Smallsat Connected Optical Positioning Entity

Testing Readiness Review

Customer: Steve Thilker, Raytheon
Faculty Advisor: Zoltan Sternovsky

Group Members: Mattia Astarita, Nick Cenedella, Connor Kerry, Greg Kondor, Nolan Lee, Guy Margalit, Mason Markle, Jakob Mitchell, Zach Schira, Pepe Feu Vidal, Alec Viets

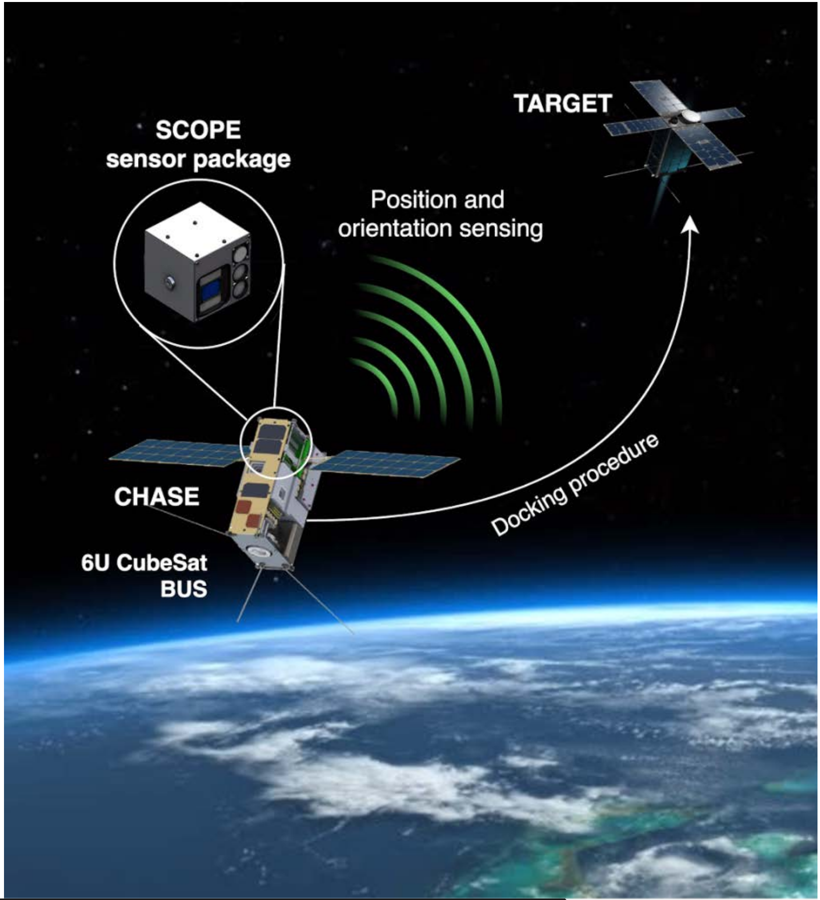
Presentation Outline

Sections	Presenter(s)
Project Description	Connor
Schedule	Mason
Testing: Components	Pepe
Testing: Set Up	Mattia
Testing: Test One and Two	Jake
Budget	Nolan

Overview

Project Objectives

Design, build, and test a proof-of-concept sensor package that collects **relative motion** and **orientation** data of a TARGET satellite for output to the CHASE satellite on-board attitude control system.



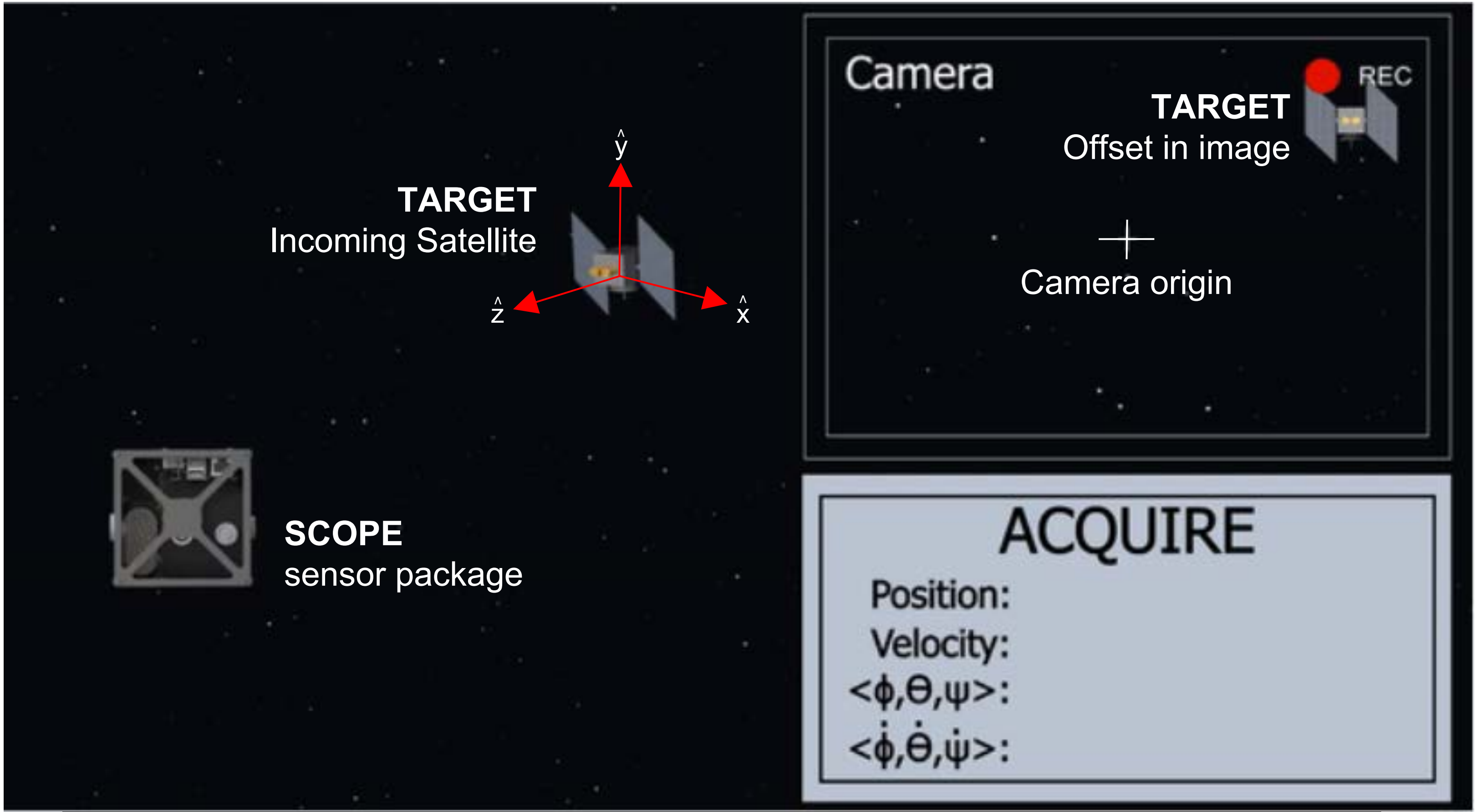
Levels of Success

Level 1: Detect and return data outputs for a target satellite with known markers.

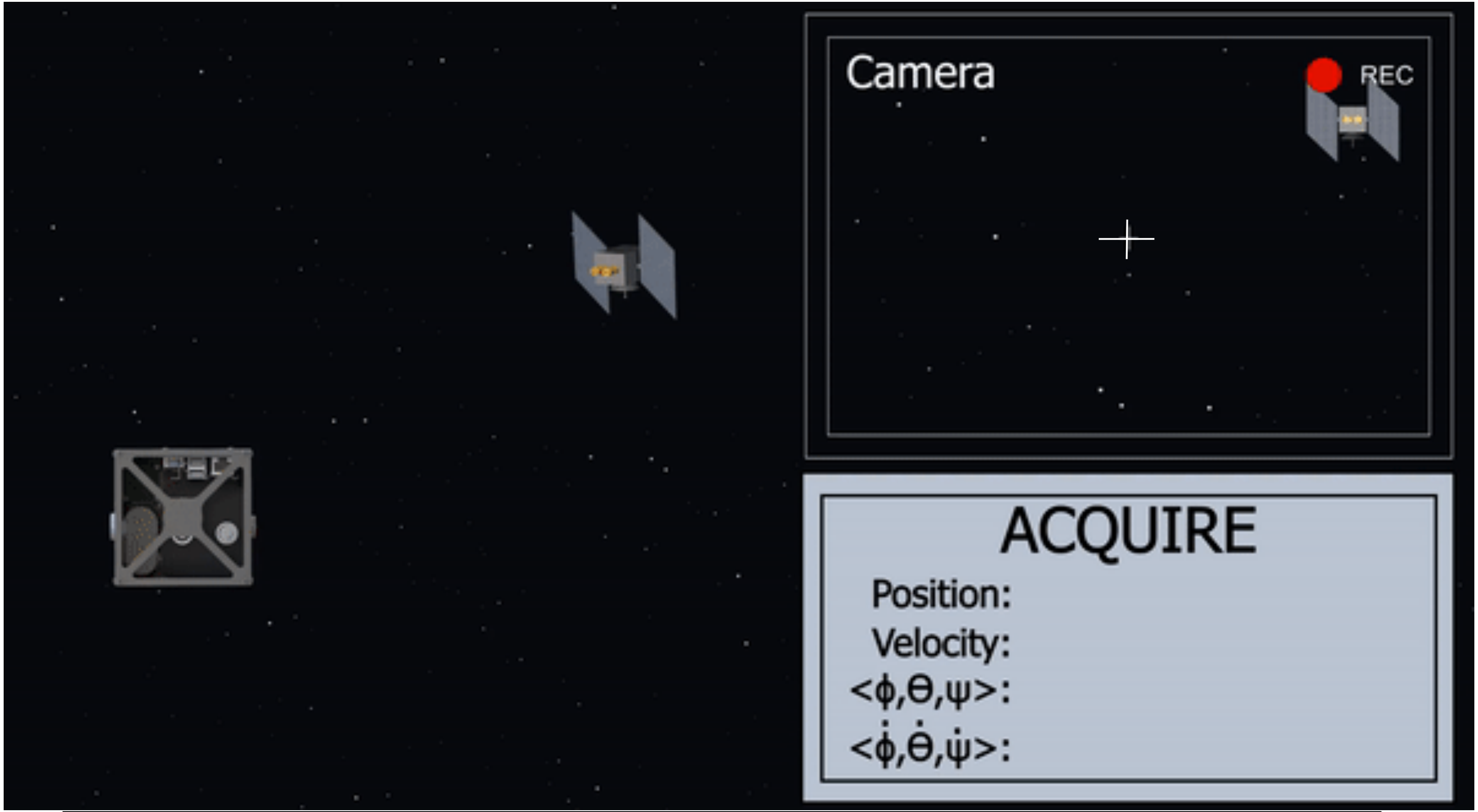
Level 2: Detect and return data outputs of a target satellite with no markers, but with a known 3-D model.

Level 3: Detect and return data outputs of an unknown target satellite

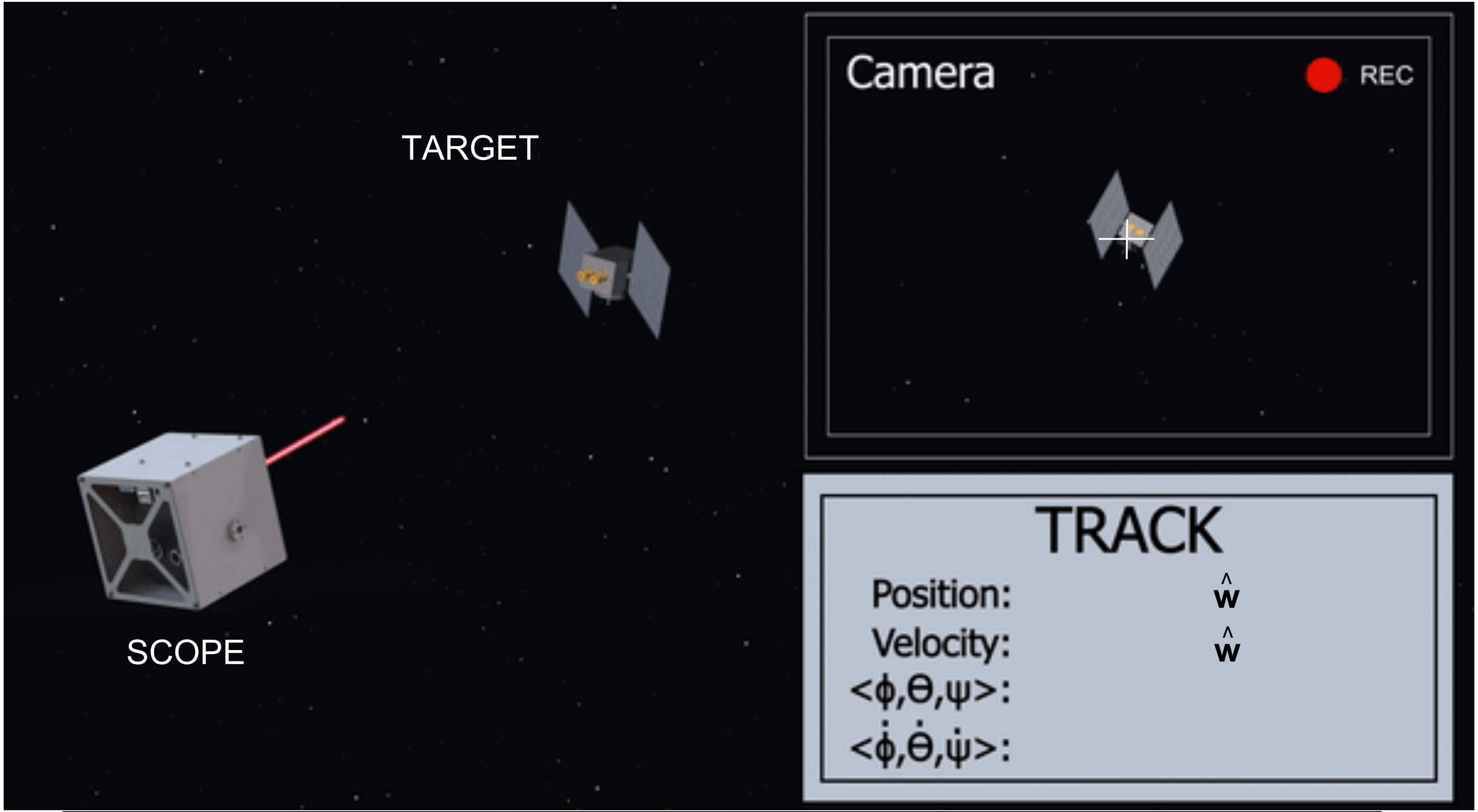
Mission CONOPS



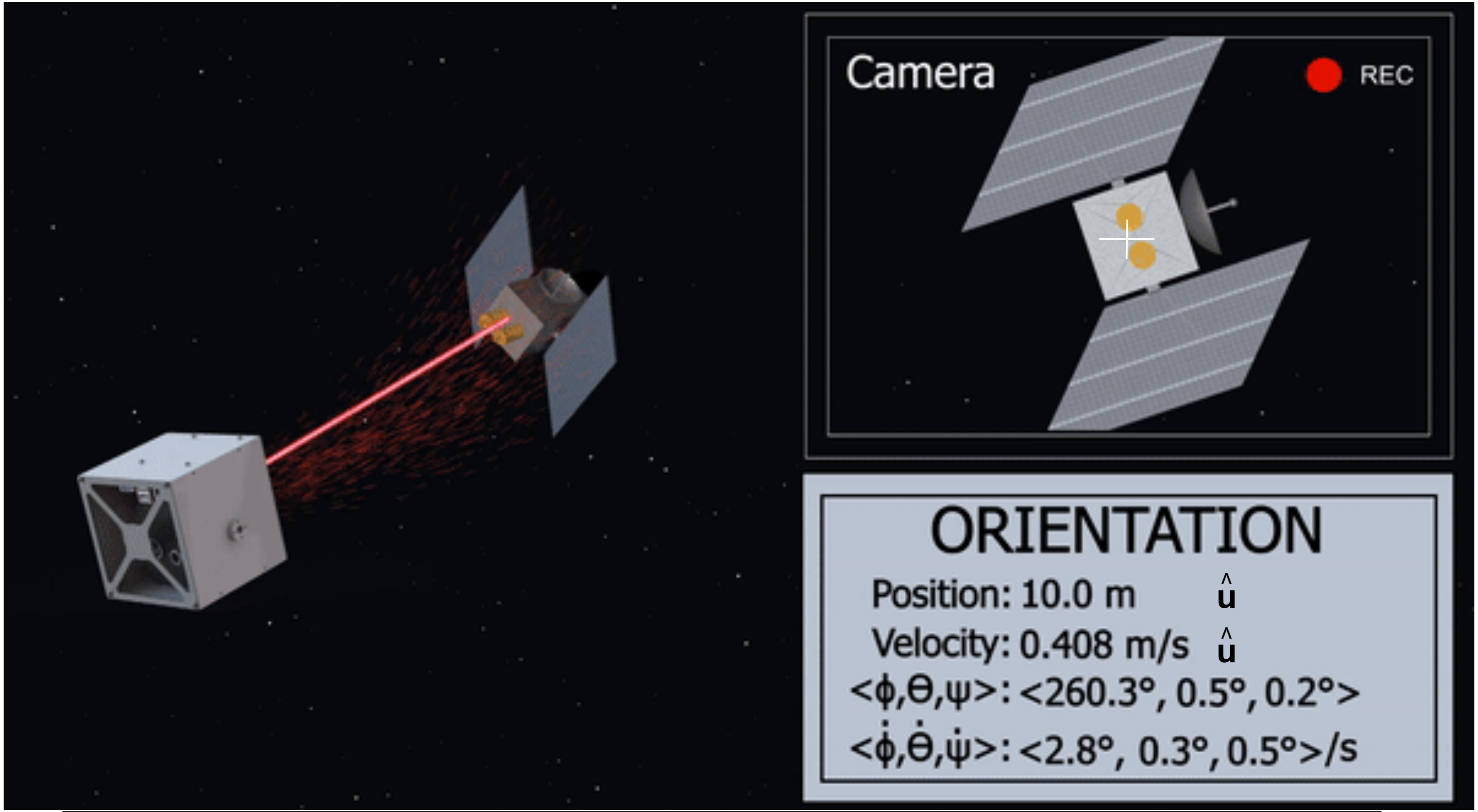
Mission CONOPS



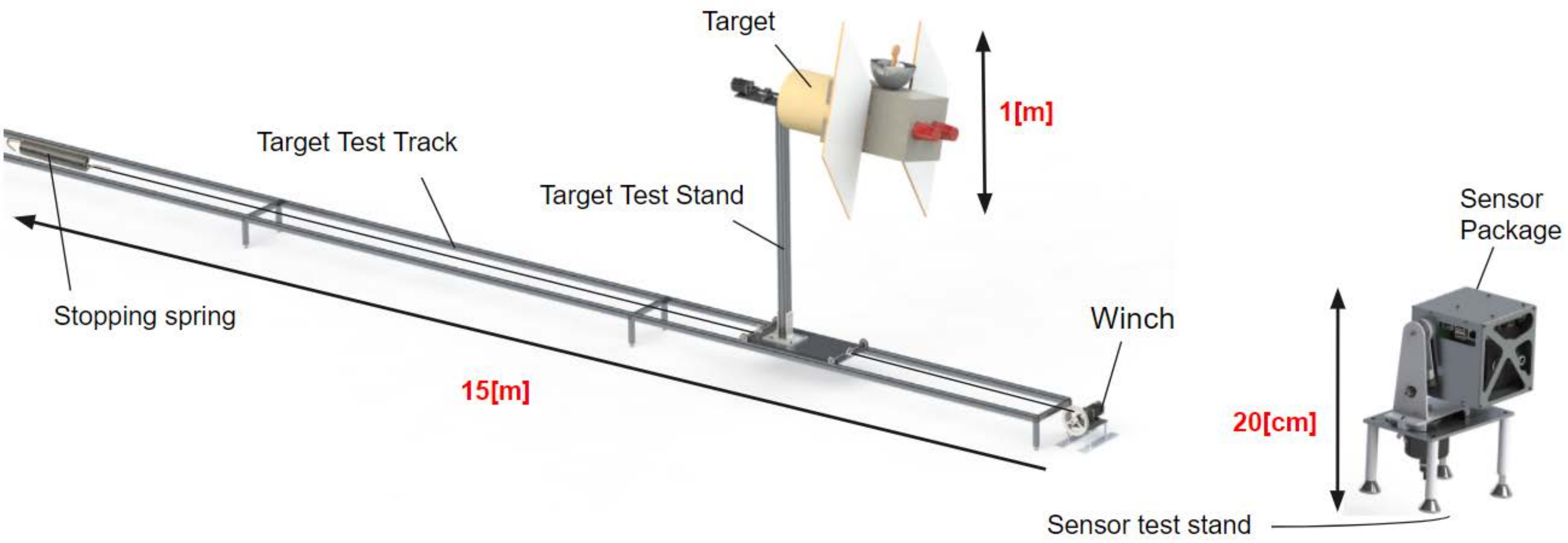
Mission CONOPS



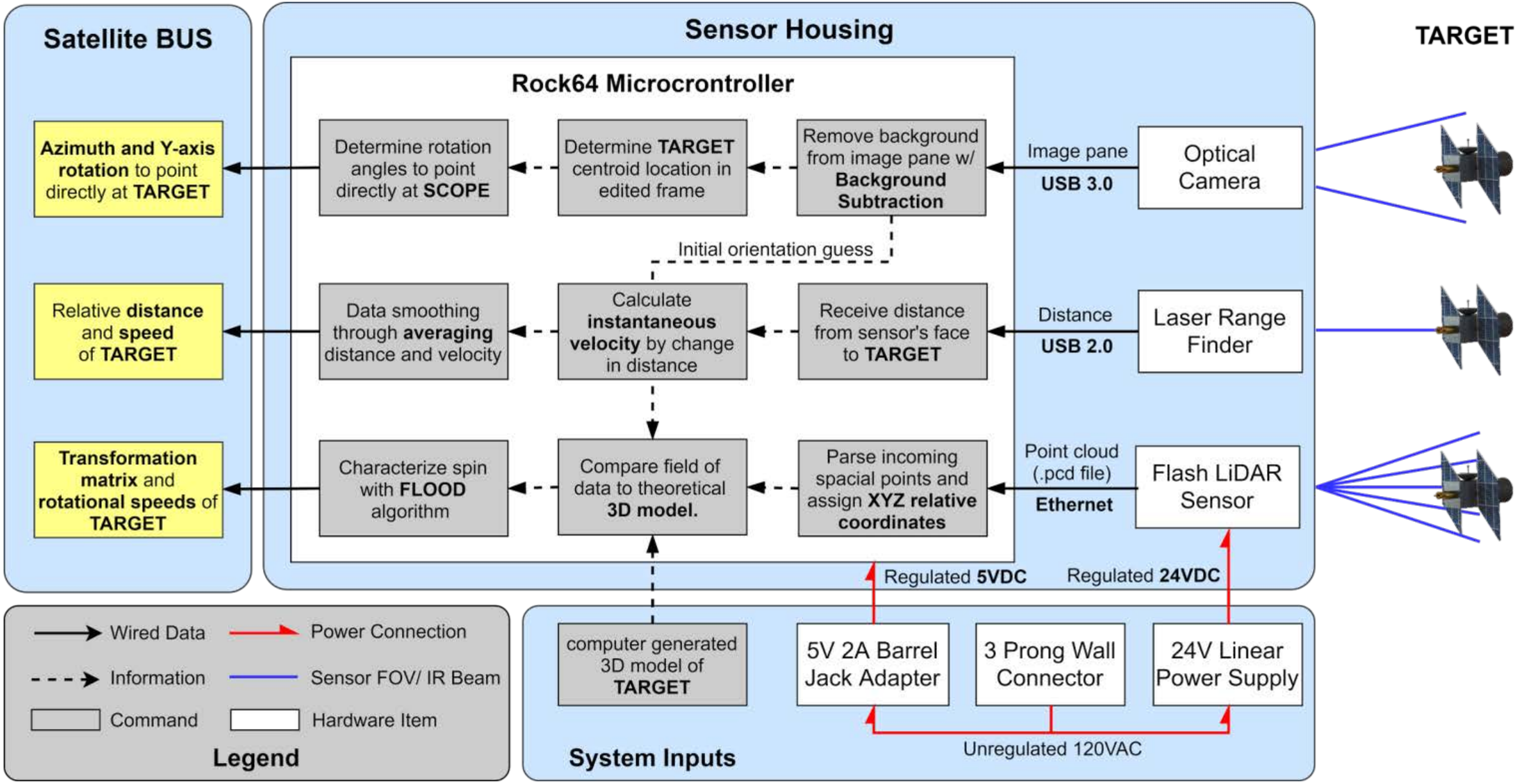
Mission CONOPS



Testing Components Overview



Functional Block Diagram



Critical Project Elements

Centroid Determination

1. Use Background Subtraction to Detect **TARGET**.
2. Return Location in FOV for determining ADCS turning angles.

Position and Velocity Determination

1. Gather and smooth distance of **TARGET** data from laser rangefinder.
2. Return position and velocity of **TARGET** satellite.

