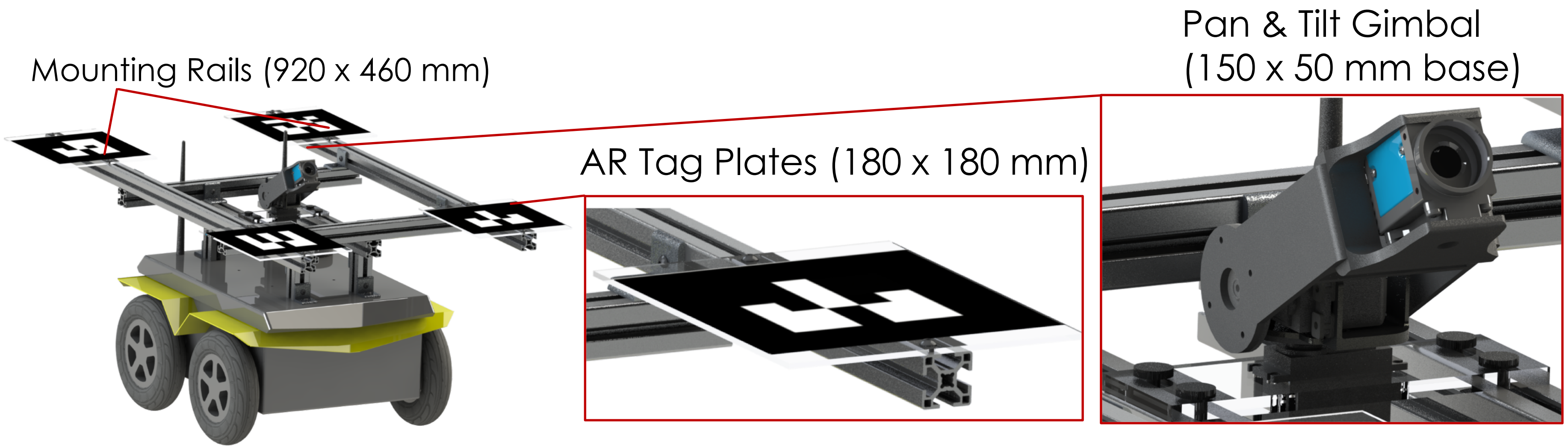


UGV Payload

- Wireless channels and IMU already included in Jackal
- 80-20 Frame for AR Tag mount
- Heat rejection fins implemented on camera
- 360˚ Feedback Servos on Gimbal

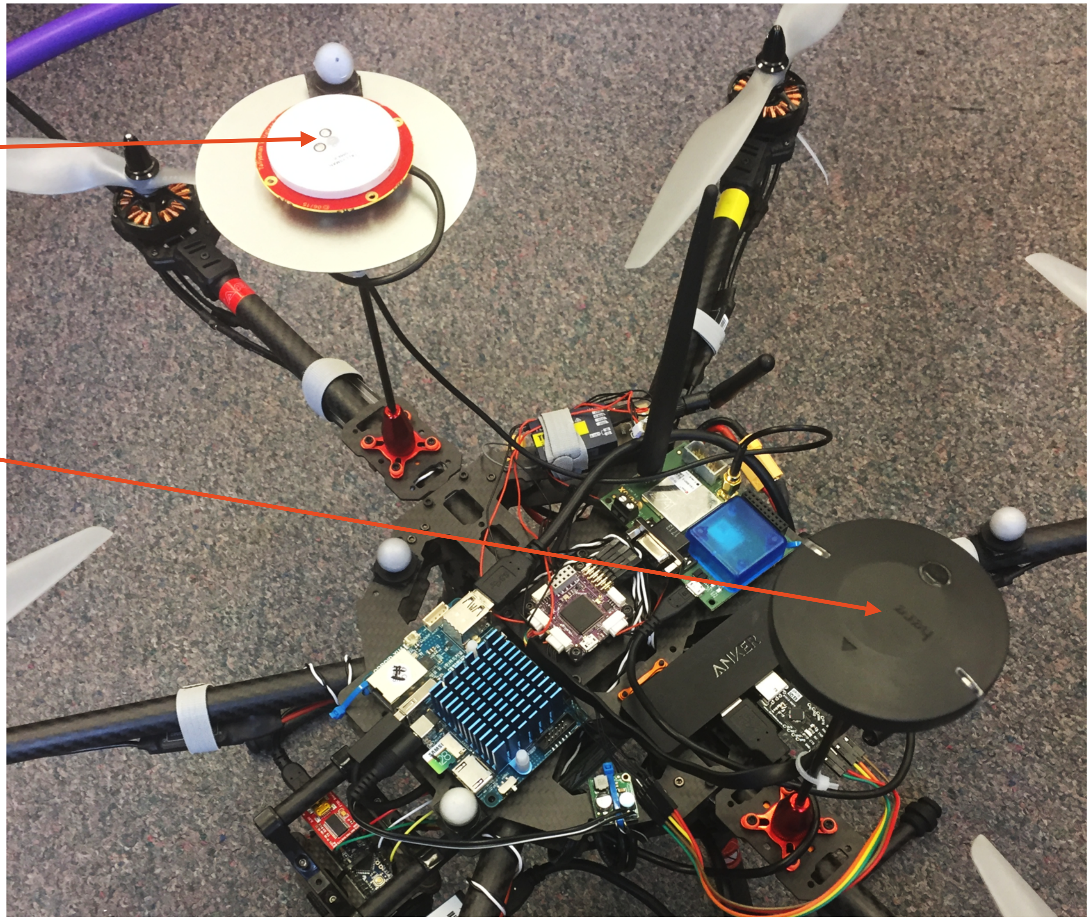






Changes since TRR

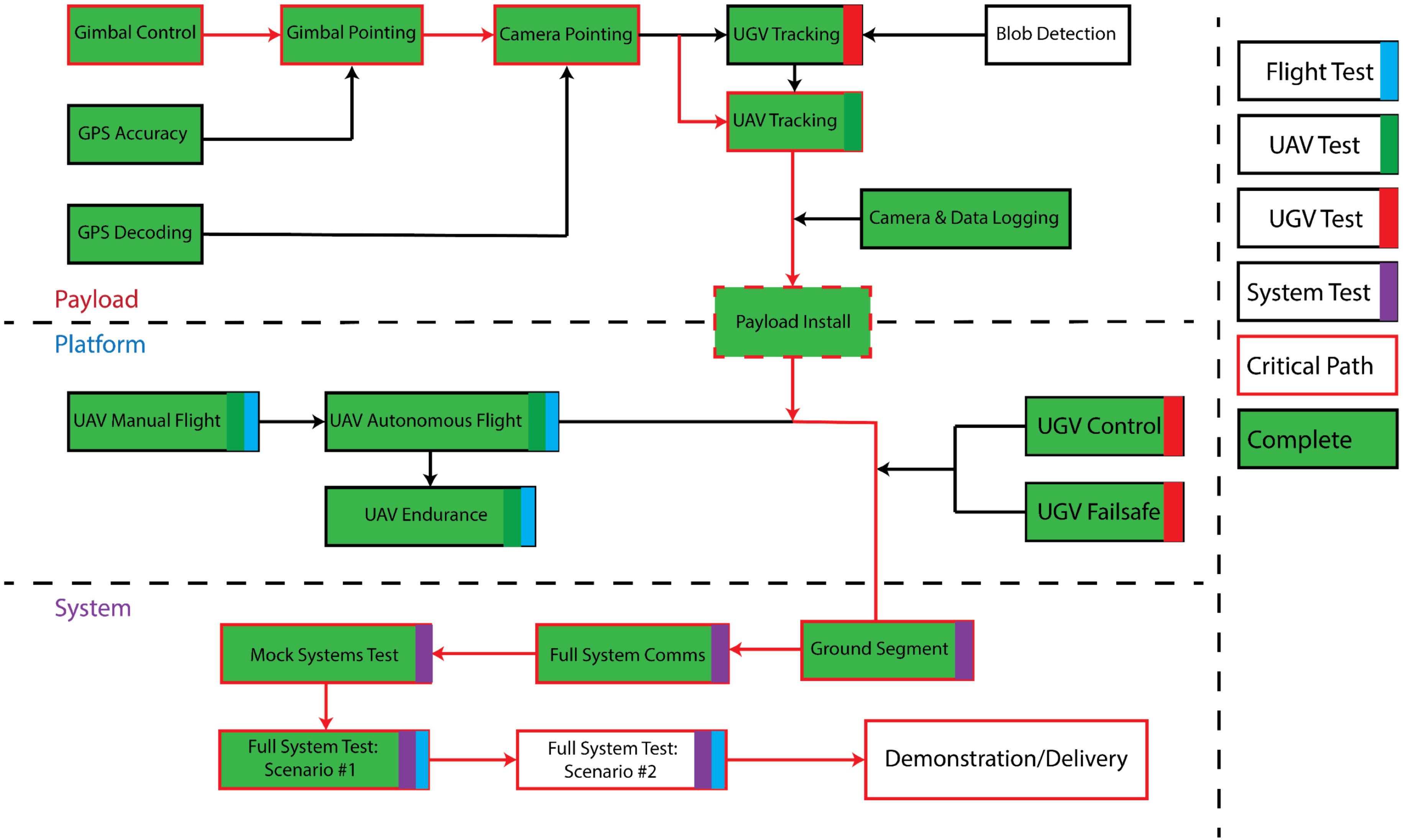
- The addition of a **second GPS** on the UAV.
  - The current GPS receiver: **C94-M8P**, although great for relative position, is not sufficient for the flight controller on the UAV.
  - Max update rate was **2 Hz**.
- Added a new GPS: **Here GNSS for Pixhawk 2.1**
  - Max update rate is **10 Hz.**
- **The Here GPS will be used for the flight controller, while the C94's will still be used for relative positioning.**



- Increased UAV mass by 8.6 oz causing a 38 second endurance reduction.
- Additional 35 mA current draw (0.175% of typical current draw.

Testing Overview

Testing Flow Chart



Testing Locations

- 3 Major testing locations, RIFLE, CU South Boulder, Business field
- RIFLE used for debugging and integration multiple times per week
  - VICON allows quick integration of changes and update of software
  - Able to work multiple times per week
- Business field used to verify GPS and camera operation
  - Allows 30m distance requirements, as well as GPS to operate properly
- CU South Boulder used for outdoor system level testing
  - Authorized to fly at South Boulder on a limited basis
  - Allows full system operation outdoors

Testing Verification Matrix

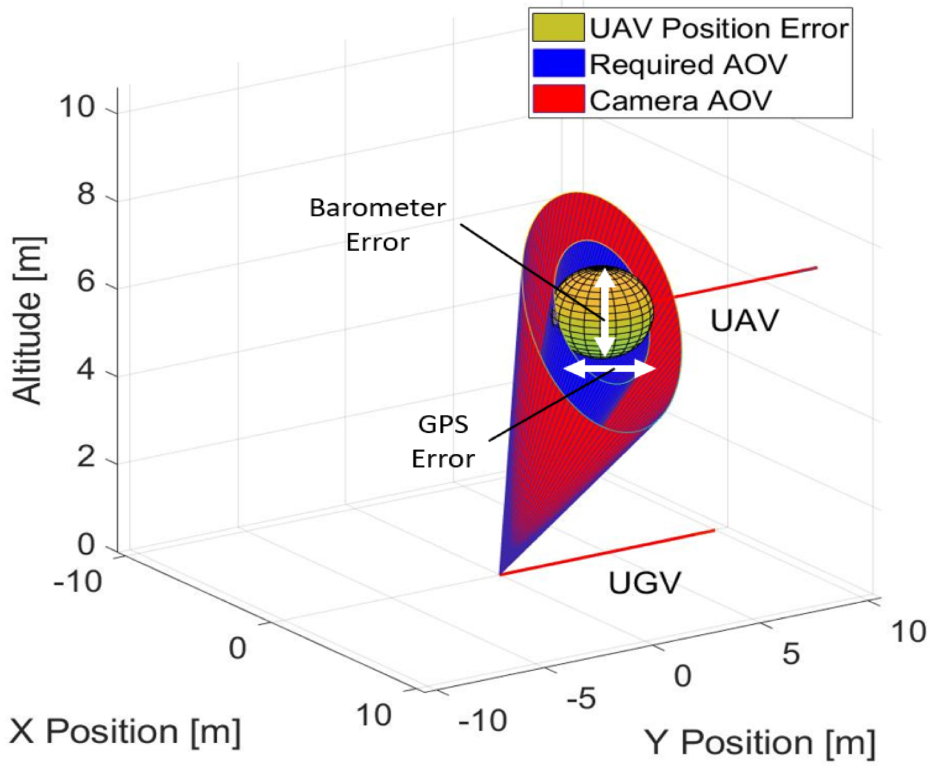
Subsystem Test	Design Requirements	Model to Validate	Completed
Camera Pointing	DR 3.1	AOV Model	X
GPS Accuracy	DR 3.1, 8.4	GPS Error	X
Tracking	FR 3.0	Gazebo	X
UAV Manual Flight	DR 5.1	-	X
UAV Auto Flight	DR 9.3	-	X
UAV Endurance	DR 1.1, 7.1, 7.4	Power Model	X
Comms Test	DR 8.2, 8.4	Range	Combined into Systems test
Full System Test	DR 4.1	Gazebo	X

Key
Payload
Platform
System

Testing Results: Unit Testing

GPS Accuracy Verification

Reasoning: To determine the accuracy of the RTK GPS units. This will ensure that it will be sufficient enough for the tracking requirements and validate our model.



Testing Prerequisites:
- MATLAB parsing tools developed.

Equipment and Facilities:
- C94-M8P GPS units w/Antennas
- 2 Laptops
- Business Field

Recorded Data:
- Position Data (Lat, Lon, Alt) [1 Hz]
- Velocity Data in NED Frame [1 Hz]
- Relative Position Vector from UGV to UAV [1 Hz]

Verified Design Requirements:
DR 3.2, 3.4, 8.4

Success Criteria:
- Standard Deviation < 0.973 m
- Handles data throughput of all necessary messages

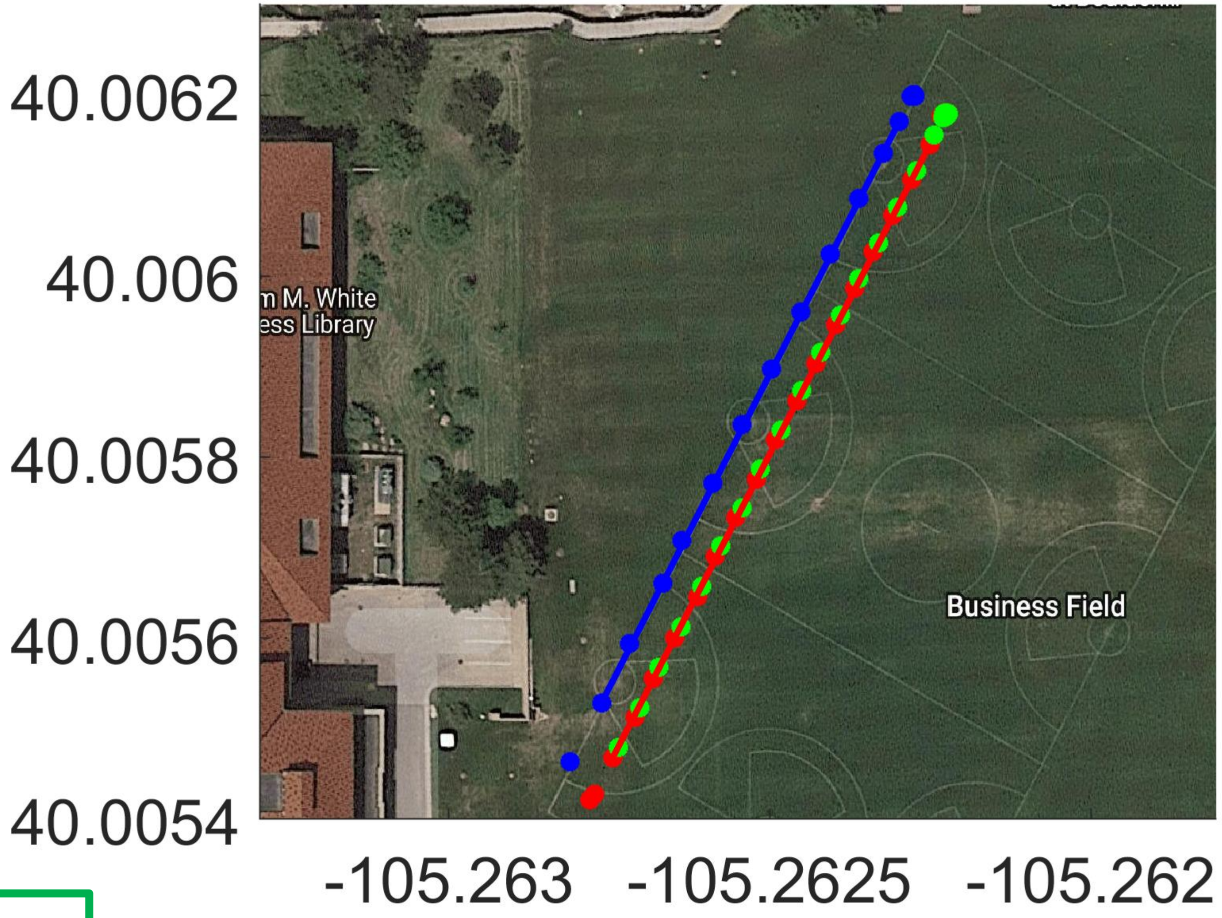
GPS Accuracy Verification - Results

Test Completed

- Dynamic test, where both units move along parallel lines was conducted.
  - Relative distance kept close to constant.

