WILD Goblin Sensor Pod Design, Development, and Integration

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Final Presentation

Wednesday, October 15, 2014

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Outline

- WILD Goblin Concept
- Software Design
  - Turret Control
  - Turret Stability
- Mechanical Design
  - Design Requirements
  - Design Process
  - Final Sensor Turret
- Integration Tests
  - Point-to-point movement
  - Results
- Future Work

WILD Goblin Concept

- **WILD Goblin project**
  - **Smart Unmanned Aerial Vehicle (UAV)**
  - **Performs autonomous reconnaissance**
- **BAE Coyote Airframe based**
- **"Piggyback Deployment"**
- **Missions**
  - **Border patrol, infrastructure patrol, and security**
  - **Identifying targets in heavy clutter**
  - **Searching for camouflaged and concealed targets**

Coyote Animation

Coyote and its Sonobuoy Tube

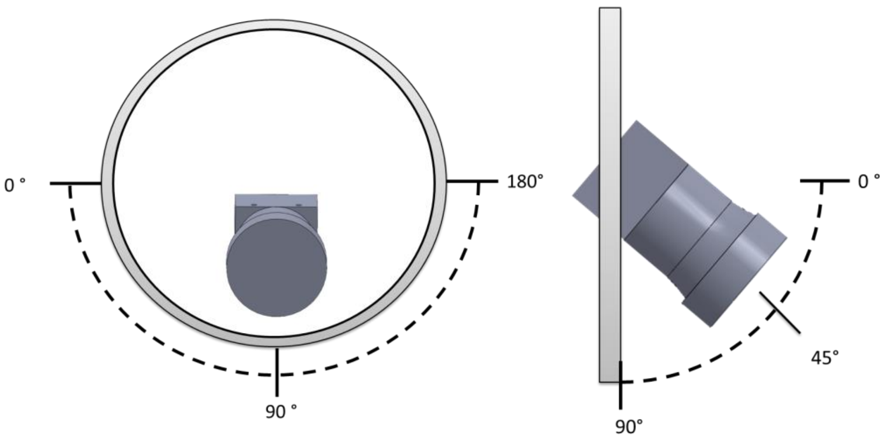
Motivation

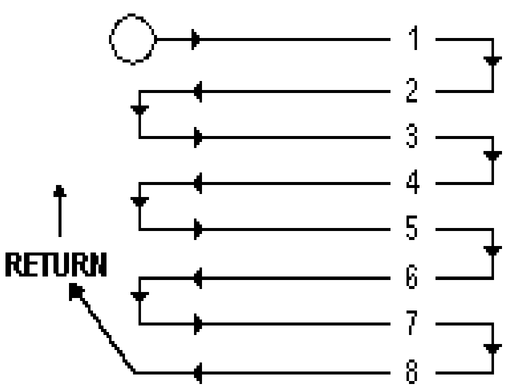
- **COTS UAV turrets available**
  - **Not optimized for our required SWaP constraints**
  - **Challenging to facilitate the desired scan geometry in the confined space of a SUAV**

- **COTS sensor systems available**
  - **Not optimized for our target set**

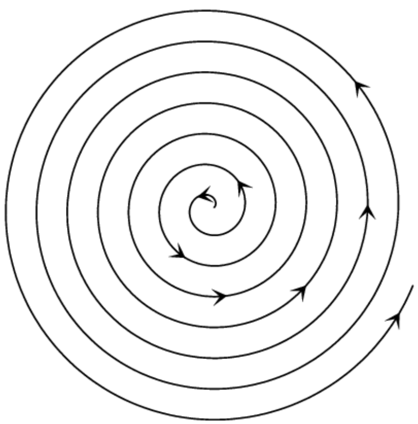
Goals

- **Design a sensor turret**
  - **Houses a laser rangefinder, short-wave infrared camera, and long-wave infrared camera**
  - **Mechanical Design**
    - **Roll-tilt turret**
  - **Software Design**
    - **Precision scans and target tracking**

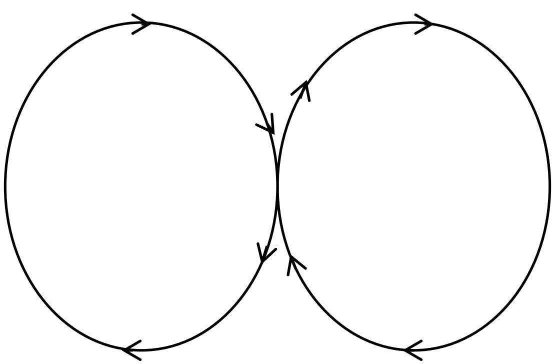




Raster Scan



Spiral Scan



Clover Scan

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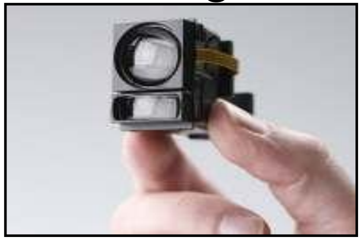
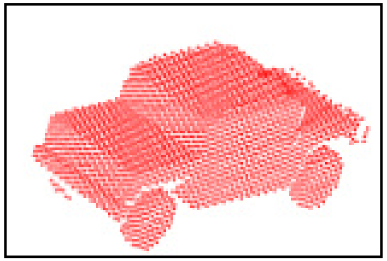
Sensor Pod