Four main CPE's define SCOPES largest challenges

Orientation and Roll rate Determination

1. Return orientation of **TARGET** within 1 deg of actual.
2. Return angular rates of **TARGET** within 1% of actual.

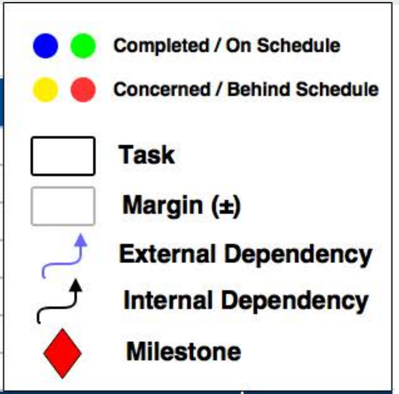
1-U Satellite Constraints

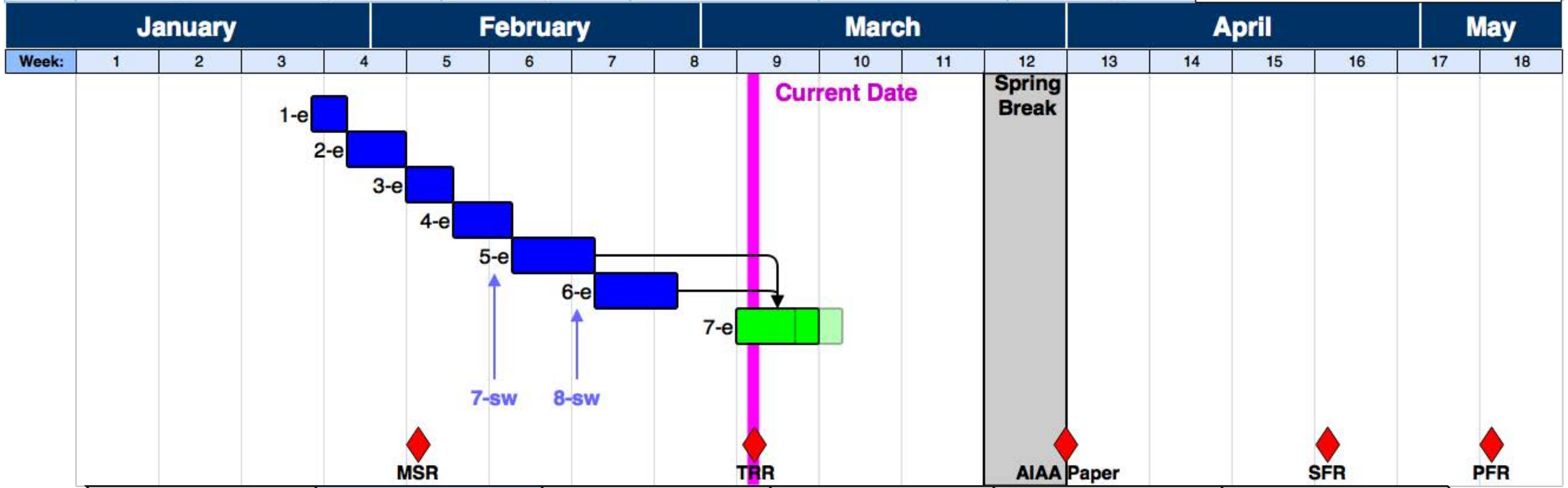
1. Mass is less than **1.33[kg]**
2. Dimensions fit within **10x10x10[cm]**
3. Data is written at a rate faster than **2[Hz]**
4. Average power remains below **20W**

Project Schedule

Electrical Schedule

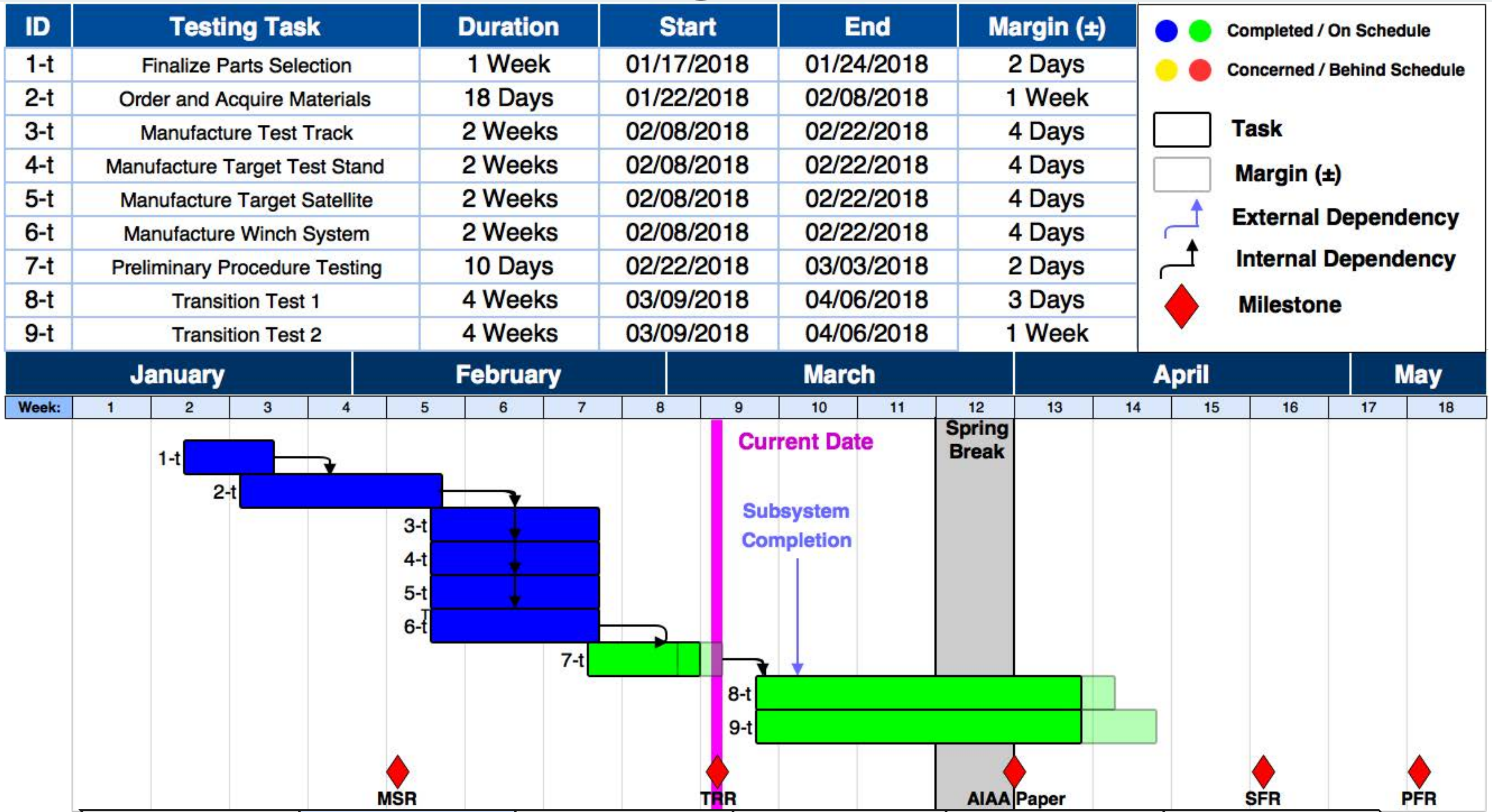
ID	Electrical Task	Duration	Start	End	Margin (±)
1-e	Configure Rock64	3 Days	01/27/2018	01/29/2018	1 Day
2-e	Configure Visual Camera w/ Rock64	5 Days	01/30/2018	02/03/2018	2 Days
3-e	Configure LRF w/ Rock64	4 Days	02/04/2018	02/07/2018	1 Day
4-e	Configure LiDar w/ Rock64	5 Days	02/08/2018	02/12/2018	2 Days
5-e	Debug Acquire/Track Alg. on Rock64	7 Days	02/13/2018	02/19/2018	2 Days
6-e	Debug Orientation Alg. on Rock64	7 Days	02/20/2018	02/26/2018	2 Days
7-e	Finalize Algorithm Testing on Rock64	7 Days	03/04/2018	03/10/2018	2 Days





Testing Schedule

ID	Testing Task	Duration	Start	End	Margin (±)
1-t	Finalize Parts Selection	1 Week	01/17/2018	01/24/2018	2 Days
2-t	Order and Acquire Materials	18 Days	01/22/2018	02/08/2018	1 Week
3-t	Manufacture Test Track	2 Weeks	02/08/2018	02/22/2018	4 Days
4-t	Manufacture Target Test Stand	2 Weeks	02/08/2018	02/22/2018	4 Days
5-t	Manufacture Target Satellite	2 Weeks	02/08/2018	02/22/2018	4 Days
6-t	Manufacture Winch System	2 Weeks	02/08/2018	02/22/2018	4 Days
7-t	Preliminary Procedure Testing	10 Days	02/22/2018	03/03/2018	2 Days
8-t	Transition Test 1	4 Weeks	03/09/2018	04/06/2018	3 Days
9-t	Transition Test 2	4 Weeks	03/09/2018	04/06/2018	1 Week



Overview | *Schedule* | *Test Overview* | *Systems Tests* | *Final Tests* | *Budget*

Schedule Overview

ID	Hardware Task	Duration	Start	End	Margin (±)
1-h	SCOPE Front Face	2 Days	02/01/2018	02/02/2018	1 Day
2-h	SCOPE Top	1 Day	02/02/2018	02/02/2018	1 Day
3-h	SCOPE Back	2 Days	02/05/2018	02/06/2018	1 Day
4-h	SCOPE Left Face	2 Days	02/07/2018	02/08/2018	1 Day
5-h	SCOPE Bottom Face	2 Days	02/08/2018	02/09/2018	1 Day
6-h	SCOPE Right Face	1 Day	02/12/2018	02/12/2018	1 Day
7-h	TEST STAND Left Arm	2 Days	01/22/2018	01/23/2018	1 Day
8-h	TEST STAND Right Arm	2 Days	01/22/2018	01/23/2018	1 Day
9-h	TEST STAND Mounting Plate	2 Days	01/31/2018	02/01/2018	1 Day
10-h	TEST STAND Bottom Arm	7 Days	02/01/2018	02/06/2018	2 Days
11-h	TEST STAND Key(x2)	3 Days	02/12/2018	02/14/2018	1 Day
12-h	TEST STAND Rods	1 Day	02/14/2018	02/14/2018	1 Day
13-h	TARGET STAND Bottom Plate	1 Day	02/20/2018	02/20/2018	1 Day
14-h	TARGET STAND Right Arm	1 Day	02/21/2018	02/21/2018	1 Day
15-h	TARGET STAND Bottom Arm	1 Day	02/22/2018	02/22/2018	1 Day
ID	**Software Task**	**Duration**	**Start**	**End**	**Margin (±)**
1-sw	Move Acquire Algorithm to C++	1.5 Weeks	01/16/2018	01/26/2018	3 Days
2-sw	Orientation Algorithm Unit Tests	2 Weeks	01/16/2018	01/30/2018	4 Days
3-sw	Improve Orientation at Close Range	2 Weeks	01/22/2018	02/05/2018	4 Days
4-sw	Acquire Algorithm Unit Tests	2 Weeks	01/26/2018	02/09/2018	4 Days
5-sw	Test Algorithms on Rock64	1 Week	01/26/2018	02/02/2018	2 Days
6-sw	Develop/Integrate Camera Driver	2 Weeks	01/26/2018	02/09/2018	3 Days
7-sw	Develop/Integrate LRF Driver	2 Weeks	01/26/2018	02/09/2018	3 Days
8-sw	Develop/Integrate LiDar Driver	2 Weeks	01/26/2018	02/09/2018	5 Days
9-sw	Develop/Integrate Overall Driver	3 Weeks	01/30/2018	02/20/2018	6 Days
ID	**Electrical Task**	**Duration**	**Start**	**End**	**Margin (±)**
1-e	Configure Rock64	3 Days	01/27/2018	01/29/2018	1 Day
2-e	Configure Visual Camera w/ Rock64	5 Days	01/30/2018	02/03/2018	2 Days
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ID	**Testing Task**	**Duration**	**Start**	**End**	**Margin (±)**
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4-t	Manufacture Target Test Stand	2 Weeks	02/08/2018	02/22/2018	4 Days
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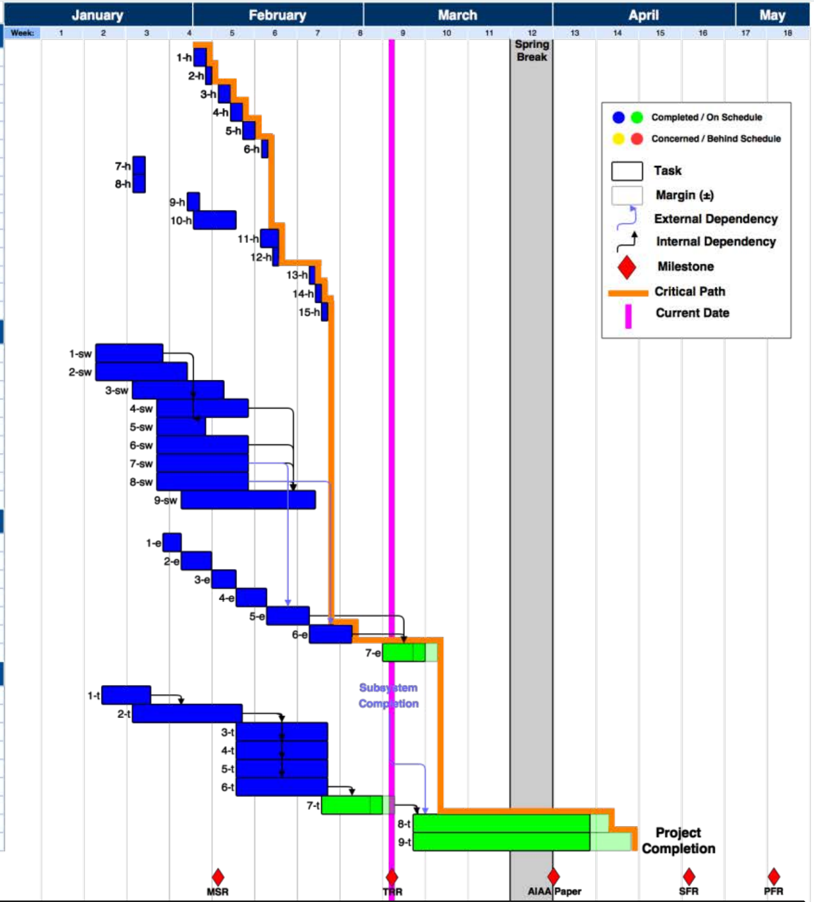


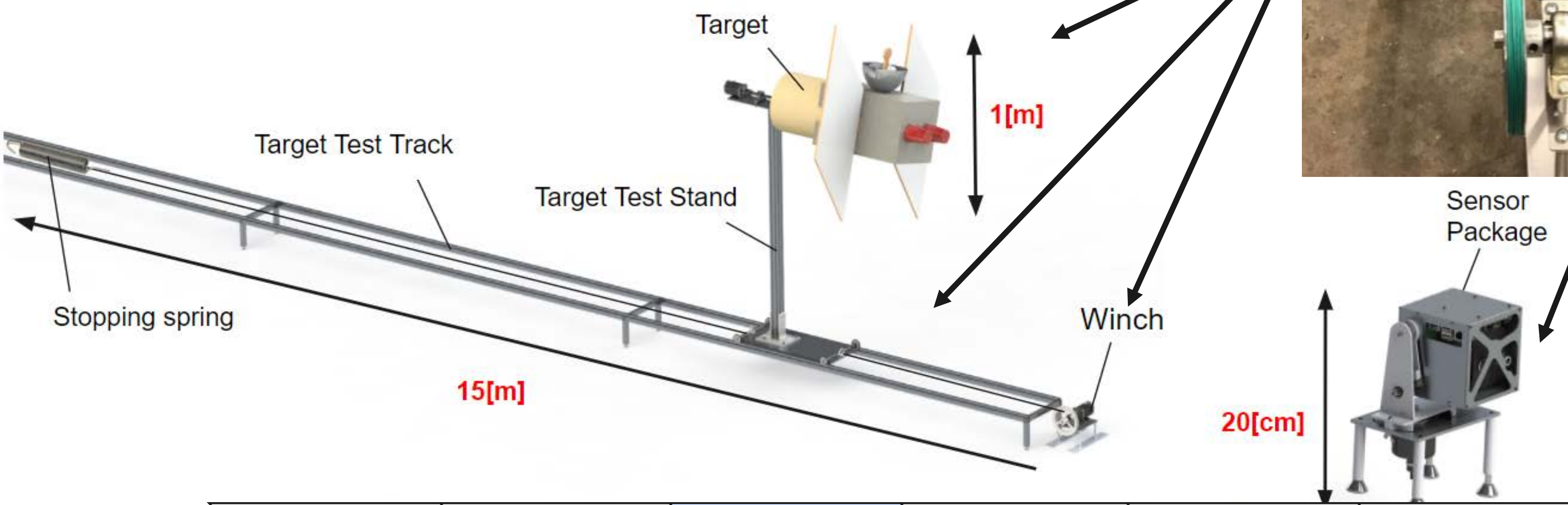
Test Overview

Task Summary

Systems	Completed	In Progress	Behind Schedule
Hardware	Manufacturing of SCOPE sensor package	Adjustment of TARGET to make more antisymmetric	Alignment of Camera and LRF
	Manufacturing of SCOPE test stand		
	Manufacturing and assembly of test articles		
Software/Electrical	Sensor/software integration with microcontroller	Tuning algorithm parameters for test setup	Collecting data from Acuity testing LRF

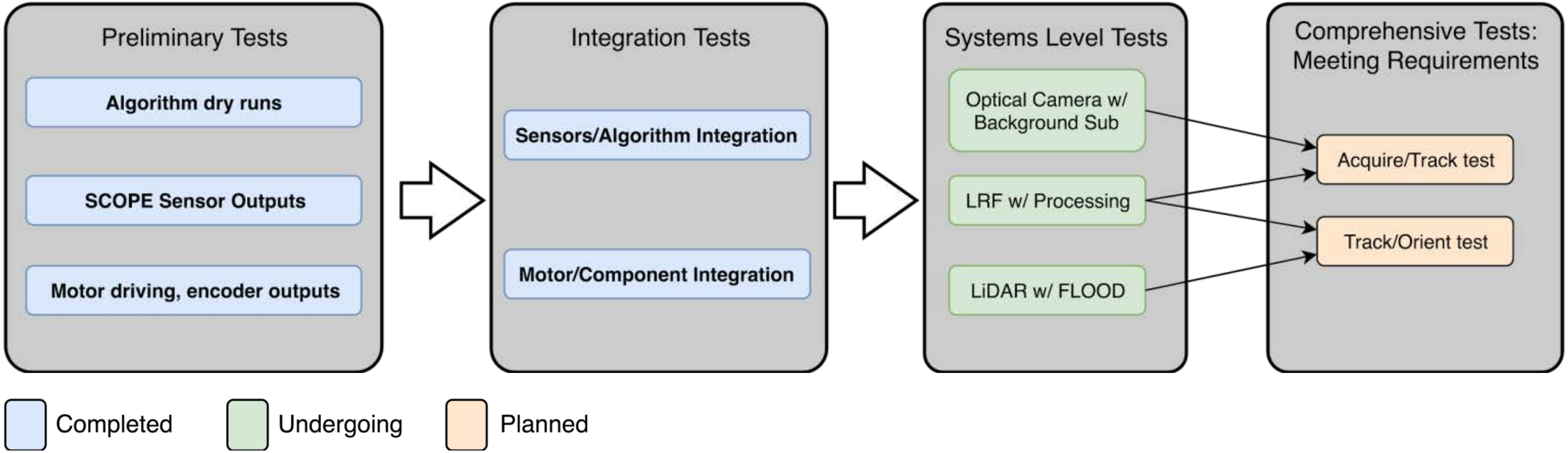
Design Fabrication Complete

All Components have been manufactured and assembled.



Overview | Schedule | Test Overview | Systems Tests | Final Tests | Budget

Testing Flow



Takeaways
Currently conducting systems level tests to ensure test equipment can fulfill design requirements
Moving onto final tests, scheduled this friday

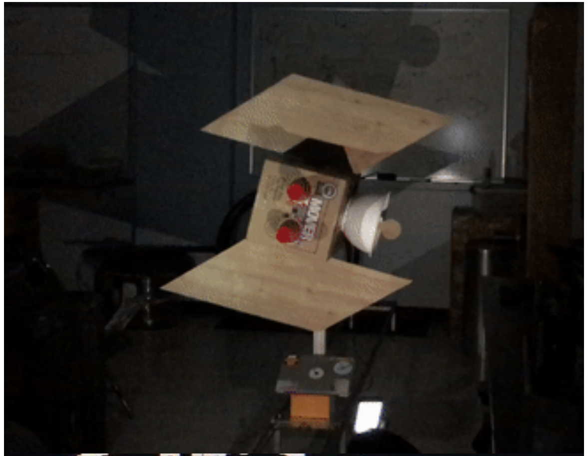
Systems Testing

Camera with Background Subtraction Test

Objectives:
- Able to detect target and find centroid/turning angles within 60s of turn on
- Show turning angles output by BGSUB are accurate

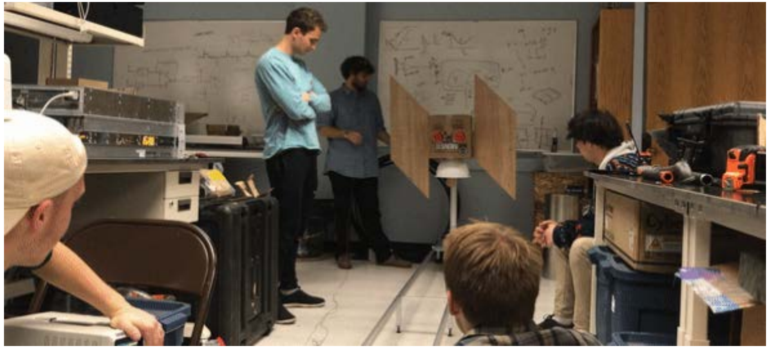
Risk Reduction:
- Verification that LRF's laser will be accurately pointed to hit TARGET

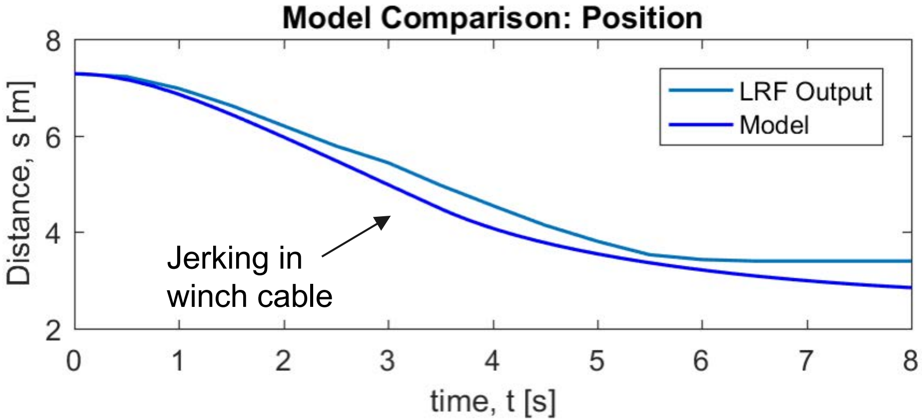
Associated Model:
- Blender simulation of TARGET with camera and BGSUB

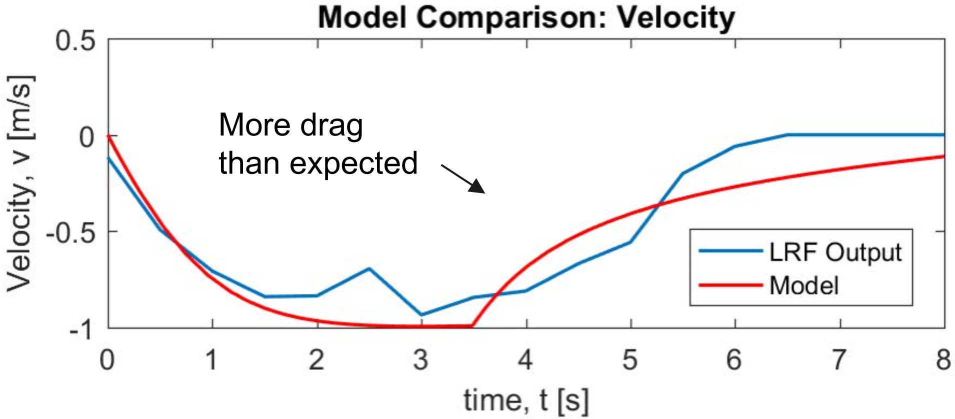


Takeaways
Need to adjust parameters of background subtraction algorithm based on threshold distance and range from TARGET
Spray painting TARGET white + better lighting will allow algorithm to work better
Need to fix contour calculation

Laser Range Finder with Moving Target Test





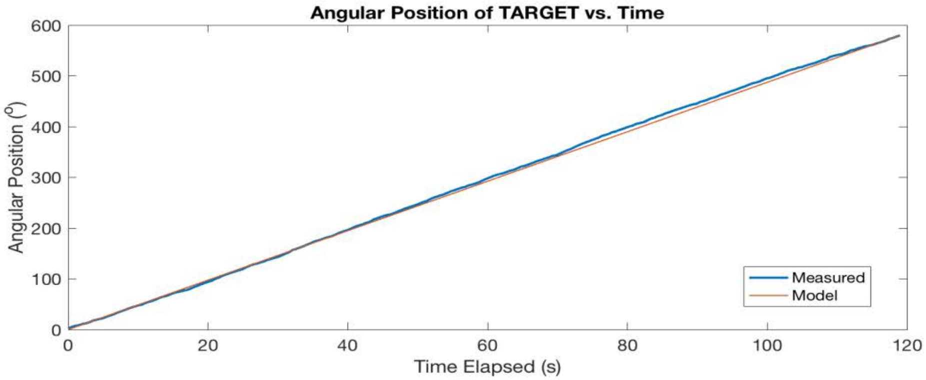


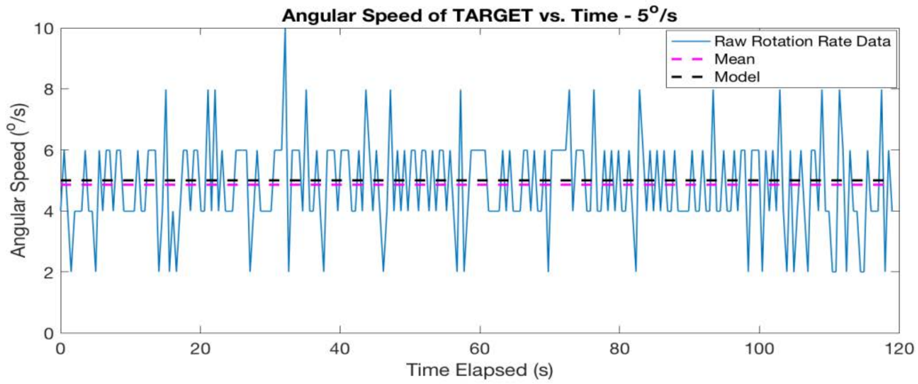
Objective: Confirm TARGET can translate at **0.1-1[m/s]** similar to model (shown right) for track phase.