Accuracy

- UGV average deviation from line: 14 cm
  - Std Dev: 11 cm
- UAV average deviation from line: 11 cm
  - Std Dev: 8 cm



Success Criteria:

- Standard Deviation < 0.973 m: PASS
- Handles data throughput of all necessary messages: PASS

GPS Accuracy Verification - Results

<u>Test Completed</u>

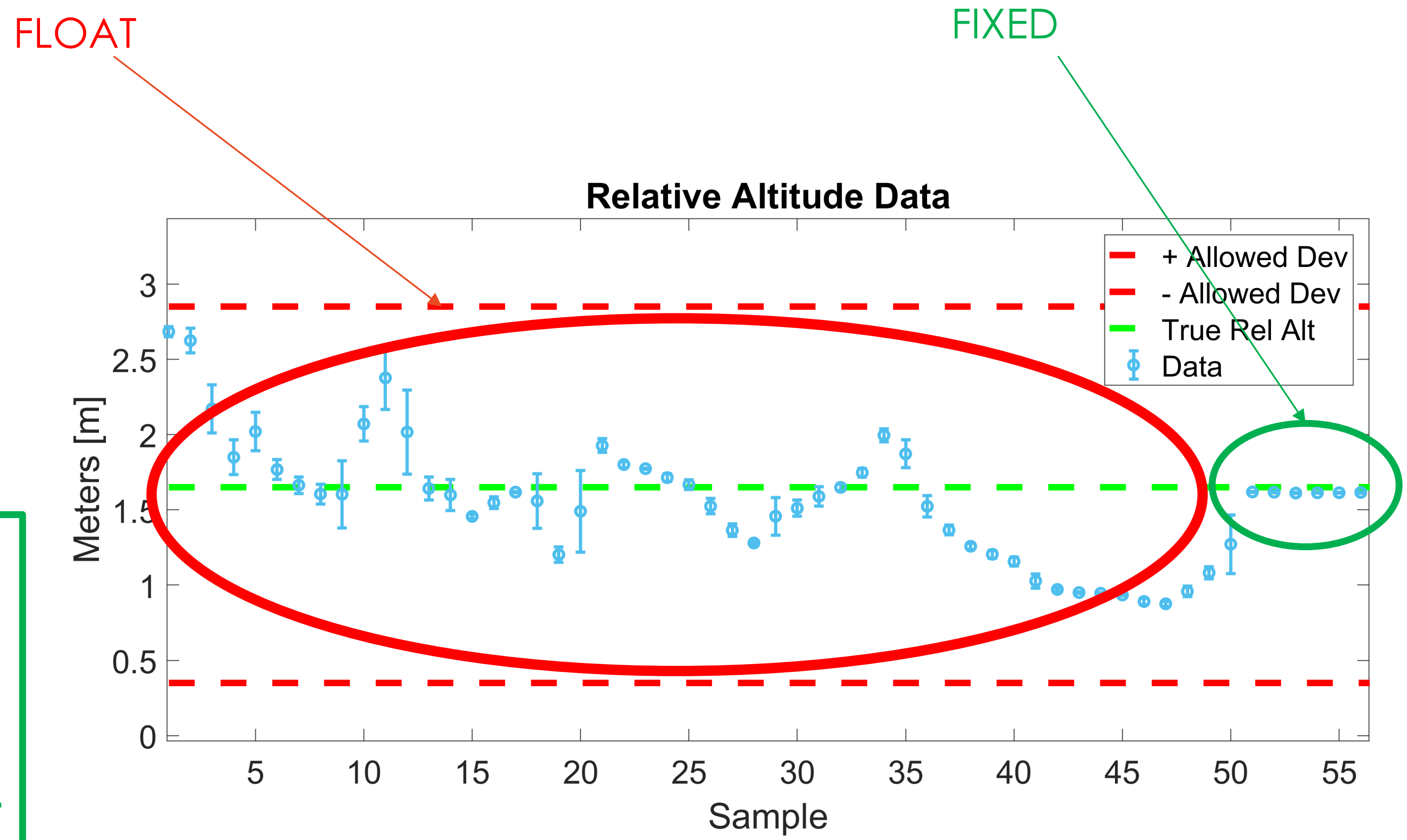
- Dynamic test, where both units move along parallel lines was conducted.
    - Relative altitude kept close to constant.

<u>Accuracy</u>

- Relative altitude in FLOAT mode has range of 3 m.
- Relative altitude in FIXED mode has 3 cm-level range.

<u>Meeting Requirement?</u>

- In FLOAT mode: SD = 0.4332 m < 0.973 m
- In FIXED mode: SD = 0.0686 m << 0.973 m
- **Both modes meet requirement**



Camera Resolution Verification

Reasoning: Verify that the camera resolution satisfies FR 3.0. At maximum range of 30 m, the resolution must be greater than 3 inches per pixel.

Testing Prerequisites:

- Camera software integration

Equipment and Facilities:

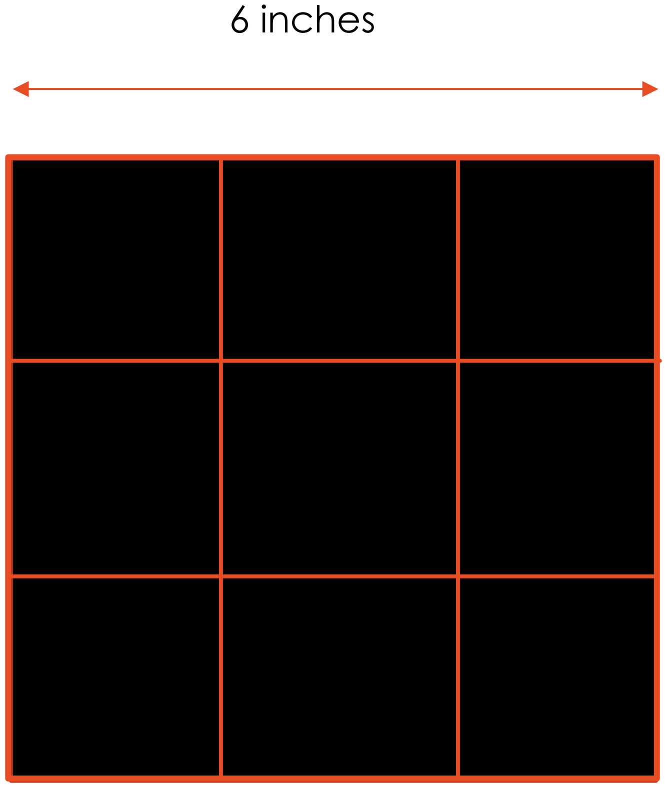
- Camera
- Computer
- 6in x 6in test square

Recorded Data:

- Image of 6in x 6in square at 30 m
- How many pixels are recorded in image of square

Verified Design Requirements:

- DR 4.1



(Pixel grid overlayed on black square)

Success Criteria:
- Greater than 3"/pixel
- Camera resolution shall be ≥ 1920x1080

Camera Resolution Verification - Results

- Conservative boundary found to be 9x10 pixels
- Realistic boundary found to be 11x12 pixels
- Lower value of inches/pixel means higher resolution

Scenario	Value: Inches/Pixel	Requirement Met?
Predicted result	.492	Yes
Result (conservative)	.632	Yes
Result (realistic)	.522	Yes
Requirement	3.0	N/A

Success Criteria:

- Greater than 3”/pixel: PASS
- Camera resolution shall be ≥ 1920x1080: PASS

Testing Results: Subsystem Testing

Power Model Verification

Reasoning: UAV flight to validate the accuracy of the power model developed in the previous semester. Two flights for each battery pack.

Testing Prerequisites:
- Manual Flight

Equipment and Facilities:
- VICON space (RECUV Fleming Lab)
- VICON markers
- UAV Transmitter
- Stopwatch

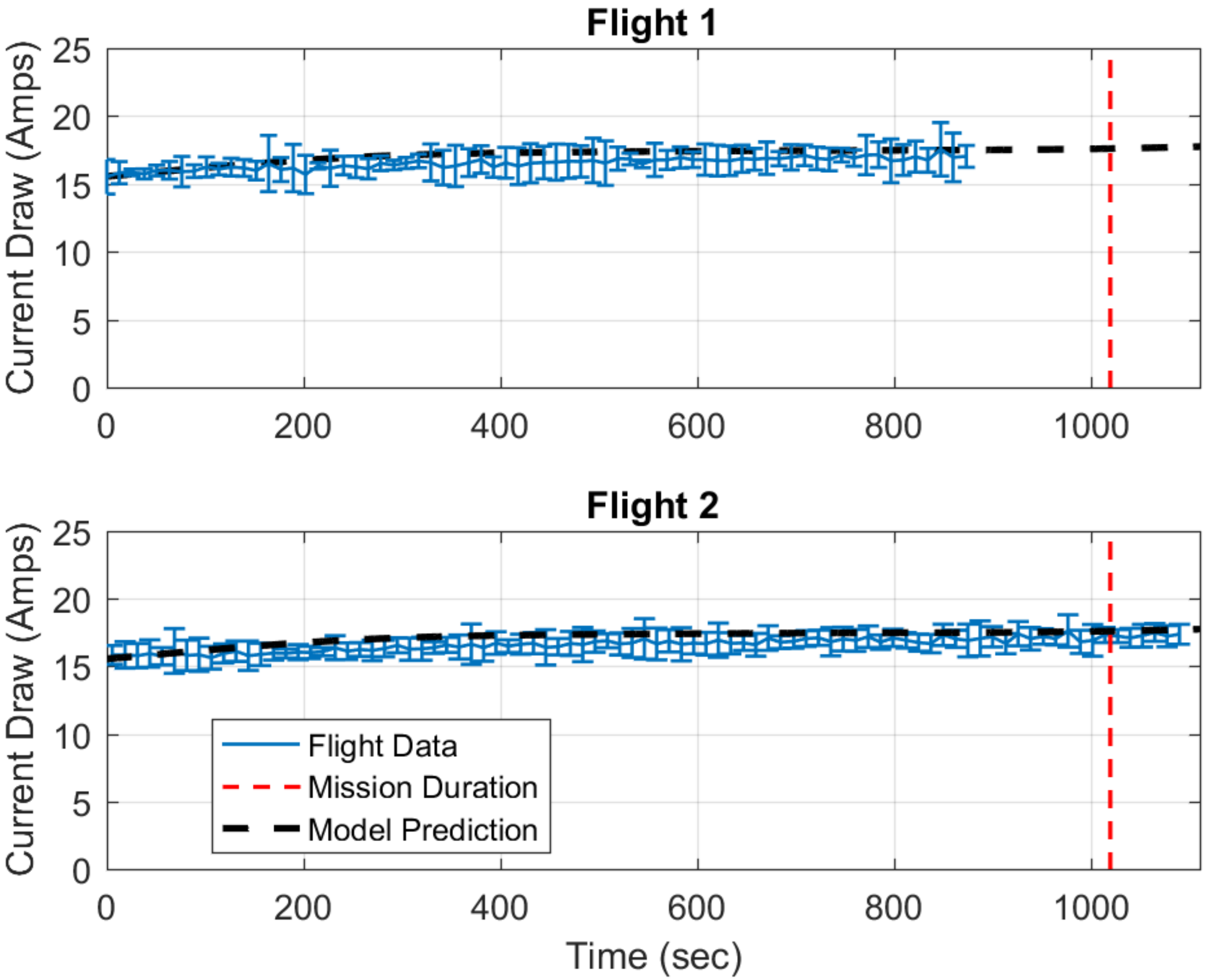
Risks:
- UAV crash/damage
- LiPo battery damage
- Damage to VICON space

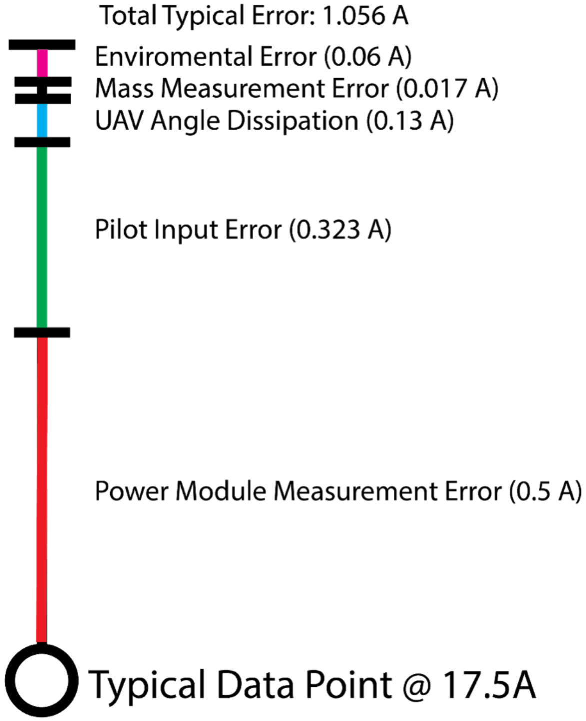
Recorded Data:
- Amperage [100 Hz]
- Voltage [100 Hz]
- Throttle input [100 Hz]
- Flight time
- UAV flight mass 3.3 [kg]

Verified Design Requirements:
DR 1.1, 7.1, 7.4

Success Criteria:
- UAV flight for >18.15 minutes
- Data recorded for flight duration and offloaded between flights