- Jenoptik DLEM-SR Laser Rangefinder
  - Laser: 1.55 micron
  - 5 km, 25 Hz, <1 m resolution
- Sensors Unlimited Micro-SWIR (short-wave infrared) Camera
  - Standard Spectral Response: 0.9 – 1.7 micron
- FLIR Quark LWIR (long-wave infrared) Camera
  - Spectral Band: 7.5 – 13.5 micron

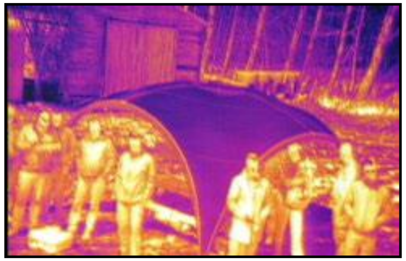
Laser Rangefinder





SWIR

LWIR



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Software Design - Turret Control

- **Serial Commands**
  - **Point to point**
  - **Speed control**
  - **Home**
  - **Heartbeat**
  - **Status**
  - **Scan**
- **Point and scan programs were completed using only the microcontroller**

Point to Point Movement with Speed Change

Demonstration of point to point movement

Software Design - Turret Control

- **Raster Scan**
  - **Used on stationary targets usually while orbiting**
  - **Able to change speeds**
  - **Input a height and a width**
  - **Acquire time of specific point**

Raster Scan

Raster scan performed using a roll-tilt turret aimed at a target board

Software Design - Turret Control

- **Spiral Scan**
  - **Used for moving targets**
  - **Starts in center of desired spiral**
    - **Input a radius and density**
    - **Returns back to center when complete**
  - **Returns all the points in order to get the time at which the desired point occurred**

Spiral Scan

Spiral scan performed using a roll-tilt turret aimed at a target board

Software Design - Turret Control

- **Clover Scan**
  - **Used to replicate a convoy driver (human-behavior)**
  - **Starts in center, performs a clover with a desired number of leaves at a certain radius**
  - **Enter a desired point to get the time at which that point occurred**

Clover Scan – Figure 8

Figure 8 clover scan performed using a roll-tilt turret aimed at a target board

Clover Scan – 6 Leaves

6 leaved clover scan performed using a roll-tilt turret aimed at a target board

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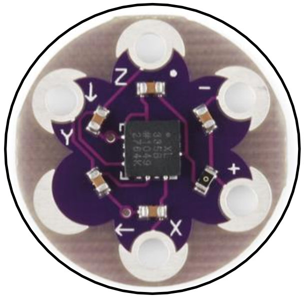
Software Design - Turret Stability

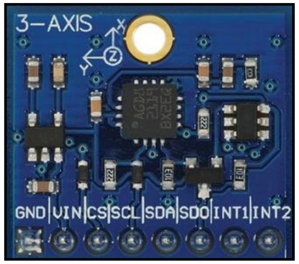
- **Once the desired coordinates are sent to the turret, an accelerometer and a gyroscope are used to stabilize the turret in a specified orientation.**
  - **Inertial Measurement Unit (IMU)**