Risk Reduction: Allows the team to change torque given by winch to yield consistent data.

Associated Model: TARGET translation model.

Encoder Readings for Rotating Target Test





Objective: Confirm TARGET can rotate at **1-5[deg/s]** similar to model (shown left) for final "end-to-end" tests.

Risk Reduction: Allows the team to change torque given by winch to yield consistent data.

Associated Model: TARGET rotationmodel.

Takeaways
Increase PPR of motor to smooth out angular velocity encoder results.

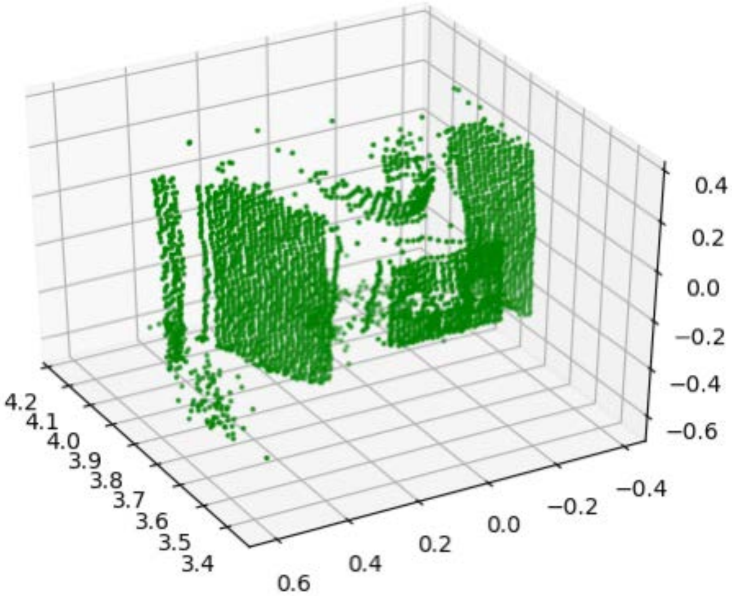
LiDAR with FLOOD Algorithm

Objective: Confirm FLOOD can **determine orientation** to within **1[deg]** accuracy and **rotation rate** to within **1[deg/s]**.

Risk Reduction: Verified that LiDAR is fully integrated with software.

Associated Model: Blender simulations with FLOOD algorithm.

Takeaways
Algorithm is struggling to accurately predict orientation under current testing setup
Experimenting with model modifications to make orientation prediction easier (Simulations have shown that removing 1 solar panel substantially improves accuracy).
Actual images from LiDAR contain bad points that were not present in Blender simulations. Working on simple filter to remove these



Final Tests

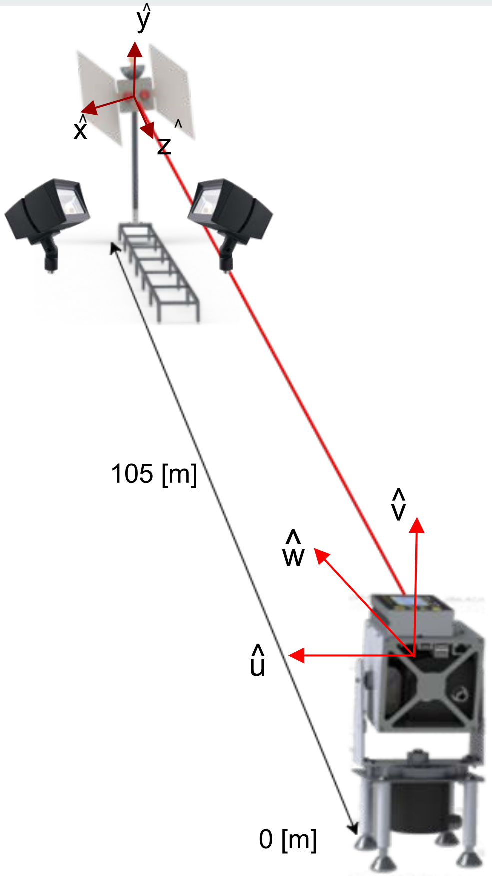
Acquire/Track Test Setup

Requirements Verified	
FR 2	The sensor package shall output the target satellite's relative position upon detection.
FR 3	The sensor package shall output the target satellite’s relative velocity upon detection.
FR 4	The sensor package shall output the target satellite’s relative orientation upon detection.
FR 5	The sensor package shall output the target satellite's relative rotation rate upon detection.
FR 6	The sensor package shall output target satellite data at a set frequency.

Acquire/Track Test Logistics

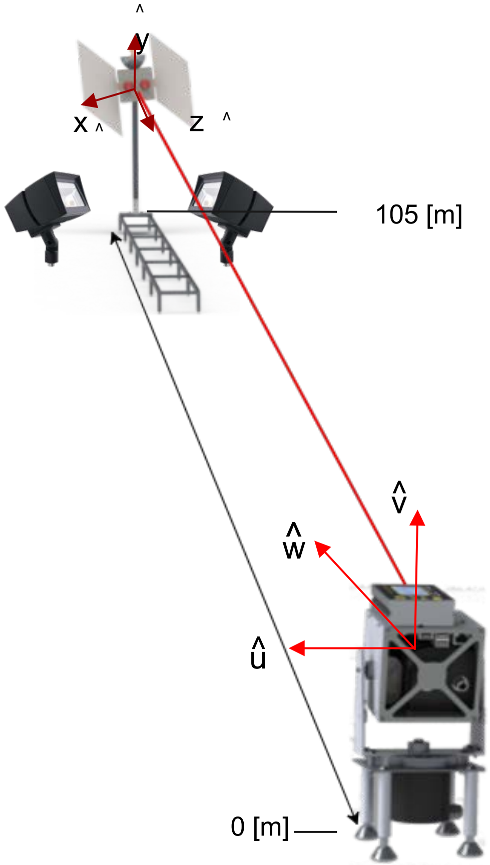
Location	ITLL Hallway
Timing	March **9th-10th** and March **16th-17th**

Data Collected	Method of Collection
Turning Angles for SCOPE to point at center of TARGET	SCOPE Cam w/ BGSUB through HDMI
Position and **velocity** of **TARGET** with respect to **SCOPE** body frame.	Acuity LRF vs. **SCOPE** sensor package



Acquire/Track Procedure

1	Offset the pointing of **SCOPE** sensor package to align **TARGET** in the visual camera's FOV.
2	Target Rotates about **Z axis** at **1-5[deg/s]**.
3	Adjust Pointing of **SCOPE** based on angles outputted from the sensor package.
4	Save data and sync test equipment with SCOPE's microcontroller.
5	Translate TARGET along **Z axis** at **0.1-1[m/s]**.
6	Save position and velocity data from LRF and sync with test equipment.
7	Post-process and analyze data collected.



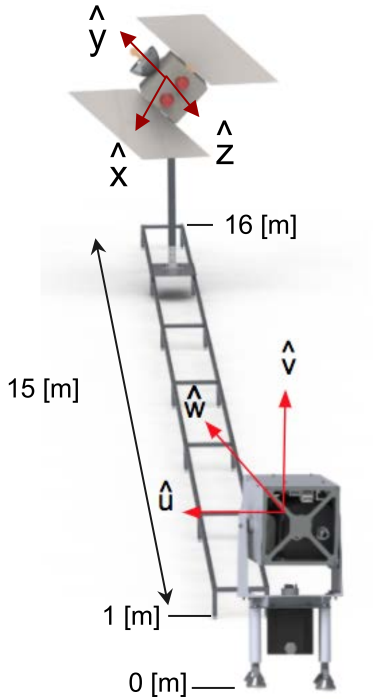
Track/Orientation Test Setup

Requirements Verified	
FR 1	The sensor package shall be capable of detecting a target satellite.
FR 2	The sensor package shall output the target satellite's relative position upon detection.
FR 3	The sensor package shall output the target satellite's relative velocity upon detection.
FR 6	The sensor package shall output target satellite data at a set frequency.

Track/Orientation Test

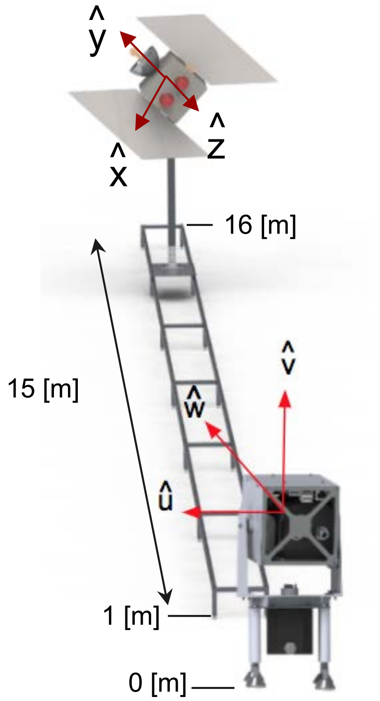
Location	ITLL Hallway
Timing	March **9th-10th** and March **16th-17th**

Data Collected	Method of Collection
Position and **velocity** of **TARGET** with respect to **SCOPE** body frame.	Acuity LRF vs. **SCOPE** sensor package
Orientation and **rotation rates** about **TARGET**'s Z axis.	Rotary Encoder placed on **TARGET**'s rotational motor



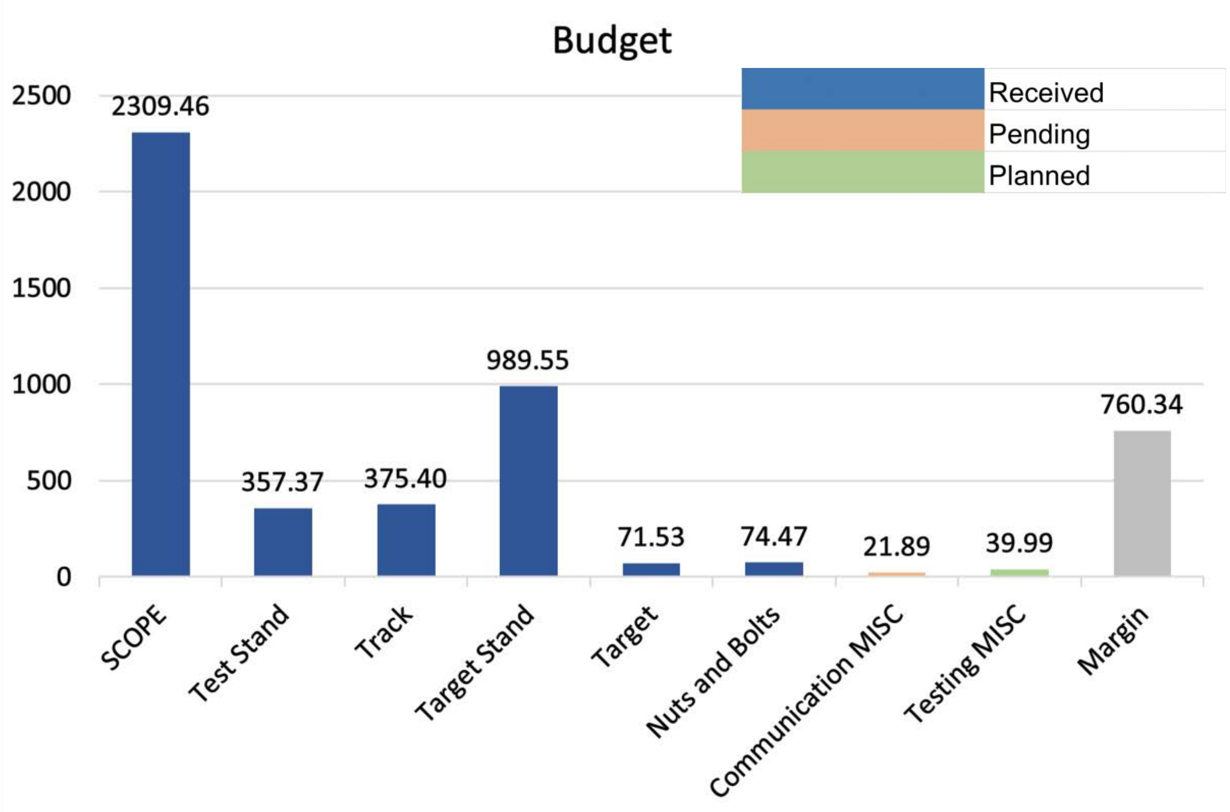
Track/Orientation Procedure

1	Align the axes of **SCOPE** and **TARGET**
2	Target Rotates about **Z axis** at **1-5[deg/s]**.
3	Adjust Pointing of **SCOPE** based on angles outputted from the sensor package.
4	Save position and velocity data from LRF and sync with test equipment.
5	Translate TARGET along Z axis at **0.1[m/s]**.
6	Output **orientation data** from **SCOPE** and sync with rotational encoder truth measurement.
7	Post-process and analyze data collected.



Cost Plan

Cost Plan



Item	Lead time
Test Stand Encoder	1 Week

Used	$4,199.66
Planned	$40
Total	$5,000
Margin	$760.34

Acknowledgments

We would like to thank **Trudy Schwartz, Bobby Hodgkinson**, **Matt Rhode,** and **Adrian Stang** for their guidance with the testing design.

We would also like to thank **Zoltan Sternovsky** for general project guidance.

Thank you to **Lee** and **Tim** for presentation practice help and feedback.

Thank you for your support!

Questions?

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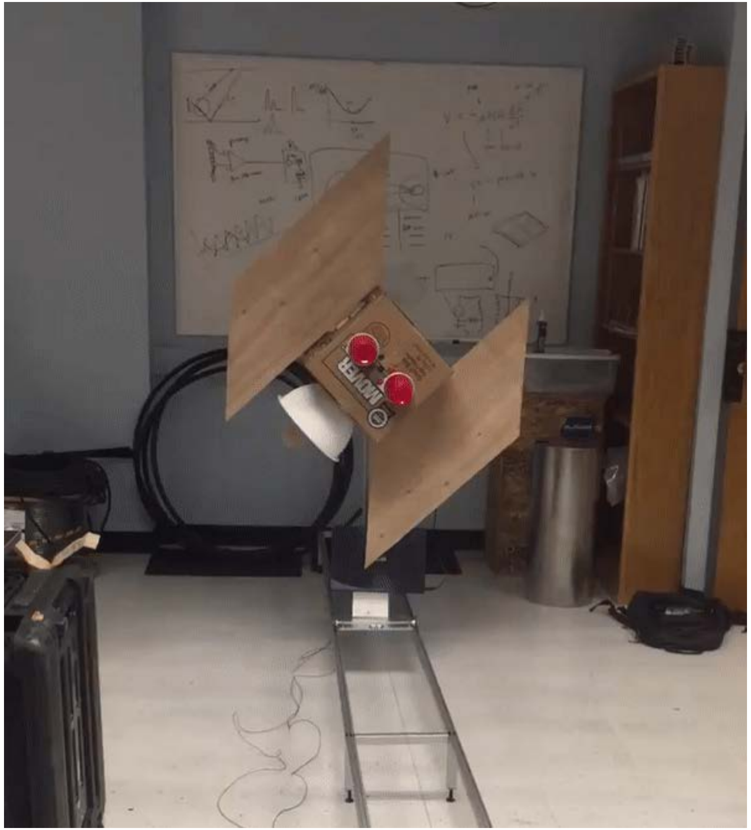
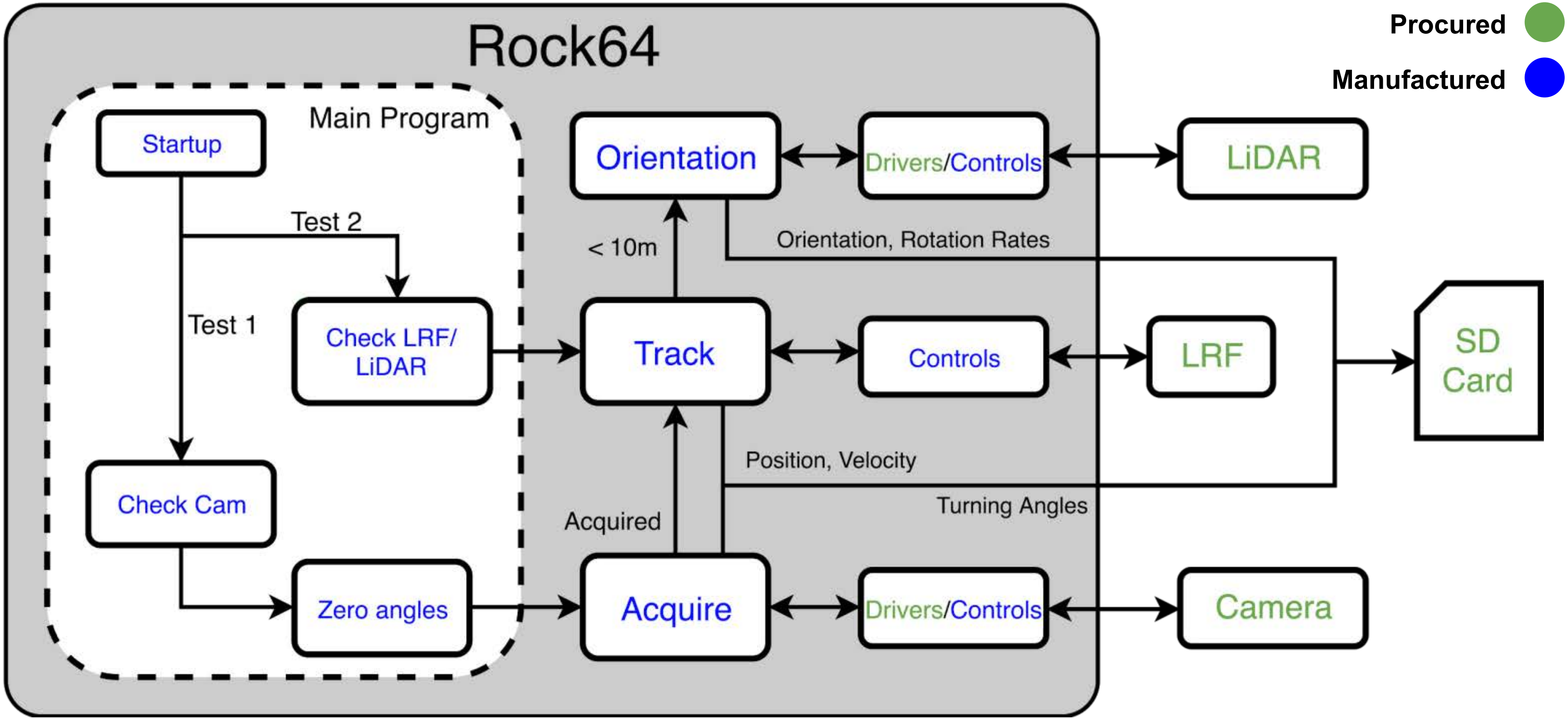
Preliminary Testing of Motors w/ Test Stand



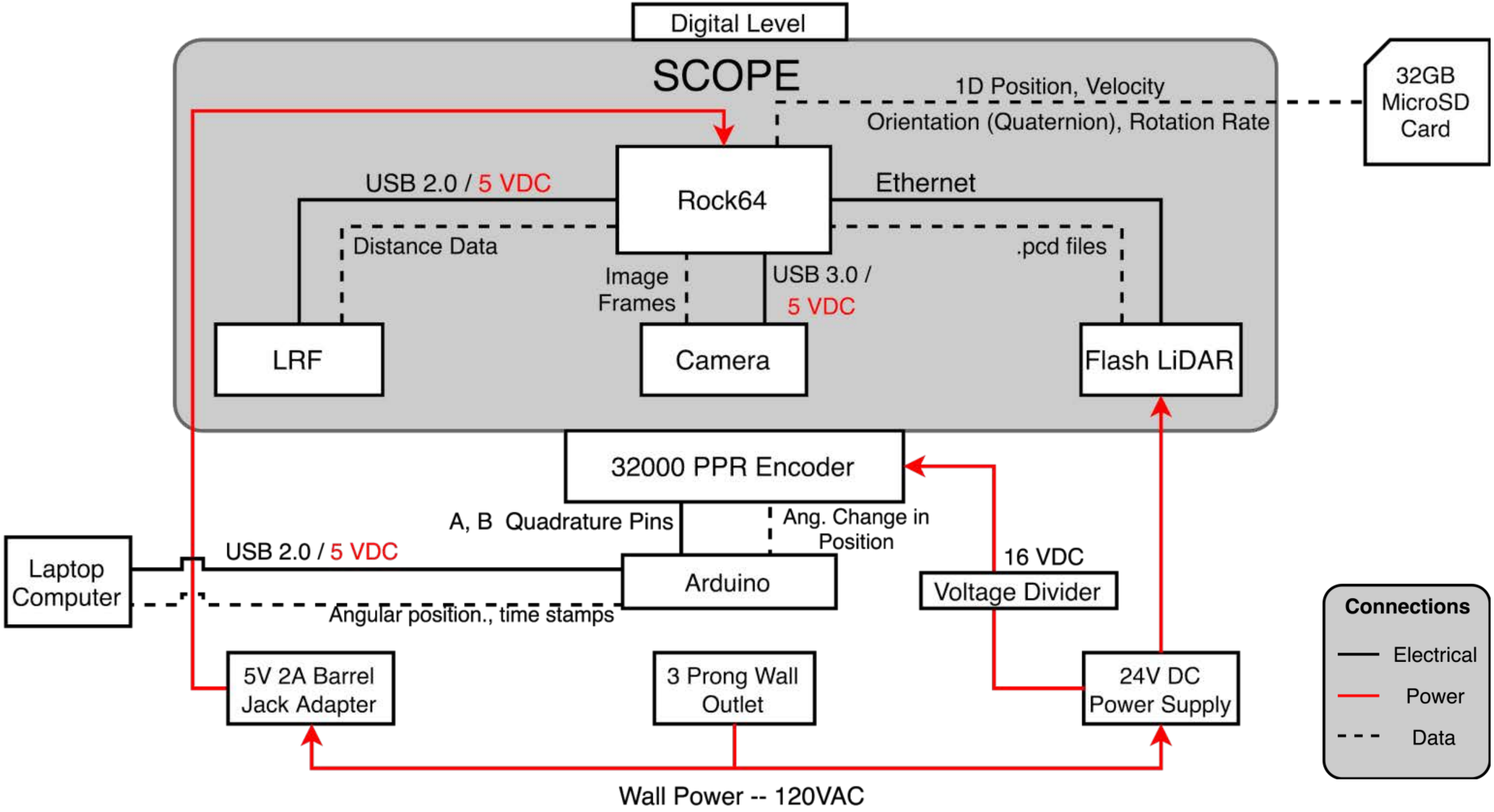
1st Setup Findings:

- Winch motor can pull target stand at 0.1 m/s and up to 1 m/s
- TARGET Rotating motor can rotate target satellite at 1 deg/s up to 5 deg/s