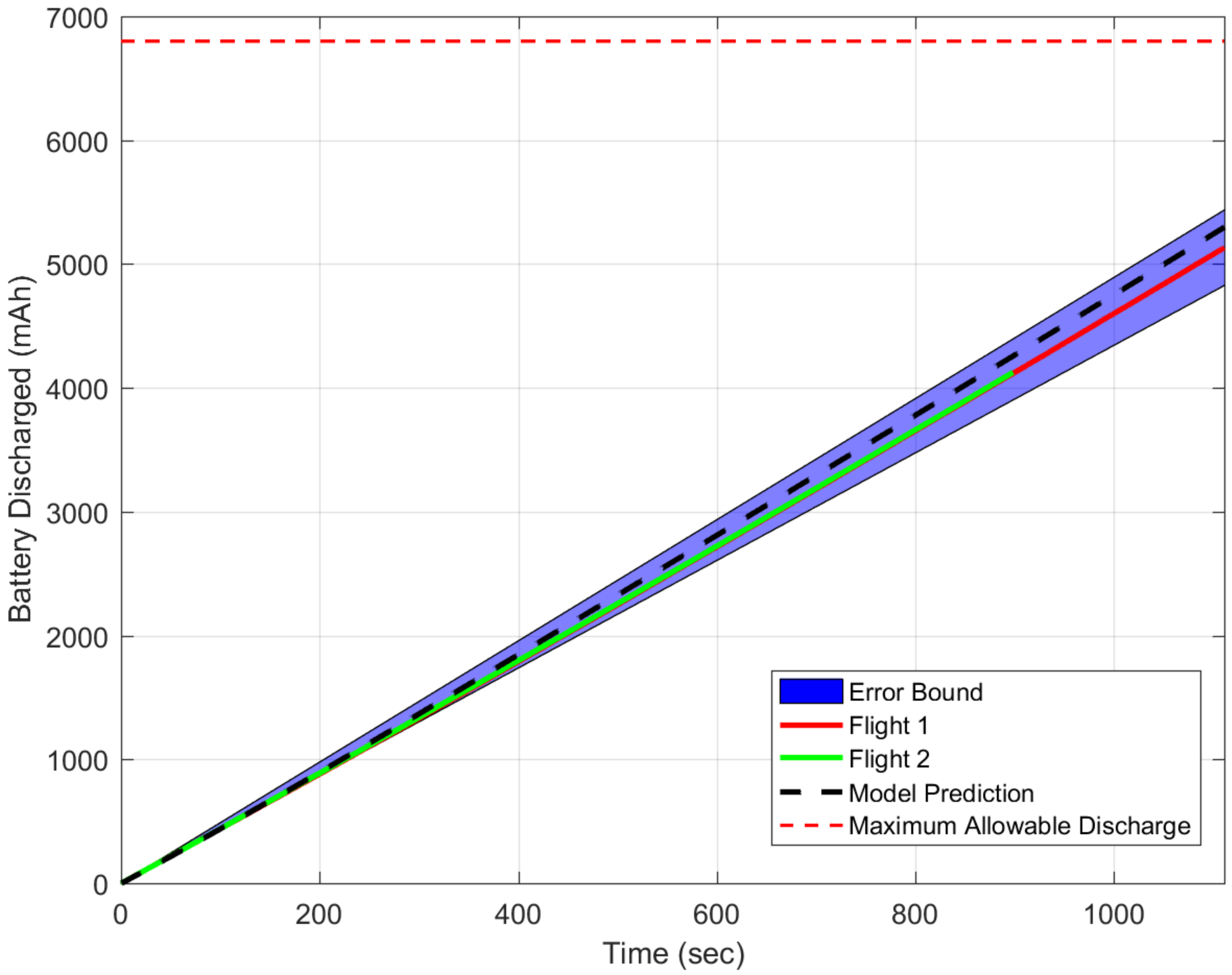
Power Model Verification - Results





Flight 1 σ: 0.83 A

Flight 2 σ: 1.02 A



1177 mAh reserve (17% of useable battery life)

5.56 A continuous payload draw allowable

At 18.5 minutes: 1.03% deviation from model

1.75 A typical draw

<u>Success Criteria:</u>

- UAV flight for >18.15 minutes: PASS
- Data recorded for flight duration and offloaded between flights: PASS

Gimbal Pointing Test

Reasoning: Verify that the gimbal pointing software and hardware works to desired specifications. Characterize pointing error in gimbal mechanism. Validate Gazebo models.

Testing Prerequisites:

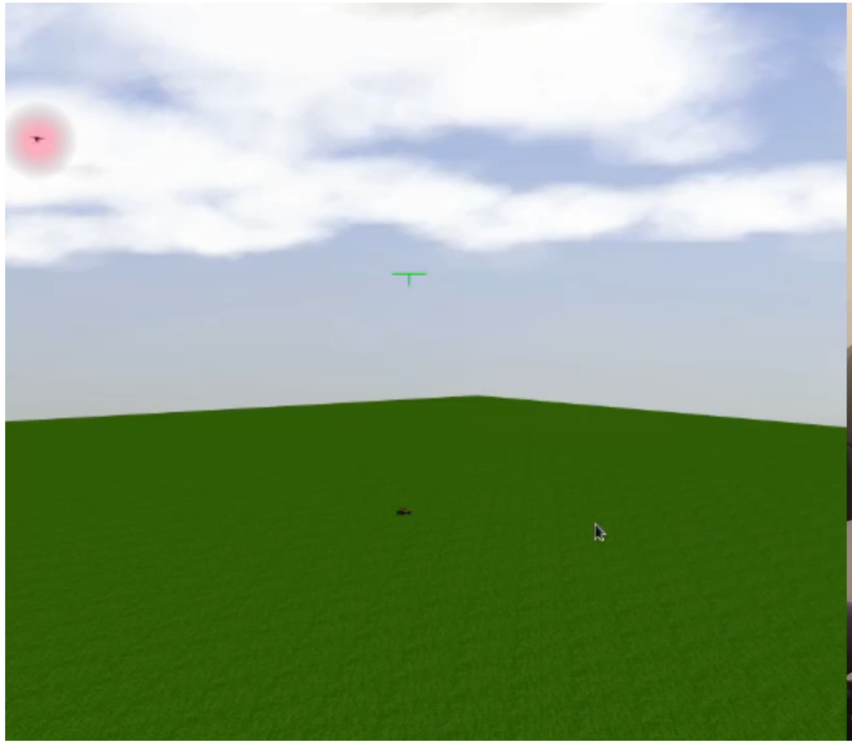
- Gimbal unit test
- GPS unit test
- Odroid unit test
- Camera unit test

Equipment and Facilities:

- VICON space (RECUV Fleming Lab)
- UGV
- UAV

Risks:

- Damage to camera.
- Damage to gimbal
- Damage to GPS units



Verified Design Requirements:
DR 3.1, 3.2

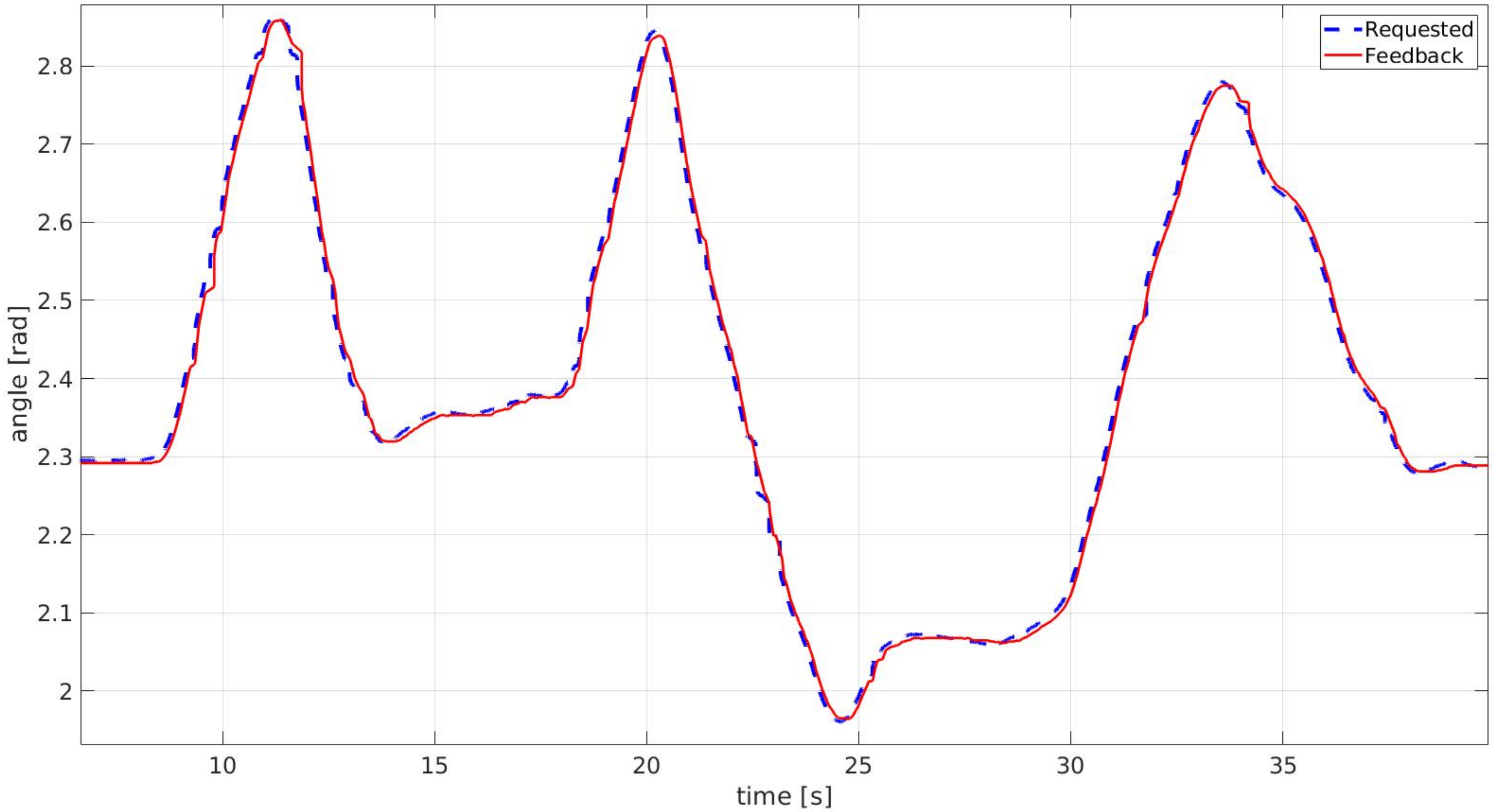
Recorded Data:

- Images [7 Hz]
- GPS [2 Hz]
- Pointing angles 2 Hz]

Success Criteria:

- Gimbal keeps vehicle in 90% of frames
- Gimbal achieves requested angle

Gimbal Pointing Test - Results

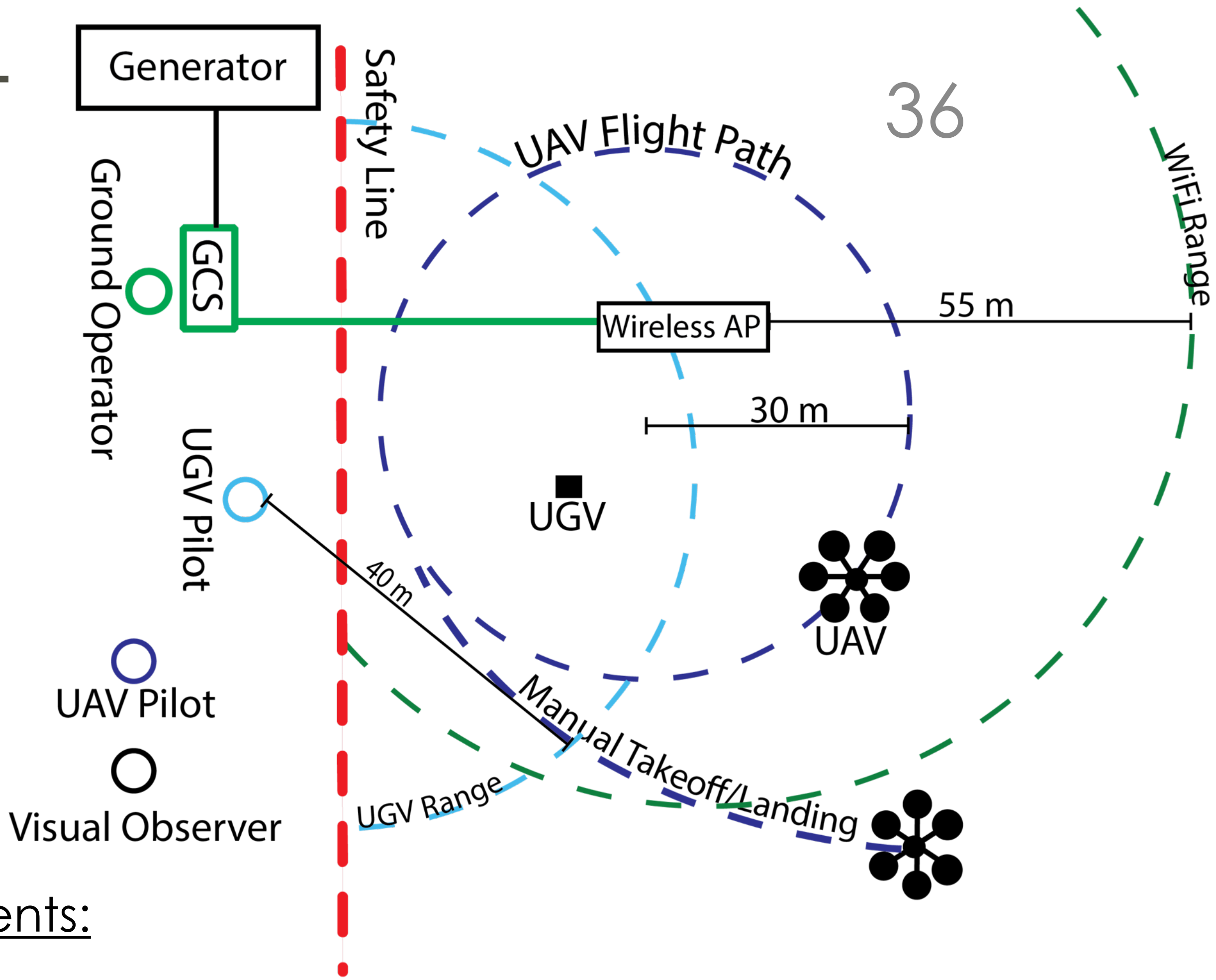


<u>Success Criteria:</u>

- Gimbal keeps vehicle in 90% of frames: PASS
- Gimbal achieves requested angle: PASS

Testing Results: Systems Testing

Full System Outdoor Test



<u>Reasoning:</u> Verify operation of entire system. Quantify performance of system.