- **Decouple sensor field of view (FOV) from the motion of the aircraft**

ADXL335 - Accelerometer



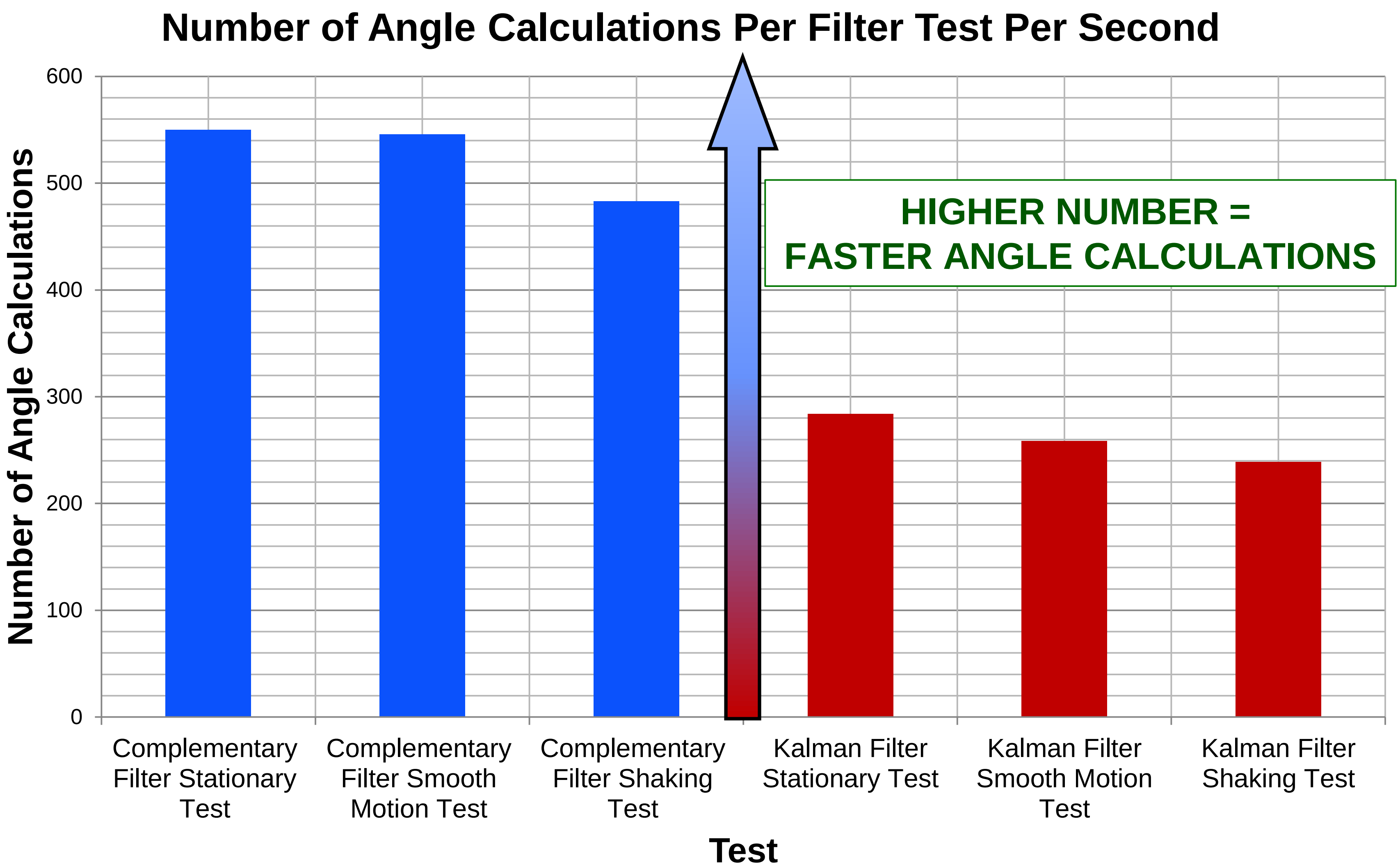
L3G4200D - Gyro



Software Design - Turret Stability

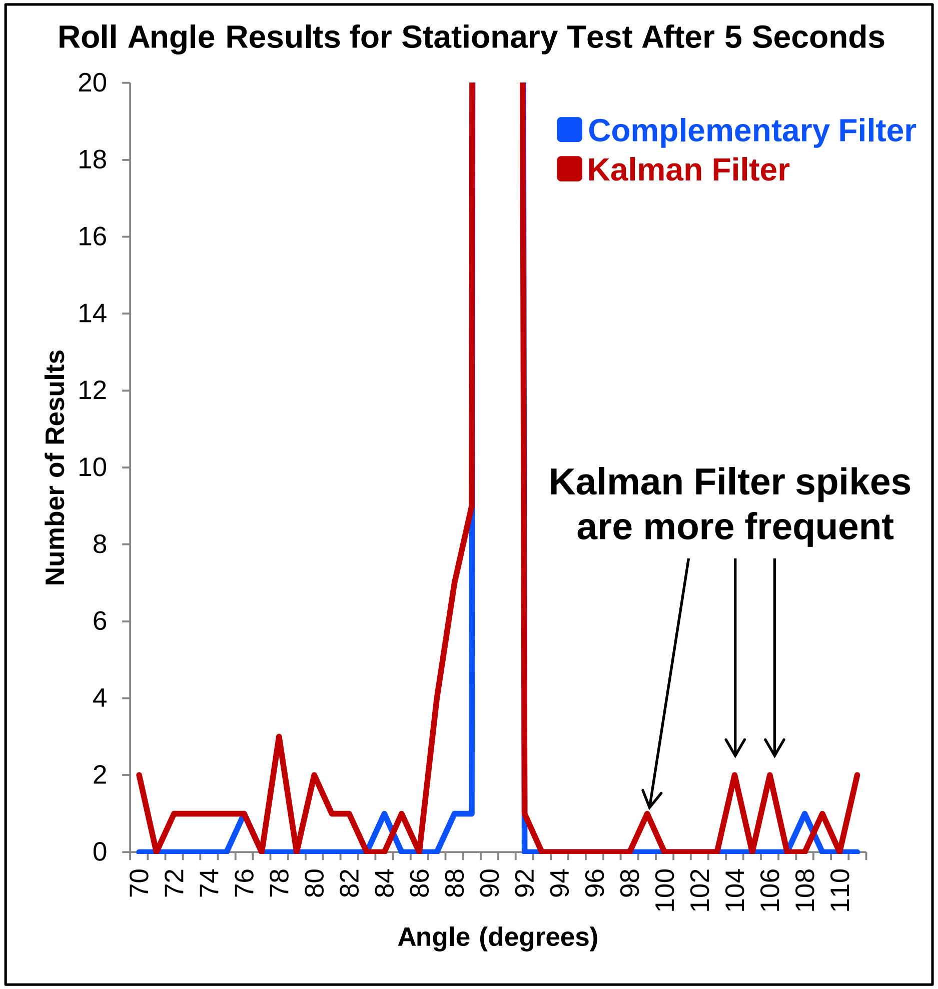
Initial Stabilizing Turret Movement

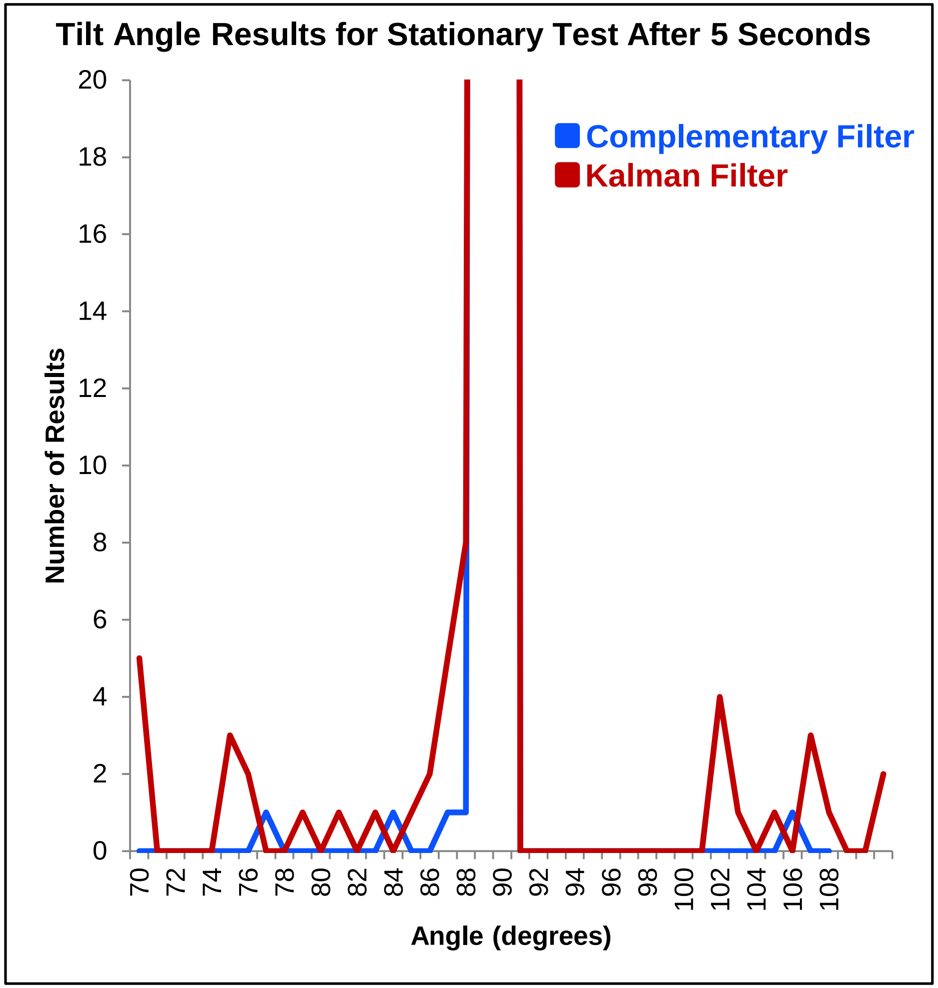
Software Design – Turret Stability



Software Design – Turret Stability

- **Complementary filter** was compared to **Kalman Filter**





Software Design - Turret Stability

Test Turret Staying Focused around a Point

Test Turret View

Camera View

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Requirements

ID	Category	Requirement
R01	Weight	The turret assembly without sensors shall weigh less than 17 ounces.
R02	Size	The outer diameter of the turret assembly shall be less than 5.375”.
R03	Size	The complete length of the turret assembly shall be no longer than 5".
R04	Torque - Tilt Platform	The torque supplied to actuate the tilt platform shall be more than 10 oz-in, with a goal of at least 20 oz-in.
R05	Torque - Roll Platform	The torque supplied to actuate the roll platform shall be more than 20 oz-in with a goal of at least 50 oz-in.
R06	Speed - Tilt Platform	The tilt mechanism shall tilt at a rate of at least 15 degrees/second.
R07	Speed - Roll Platform	The roll mechanism shall roll at a rate of at least 15 degrees/second.

ID	Category	Requirement
R08	Acceleration - Tilt Platform	The tilt mechanism shall accelerate at a rate of at least 15 degrees/second^2.
R09	Acceleration - Roll Platform	The roll mechanism shall accelerate at a rate of at least 15 degrees/second^2.
R10	Field of Regard - Tilt Platform	The tilt mechanism shall tilt at minimum 45 degrees with a goal of 90 degrees.
R11	Field of Regard - Roll Platform	The roll mechanism shall roll a minimum of 90 degrees with a goal of 180 degrees.
R12	Sensor Capacity	The turret assembly shall hold the Jenoptik Laser Range finder, the Flir QUARK, and the Sensors Unlimited MicroSWIR.
R13	Accuracy	The accuracy of the mechanism shall be less than 1 degree (the actual position of the turret shall be within 1 degree of the specified position).
R14	Repeatability	The repeatability of the mechanism shall be less than 1 degree.