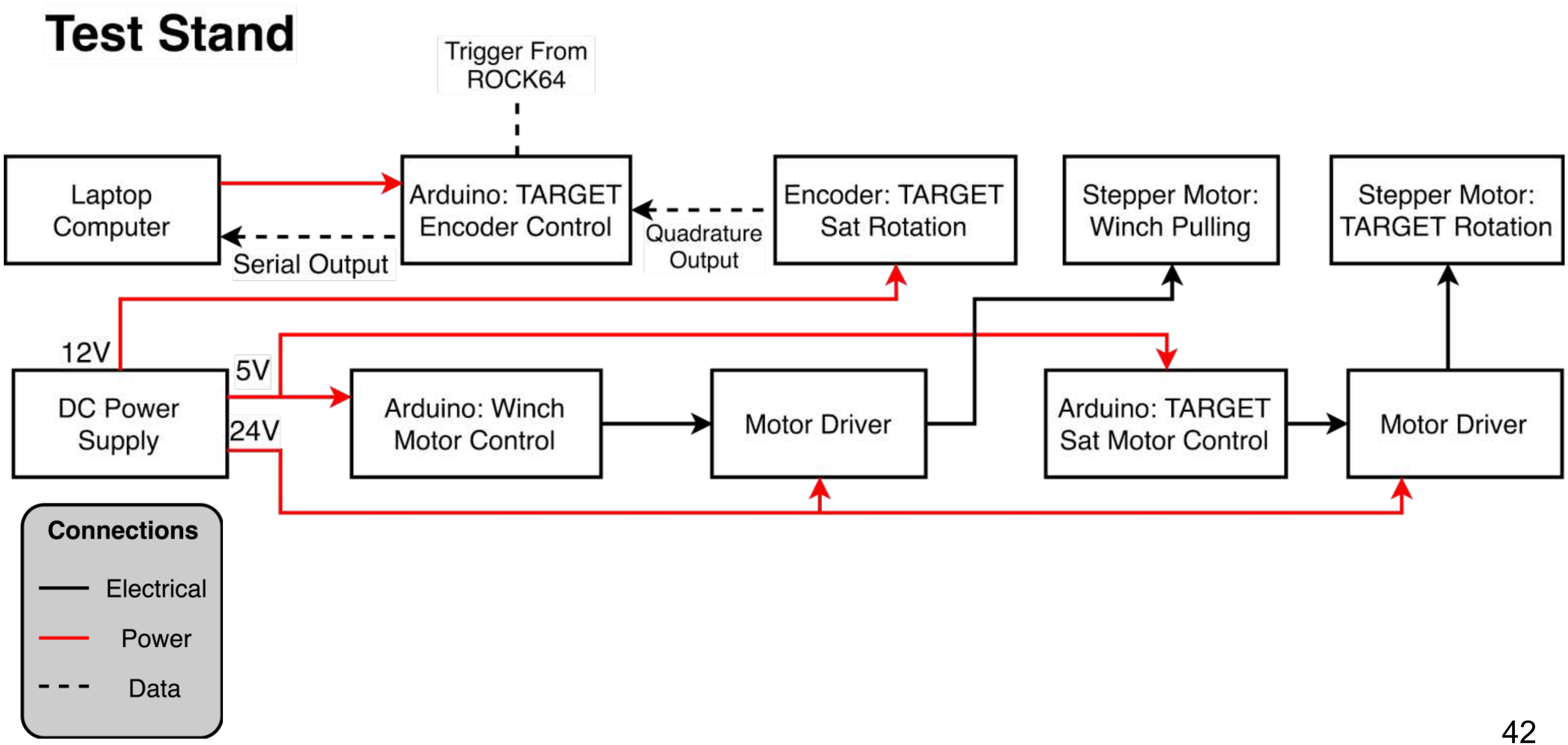
Final Test Software Architecture



Electrical Setup and Data Flow



Test Stand Electrical Setup



Preliminary Testing Complete

Requirement	Description	Complete Testing Item	Ready?
DR 3.1	The sensor package shall output the target satellite's **relative velocity** with an error of less than **1%** up until a relative velocity of **0.1[m/s]**.	Winch and testing LRF were found to produce translational velocities ranging from **0.1 to 1 [m/s]**.	✓

Put pictures of stuff from tomorrow here

Lets put a side picture of the test setup here too

Preliminary Testing Complete

Requirement	Description	Complete Testing Item	Ready?
DR 5.2	The sensor shall be able to detect target satellite rotation rates between **1[deg/s] and 5[deg/s]**	Encoder paired with the TARGET test stand confirms capability of rotating at rates from **1[deg/s]** to **5[deg/s].**	✔

Put pictures of stuff from tomorrow here

Gif of the target rotating on the stand

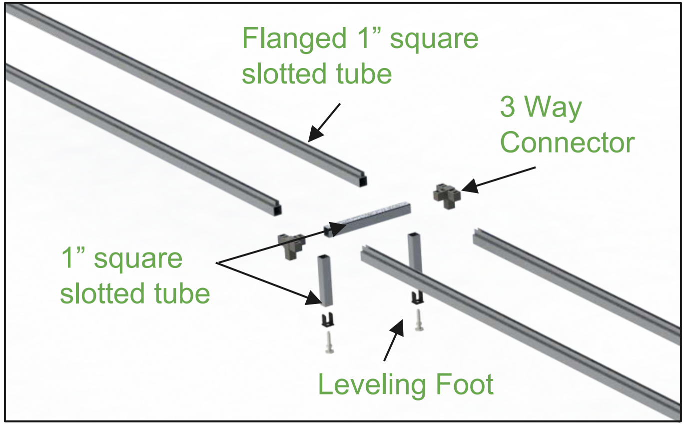
Rotational speed output from encoder

Test Plan

- **Acquire and Track Test**
  - Dependencies
    - ITLL/Engineering Center hallway availability - Already talked to Dean and outlined test plan.
    - Lighting - Received approval and ability to control lighting
  - Schedule
    - Currently Acquire and Track testing is scheduled for 3/5/18 to 3/19/18.
      - Enough time to be flexible
- **Track and Orientation Testing**
  - Dependencies
    - ITLL/Engineering Center Hallway availability and Lighting
  - Schedule
    - Track and Orientation testing is scheduled for 3/19/18 to 4/2/18
      - Orientation testing can be conducted prior than this to account for Spring Break

Track Assembled

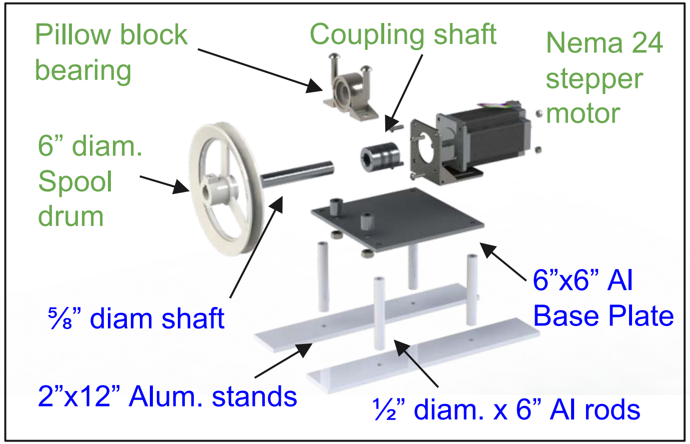
1. Track - has been taken apart into 8ft long sections (assembly time 2hrs)
2. Winch - fully assembled connects to target stand with a hook
3. Target Stand - fully assembled
4. Target- All pieces fabricated (assembly time 20 min)
5. Test stand- fully assembled
6. SCOPE sensor package
7. Testing LRF
8. Sensor Alignment



(Picture of entire track)

Winch Manufactured

1. Track - has been taken apart into 8ft long sections (assembly time 2hrs)
2. Winch - fully assembled connects to target stand through fishing line
3. Target Stand - fully assembled
4. Target- All pieces fabricated (assembly time 20 min)
5. Test stand- fully assembled
6. SCOPE sensor package
7. Testing LRF
8. Sensor Alignment

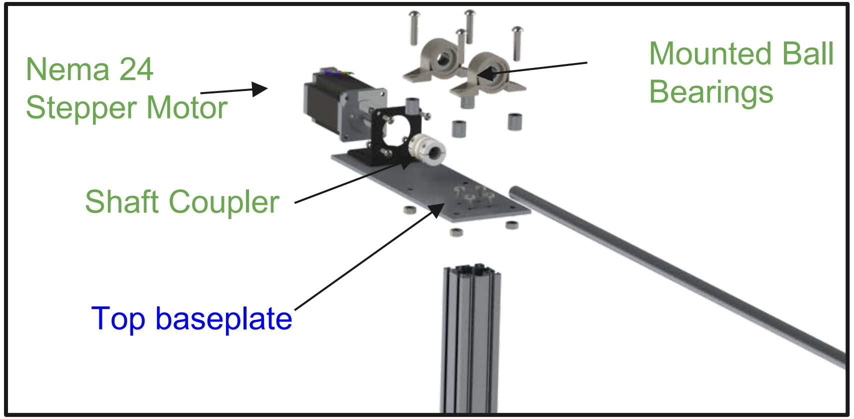


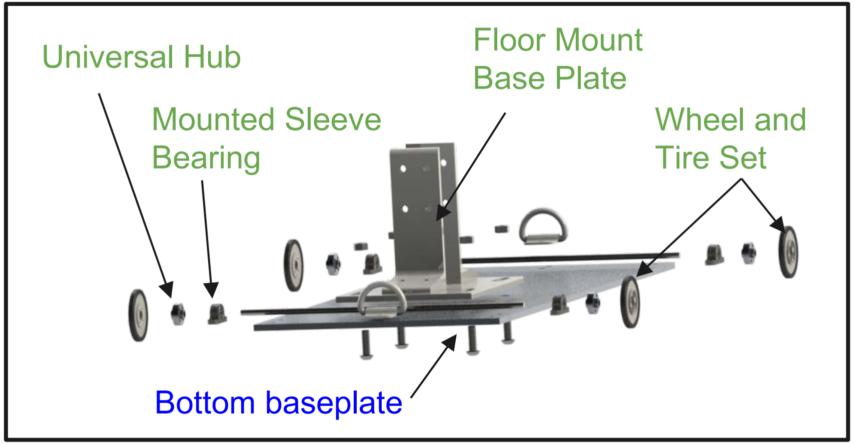
(insert winch rotation rate and velocity data of TARGET Stand)

TARGET Stand Manufactured/Assembled

1. Track - has been taken apart into 8ft long sections (assembly time 2hrs)
2. Winch - fully assembled connects to target stand with a hook
3. Target Stand - fully assembled
4. Target- All pieces fabricated (assembly time 20 min)
5. Test stand- fully assembled
6. SCOPE sensor package
7. Testing LRF
8. Sensor Alignment

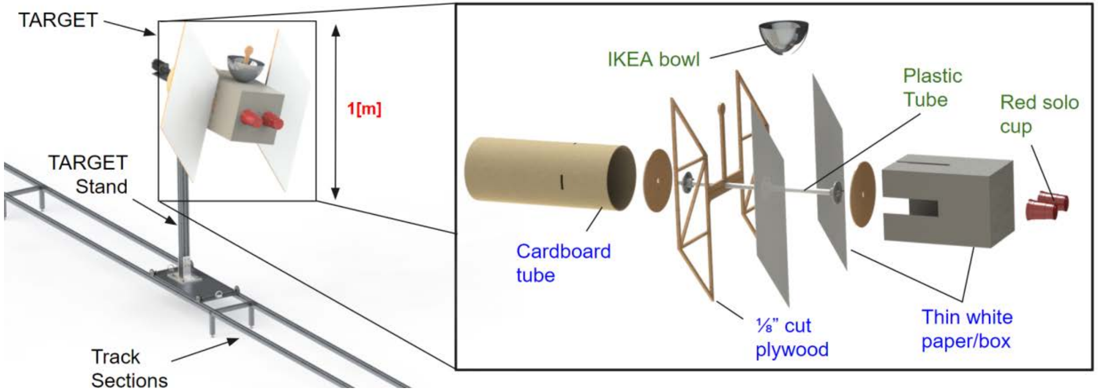
(Insert rotation position and rate from encoder)





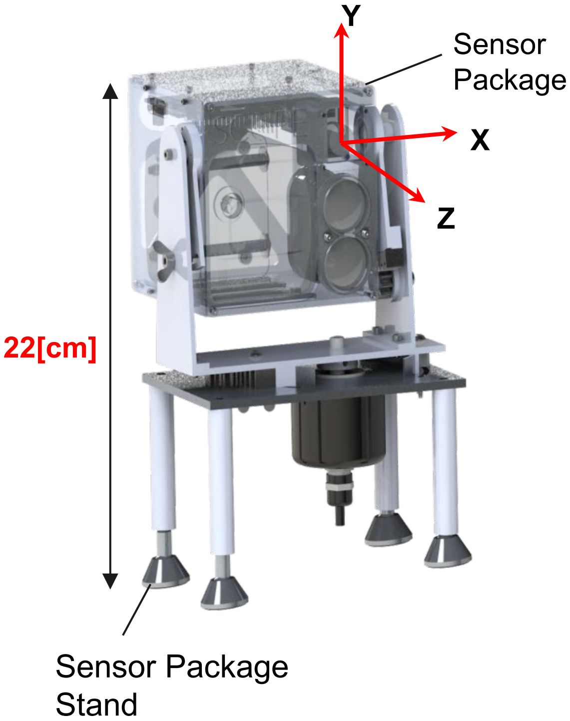
TARGET Assembled

1. Track - has been taken apart into 8ft long sections (assembly time 2hrs)
2. Winch - fully assembled connects to target stand with a hook
3. Target Stand - fully assembled
4. Target- All pieces fabricated (assembly time 20 min)
5. Test stand- fully assembled
6. SCOPE sensor package
7. Testing LRF
8. Sensor Alignment



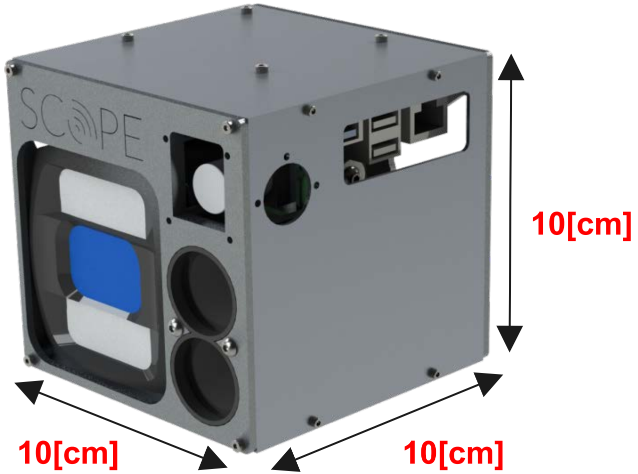
SCOPE Test Stand

1. Track - has been taken apart into 8ft long sections (assembly time 2hrs)
2. Winch - fully assembled connects to target stand with a hook
3. Target Stand - fully assembled
4. Target- All pieces fabricated
5. Test stand- fully assembled
6. SCOPE sensor package
7. Testing LRF
8. Sensor Alignment



SCOPE Shell Manufactured

1. Track - has been taken apart into 8ft long sections (assembly time 2hrs)
2. Winch - fully assembled connects to target stand with a hook
3. Target Stand - fully assembled
4. Target- All pieces fabricated (assembly time 20 min)
5. Test stand- fully assembled
6. SCOPE sensor package
7. Testing LRF
8. Sensor Alignment



Track Procedure

1. Assemble, Place, and Level Track
2. Install TARGET and Stand
3. Connect TARGET stand to Winch
4. Testing LRF positioning
5. Starting sequence
   a. Power On
   b. Data Sync

Test One	Front of track placed 90 m away from SCOPE stand
Test Two	Front of track placed 1 m away

Cycle through all track beams twice with the level to ensure smooth translation of the target stand

Materials Needed:
- Level
- Rubber Mallet
- Utility Knife
- Tape Measure

TARGET/Stand Procedure

1. Assemble and Level Track
2. Install TARGET and Stand
3. Connect TARGET stand to Winch
4. Install TARGET
5. Testing LRF positioning
6. Starting sequence
    a. Power On
    b. Data Sync

Materials Needed:

- Allen Key for Wheels
- Screw Driver
- Epoxy

(Describe changes to 3D model)

PVC pipe slides over ⅝'' rode and place screw through PVC/rod to complete installation

Winch Procedure

1. Assemble and Level Track
2. Install TARGET and Stand
3. Connect TARGET stand to Winch
4. Testing LRF positioning
5. Starting sequence
    a. Power On
    b. Data Sync

(insert winch rotation rate and velocity data of TARGET Stand)

Materials Needed:

- Fishing wire (117lb)
- Allen key
- Measuring tape

Winch is connected to:

- Power supply
- Arduino board
- BigEasy driver

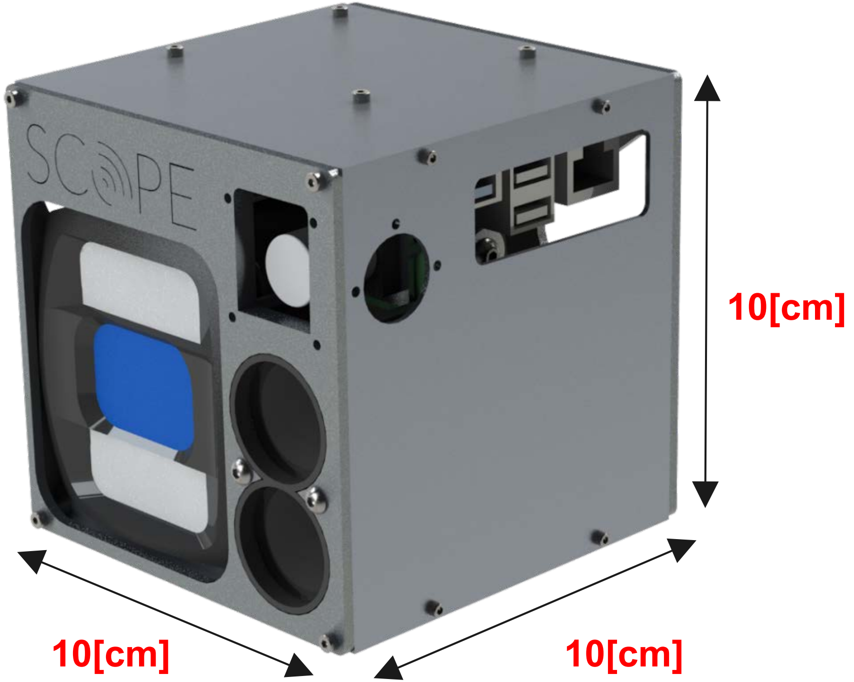
5 inch spool drum diameter houses 16ft of wire (40 laps)

Located half a meter away from the front of the track

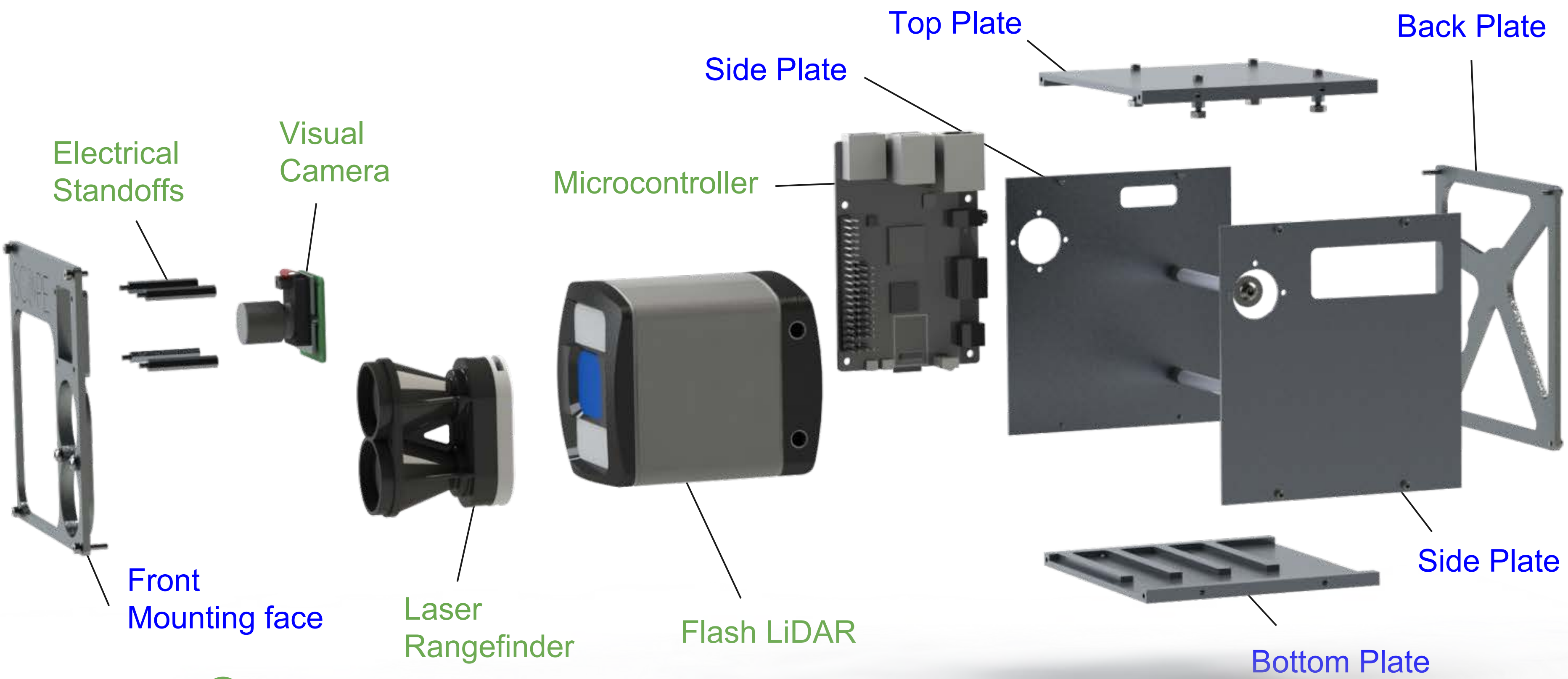
SCOPE Shell Design

Driving Requirements
DR 7.1 The sensor package shall not exceed **10x10x10[cm]**.
DR 7.2 The mass of the sensor package shall not exceed **1.33[kg]**.

Major Changes	Reason
Increased shell wall thickness from **0.05[in]** to **0.1[in]**.	Machining capability and warping.
Material changed from 6061 Al to MIC-6 Al	Higher tolerances and machinability



SCOPE Shell Design

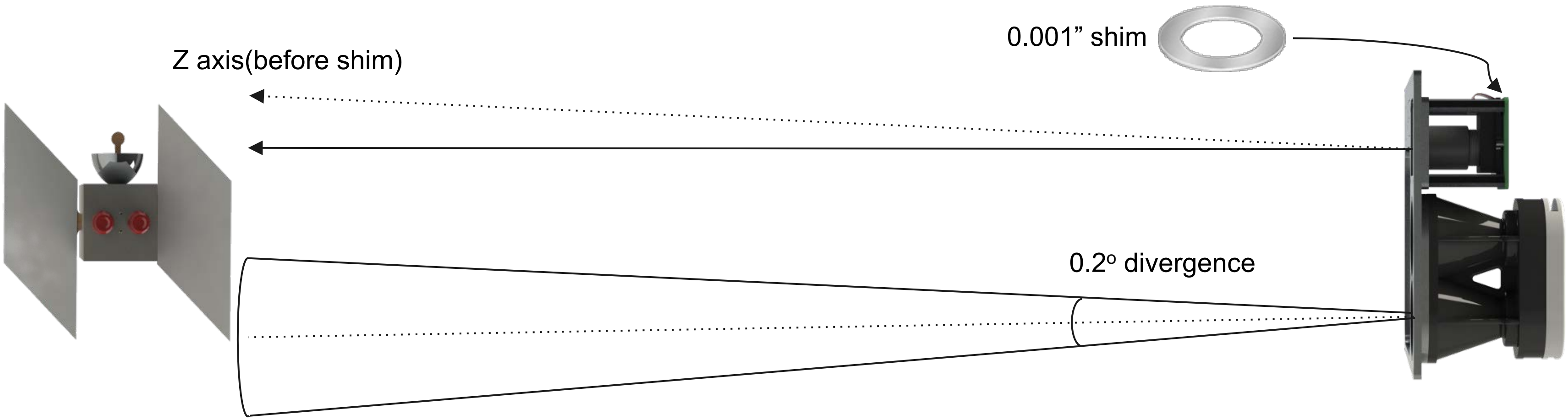


Procured

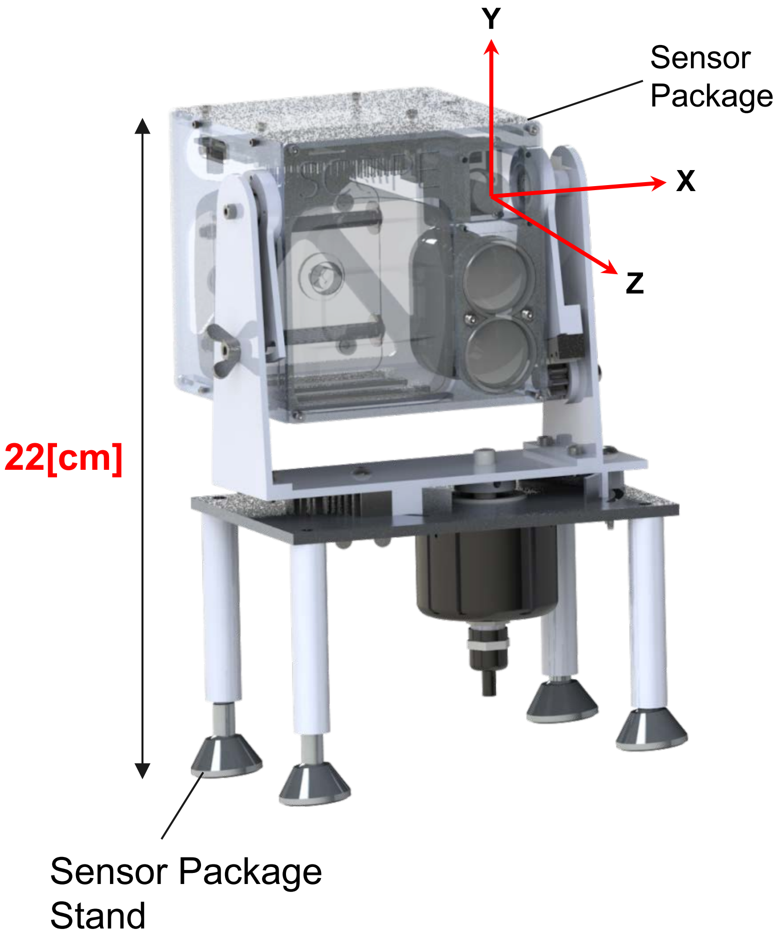
Manufactured

Shell Progress and Critical Elements

Task	Critical Elements	Next Steps
Sensor Alignment	Alignment of optical camera and laser range finder must be parallel to **0.1[deg]**.	Using shims (0.001” thickness) to alter the pointing of sensors to **10[cm]** off target**.**



SCOPE Test Stand

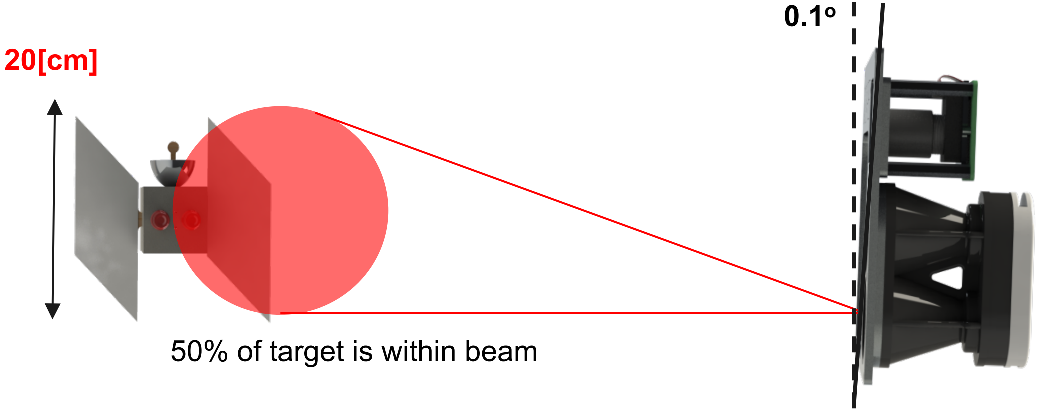


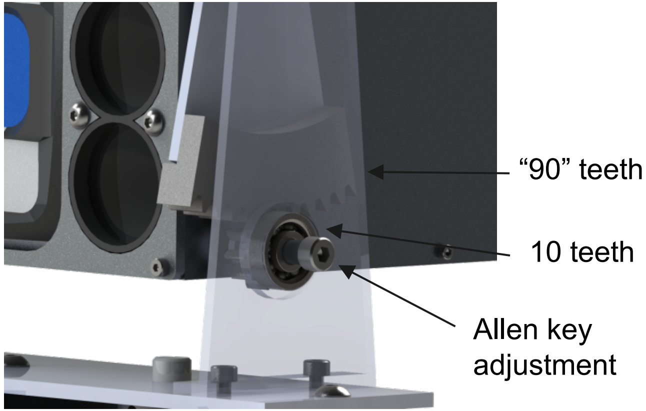
Driving Requirements
DR 1.1 The sensor shall be able to detect a target satellite with volumetric dimensions between **20x20x30 [cm]** and **1x1x1 [m]**.
DR 1.2.1 The sensor shall be able to detect a target satellite at a range of **100 [m].**

Major Changes	Reason
Added 9:1 gearing on **X** and **Y** axes.	Ease of manual turning.
Material thicknesses increased	Machinability and warping.