<u>Testing Prerequisites:</u>
- Mock Systems Test

<u>Equipment and Facilities:</u>
- CU South Boulder
- UAV/UGV Pair
- Ground stations
- UAV Transmitter
- Stopwatch

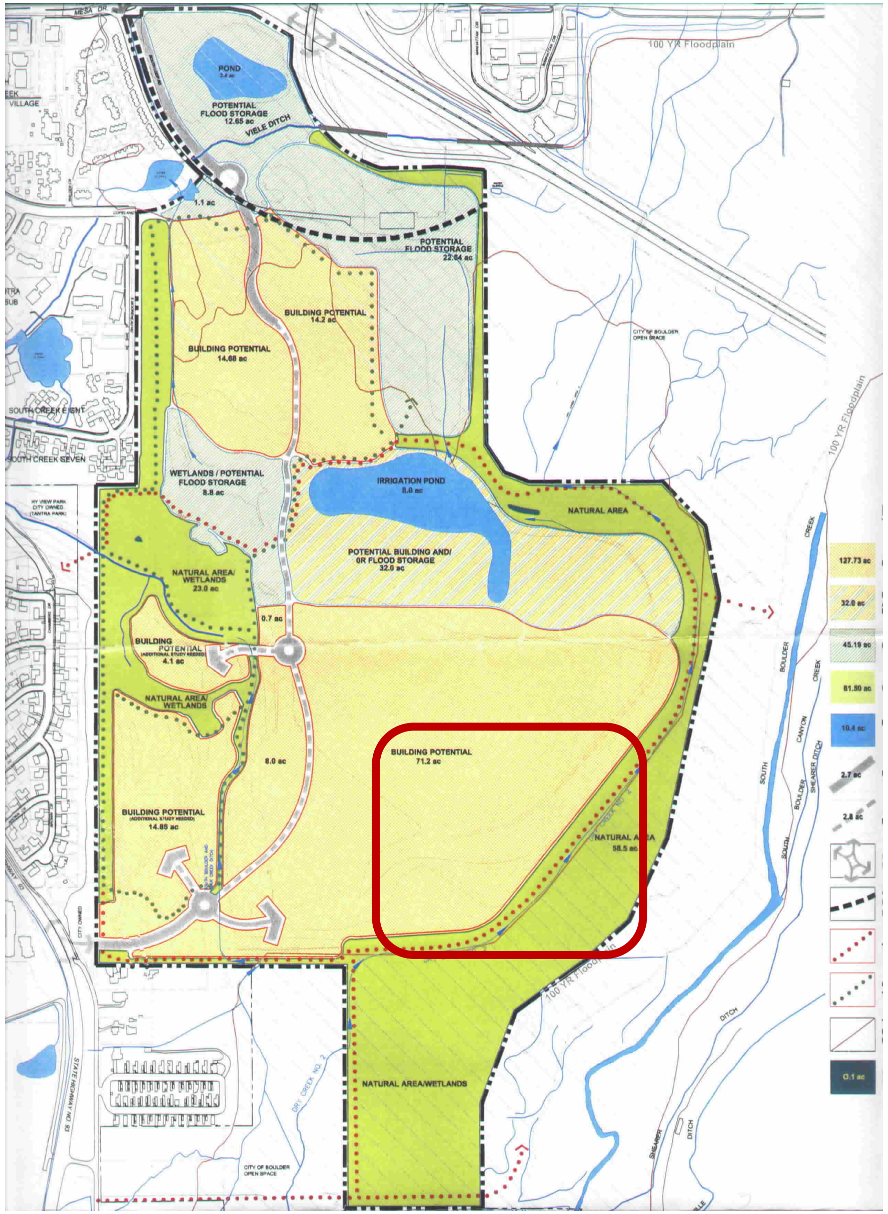
<u>Verified Design Requirements:</u>
DR: 4.1

<u>Risks:</u>
- UAV crash/damage
- LiPo battery damage

<u>Recorded Data:</u>
- Flight time
- Image Data
- Relative Position
- Control Inputs

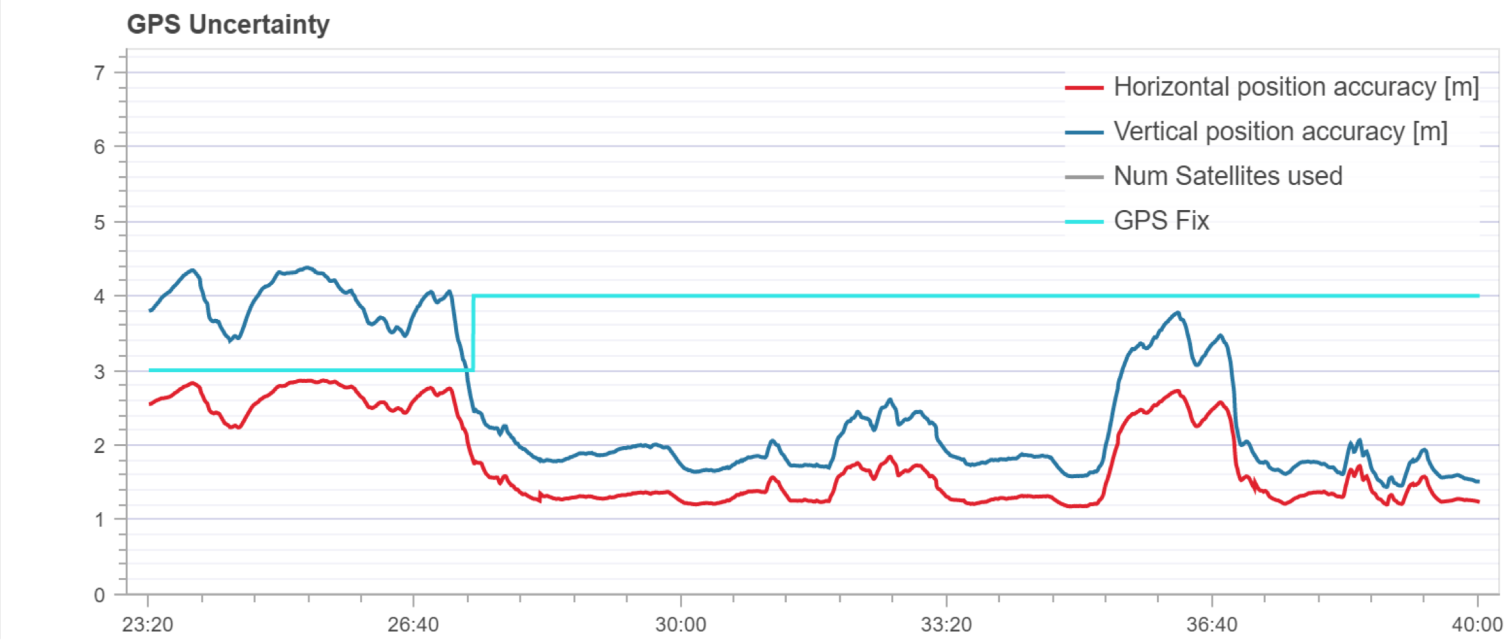
<u>Success Criteria:</u>
- UAV flight for >18.15 minutes
- Full Data Collection
- Vehicle in 90% of frames

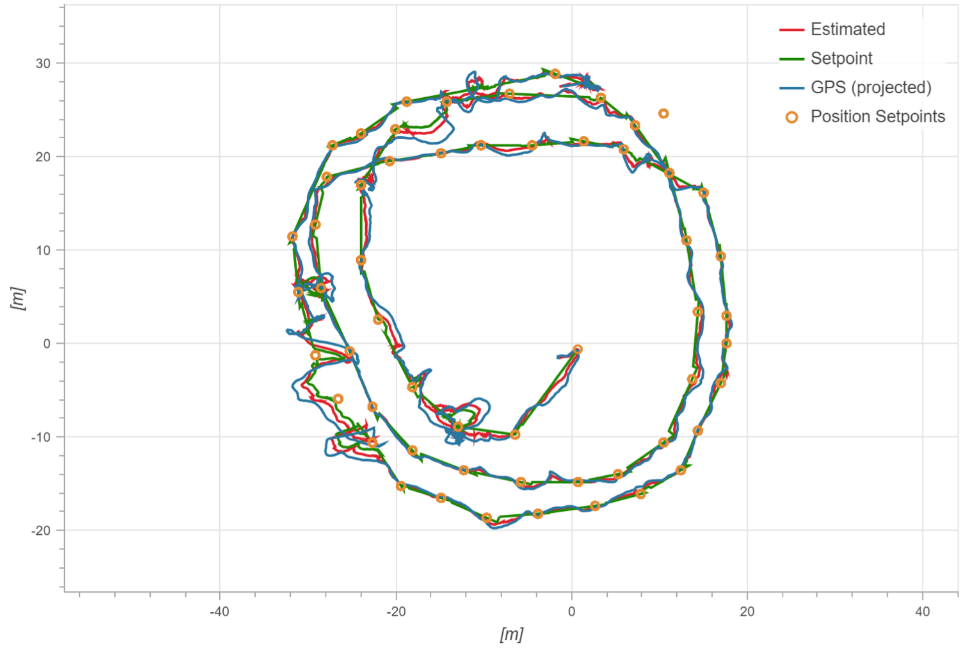
Full System Outdoor Test



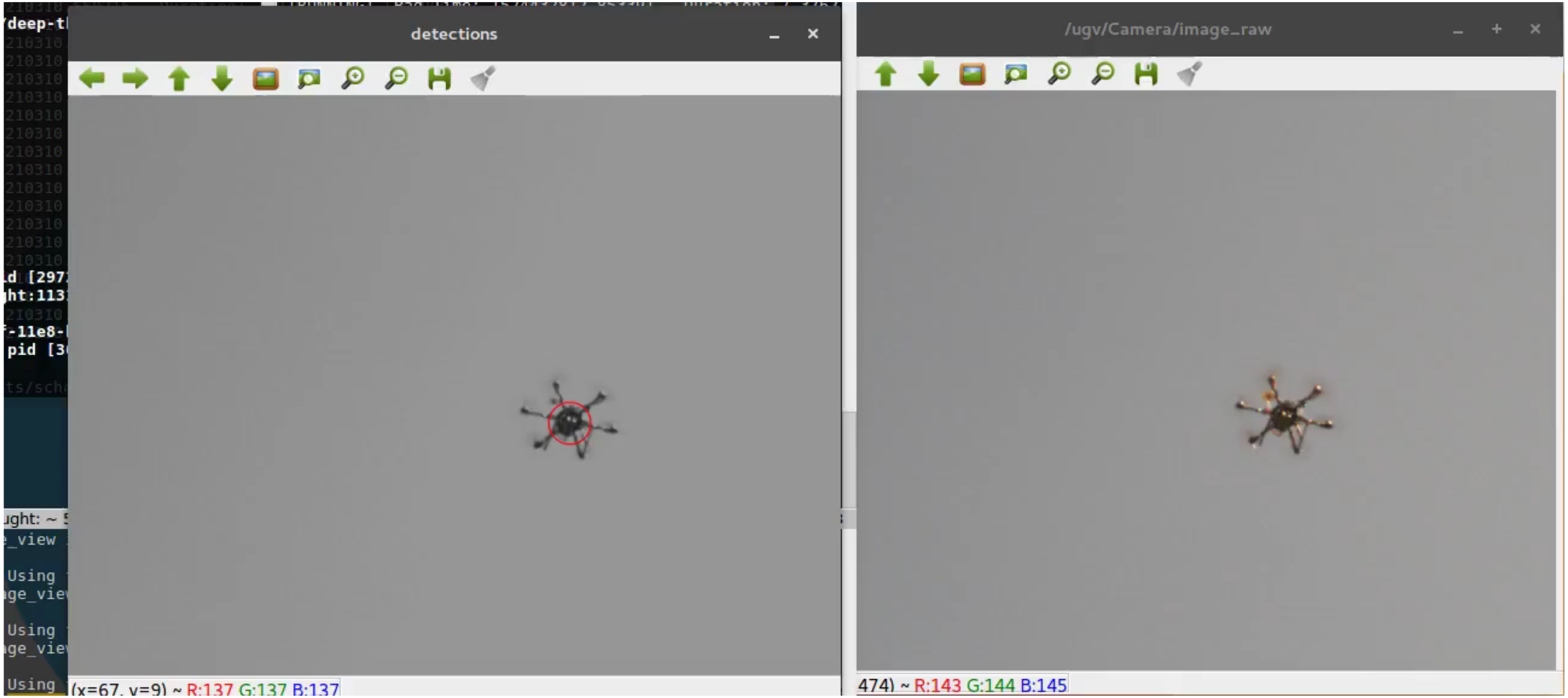
Full System Outdoor Test - Results

- Full system test completed 4/22/2018
- UAV Flight with UGV stationary and tracking
- Completed 16:36 of data collection
- UGV within 89.95% of frames
- UAV within 85.95% of frames





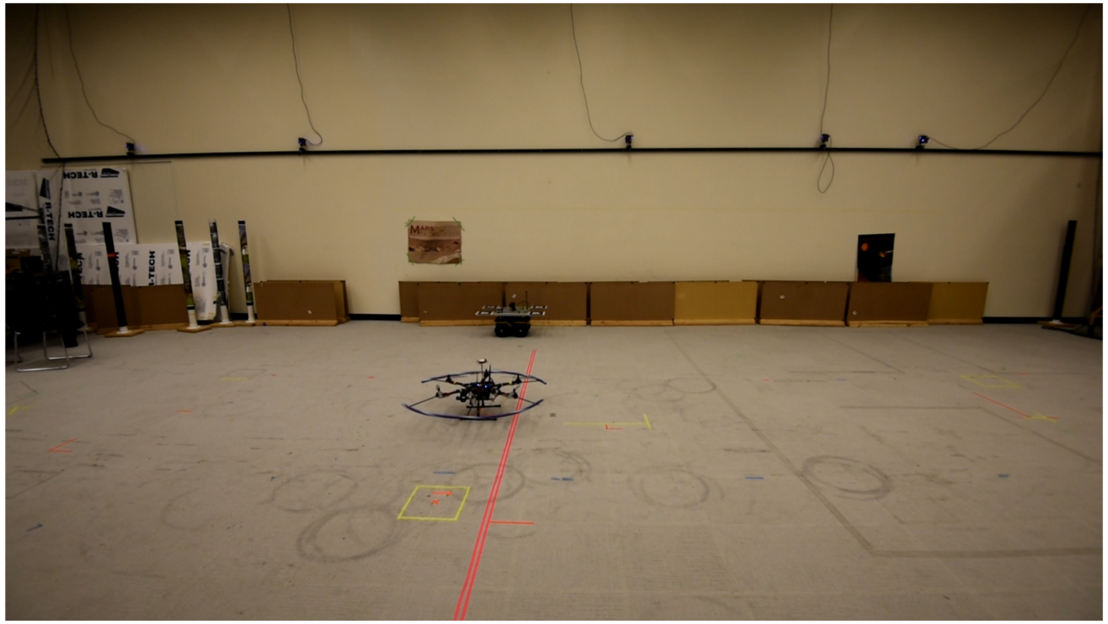
Full System Outdoor Test – UGV Perspective and Blob Detection



Full System Outdoor Test – UAV perspective

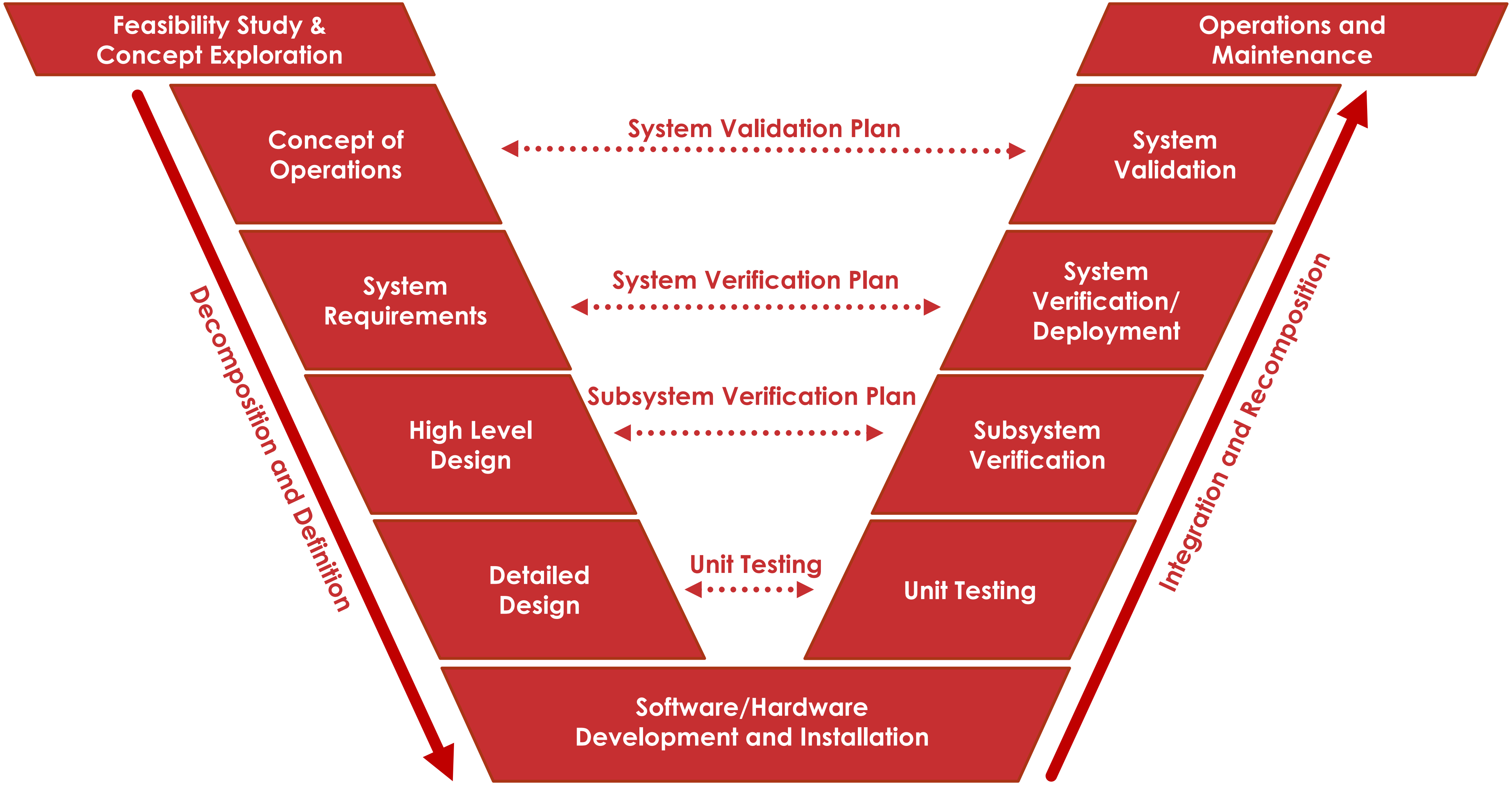
Testing Limitations and Failures

- Testing of aerial projects presents high risk testing scenarios during full systems testing
  - Experienced one major crash resulting in catastrophic damage to UAV
- Testing time was not used effectively, sometimes testing time became debugging time
- Misunderstanding of flight modes caused catastrophic crash of UAV