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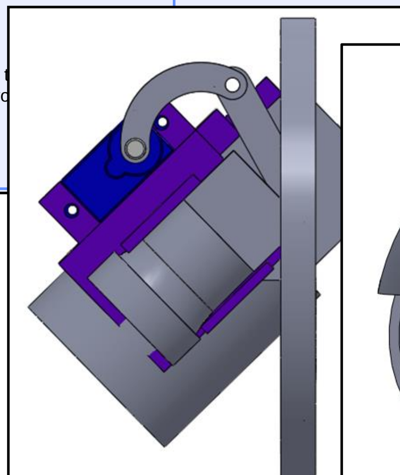
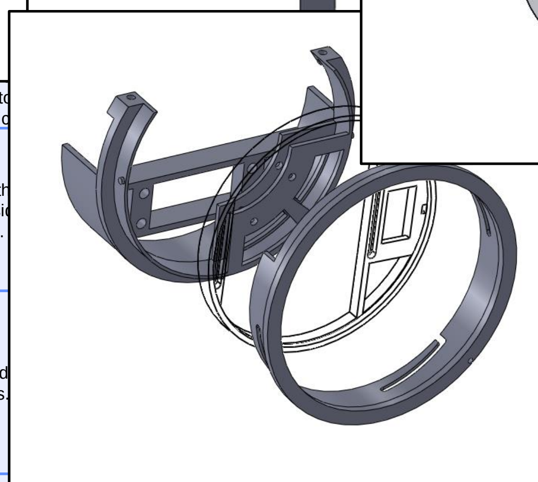
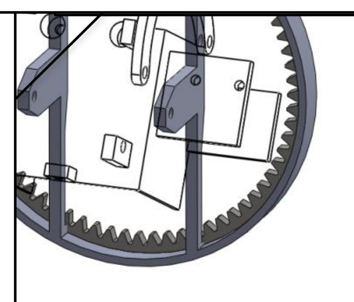
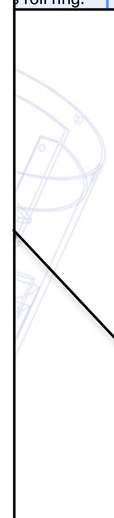
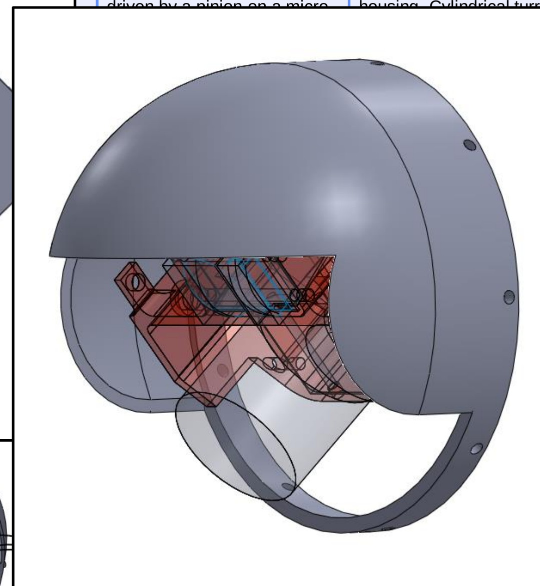
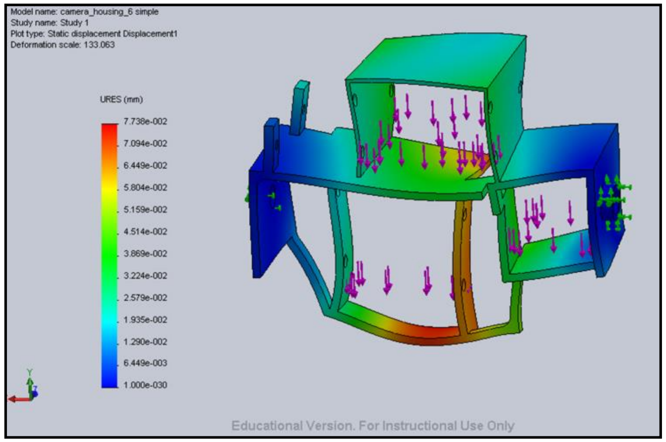
Design: Iterations

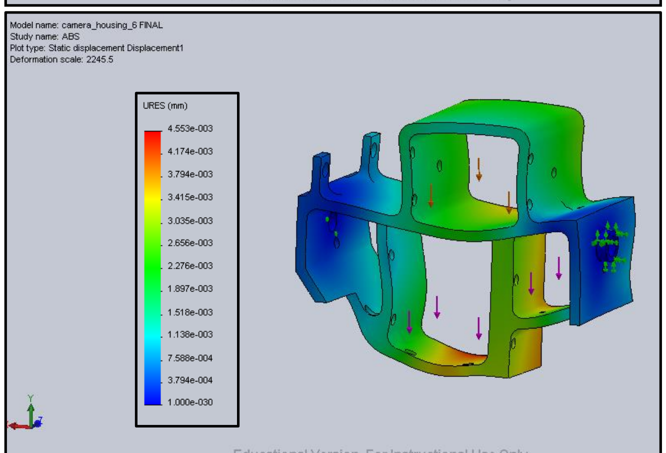
Iteration	Description of Item in Iteration						Issues Found
	Sensor Housing	Roll Ring	Roll Mechanism	Tilt Mechanism	Turret Housing	Nosecone	
1	Three pockets (one for each of the three sensors).	0.2 inches t micro servo		Complex Motion. Rack gear driven by a pinion on a micro	Retain 2013 senior project turret housing. Cylindrical turret housing duced for ylindrical s roll ring.	Cut in half to expose the sensors. Anchored to the Goblin Body, does not move with roll or tilt mechanism.	• Sensor Housing did not fit the sensors. • Roll Mechanism requires a 1:1 ratio to reach the desired range of motion (180 degrees) • Turret Housing: Keyway causes hold on roll ring to be loose. • Roll Ring: Servo collides with pinion gear driving the roll mechanism
2	No Change	Ring w servo gears				o Change	• Sensors did not fit into the sensor housing. • Servo did not fit into the servo housing, likely due to an inaccurate servo CAD model.
3	Redesigned to fit sensors. Thinned or removed walls between sensors to decrease size of the sensor housing. Added screw holes for all sensors.	Remo leavin attach senso				o Change	•Tilt mechanism did not have full 90 degrees of motion. • Roll ring collided with the gear driving the internal gear, needed to cut a piece out of the vertical bar of the roll ring.
4	No Change	Added the ve rather screws to the vertic				o Change	• Too much modularity on the design made the assembly very difficult to put together.
5	Redesigned sensor housing to allow more space for the SWIR lens. Moved the Laser Rangefinder to the top of the housing.	Moved th the outsi housing.			ngs, servo ly into one the number y.	hanged nose cone to attach to roll ring rather than Goblin body, allowing the nose cone to rotate with the roll mechanism. Changed the cut of the nose cone to cover more of the opening.	• Gears were all 3D printed and did not mesh well. • Gear attached to tilt servo collided with nosecone in fully retracted position.
6	Altered the sensor housing to make it machinable by increasing wall thickness and adding fillets to inside corners.	Reduced brackets.			e shafts new	No Change	• Roll servo does not line up well with the shaft causing grinding and vibration. • gears for tilt mechanism are plastic and do not attach well to the micro servo.
7	Changed the micro servo mount to accommodate a new micro servo.	No Change	Realigned servo and shaft.	Used new micro servo with standard spline size as well as a gear which attaches directly to the standard spline.	Extended the length of the turret housing to add another sensor. Added ledges with holes to allow shelves for electronics to be added .	No Change.	