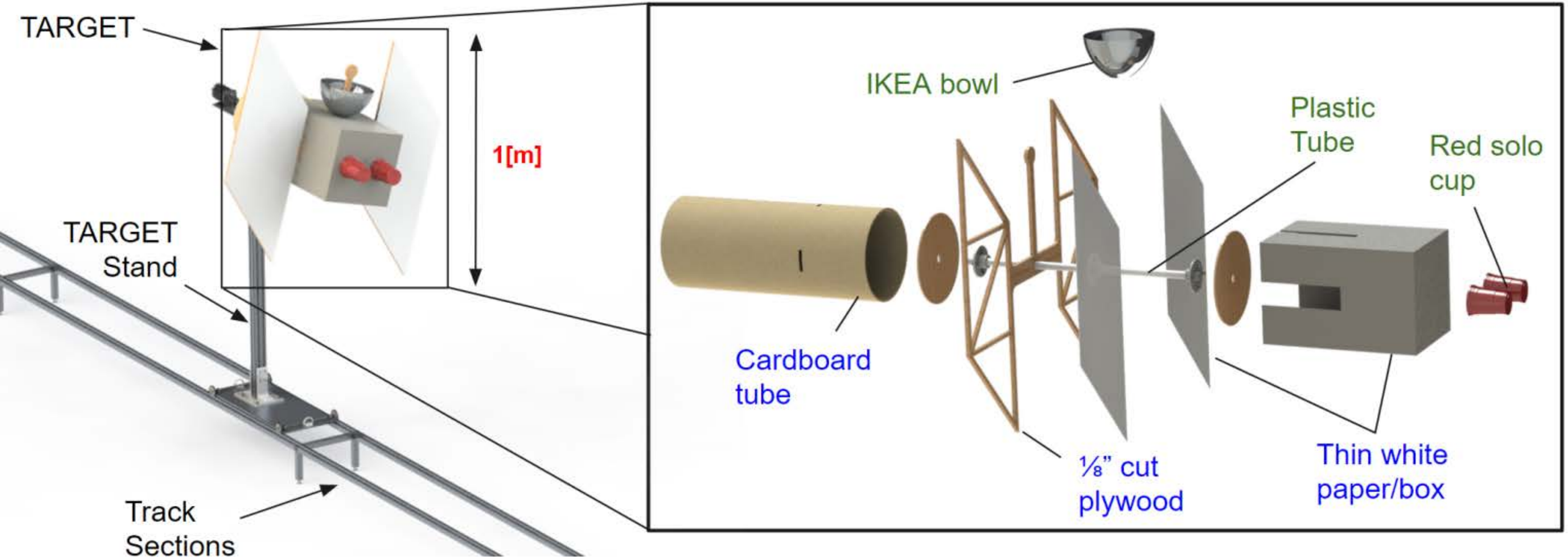
Test Stand Progress and Critical Element

Task	Critical Elements	Next Steps
Sensor Package Actuation	Test Stand must be manually adjusted by **0.1[deg]** to capture at least half of smallest TARGET.	Implementing **9:1** 3D printed **gearing** into test stand for ease of manual adjustment.

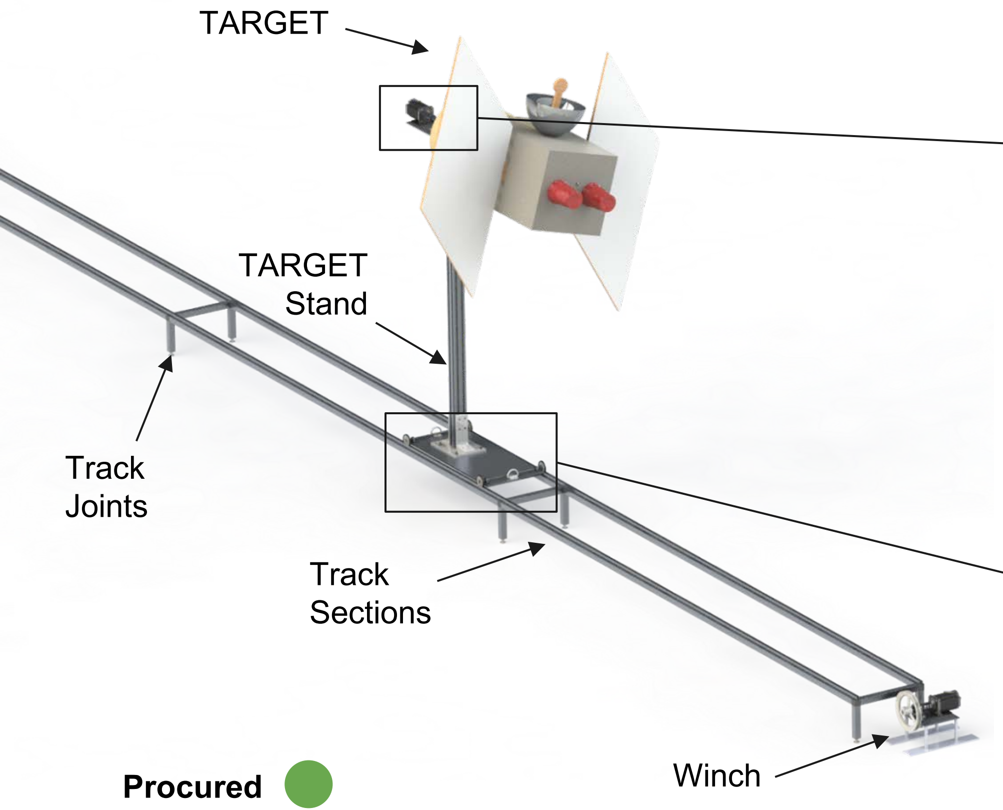


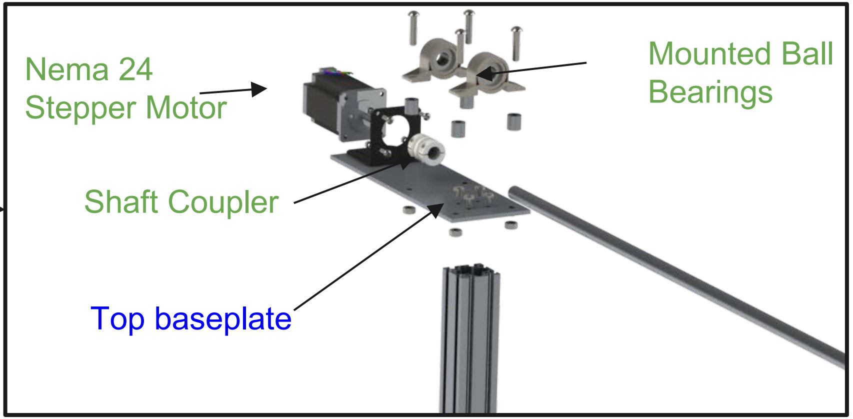


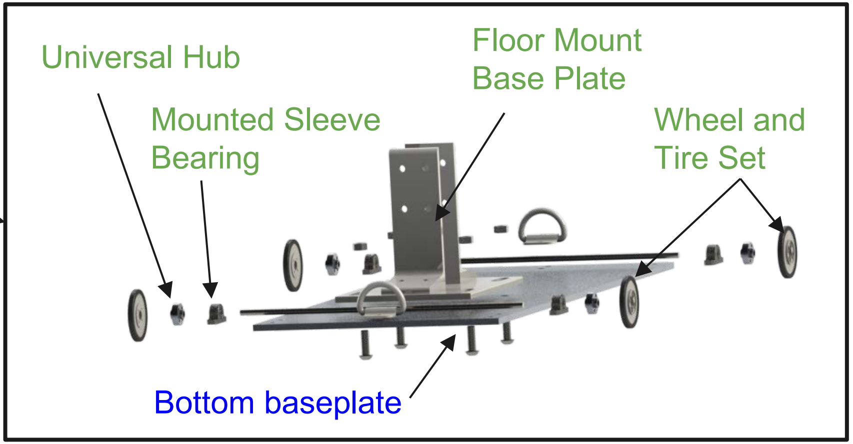
Target Satellite Progress



Target Test Stand Design - 2 Machined Parts





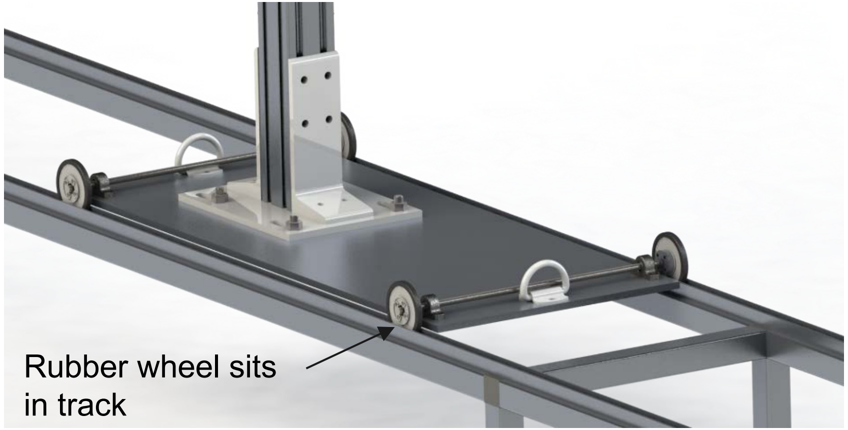


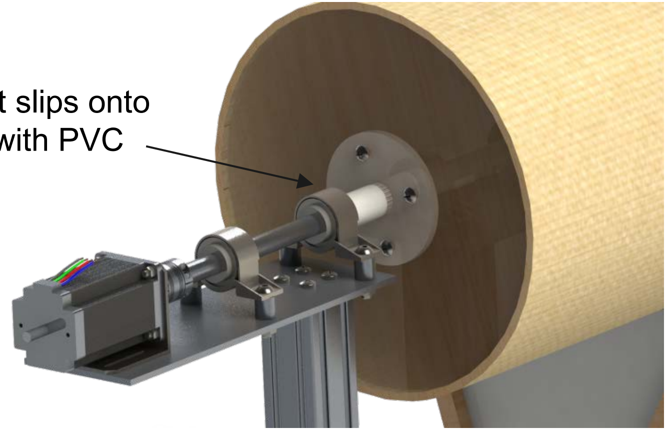
Procured

Manufactured

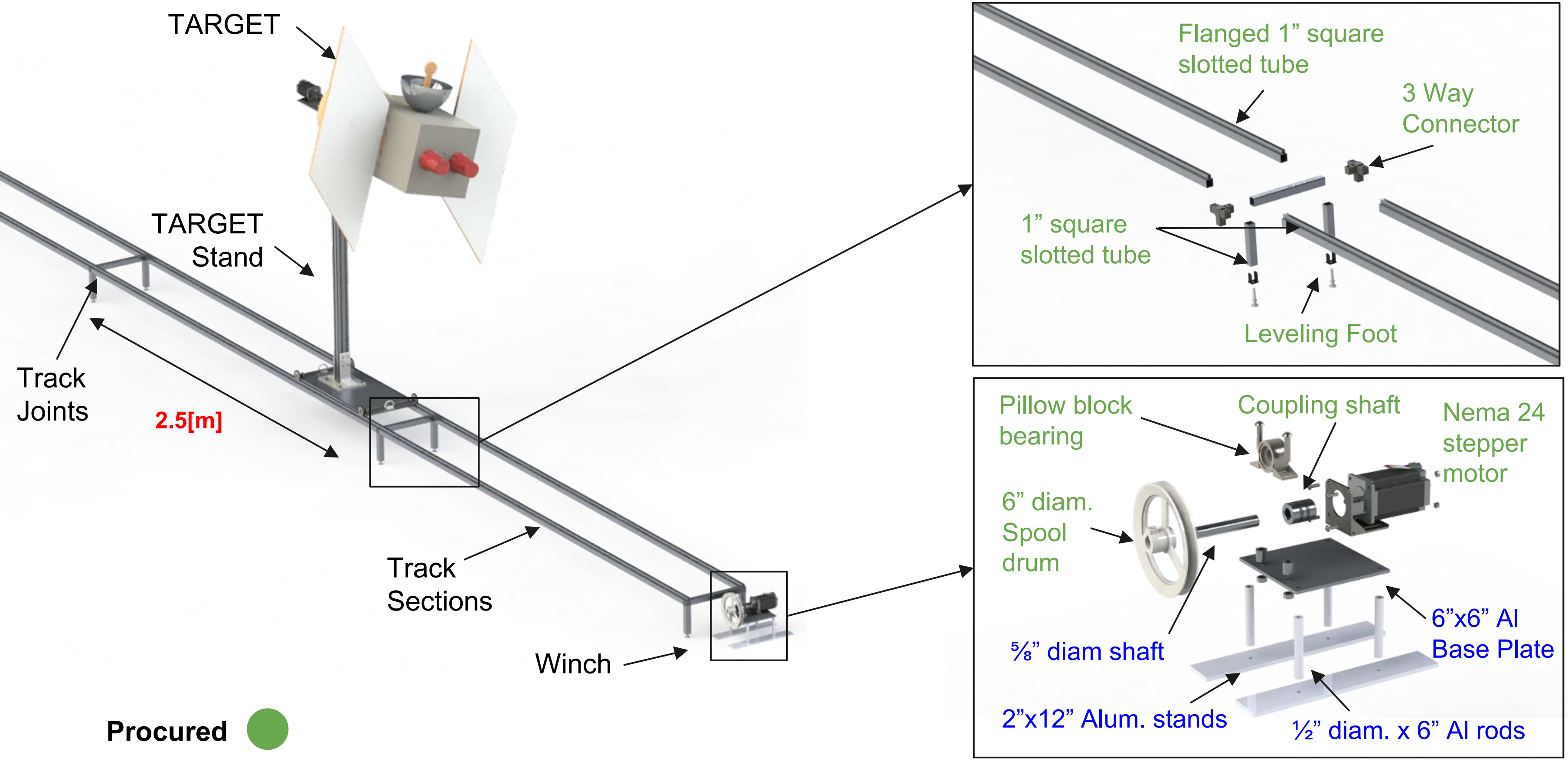
Target Test Stand Progress

Task	Critical Elements	Next Steps
Track Integration	Stability of wheels on track to allow for smooth movement	Using rubber for better traction vs. using nylon wheel for less friction.





Track System - COTS Components

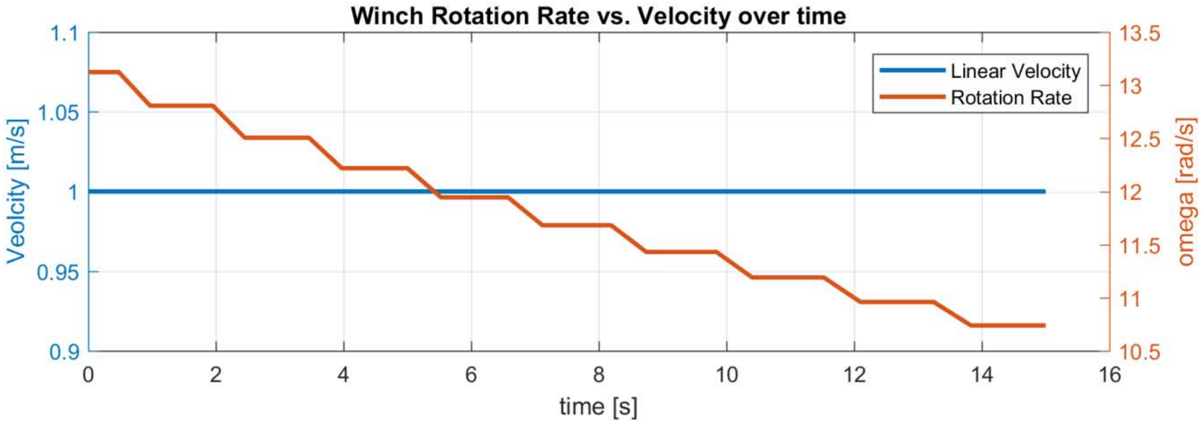


Procured (green)

Manufactured (blue)

Winch Progress and Critical Elements

Task	Critical Elements	Next Steps
Winch - Target implementation	Controlling the speed of the target between **0.1[m/s]** and **1[m/s]**.	Create torque curves for the stepper motor.
	Stopping the target before the end of the track to ensure no damage to test setup	Determining the spring needed through testing and theory.



The radius of the spool (**7.62 [cm])** will increase after every 2 revolutions. 1 m/s can be achieved with the following rotation rates over time.

Background Subtraction

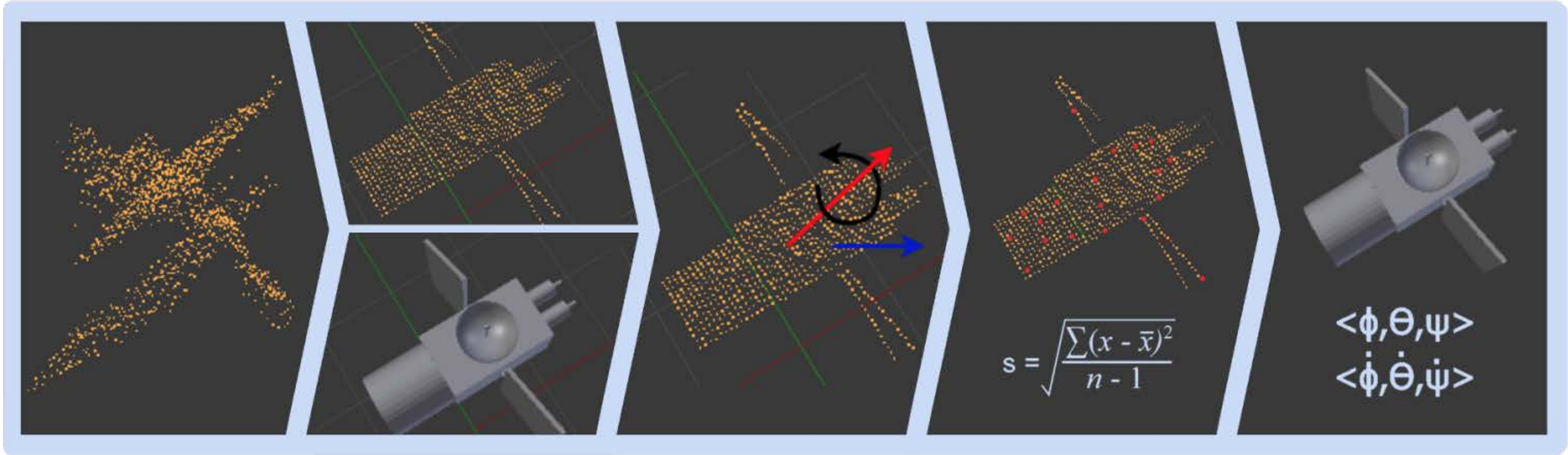
DR 1.2.1 The sensor shall be able to detect a target satellite at a range of 100 [m].

Camera Subtract Dilate Contour Centroid

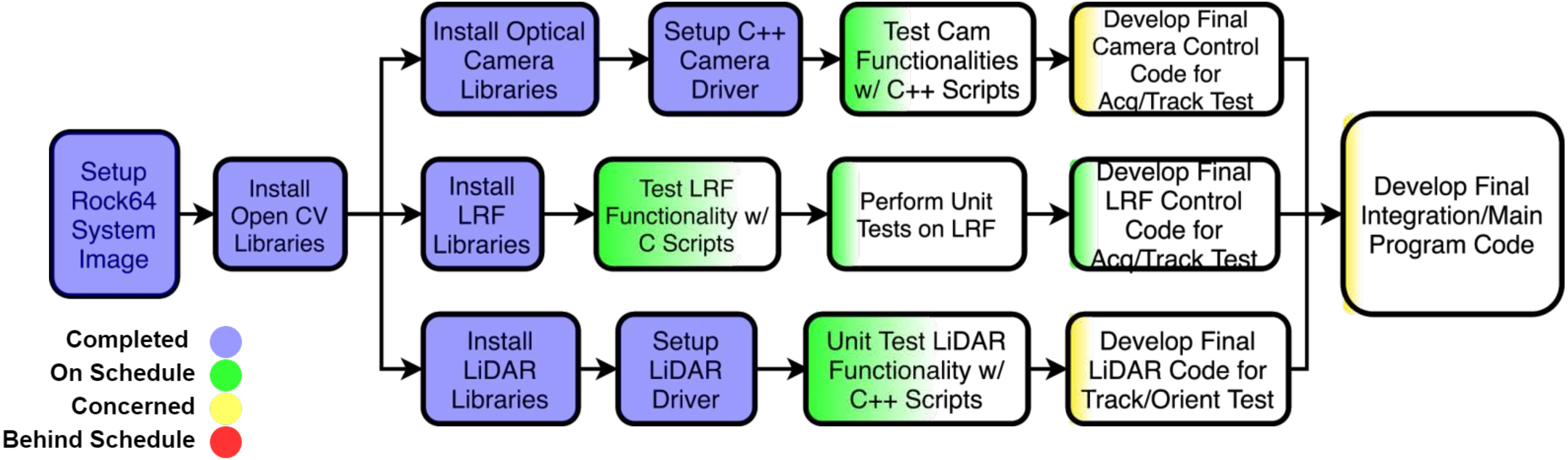
Iterative Closest Point ~ FLOOD

DR 4.1 The sensor package shall output the target satellite's relative orientation at a starting range of 10[m].