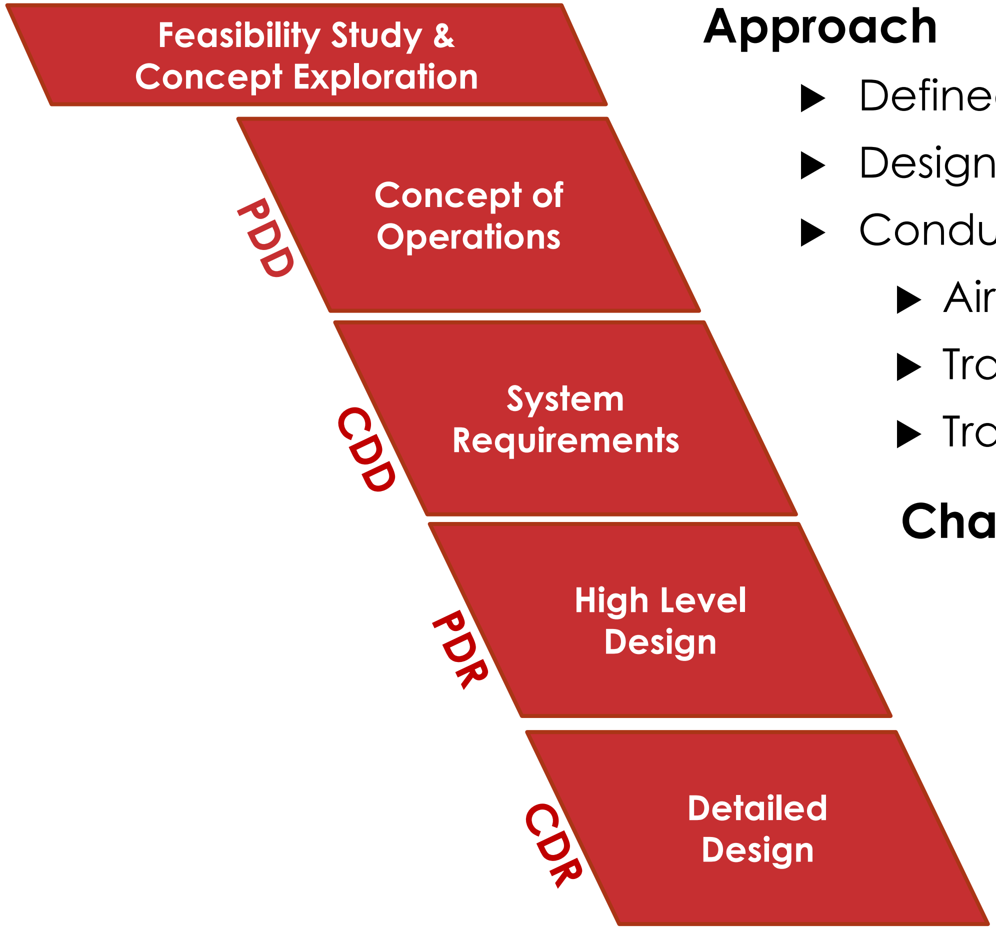


Systems Engineering

Systems Engineering Approach



Decomposition and Definition

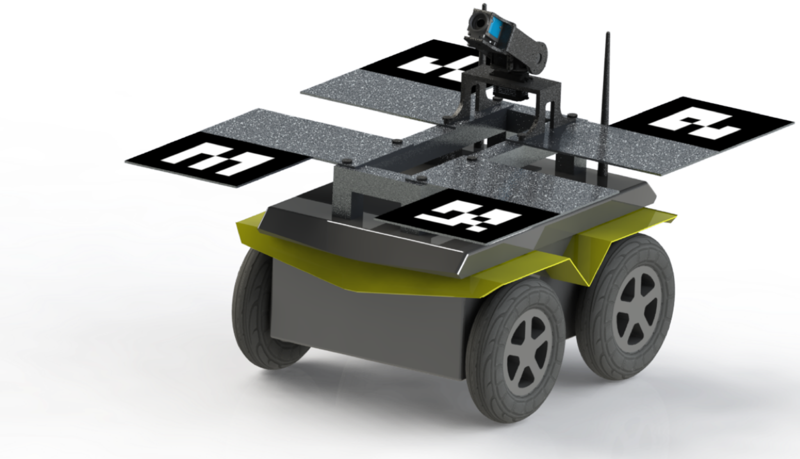


Approach

- Defined detailed requirements
- Designed CONOPS
- Conducted Trade Studies
  - Air Vehicle
  - Tracking Method
  - Tracking Hardware

Challenges

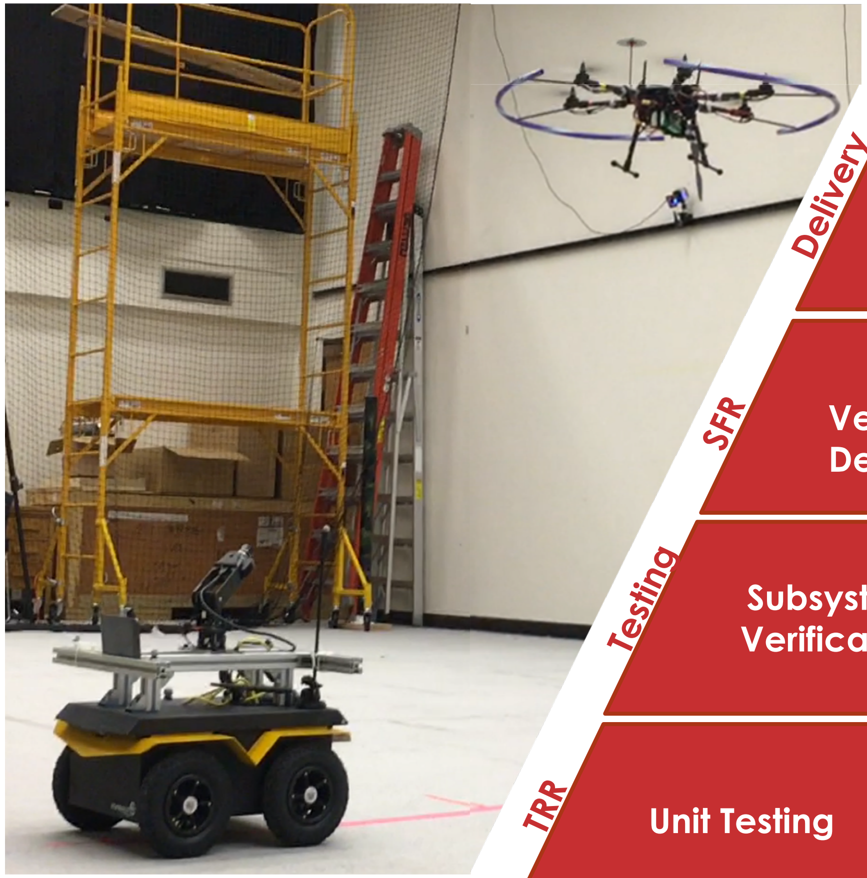
- Identifying unnamed sub-requirements necessary for project success.
- Ensuring selected components would interface with each other.



Lessons Learned

- Trade studies are critical to overcome preconceived designs.
- Definition of unambiguous requirements are essential
- Communication with customer is invaluable

Integration and Recomposition



Operations and Maintenance
Delivery
System Validation
SFR
System Verification/ Deployment
Testing
Subsystem Verification
TRR
Unit Testing
MSR
Software/Hardware Development and Installation

Approach

- Created diagram of required software
- Manufactured and assembled hardware
- Performed integration of software with ROS
- Utilized indoor flight testing extensively

Challenges

- Mitigating damage from crashes
- Scheduling outdoor testing around weather constraints
- Lack of documentation from customer provided equipment
- Communication of required deliverables from other teams

Lessons Learned

- Have a plan to parallelize development, integration and testing.
- Beware of bottlenecks such as space availability, weather constraints, part lead times, etc.

Project Management

Project Management Approach

<u>Objective:</u> Allow the team to focus on project development and completion

- Assume administrative and budget concerns in conjunction with CFO
- Assume course assignments such as presentations and papers, using minimal help from team. Use team for finalizing assignments and for detailed knowledge on required topics.
- Allow team members to work autonomously on objectives while only giving scheduling direction for overarching goals.

Project Management Approach

Successes	Difficulties	Lessons Learned
Team worked efficiently and with purpose which allowed the project to progress further than initially expected.	Keeping all 11 team members up-to-date on topics that were being worked on.	Stay ahead on organization.
Team member autonomy allowed team members to get tasks thoroughly completed in an efficient time frame.	Scheduling team member time.	Document everything.
Project would not have been as smooth without independent and motivated team members.	Staying motivated in the face of challenges.	Schedule time early and often

Budget Comparison

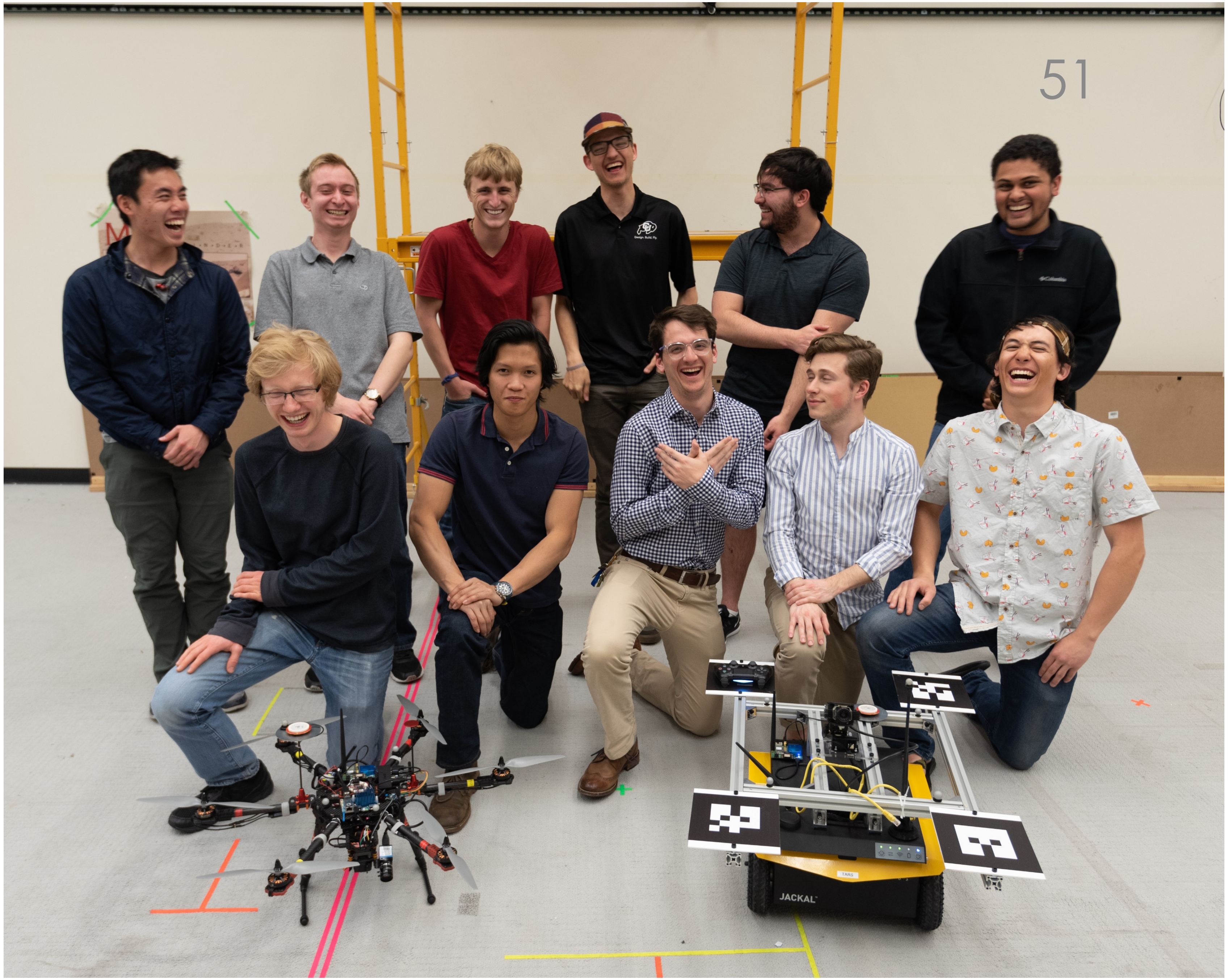
Subsystem	CDR Cost	Current Cost	$ Difference	Major Differences
Vision HW	$ 1,505.00	$ 1,994.00	+ $ 489.00	Incorrect lens purchase
UAV HW	$ 1,682.55	$ 1,396.84	- $ 285.71	No carbon rods
Sensor HW	$ 400.00	$ 747.09	+ $ 347.09	GPS Antennas, Faster Receiver, Mounts
CPU HW	$ 230.00	$ 496.21	+ $ 266.21	ODROID eMMC's, Voltage Regulators
Gimbal HW	$ 175.00	$ 570.07	+ $ 395.07	UAV Gimbal, Servos
Comms HW	$ 274.00	$ 330.16	+ $ 56.16	RC Controller, WiFi Modules
UGV HW	$ 0.00	$ 302.93	+ $ 302.93	3030 Steel, AR Tags
Misc HW	$ 30.00	$ 251.87	+ $ 221.87	VICON markers, 128 GB USB, Rechargeable Batteries
Admin	$ 200.00	$ 46.59	- $ 153.41	
Money Spent	**$ 4496.00**	**$ 6,147.63**	**+ $ 1,651.63**	
Remaining Funds	**$ 1,504.00**	**$ 852.37**	**- $ 651.63**	
Total	**$ 6,000.00**	**$ 7,000.00**	**+ $ 1,000**	Extra $1000 from Customer

Industry Cost

- Assuming average yearly salary of $ 65,000
  - Hourly rate: $ 31.25
- Total hours worked: ~ 5640
  - Cost: **$ 176,250**
- Overhead assumed at 200 %
  - Cost: **$ 352,500**
- Supplies:
  - Cost: **$ 16,150**

- TOTAL: **$ 544,900**

Thank you!




Questions?