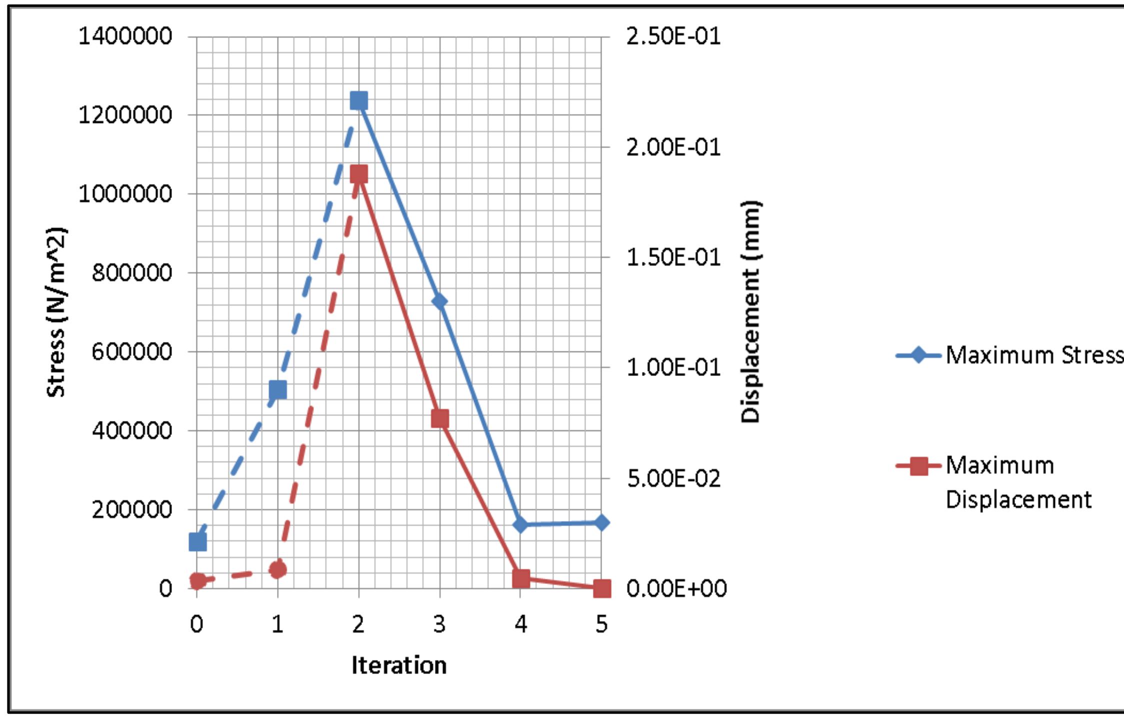
Analysis: Sensor Housing

Simulated Maximum Displacement of Iteration 3 (top) and Iteration 4 (bottom)