Initial Rotation and Translation | Compare Point Cloud and 3D Model | Apply Ideal Rotation and Translation | Remove Error based on Threshold | Output Data to SD Card



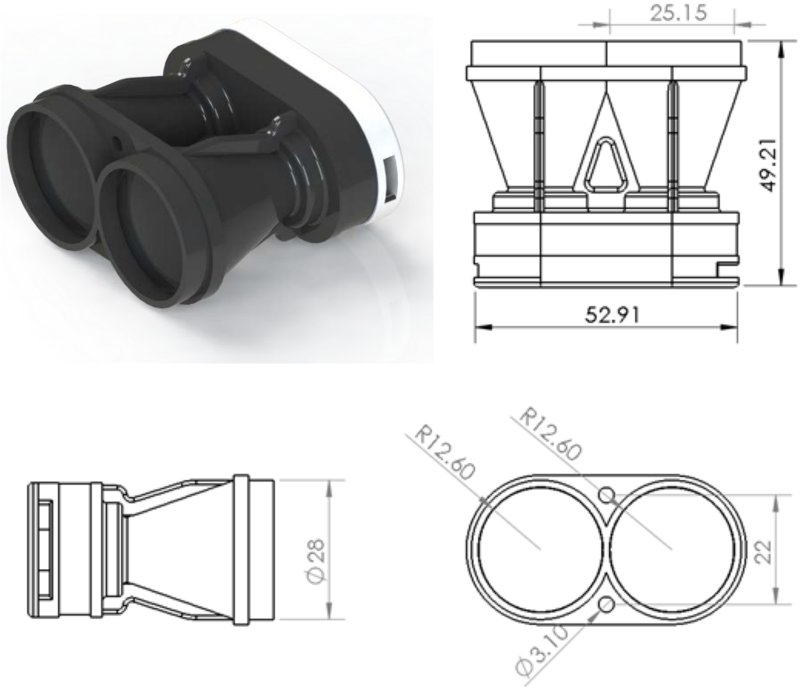
Software Integration Tasks and Progress (Option 1)



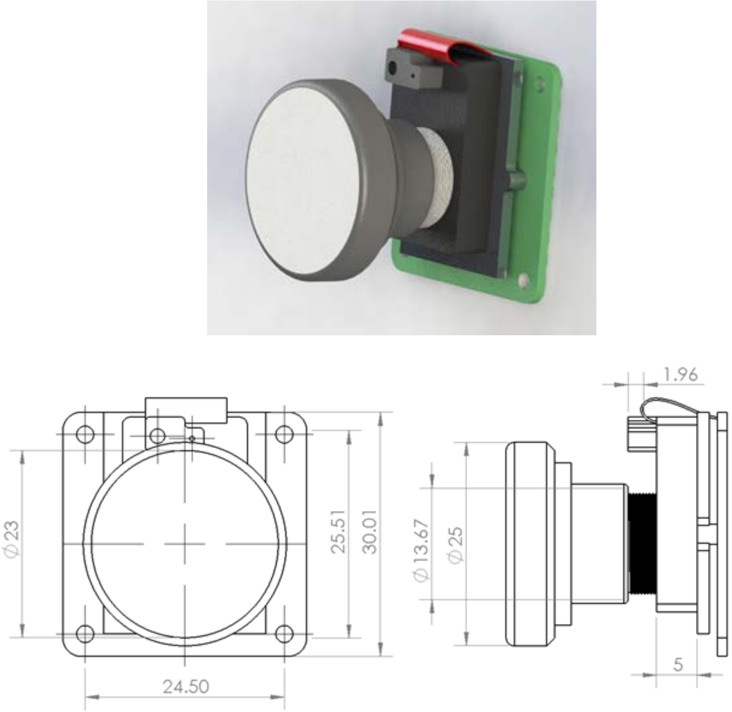
Task	Critical Elements	Concerns
Develop Cam Control Code for Acq/Track Test	Customized Control, Resolution/FPS	Lag from high res, AF/Settings for diff. situations
Develop LiDAR Control Code for Track/Orient	Computation Time/Reading large frame	Lag from high res and preprocessing of pixels
Overall S/W Integration/Main program dev.	Computation Time, Output Accuracies	2Hz Output Freq, Requirement accuracies

Sensors and Rock64 Diagrams

Laser Rangefinder

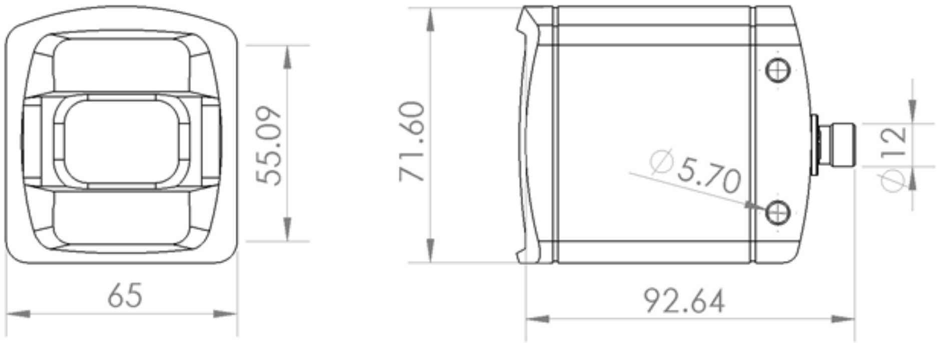


Visual Camera

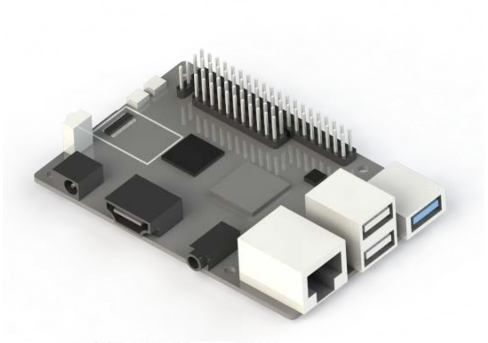


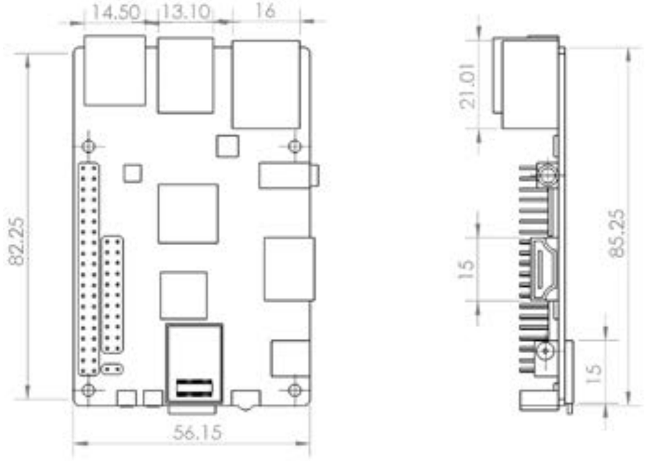
Sensors and Rock64 Diagrams

Flash LiDAR



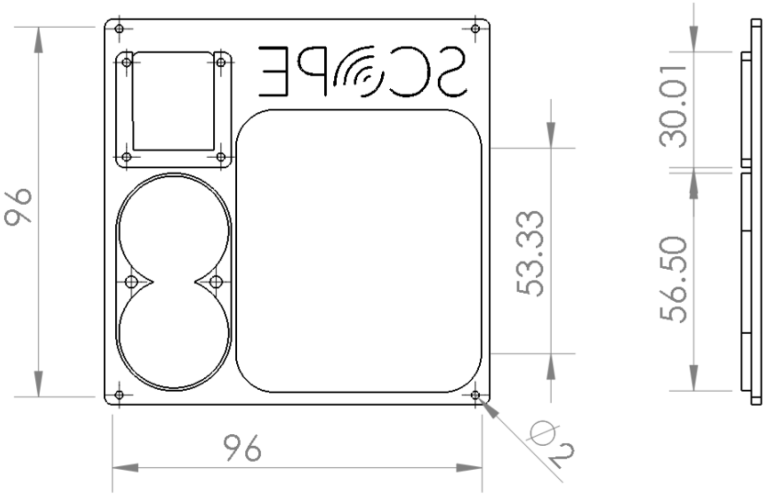
Rock64 Microcontroller



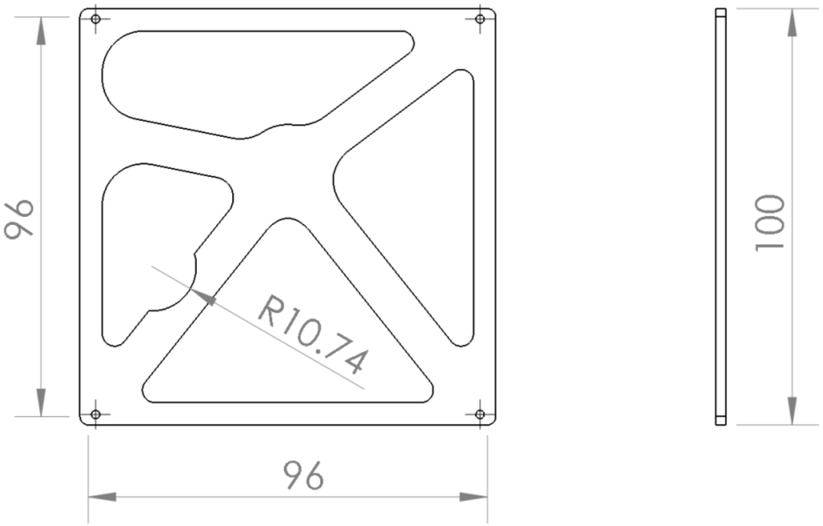


Shell Diagrams

Mount Face



Back Plate

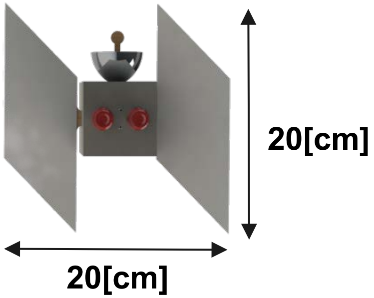


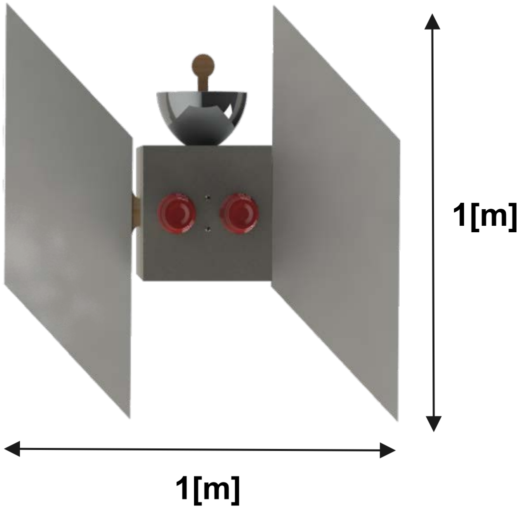
TARGET Model

Driving Requirements for **Physical Characteristics**
DR 1.1: The sensor shall be able to detect a target satellite with volumetric dimensions between **20x20x30 [cm]** and **1x1x1 [m]**.
DR 1.4: The sensor shall be able to detect a target satellite under **favorable lighting conditions**.*

Driving Requirements for **Motion Characteristics**
DR 1.2: The sensor shall be able to detect a target satellite at a range of **100 [m].**
DR 3.1: The sensor package shall output the target satellite's relative velocity with an error of less than 1% with a relative velocity of **0.1[m/s]** to **1[m/s]**.
DR 5.2: The sensor shall be able to detect target satellite rotation rates between **1[deg/s]** and **5[deg/s]**.

*Favorable lighting conditions assumes diffusive white light on diffusive white paper





Test 1

Assumptions:

- The rail system allows the cart to move perfectly straight:
  - i.e the side to side motion is constrained and can be assumed to be so small that it is negligible
- The motor does not fluctuate:
  - i.e the motor pulls at a constant angular velocity and there is no noise or fluctuations in this velocity
- The target satellite will be moving at a constant rate of .1 m/s during the “Acquire phase” and then speed up to testing speeds for the remainder of the test

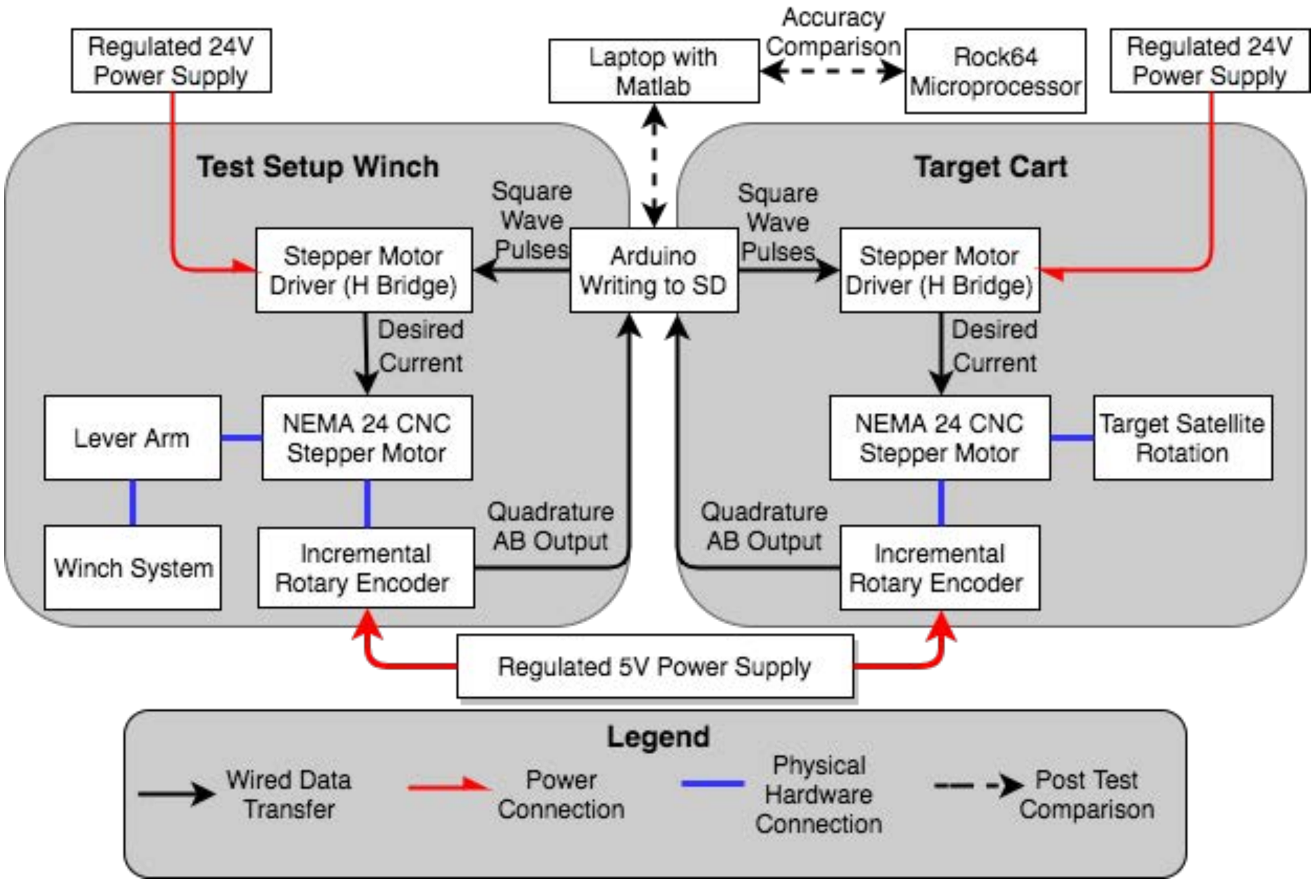
Phases:

- Set SCOPE at origin, 0 m
- Use a tape measure, (EC class 1) to set the rail at a distance that will cover 90m - 105m from SCOPE
- Turn on SCOPE and position it down the line of sight from the target
- Set the first 60s of target movement to .1 m/s and the remainder of the test to .1 m/s
- Turn on the motor/microcontroller setup
- Repeat steps 4 and 5 with varying remainder of test velocities from .1 m/s to 1 m/s.

Fulfilling Functional Requirements

Functional Requirements	Test
FR 1	Transition Test 1
FR 2	Transition Test 1
FR 3	Transition Test 1
FR 4	Transition Test 2
FR 5	Transition Test 2
FR 6	Inspection
FR 7	Inspection

Testing Hardware Flow Chart



FEA Mesh and Parameters (thermal)

<u>All bodies have constant material properties:</u>

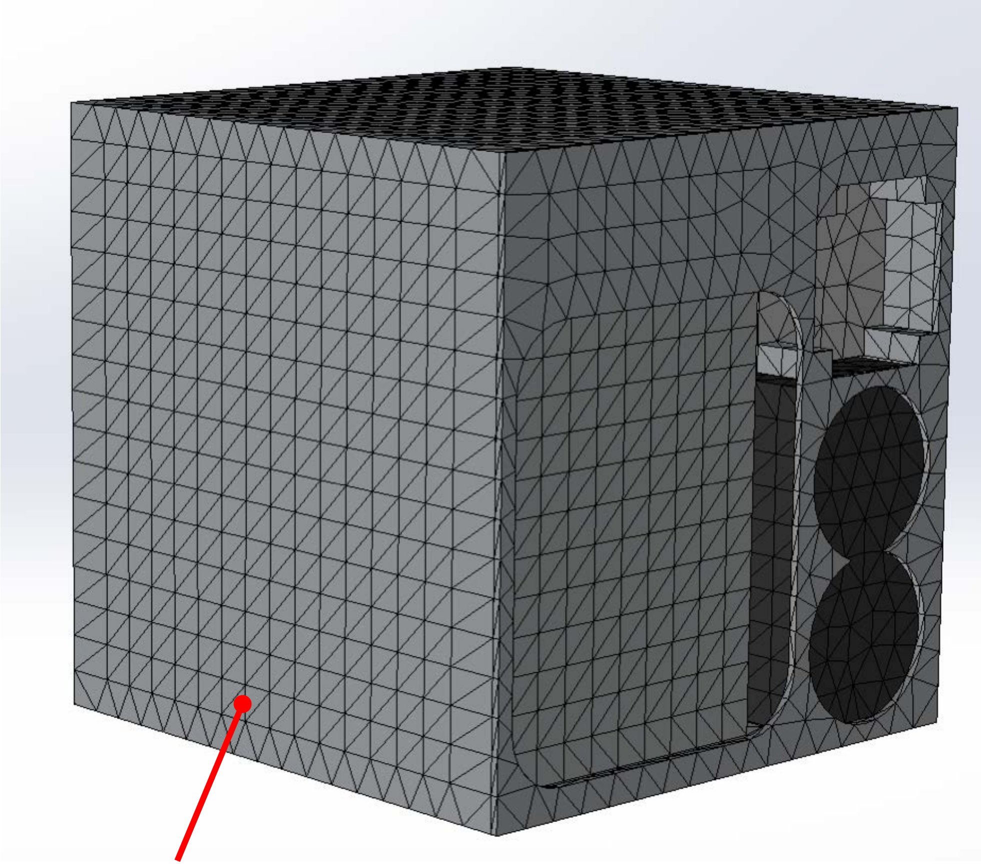
Component(s): Shell
Material: 6061 Aluminum Alloy
Thermal Conductivity: 170 W/(m*K)

Component(s): Laser Rangefinder
Material: ABS PC
Thermal Conductivity: 0.2618 W/(m*K)

Component(s): Rock64 Board
Material: Non-conductive PCB Substrate
Thermal Conductivity: 0.2256 W/(m*K)

Component(s): Visual Camera, 03D301 LiDAR
Material: ABS PC/6061 Aluminum
Thermal Conductivity: 85 W/(m*K)

Contact Resistance: 2.5x10^-4 W*m^2/K



Triangular based mesh

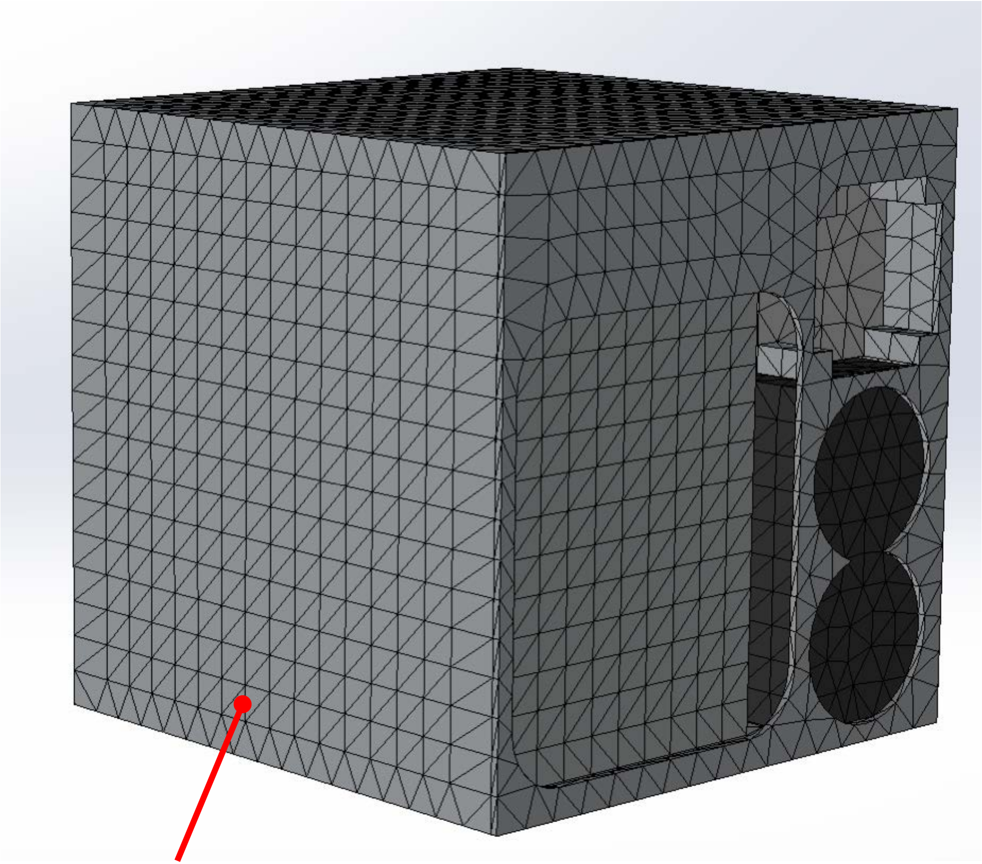
FEA Mesh and Parameters (thermal)

Model uses the following conditions:

Ambient Temperature: 290K

Thermal Emissivity: 0.12

Contact Resistance: 2.5x10^-4 W*m^2/K



Triangular based mesh

Various Power Outputs

Component	Low Power	Peak Power	Mean Power
Rock64 Media Board	1.25W	10W	**2.5W**
IFM 03D301 Flash LiDAR	5W	48W	**10W**
DFK AFUJ003-M12	n/a	5W	**1.25W**
SC30-C Laser Rangefinder	n/a	5W	**1.25W**

Sources

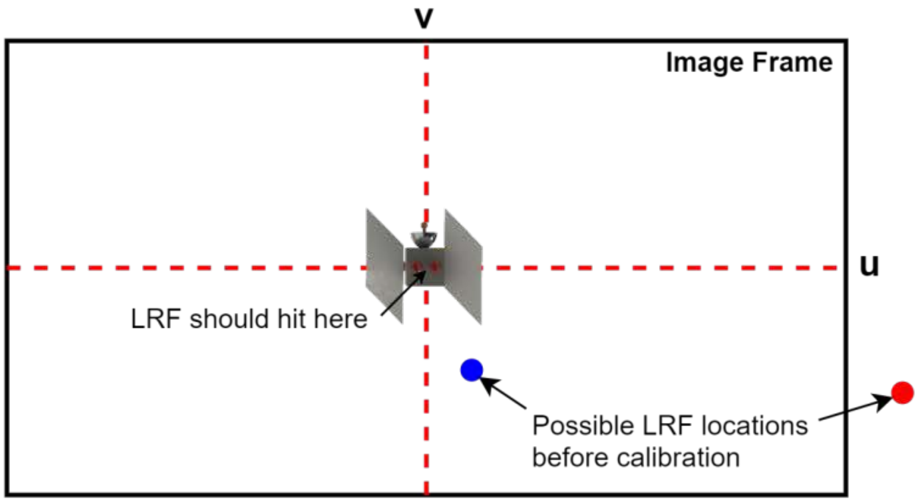
Rock64: https://forum.pine64.org/showthread.php?tid=1220
AFUJ003: https://www.theimagingsource.com/products/autofocus-cameras/usb-3.0-color/dfkafuj003m12/
SC30-C: https://www.parallax.com/product/28058
03D301: https://www.ifm.com/hu/en/product/O3D301

Various Operational Temperatures

Component	Peak Operational Temperature	Maximum Predicted Temperature
Rock64 Media Board	65°C	42°C
IFM 03D301 Flash LiDAR	50°C	30°C
DFK AFUJ003-M12	45°C	27°C
SC30-C Laser Rangefinder	40°C	26°C

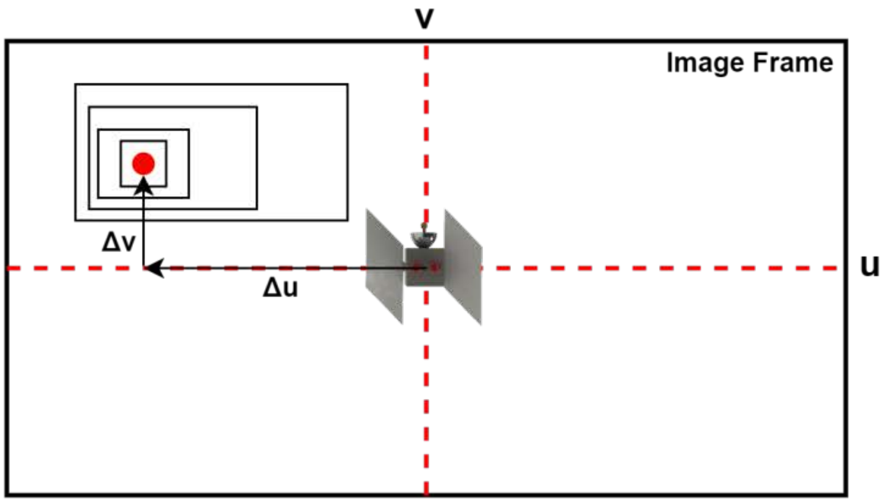
Sources
Rock64: https://forum.pine64.org/showthread.php?tid=1220
AFUJ003: https://www.theimagingsource.com/products/autofocus-cameras/usb-3.0-color/dfkafuj003m12/
SC30-C: https://www.parallax.com/product/28058
03D301: https://www.ifm.com/hu/en/product/O3D301

Sensor Calibration



If ●, then the origin of the image frame can be moved to that point.