Backup Slides

Levels of Success: Vision

<table>
<tr><th>Level 1</th><th>Level 2</th><th>Level 3 (Design Target)</th></tr>
<tr>
<td>

UAV shall track (keep in frame) UGV at range of 10-30 m.
Visual system extrinsics and intrinsics must be identified.
Image resolution must be less than or equal to 3 in/pixel at maximum range of 30 m.
Neither vehicle is moving.

</td>
<td>

Level 1
AND UGV shall track UAV at maximum range of 30 m.
AND UAV shall identify target in 90% of captured frames within range.
INSTEAD only UAV shall be moving.

</td>
<td>

Level 2
AND both UAV and UGV shall record if target is in frame.
INSTEAD UGV shall also be moving while not tracking.
AND UGV shall identify target in 90% of captured frames within range, while UAV is in flight.
AND shall not lose target for more than 3 seconds

</td>
</tr>
</table>

Levels of Success: Structure

Level 1	Level 2	Level 3 (Design Target)
▶ UAV total weight <50 lbs. ▶ UGV payload <44 lbs. ▶ UAV and UGV untethered. ▶ Batteries are field-accessible.	▶ Level 1	▶ Level 2 ▶ AND vision system shall have type S, C, or SC mount. ▶ AND vision system shall communicate with vehicle over USB 3.0.

Levels of Success: Captured Data

Level 1	Level 2	Level 3 (Design Target)
▶ Use at least one ≥128 GB removable storage. ▶ Store battery life estimate. ▶ Store package temperature. ▶ Store control input data. ▶ Store GPS/ephemeris receiver data. ▶ Store IMU data. ▶ Store state estimation data. ▶ Use lossless image compression to store all image frames during tracking. ▶ Have ≥20 GB data storage margin	▶ Level 1 ▶ AND all data shall be formatted in a ROS bag.	▶ Level 2 ▶ AND store magnetometer data. ▶ AND store barometer data.

Levels of Success: Controls

Level 1	Level 2	Level 3 (Design Target)
▶ UAV flight remotely piloted. ▶ UGV operation remotely piloted. ▶ UGV shall operate up to 0.5 m/s. ▶ UAV and UGV have kill autonomy switch. ▶ UAV will have emergency land switch. ▶ Controls algorithms shall be compatible with ROS. ▶ UAV must be able to maintain fixed altitude hover at any desired line of sight at 10-30m from stationary UGV.	▶ Level 1 ▶ AND UAV must be able to maintain fixed altitude orbital motion at any desired line of sight at 10-30 m from moving or stationary UGV.	▶ Level 2 ▶ INSTEAD only UAV takeoff and landing remotely piloted ▶ INSTEAD UAV tracking flight autonomous. ▶ AND control station displays map overlay of UAV/UGV positions. ▶ AND control station displays battery status, flight timer, vehicle's available storage, and current control mode.

Levels of Success: Communications

Level 1	Level 2	Level 3 (Design Target)
▶ Dedicated control station for UAV. ▶ Dedicated control station for UGV. ▶ Control station and vehicle shall communicate over ISM RF link. ▶ Switch target tracking on/off via wireless command. ▶ Control stations shall relay current control status (auto/manual piloting).	▶ Level 1 ▶ AND continuous GPS data sharing between both vehicles and respective control stations during operations within range. ▶ AND continuous state estimation data sharing between both during operations within range.	▶ Level 2 ▶ AND vehicles shall communicate visual tracking status and state data to control stations.

Levels of Success: Electronics and Software

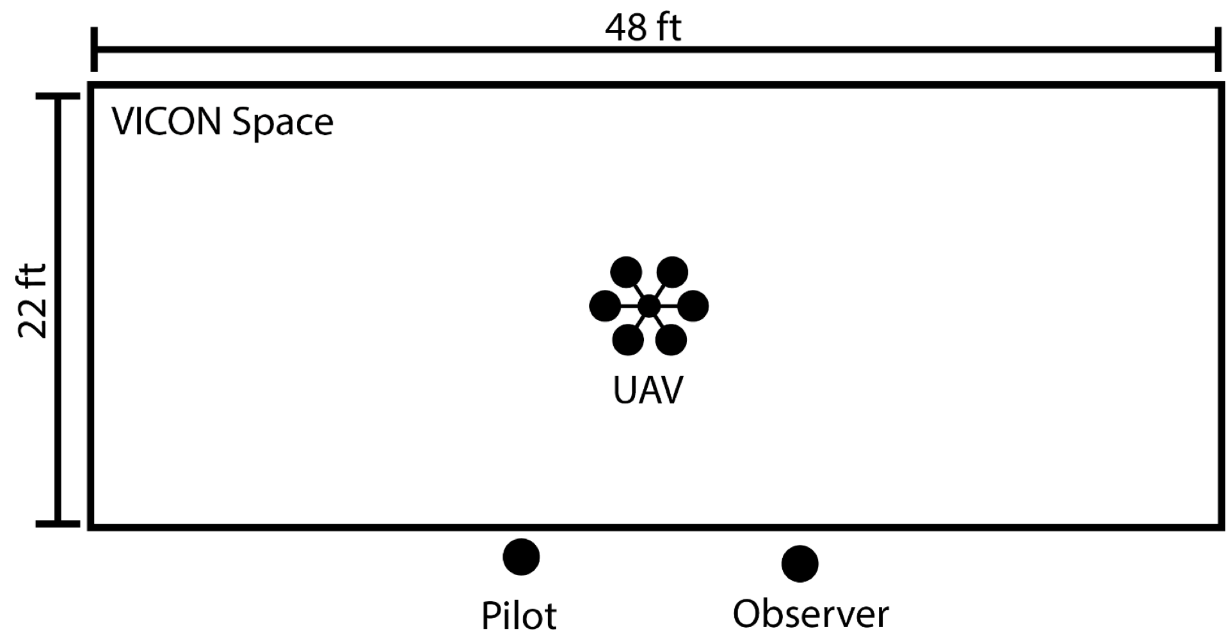
Level 1	Level 2	Level 3 (Design Target)
▶ 15 minute tracking endurance for UAV. ▶ 15 minute tracking endurance for UGV. ▶ Shall have the ability to cold swap batteries. ▶ Shall integrate GPS. ▶ Shall integrate IMU. ▶ Shall integrate visible spectrum imaging system. ▶ Shall boot into low power mode. ▶ Shall be OpenCL 1.1 capable. ▶ Shall have hardware floating point acceleration.	▶ Level 1	▶ Level 2 ▶ AND shall integrate magnetometer. ▶ AND shall integrate barometer.

Levels of Success: Management

Level 1	Level 2	Level 3 (Design Target)
▶ Adhere to UCB UAS FOM. ▶ Keep best safety practices. ▶ Acquire all relevant certifications. ▶ No DJI or prohibited components. ▶ Safety and Testing Officers shall oversee all tests. ▶ Project cost shall remain under budget.	▶ Level 1	▶ Level 2

Manual Flight

Reasoning: Determine flight characteristics of UAV platform. Ensure UAV is flyable and stable during manual flight operations using proxy masses for payload simulation.



Testing Prerequisites:
- UAV Built
- Proxy Masses
- Pixracer Unit Testing

Equipment and Facilities:
- VICON space (RECUV Fleming Lab)
- VICON markers
- UAV Transmitter
- Stopwatch

Risks:
- UAV crash/damage
- LiPo battery damage
- Damage to VICON space

Verified Design Requirements:
DR: 5.1

Recorded Data:
- Flight Time
- VICON data

Success Criteria:
- UAV flight for >18.15 minutes
- UAV stable in flight

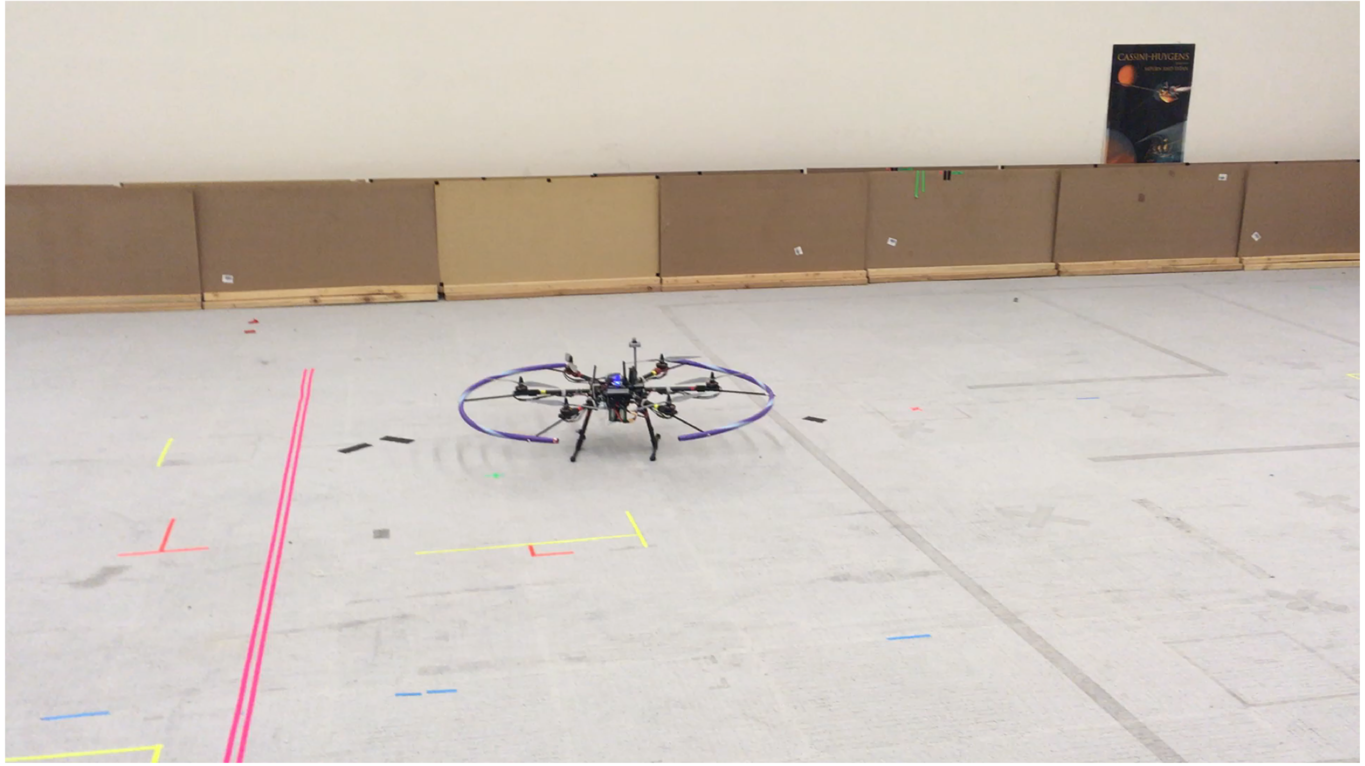
Manual Flight - Results

Two tests completed:

- Test 1
  - Flight Length: 15:03
  - VICON data collected
- Test 2
  - Flight Length: 18:36
  - VICON data collected

Results:

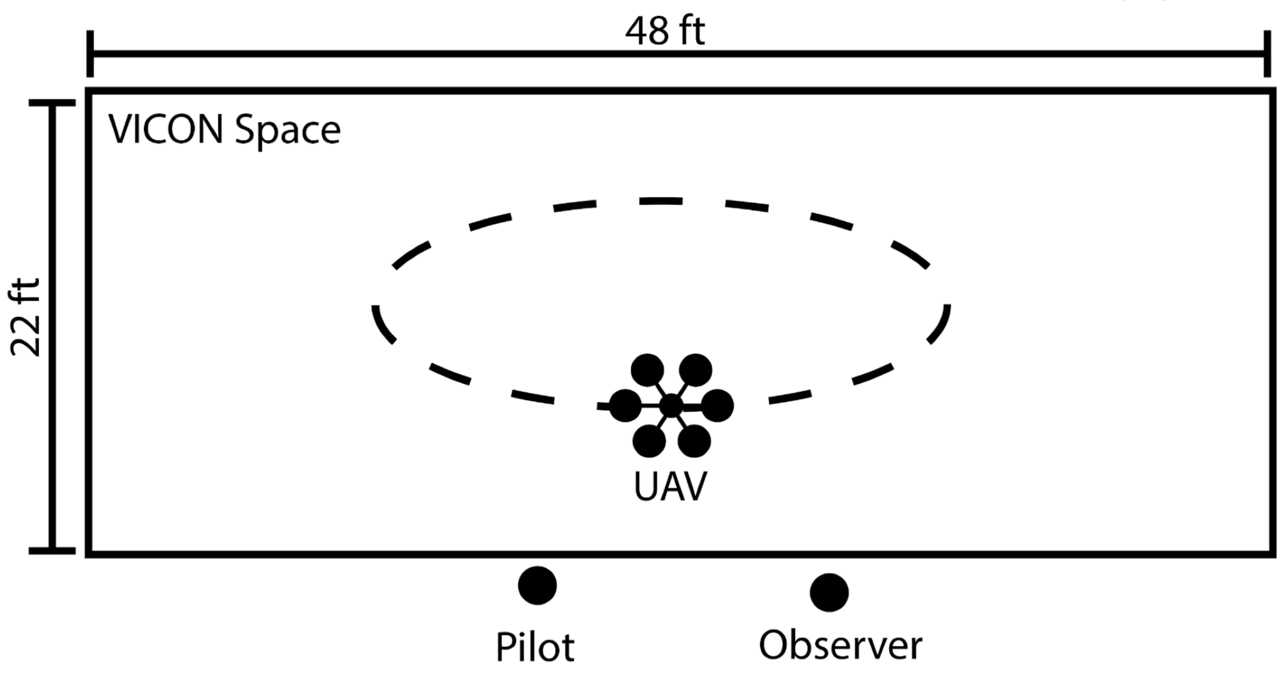
- No major damage to UAV
- Safety hoop needed to be refitted
- Testing concluded after impact
- Automatic landing successful



Success Criteria:

- UAV flight for >18.15 minutes: PASS
- UAV stable in flight: PASS

Automatic Flight



Reasoning: Verify operation of the pixracer's automatic flight system and waypoint positioning system.