Overall Maximum Stress and Displacement under Simulated Sensor Load



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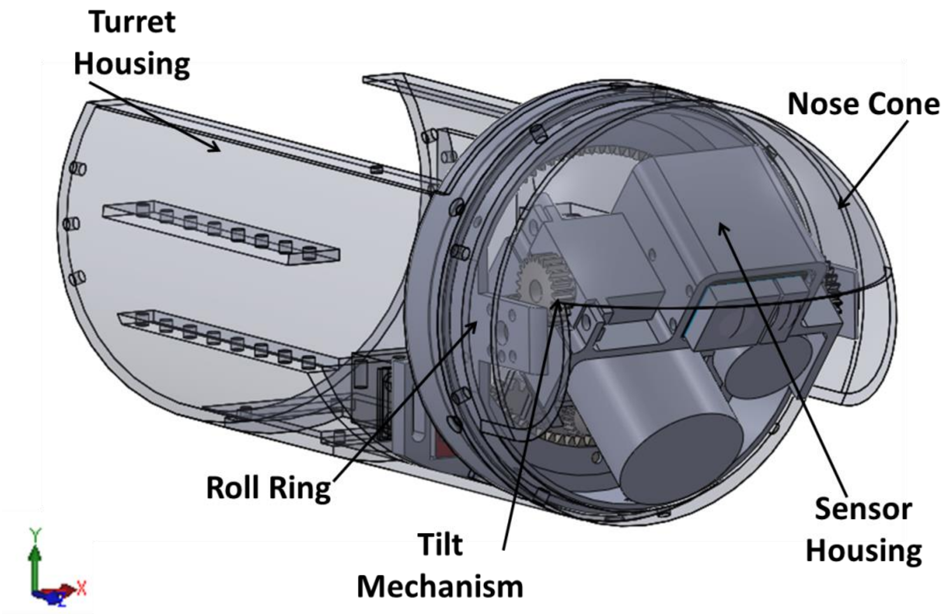
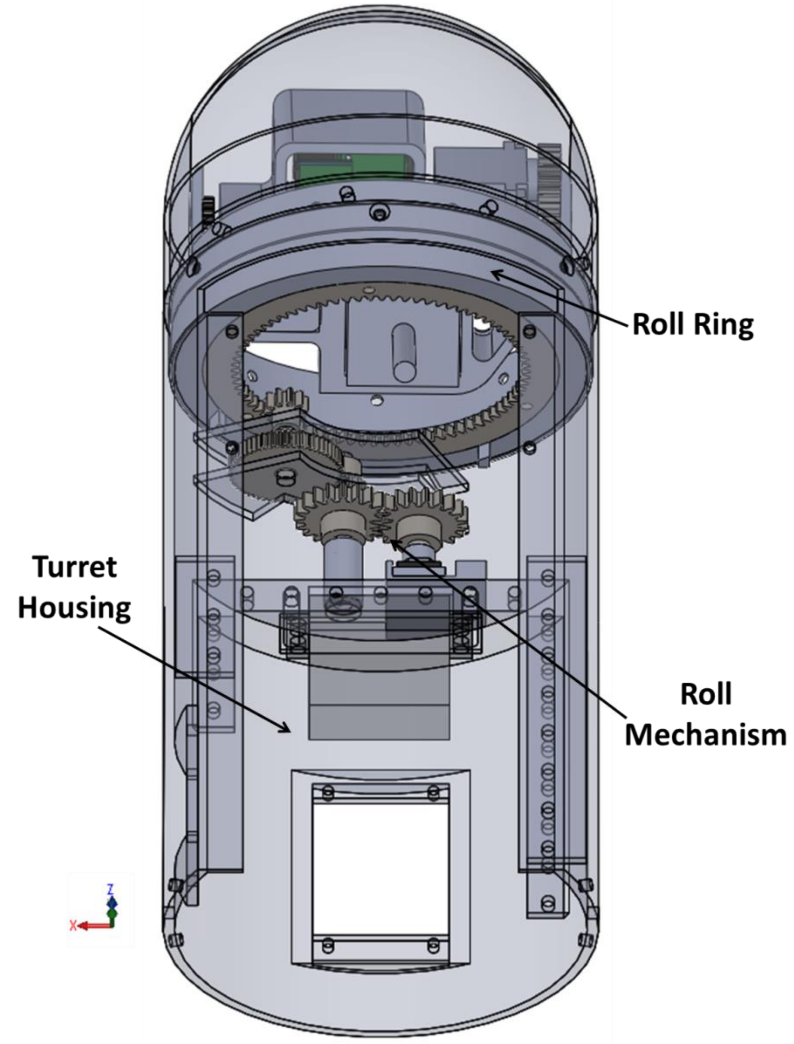
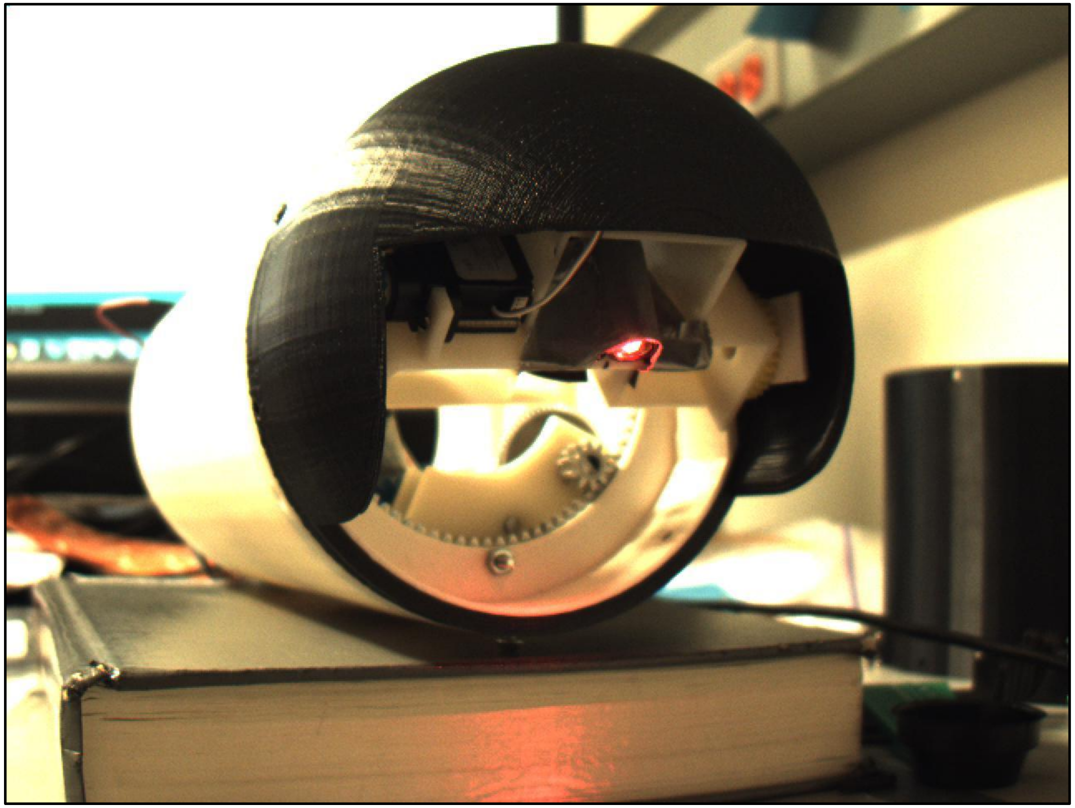
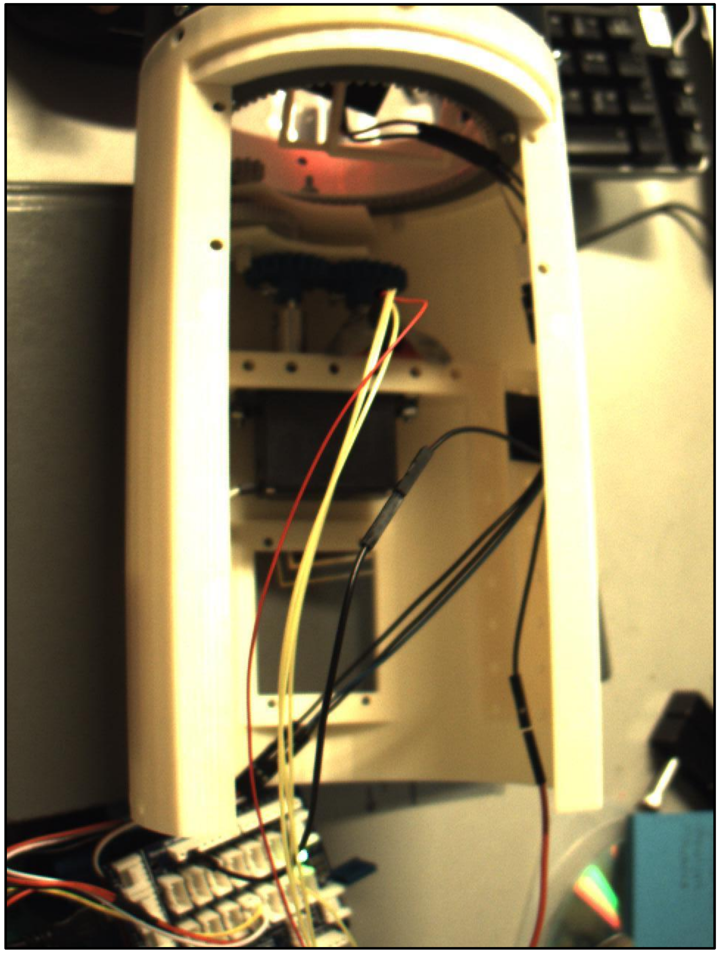
Final SolidWorks Model