If ●, then mechanical techniques can adjust camera pointing.



1. Localize offset point with cardboard, decreasing in size.
2. Measure the distance offset and apply correction.

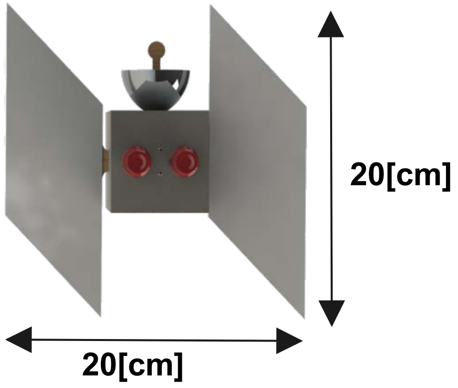
Minimum Pointing Accuracy

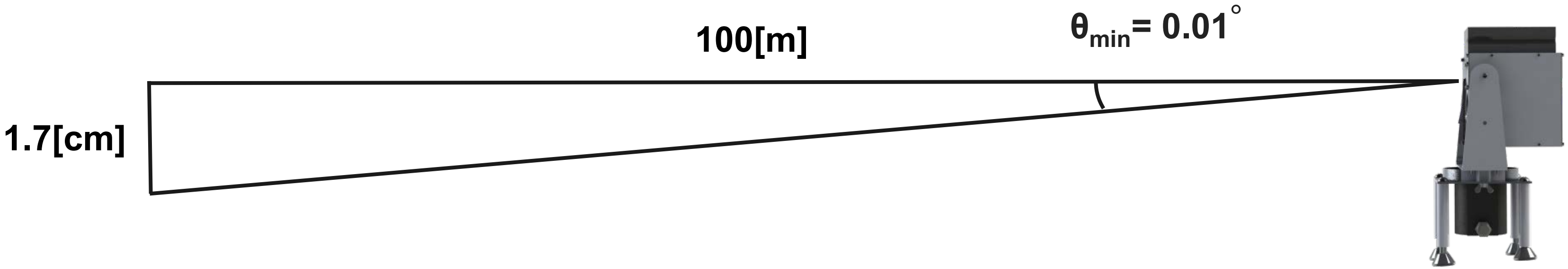
The minimum sized model defines the pointing accuracy to be required as a **20[cm]** vertical and horizontal resolution.

This means that the sensor package must be able to rotate at **0.115[deg]** per step.

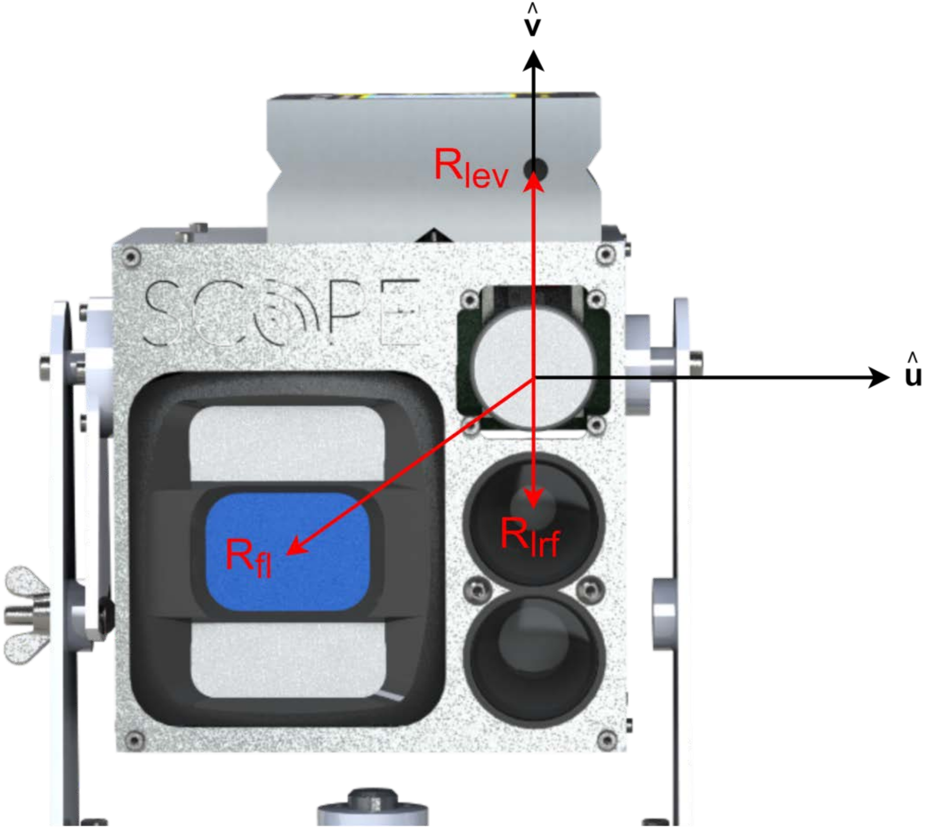
The resolution of our **sensor test stand encoders and digital level** give a resolution of **0.01[deg].**

Therefore, we can measure up to **1.7[cm]** per step





Sensor Face Offset



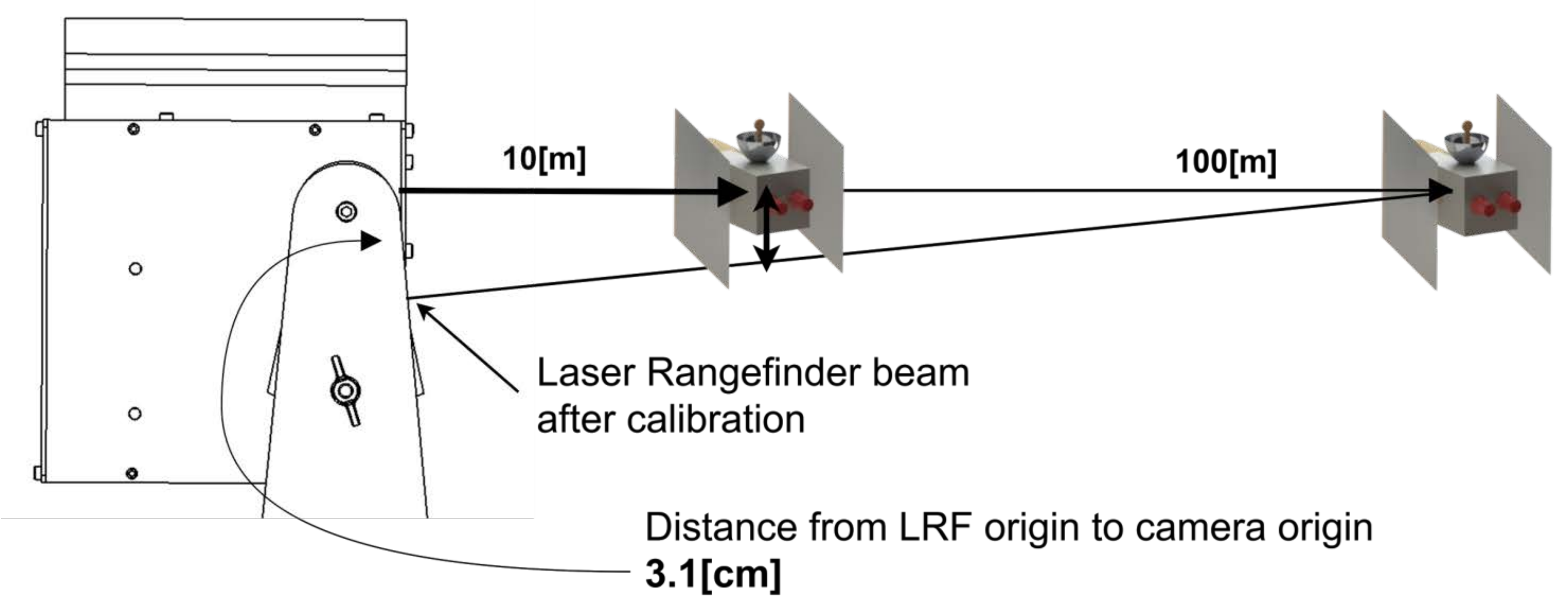
All offsets are accounted for in software

R_{lev} = <0,38,0> [mm]

R_{lrf} = <0,-31,0> [mm]

R_{fl} = <-49,-35,0> [mm]

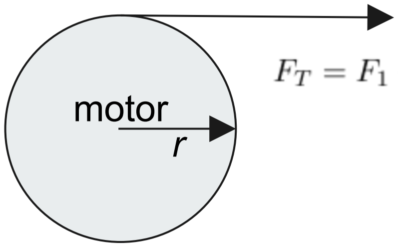
Error Due to Face Offset



This offset causes error in pointing as the object gets closer.

At **10[m]**, the closest position in which the laser rangefinder is used, this error (vertical offset) is **2.79[cm].**

Track Motor math



$$F_T = F_1 + F_2$$

Givens:

$$r = 5\ cm$$
$$F_1 = 20\ N$$
$$\sigma = 1.5$$

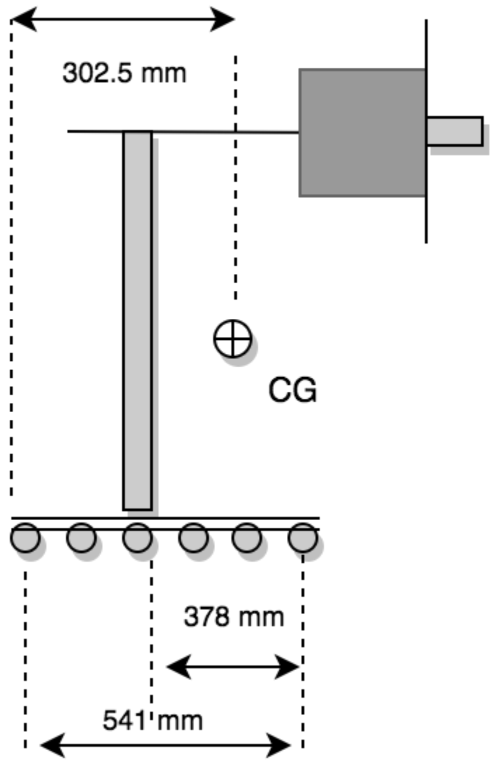
Analysis:

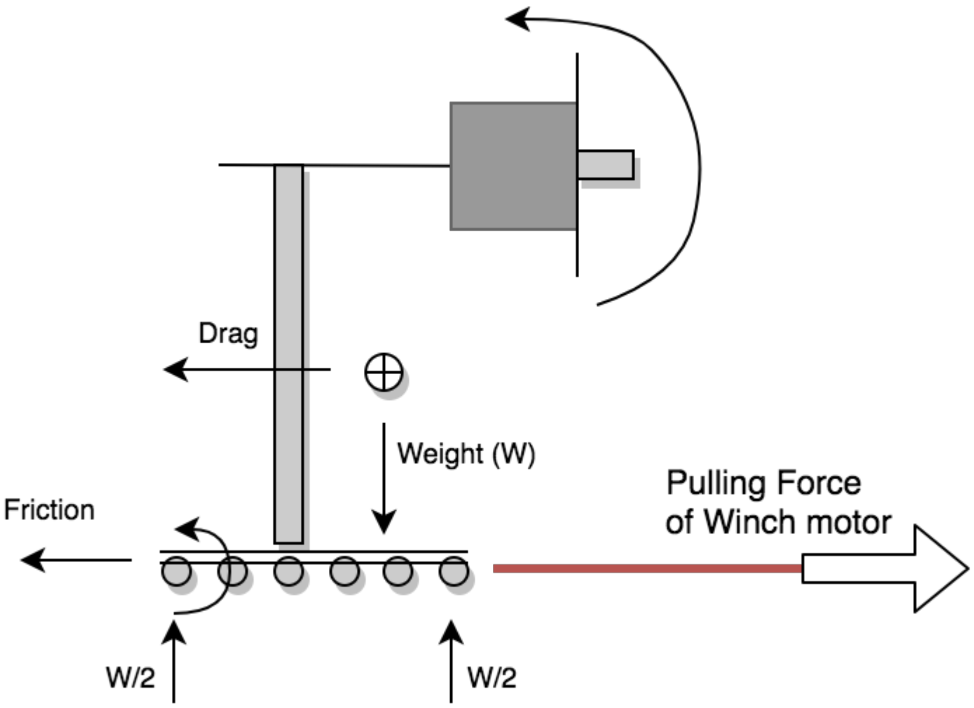
$$a = 1.5\ m/s^2$$
$$m = F_1/a = 2.040\ kg$$
$$F_2 = ma = 3.06\ N$$
$$F_T = F_1 + F_2 = 23.06\ N$$
$$T = F_T r = 1.153\ Nm$$
$$\boxed{T_F = T\sigma = 1.7295\ Nm}$$
$$\boxed{P_F = F v_{max}\sigma = 34.59\ W}$$
$$\boxed{\omega_{max} = v_{max}/r = 12.5\ rad/s = 190.98\ RPM}$$
$$\boxed{\omega_{min} = v_{max}/r = 12.5\ rad/s = 19.09\ RPM}$$

Conclusions:

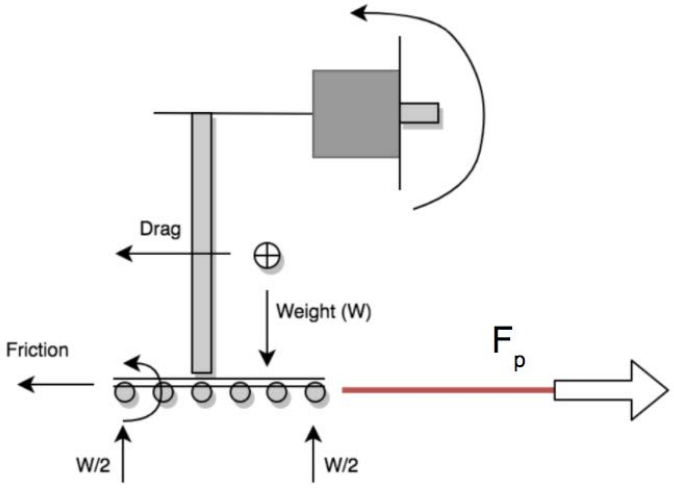
Need pullout torque at least 2 Nm between ~19 RPM and 190 RPM
Need 34.59 W for power

Velocity control - FBDs





Torque calculations



Givens:

$$r = 0.0762m$$

$$F_s = 12.34N$$

$$ma = 12.5 * 0.2 = 2.5N$$

$$D = 1/2 * \rho V^2 C_d A = 0.7989N$$

Analysis:

$$F_{tot} = -F_s - D + F_p = ma$$

$$F_p = F_s + D + ma = 15.6289N$$

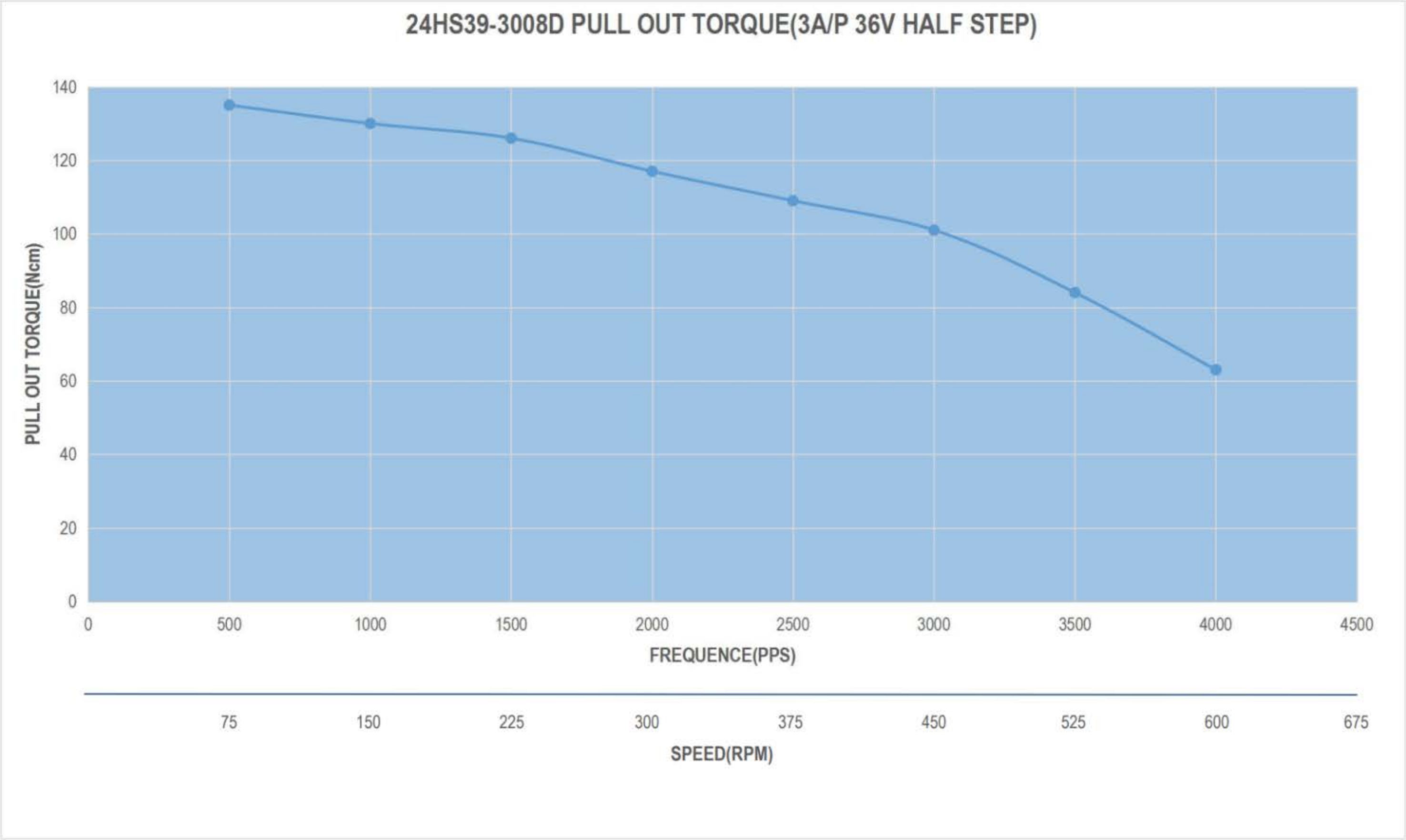
$$T = F_p * r = 1.19Nm$$

at $v_{max} = 1m/s$: $\omega = v/r = 125RPM$

Conclusions:

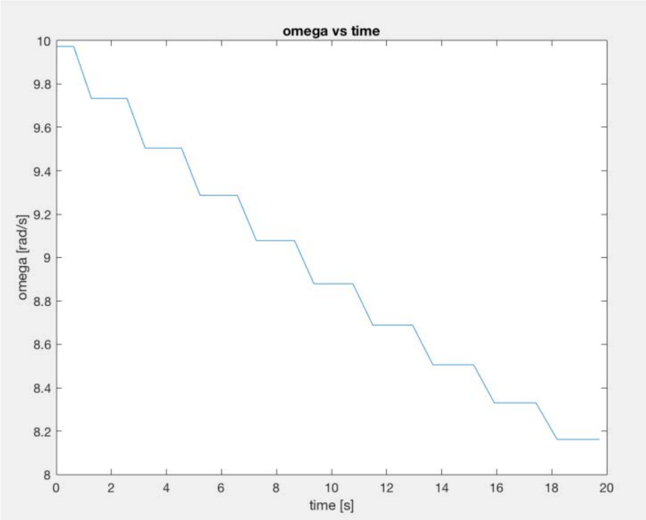
The needed Torque at 125 RPM is 1.19Nm. Looking at the Pullout torque curve one the next slide, it is possible to conclude that the motor will provide sufficient torque for the test stand to move as needed

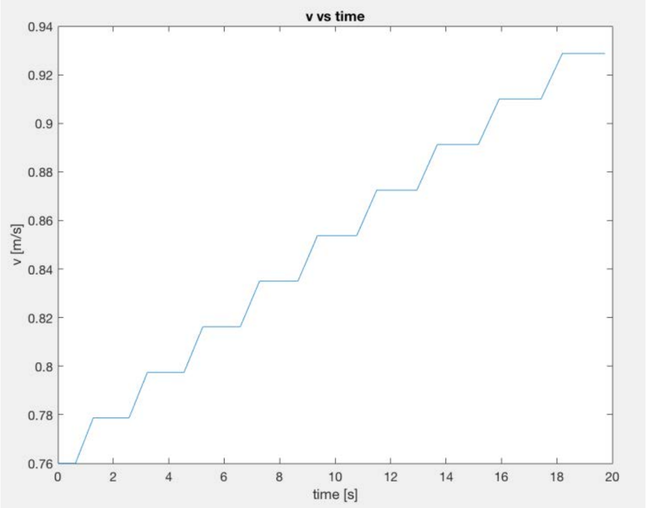
Torque vs RPM



Velocity Changes of Target Test Stand

assume that it takes 2 rotations before the cable start piling on top of each other

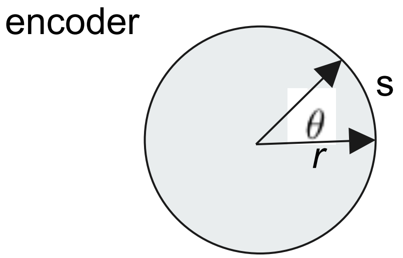




If we had to maintain a constant velocity when v_0 = 0.7 m/s, this is how we should decrease the angular velocity for the winch

If instead we maintained a constant angular rotation throughout the whole experiment, starting with our velocity would increase if we started at v_0 = 0.7 m/s,

Track Encoder math



Analysis:

$$ppr = 2\pi/\theta = 314.159$$

$$f_{max} = \omega_{max}/\theta = 1000Hz$$

$$f_{min} = \omega_{min}/\theta = 100Hz$$

Givens:

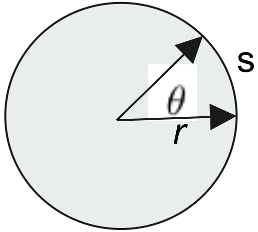
Choose s = 1 mm (accuracy at 1 m) one order of magnitude greater than Functional requirement

$$r = 5\ cm$$
$$\theta = s/r = 0.02\ rad$$
$$\omega_{max} = 190.98\ RPM$$
$$\omega_{min} = 19.09\ RPM$$

Conclusions:

- Need at least 314 pulses per rev
- Need a min frequency of 1000 Hz

Orientation Encoder math



Givens:

$$r = 5\ cm$$
$$\omega_{max} = 5\ deg/s$$
$$\omega_{min} = 1\ deg/s$$

Analysis:

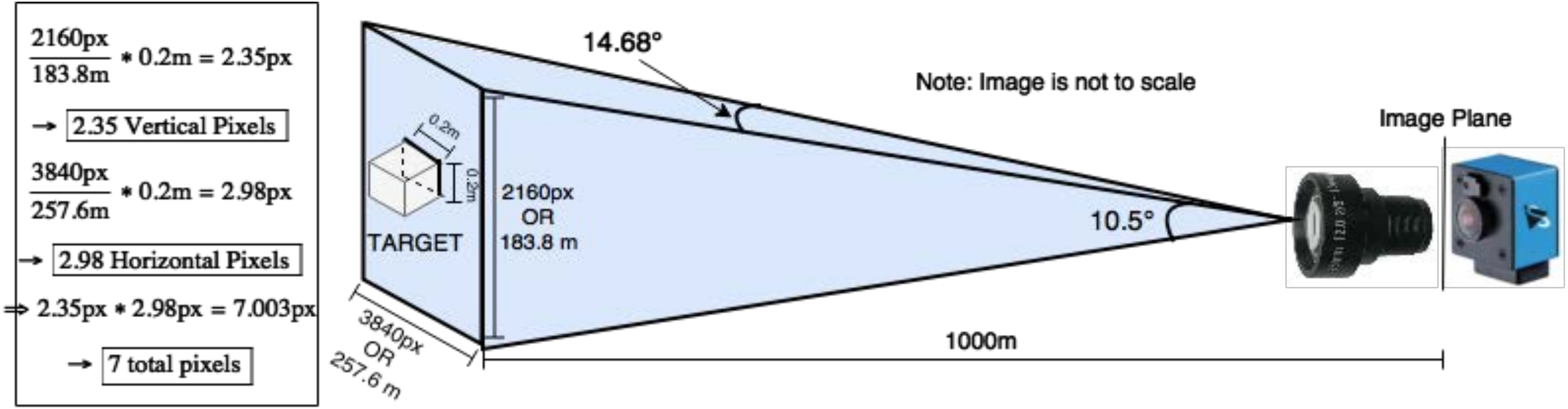
Choose detection angle to be 0.1 deg (one order of magnitude greater than functional requirement)

$$\theta = 0.1\ deg$$
$$\boxed{ppr = 360deg/\theta = 3600}$$
$$\boxed{f_{max} = \omega_{max}/\theta = 50\ Hz}$$
$$\boxed{f_{min} = \omega_{min}/\theta = 10\ Hz}$$

Conclusions:

- Need at least 3600 pulses per rev
- Need a min frequency of 50 Hz

1km Infeasibility



Allowable pixel error for background subtraction: 7px

Autofocus capabilities

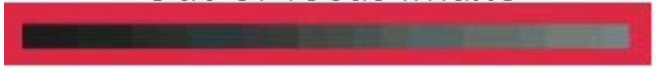
Two types: Passive and Active

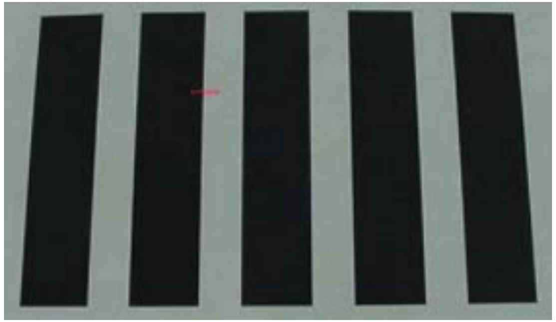
1. Active uses SONAR or IR
2. Passive uses pixel comparison and computer analysis

Passive: Determines blurriness of image → adjusts to find min. Blurriness

- Determines blurriness by contrast of edge pixels

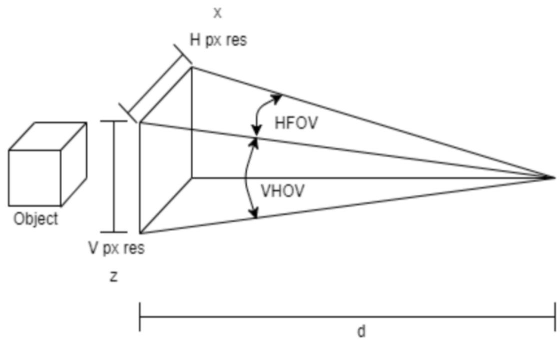
Out-of-focus image





In-focus image

Flash LiDAR Resolution



$$x = 2d \tan\left(\frac{hfov}{2}\right)$$

$$z = 2d \tan\left(\frac{vfov}{2}\right)$$

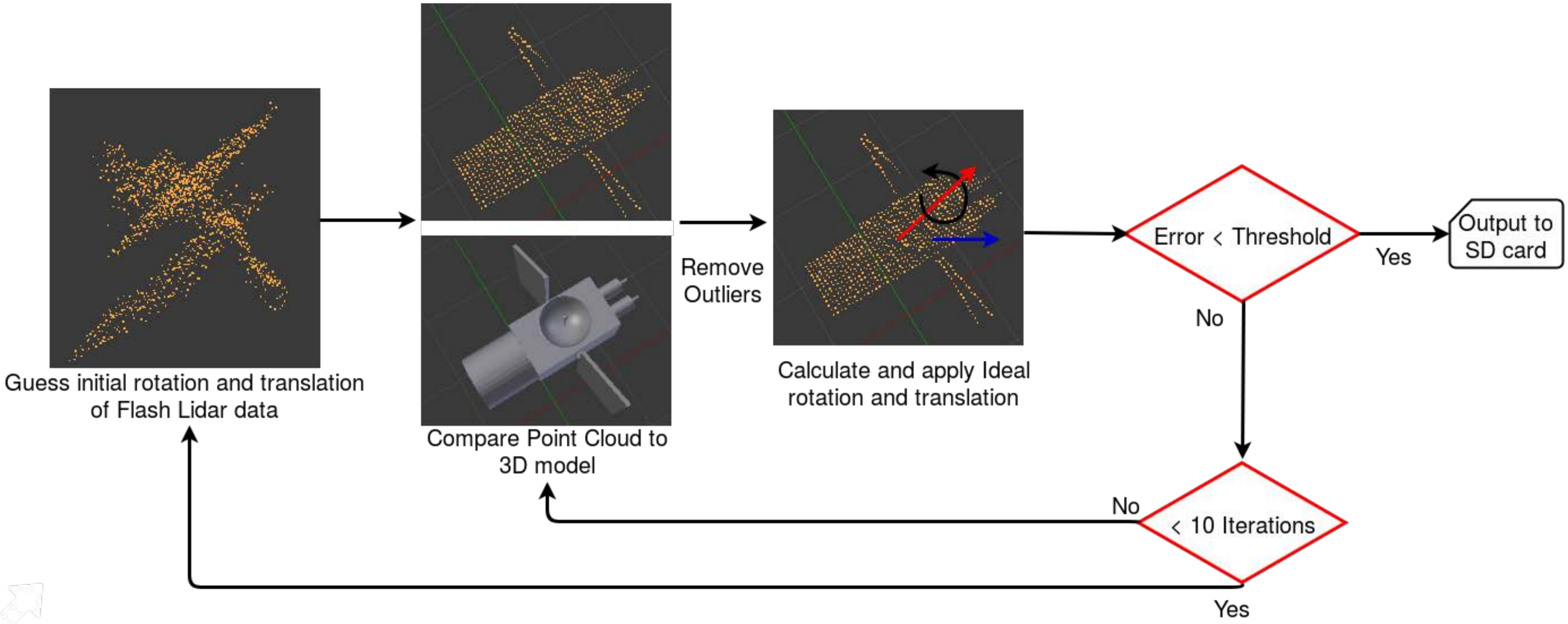
$$horizontalpix/m = \frac{HpxRes}{x}$$

$$verticalpix/m = \frac{VpxRes}{x}$$

$$\frac{TotalPixelRes}{m^2} = horizontalpix/m * verticalpix/m$$

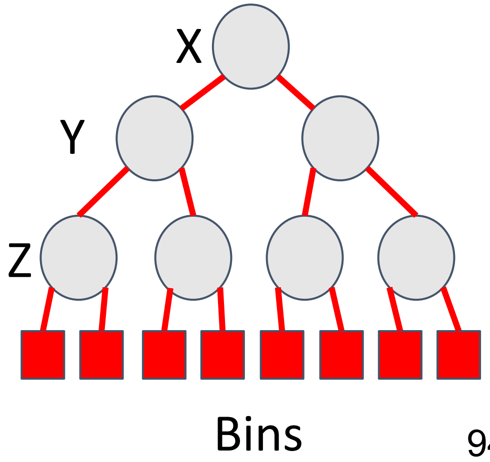
IFM O3D301	FOV:40X30	RES:176X132	20 x 20 cm	1 x 1 m
Distance (m)	total (px/m^2)	(cm^2/pixel)	Pixel per object	Pixel per object
11	492	20.32	20	492
10	596	16.79	24	596
9	735	13.60	29	735
8	931	10.75	37	931
7	1215	8.23	49	1215
6	1654	6.04	66	1654
5	2382	4.20	95	2382
4	3722	2.69	149	3722
3	6617	1.51	265	6617
2	14888	0.67	596	14888
1	59554	0.17	2382	59554

FLOOD Explained



FLOOD Explained- K-D Search

1. Faces from 3D model are stored in bins in a k-d tree data structure
   a. Each bin represents a 3D box
2. For each point from our Lidar scan traverse down to bin containing that point
3. Check the distance from point to each face contained in bin
4. Repeat step 3 for neighboring bins if the distance to the edge of that bin is less than the current minimum found distance



FLOOD Explained

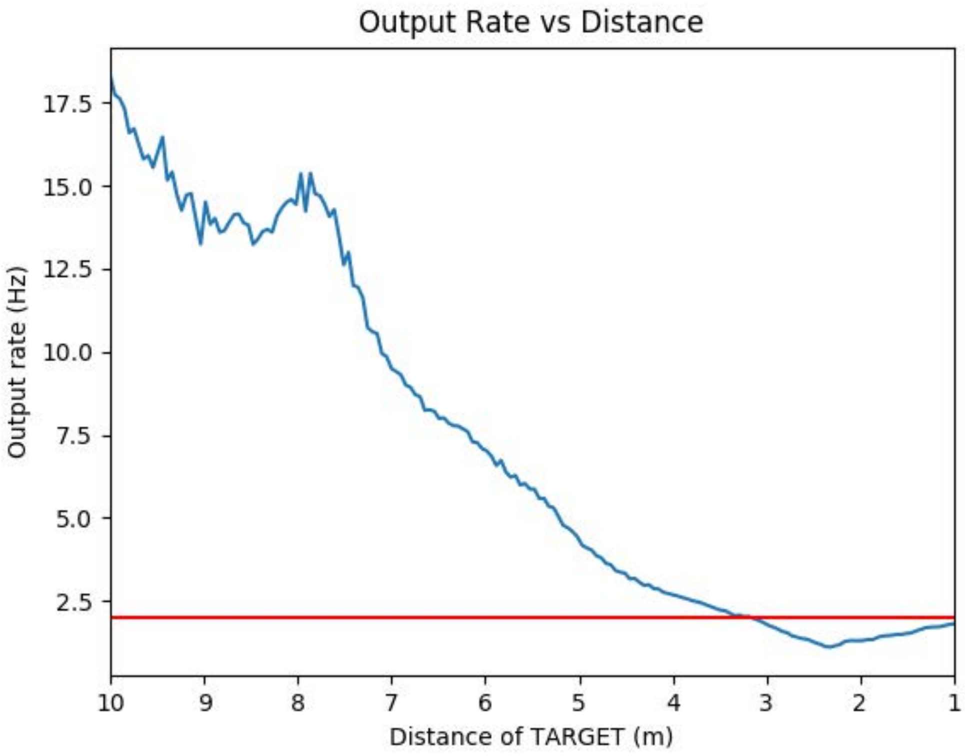
Given the two point cloud sets M and D, where D is the set produced by the LiDAR scan, and M is the set derived from the model. For each point $d_i \in \mathbb{R}^3$ in D, and a rotation R and translation t, there is a point c_i such that.

$$c_i = arg \min_{c_k \in M} \parallel (Rd_i + t) - c_k \parallel, \qquad \forall i = 1...m \tag{1}$$

t and R are then calculated using the following error function.

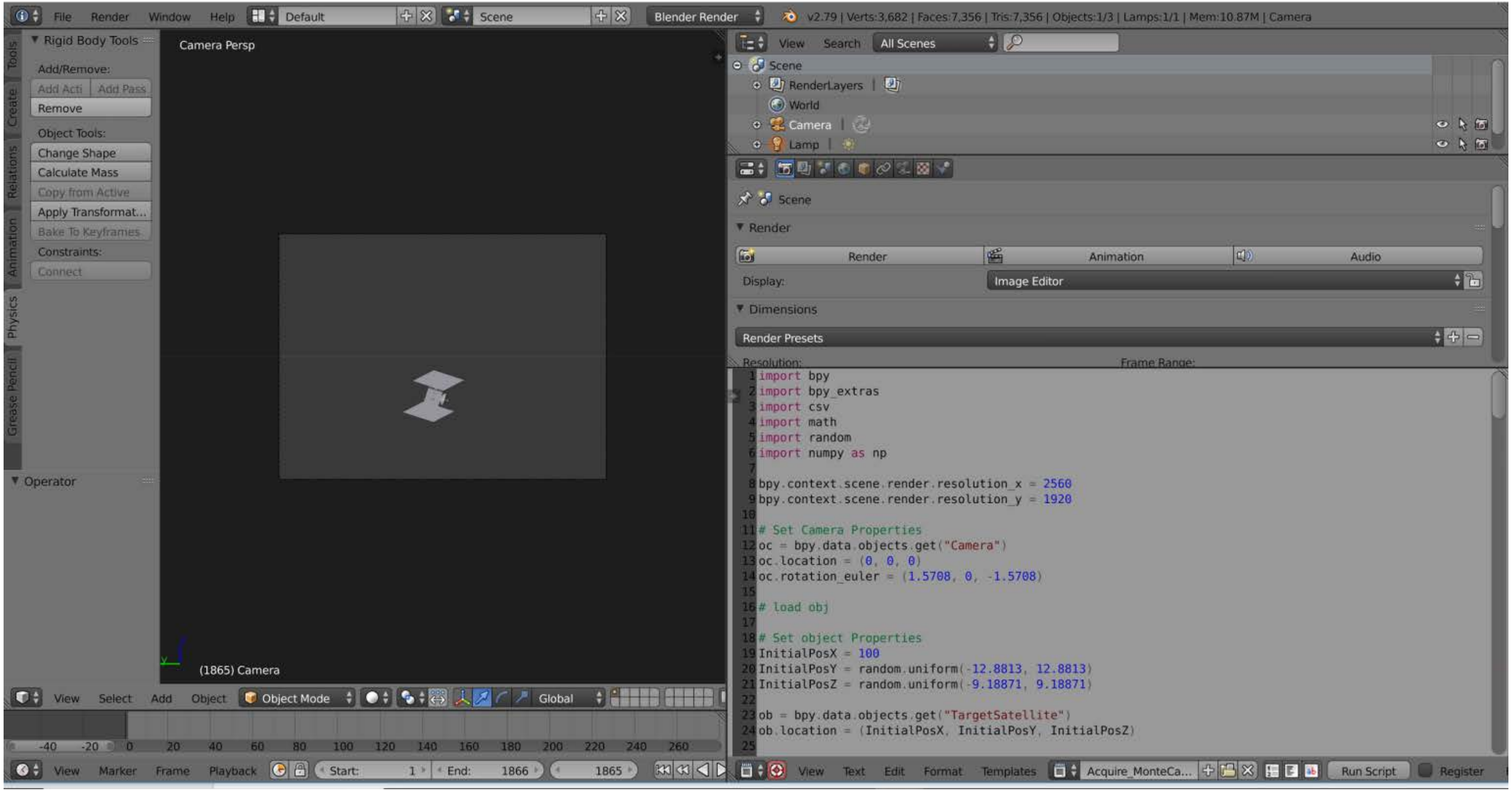
$$\epsilon = \frac{1}{m} \min_{t,R} \sum_{i=1}^{m} \parallel Rd_i + t - c_i \parallel^2 \tag{2}$$

FLOOD Timing



- Almost always above 2 Hz minimum
- Add in maximum number of points so algorithm does not have to process 10's of thousands of points

Blender


File Render Window Help Default Scene Blender Render
v2.79 | Verts:3,682 | Faces:7,356 | Tris:7,356 | Objects:1/3 | Lamps:1/1 | Mem:10.87M | Camera
Rigid Body Tools
Add/Remove:
Add Acti
Add Pass
Remove
Object Tools:
Change Shape
Calculate Mass
Copy from Active
Apply Transformat...
Bake To Keyframes
Constraints:
Connect
Operator
Tools
Create
Relations
Animation
Physics
Grease Pencil
Camera Persp
(1865) Camera
View Select Add Object Object Mode Global
View Marker Frame Playback Start: 1 End: 1866 1865
View Search All Scenes
Scene
RenderLayers
World
Camera
Lamp
Scene
Render
Render
Animation
Audio
Display: Image Editor
Dimensions
Render Presets
Resolution:
Frame Range:
import bpy
import bpy_extras
import csv
import math
import random
import numpy as np
bpy.context.scene.render.resolution_x = 2560
bpy.context.scene.render.resolution_y = 1920
# Set Camera Properties
oc = bpy.data.objects.get("Camera")
oc.location = (0, 0, 0)
oc.rotation_euler = (1.5708, 0, -1.5708)
# load obj
# Set object Properties
InitialPosX = 100
InitialPosY = random.uniform(-12.8813, 12.8813)
InitialPosZ = random.uniform(-9.18871, 9.18871)
ob = bpy.data.objects.get("TargetSatellite")
ob.location = (InitialPosX, InitialPosY, InitialPosZ)
View Text Edit Format Templates Acquire_MonteCa... Run Script Register

Distribution of LRF Mean

n= number of LRF returns per every system data output
σ = standard deviation of normal distribution for single LRF data output
$\bar{X}$ = the mean of all LRF data over the coarse of half a second. It should be noted the the expected value of the mean is the actual distance.
CI = Confidence Interval
$Z_{\alpha/2}$ = Normal Distribution Critical value

Important to note that the standard deviation of the mean is $\frac{\sigma}{\sqrt{n}}$

Normal distribution of mean of LRF data:

$$CI : \bar{X} \pm Z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \rightarrow Z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \leq 0.01\bar{X}$$

For a 99% confidence interval that the LRF is returning data with in one percent of actual distance, $Z_{\alpha/2} = 2.575$.

$$(2.575)\frac{\sigma}{\sqrt{n}} \leq 0.01\bar{X} \rightarrow \sigma \leq 0.003883d$$

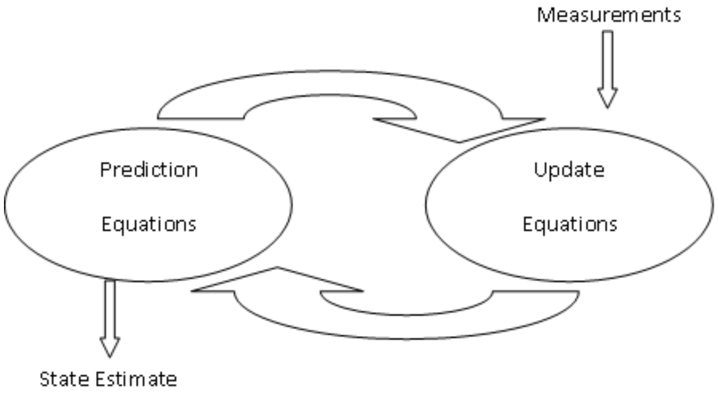
Use of Kalman Filtering

Means to use data from multiple sources in order to create a joint probability distribution that can then be used to more accurately predict the correct data parameters.

Our Date Sources:

- Laser Range Finder
- Optical Camera
- LiDar

Our goal using a Kalman filter: to optimize estimation of the state of the TARGET satellite in the Orientation Phase.



Position Error Propagation

Using the standard deviation of the position the standard deviation of the velocity can be calculated with the following equation:

$$x = a + b - c \quad \sigma_x = \sqrt{\sigma_a^2 + \sigma_b^2 + \sigma_c^2}$$

For velocity error propagation ($\sigma_{pos1} = \sigma_{pos}$):

$$vel = pos2 - pos1 \quad \sigma_{vel} = \sqrt{\sigma_{pos1}^2 + \sigma_{pos2}^2} = \sqrt{2\sigma_{pos1}^2} = \sqrt{2}\sigma_{pos}$$

Based on the velocity error propagation, the standard deviation of the laser range finder needs to be the following to satisfy 1% accuracy. The worst case is at 10m with 10 data returns per half second.

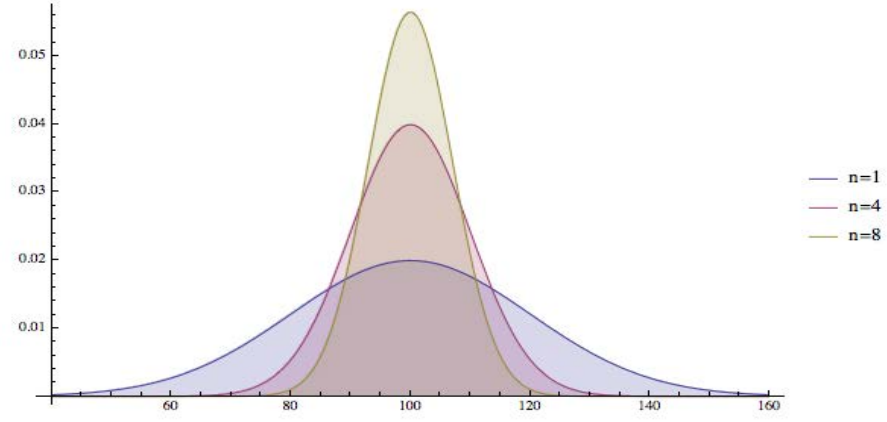
$$\sqrt{2}\sigma_{pos} \leq \sqrt{n}(0.003883)d \rightarrow \sigma_{pos} \leq \sqrt{n/2}(0.003883)d = \sqrt{5}(0.03883) = 0.0868$$

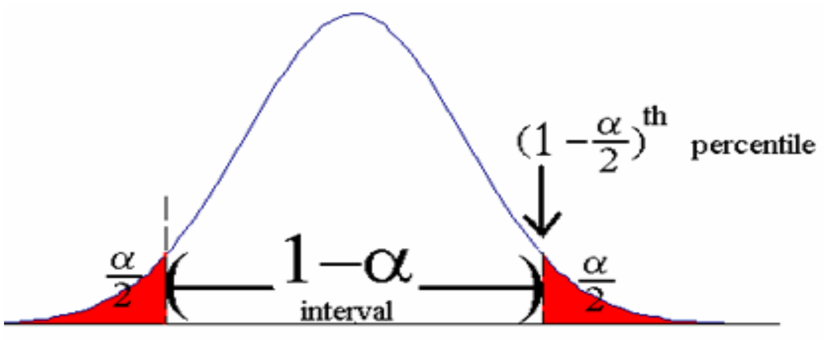
Therefore the 99% confidence interval can be calculated.

$$Z_{\alpha/2}\frac{\sigma}{\sqrt{n}} = (2.575)(0.0868/\sqrt{1}) = \pm 0.224m$$

Behavior of STD of Sample Mean-Central Limit Thm

Important to note that the standard deviation of the mean is $\frac{\sigma}{\sqrt{n}}$





OpC w/ Background subtraction

σ_n = standard deviation of vertical pointing off center in number of pixels
σ_ψ = standard deviation of horizontal pointing off center in meters
σ_θ = standard deviation of vertical pointing off center in meters
d = distance away from camera

α = horizontal full angle
β = vertical full angle
m = number of pixels in horizontal direction
n = number of pixels in vertical direction
σ_m = standard deviation of horizontal pointing off center in number of pixels

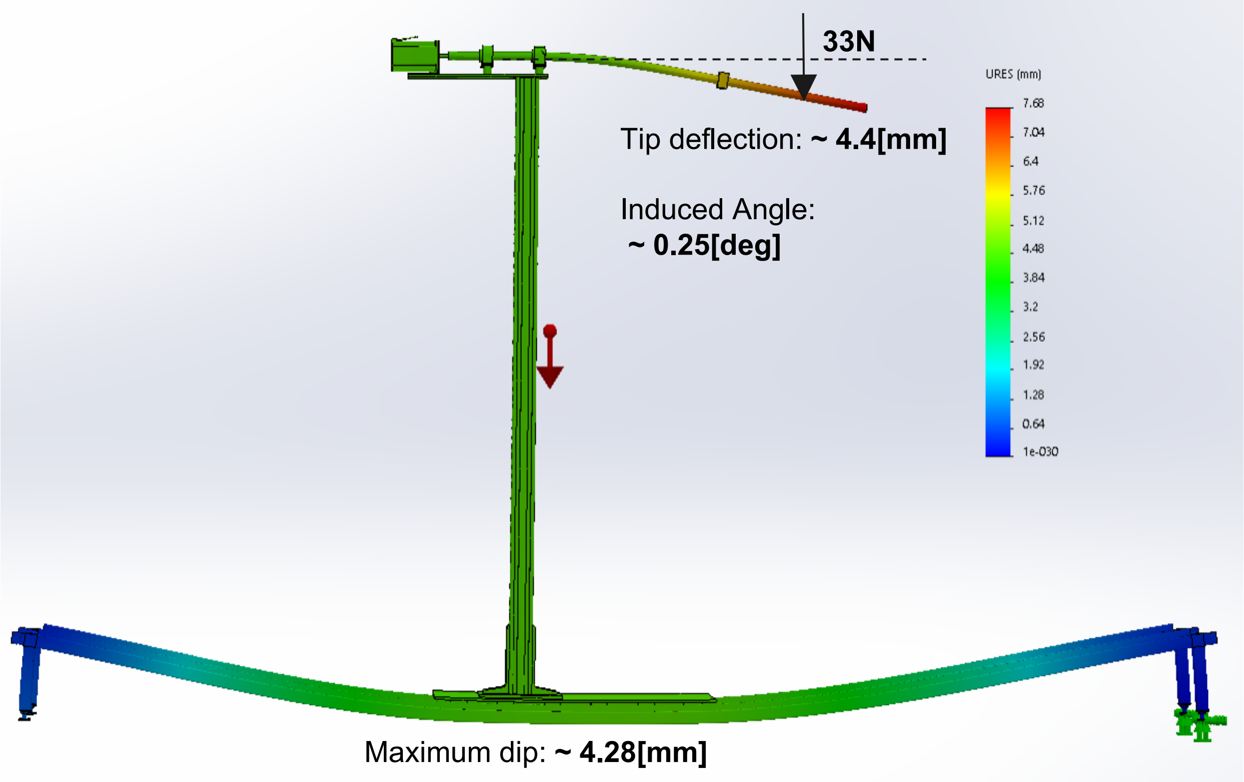
To calculate the standard deviation in terms of meters.

$$\sigma_\psi = \frac{2dtan(\frac{\alpha}{2})}{m}(\sigma_m) \quad \sigma_\theta = \frac{2dtan(\frac{\beta}{2})}{n}(\sigma_n)$$

A smaller field of view is beneficial, the alpha and beta of the hard found that is the smallest but can still fit the larger possible target in the FOV at the minimum distance of 10 m with a 25mm focal length is $\alpha = 14.68$ and $\beta = 10.5deg$

The expected value for the distance returned from the center of the object is zero so in order to construct the normal distributions for horizontal and vertical pointing.

$$\theta = \sigma_\theta Z \quad \psi = \sigma_\psi Z$$


33N
Tip deflection: ~ 4.4[mm]
Induced Angle:
~ 0.25[deg]
URES (mm)
7.68
7.04
6.4
5.76
5.12
4.48
3.84
3.2
2.56
1.92
1.28
0.64
1e-030
Maximum dip: ~ 4.28[mm]

103