Testing Prerequisites:
- Manual Flight
- Safety Systems

Equipment and Facilities:
- VICON space (RECUV Fleming Lab)
- VICON markers
- UAV Transmitter
- Stopwatch

Risks:
- UAV crash/damage
- LiPo battery damage
- Damage to VICON space

Recorded Data:
- Flight time
- VICON data
- Control Inputs

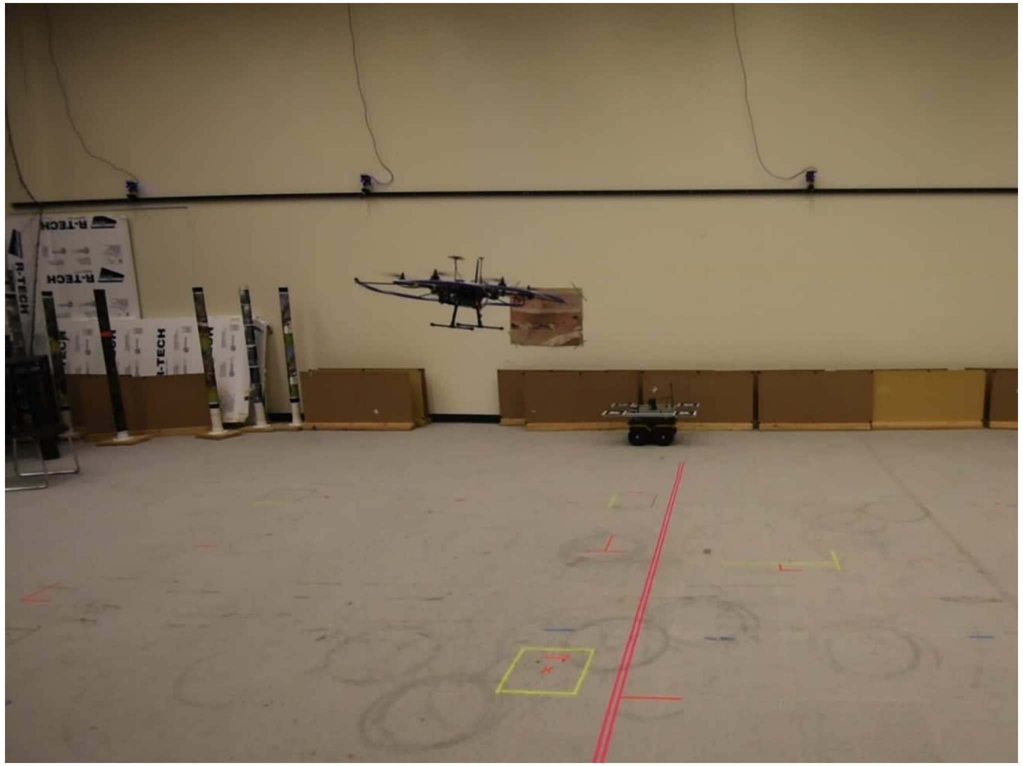
Verified Design Requirements:
DR: 9.3

Success Criteria:
- UAV flight for >18.15 minutes
- UAV stable in flight

Automatic Flight - Results

Two tests completed:

- Test 1 : Hover
  - Flight Length: 5 minutes
  - VICON data collected
- Test 2 : Automatic position control
  - Flight Length: 5 minutes
  - VICON data collected



Results:

- UAV able to hover in place with position correction
- UAV able to respond to local position flight pattern
- UAV able to yaw to point camera towards UGV
- No endurance test done on automatic flight

Success Criteria:

- UAV flight for >18.15 minutes: UNVERIFIED
- UAV stable in flight: PASS

UAV Video (full)

GPS Error (Backup)

Maximum allowable error:

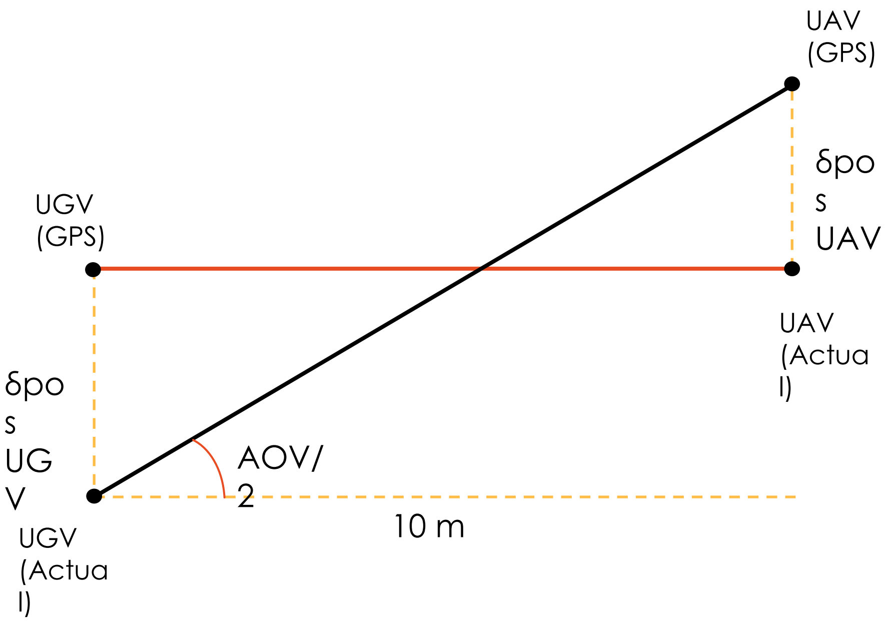
$$tan\left(\frac{AOV}{2}\right) = \frac{2\delta_{err}}{10m}$$

$$\delta_{err} = \frac{10m}{2} tan\left(\frac{28\deg}{2}\right) = 1.2466m$$

Z-score for 90% of frames is 1.281551.

$$\sigma = \frac{1.246640014m}{1.281551} = 0.9728m$$

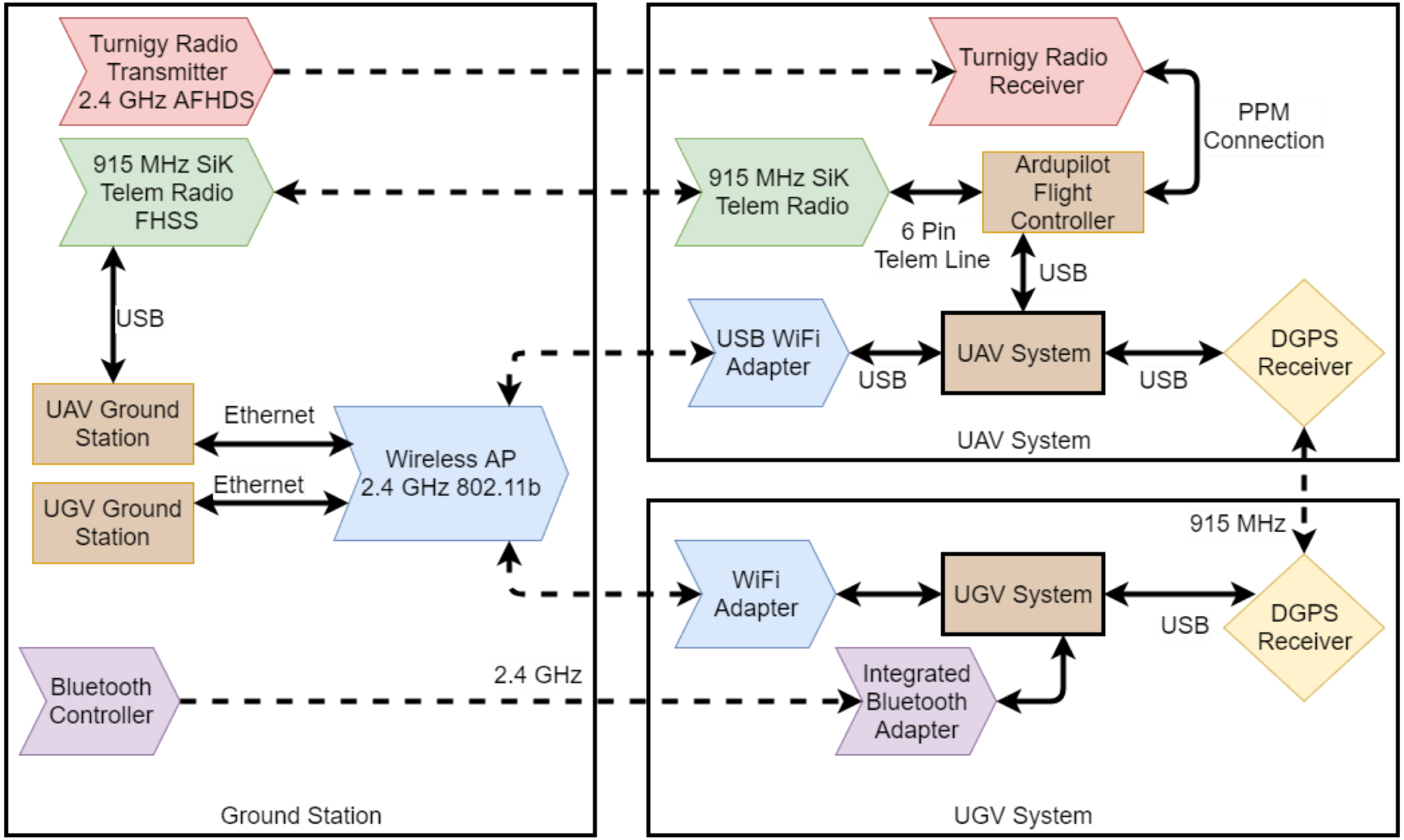
Therefore, the GPS error must have a standard of deviation less than or equal to 0.973 m in order to meet requirement.



Specific Objectives (All Level 3)

- **Vision: A moving UAV shall track the UGV at 10-30 m and be in 90 % of frames. A stationary UGV shall track the UAV at 10-30 m and be in 90 % of frames. Acquire target in less than 3 seconds.** Image resolution must be less than or equal to 3 in/pixel at 30 m.
- **Structure**: UAV < 50 lbs. UGV payload < 44 lbs. UAV and UGV are untethered. Batteries are field-accessible. Vision system shall be swappable and communicate over USB 3.0.
- **Captured Data**: Have at least 128 GB removable storage. **Store battery life estimate, package temperature, control input data, GPS/ephemeris data, IMU data, magnetometer data, and barometer data all in ROS bags w/ 20 GB storage margin.** Use lossless compression.
- **Controls**: **UAV will have emergency land switch.** Autonomous UAV tracking orbit with piloted takeoff and landing. UGV remotely piloted up to 0.5 m/s. Controls algorithms compatible with ROS. **Control station displays map overlay of UAV/UGV positions as well as battery status, flight timer, and storage capacity.**
- **Comms**: Vehicles shall communicate over ISM RF link. **Vehicles shall share GPS data, visual tracking, and state data with the control stations.**
- **Electronics/Software**: **Vehicles shall have 15 min tracking endurance.** GPS, IMU, Vision, magnetometer, and barometer shall be integrated. Shall be OpenCl 1.1 capable and have hardware floating point acceleration. Will be able to run cooperative localization algorithms on each vehicle with 50 % CPU overhead margin.
- **Management**: Adhere to UCB UAS FOM. Keep best safety practices. No DJI or prohibited components. **Project cost shall remain under budget.**

Communications Layout



UAV Gimbal Problem & Solution

- **Problem:** No way to tell where UAV gimbal was pointing.
- **Solution:** New 1D gimbal using feedback servo.

Old Gimbal	New Gimbal
167g	~75g
3-axis	1-axis
No feedback	Analog feedback

Proxy Masses

Proxy masses are needed for testing safety.

Part	Mass	Dimensions
Camera & Lens	116g	74 x 29 x 29mm
Gimbal	75g	45 x 39 x 32mm
ODroid XU4	65g	83 x 58 x 20mm
PixRacer	11g	36 x 36 x 20mm
GPS	35g	75 x 55 x 10mm
GPS Antenna	100g	30 x 30 x 100mm
Wiring	~150g	
Wireless Comms	~10g x3	10 x 10 x 10mm x3
Additional testing masses	10g x20	10 x 10 x 10mm x20

UAV Component Masses

Component	Measured Mass	Qty	Total
Frame	632g	1	632g
Propeller	24.5g	6	147g
Motor	88.2g	6	529.2g
Batt	954.5g	1	954.5g
Camera+lens	111g	1	111g
Telemetry Radio	16g	1	16g
Gimbal	76g	1	76g
Vibration Isolator	20g	1	20g
GPS System	123g	1	123g
Wifi Receiver	31g	1	31g
RC Receiver	15g	1	15g
ESC	31g	6	186g
Odroid + Arduino	120 g	1	120g
Wiring [estimate]	130g	1	130g
Total			3090g

Expected Mass: 2.9 kg

VICON motion capture

Overview: Motion capture system in RECUV indoor flight space. Allows for indoor vehicle flight tests. OTS ROS package solution: *vrpn_client_ros (virtual reality peripheral network)*

- VRPN:
  - **Inputs:** Data stream from VICON Tracker software [100Hz]
  - **Outputs:** Pose, linear and angular velocity, linear and angular acceleration of both vehicles [100Hz]
  - **Milestones:**
    - Attach motion capture markers and create VICON object for UAV and UGV [0/1]
    - Create launch file for *vrpn_client_ros* [0/1]
    - Integrate with UAV GPS collection process [0/5]
- “GPS” Handler
  - **Inputs:** Pose, linear and angular velocity, linear and angular acceleration of both vehicles
  - **Outputs:** Relative position and heading [1Hz]
  - **Milestones**:
    - Create handler [0/2]
    - Unit testing for integration [0/5]
    - Add noise to simulate sensor error [0/5]

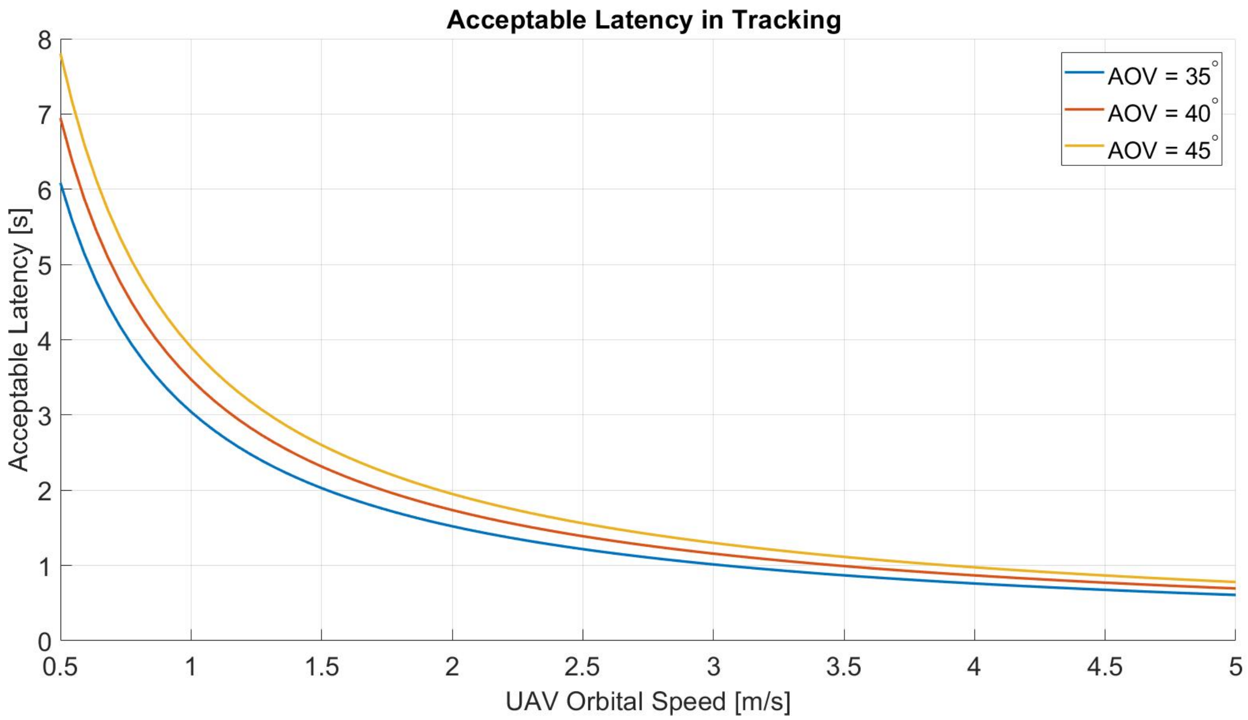
Housekeeping Data

- UAV:
  - Pixracer outputs telemetry data when requested via mavROS message [50 Hz max]
  - Housekeeping process:
    - Create and send mavROS messages
    - Send data to SD storage and and package and send to GCS
- Milestones:
  - Create and send mavROS messages [0/5]
  - Package data and send to GCS [0/2]
  - Send data to SD storage [0/2]