Final Turret Design





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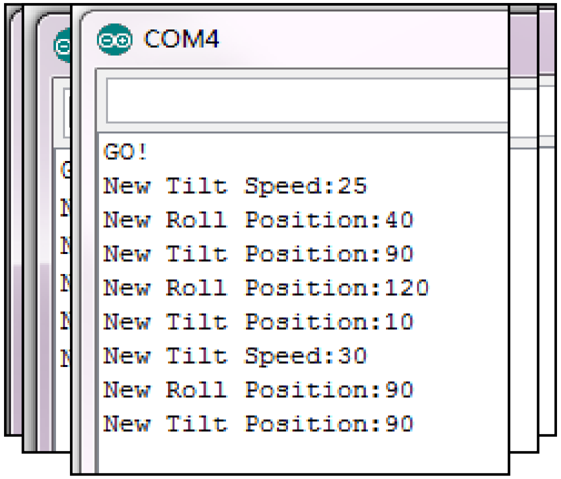
Integration Tests – Point-to-point Movement



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Results of Integration Tests

- **Integration Test 1: 8 Tests performed, 6 passed**

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R13	Accuracy	The accuracy of the mechanism shall be less than 1 degree (the actual position of the turret shall be within 1 degree of the specified position).	✗
R14	Repeatability	The repeatability of the mechanism shall be less than 1 degree.	✗

- **Accuracy:**
  - **Average Error: 5.27 degrees**
  - **Goal: 1 degree**
- **Repeatability:**
  - **Average Variance: 1.99 degrees**
  - **Goal: 1 degree**
- **Points to a Calibration Error and Hysteresis**
  - **Average Variance was 0.34 degrees when only considering movements in the same direction (i.e. up vs. down)**

Final Integration Test

Tilt

- **Accuracy:**
  - **Average Error = 0.75 degrees**
- **Repeatability:**
  - **Average Variance = 3.38 degrees**
  - **Average Variance for same direction movements= 0.41 degrees**

Roll

- **Accuracy:**
  - **Average Error = 0.44 degrees**
- **Repeatability:**
  - **Average Variance = 1.10 degrees**
  - **Average Variance for same direction movements= 0.44 degrees**

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Future Work

Target Tracking

- **Previous MQP developed a rudimentary target tracker**
- **Implementing their target tracking in our stabilization system**

From 2013 MQP

Summary

- **Implemented IMU based stabilization, automated pointing, and scan patterns**

- **Designed, built, and tested a sensor turret**
  - **Integrated mechanical and software design**

- **B term: Continuing work in closed loop target identification and target tracking**

Recognitions

- David Scott – TOIL Supervisor
- Bryce Remesch – Group 106
- Prof. Fred Looft – WPI
- Antonio Rufo – Group 106
- Prof. Ted Clancy – WPI
- Mike Pietrucha – Group 109
- Kathleen Haas – Group 43
- Sarah Curry – Group 108
- Emily Anesta – Group 39
- Devin Mulcahy – 2013 MQP
- Jonathan Dorich – 2013 MQP

Questions?