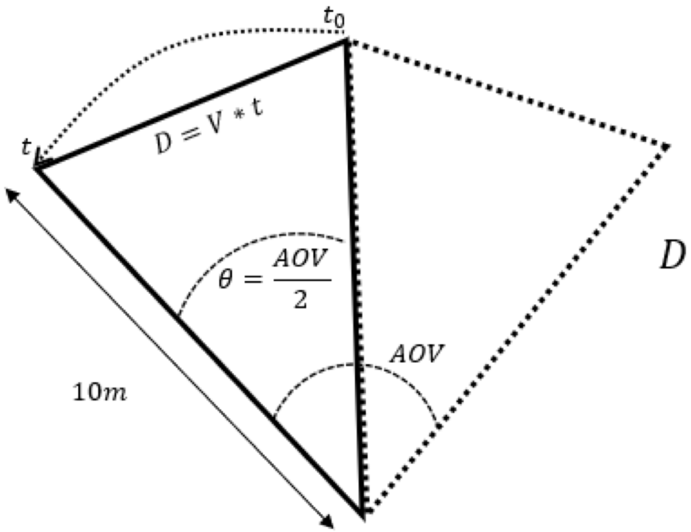
- UGV:
  - Jackal software makes temperature, battery information, command, and IMU data available out of the box [50 Hz]
  - Housekeeping process:
    - Grab data and send to SD storage and package and send to GCS
- Milestones:
  - Find all ROS topics with pertinent data [0/2]
  - Package data and send to GCS [0/2]
  - Send data to SD storage [0/2]

Latency Model

- Calculated Latency is time between pointing states
- Includes position transmission, processing, pointing commanding, and actuation



Latency Model



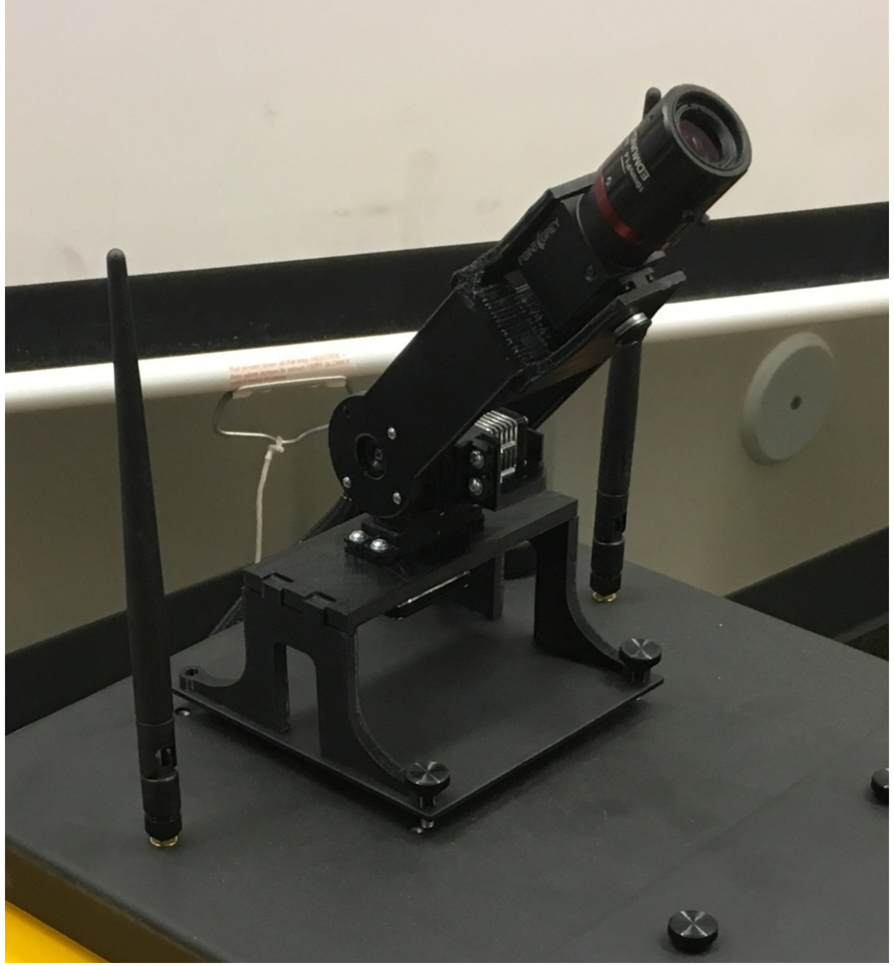
$$t - t_0 = t_{lat}$$
$$D = V * t_{lat}$$
$$D = 2 * 10m * \sin\left(\frac{\theta}{2}\right) = 2 * 10m * \sin\left(\frac{AOV/2}{2}\right)$$
$$V * t_{lat} = 2 * 10m * \sin\left(\frac{AOV/2}{2}\right)$$
$$\boldsymbol{t_{lat} = \frac{2}{V} * 10m * sin\left(\frac{AOV/2}{2}\right)}$$

Mounting Rail

- Used to mount AR tag plates and gimbal
- 8020 – 3030
- M5 bolts for mounting onto UGV
- Weight not a concern

UGB Gimbal

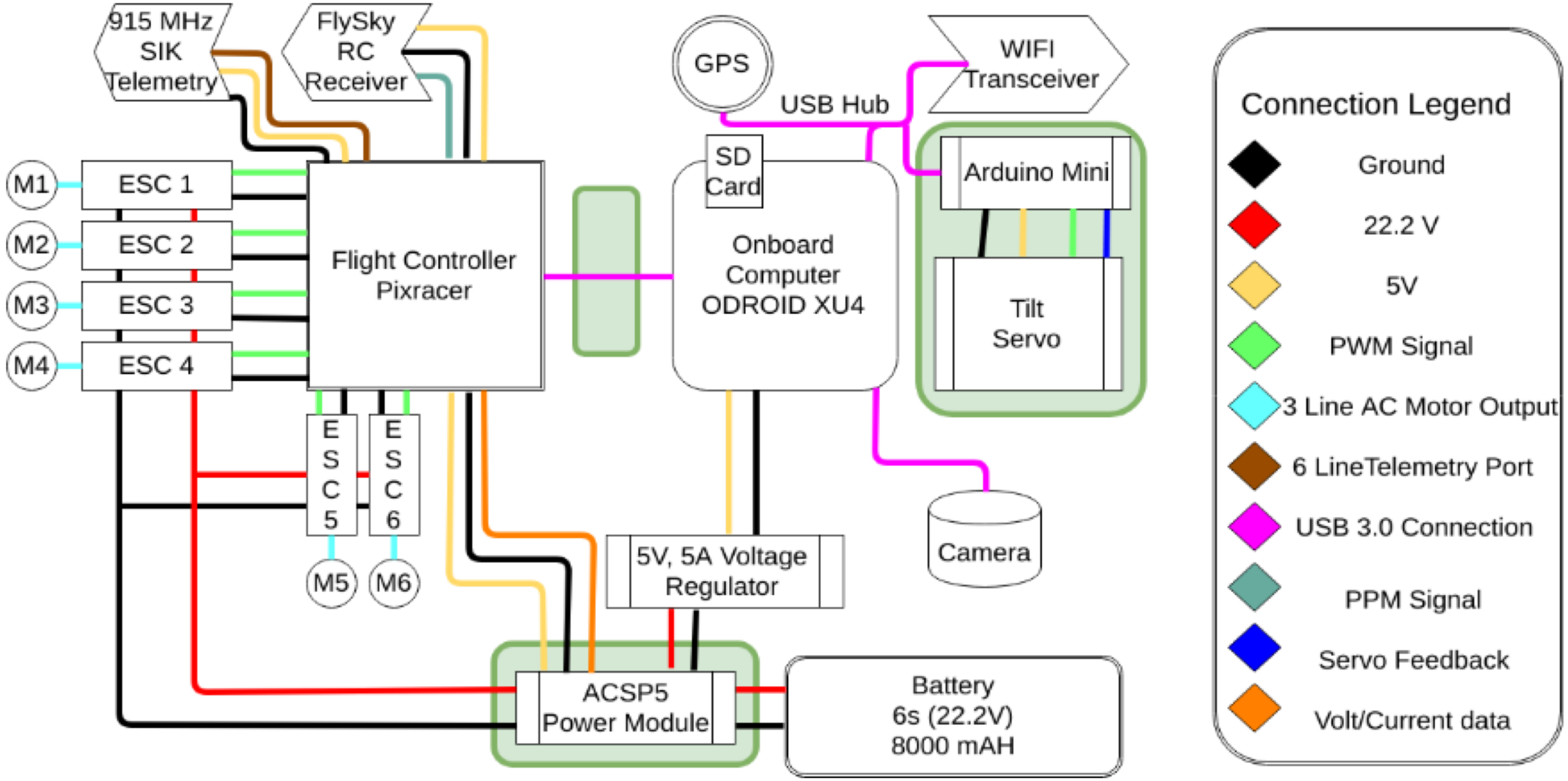
- Prototyped from CDR
- 3D printed PLA
- Tolerances sufficient (no necessity for accuracy)
- M5 bolts
- 2 x analog feedback servos
- Servo bearing on other side of tilt arm for smooth movement



GPS Configuration

- RTK Moving Baseline Mode (MB)
- Requires RTCM Messages:
  - 1077 (GPS Observations), 1087 (GLONASS Observations), 1230 (GLONASS Code-phase Biases), 4072 (uBlox Proprietary MB Message).
- Base will send RTCM messages at 19200 Baud, and Rover will receive RTCM messages at 19200 Baud.
- Both the Base and the Rover will be configured with 1 Hz navigation rate.
- Users will receive:
  - NAV-DOP, NAV-HPPOSECEF, NAV-TIMEUTC, NAV-VELNED, NAV-RELPOSNED, RXM-RAWX (Observations), RXM-SFRBX (Navigation Subframe)
  - NMEA-RMC (Recommended minimum NMEA message)

Updated Electronics Connection Diagram



Electronics Integration Status

Tested Working Connection:

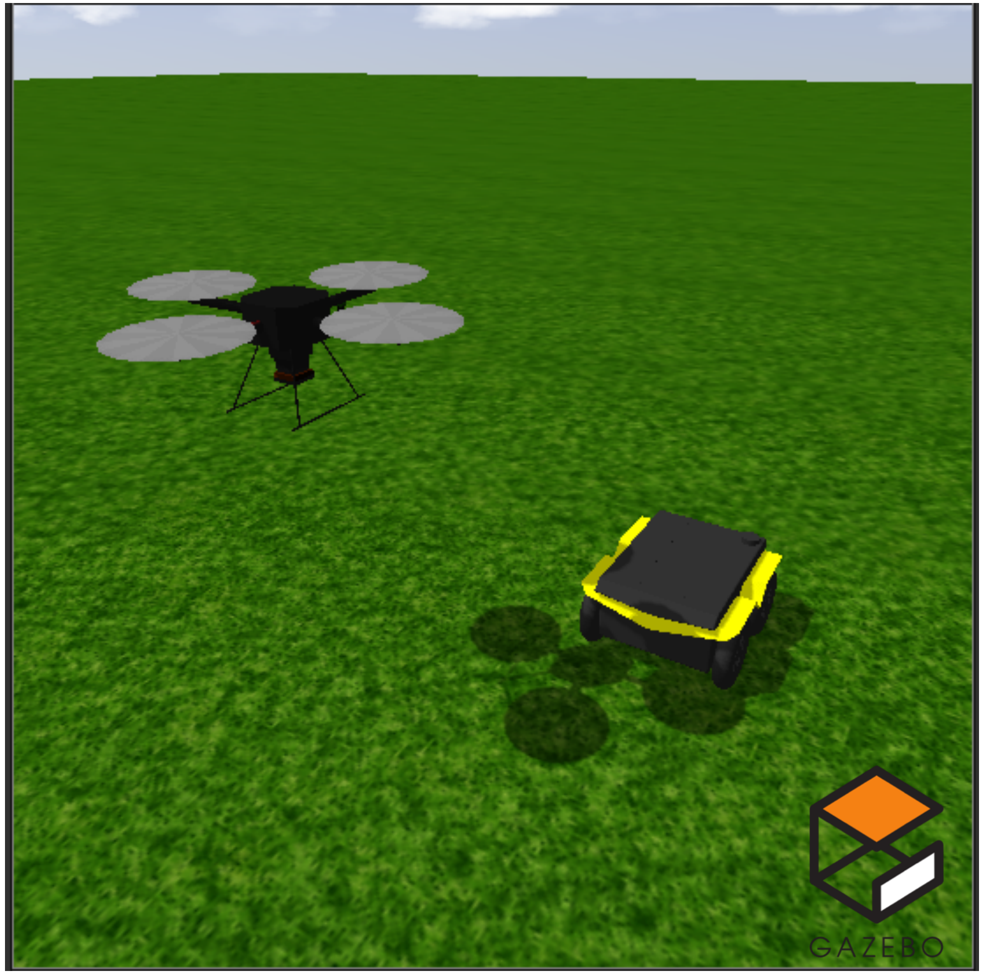
- Pixracer - Odroid Connection
- Pixracer - RC Controller
- Pixracer - Telemetry Radio
- UGV - Bluetooth
- Wifi router setup
- ODROID - Arduino – Servo

Untested Connection:

- Pixracer-ESC
- ODROID-Wifi
- ODROID-GPS
- ODROID-Camera
- UAV Power Distribution
- UGV Extra Sensors

Gazebo Overview

- ROS Simulation Tool
- Provides 3D visualization of systems
- Allows sensor emulation
- Simulates reasonable approximations of dynamics
- **Allows prototyping of RAVEN network**

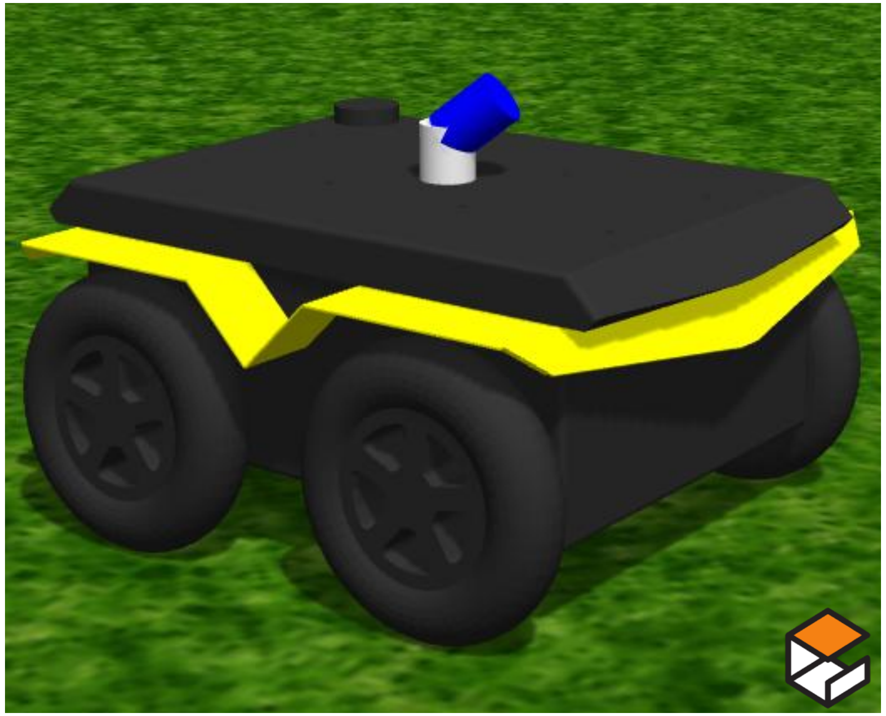


Gazebo Assumptions

- Sensors are emulated
  - Sensor traits are not yet configured
  - Sensor data source will change
- Physical characteristics
  - Magnitude of losses are unknown
  - Can change with environment

Simulated Camera and Mount

- Gazebo plugin for camera
  - Parameters
    - View distance
    - Resolution
    - Field of view
- Gazebo plugin for mount control
  - Modeled by two intersecting cylinders
  - Manually command pan and tilt joints to angles
  - Still to implement: mount tracks UAV by sharing GPS, more realistic model for camera and mount



Gazebo Playback

- A ROS Bag records ROS messages for topics that the bag is subscribed to, as well as a time record of the message.
- Using ROS playback, tools these messages can be played back in real time.
- Utilizing the Gazebo model, and replaying all ROS messages, the test conditions and results can be played back.
  - There are some limitations, based on the time difference between when a topic was published to, and when the value was processed.

UGV Gimbal Demonstration