Smallsat Connected Optical Positioning Entity

Manufacturing Status 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

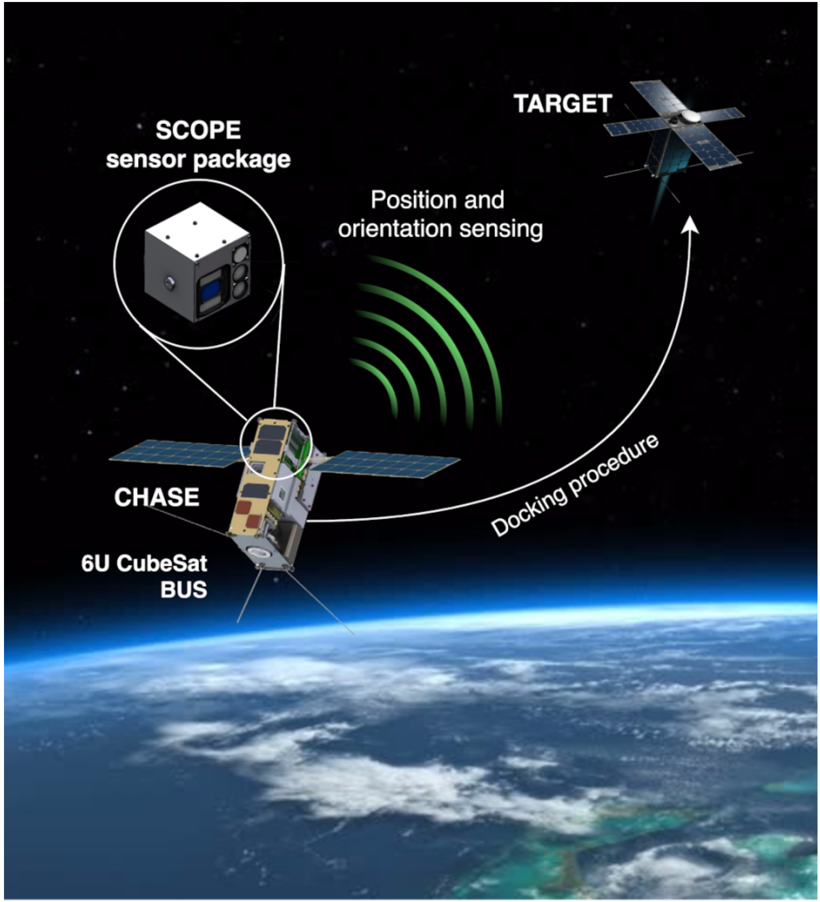
Presentation Outline

Sections	Presenter(s)
Project Description	Nick
Schedule	Mason
Manufacturing: Mechanical	Alec and Greg
Manufacturing: Software	Zach and Guy
Manufacturing: Electrical	Guy
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.



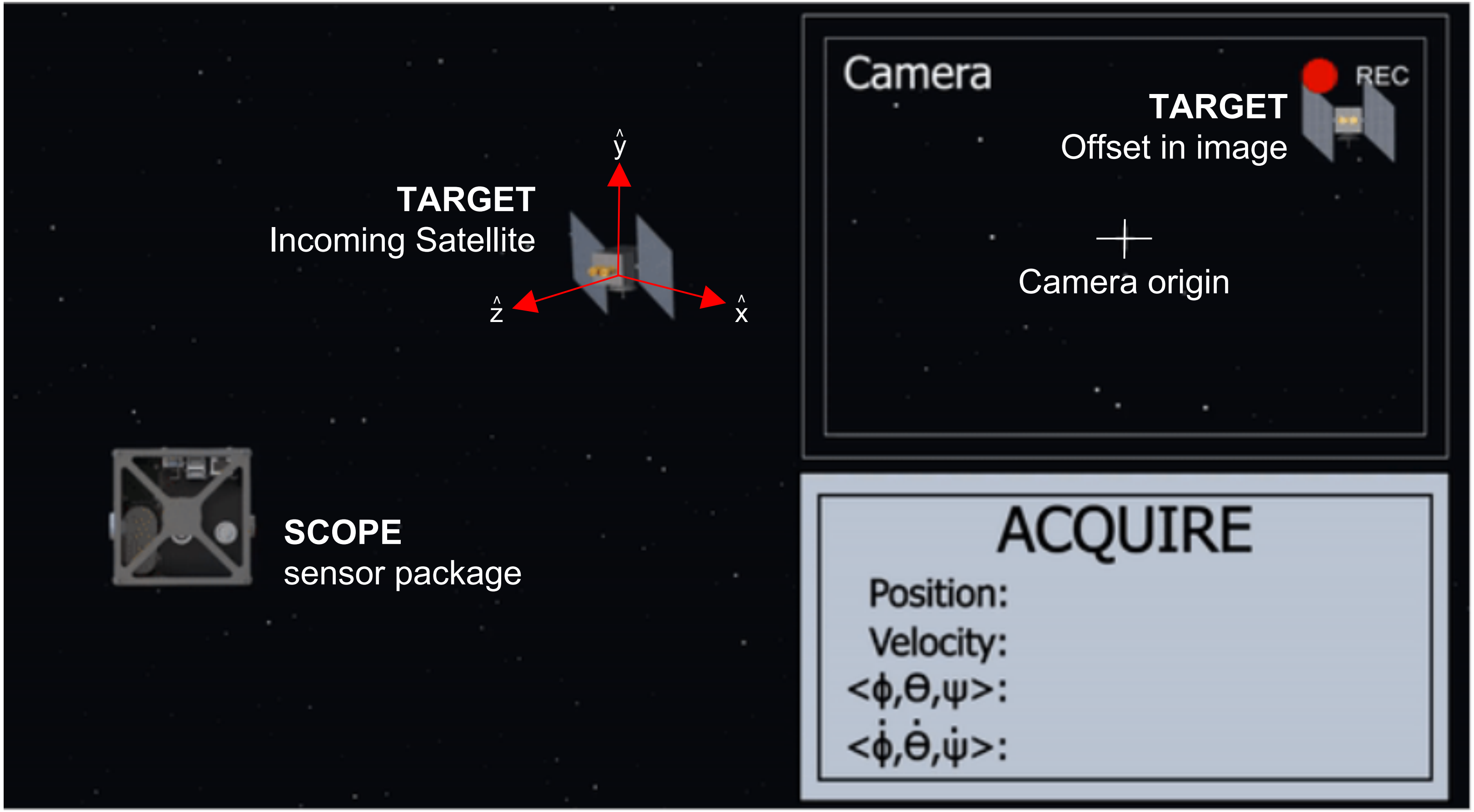
Levels of Success

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

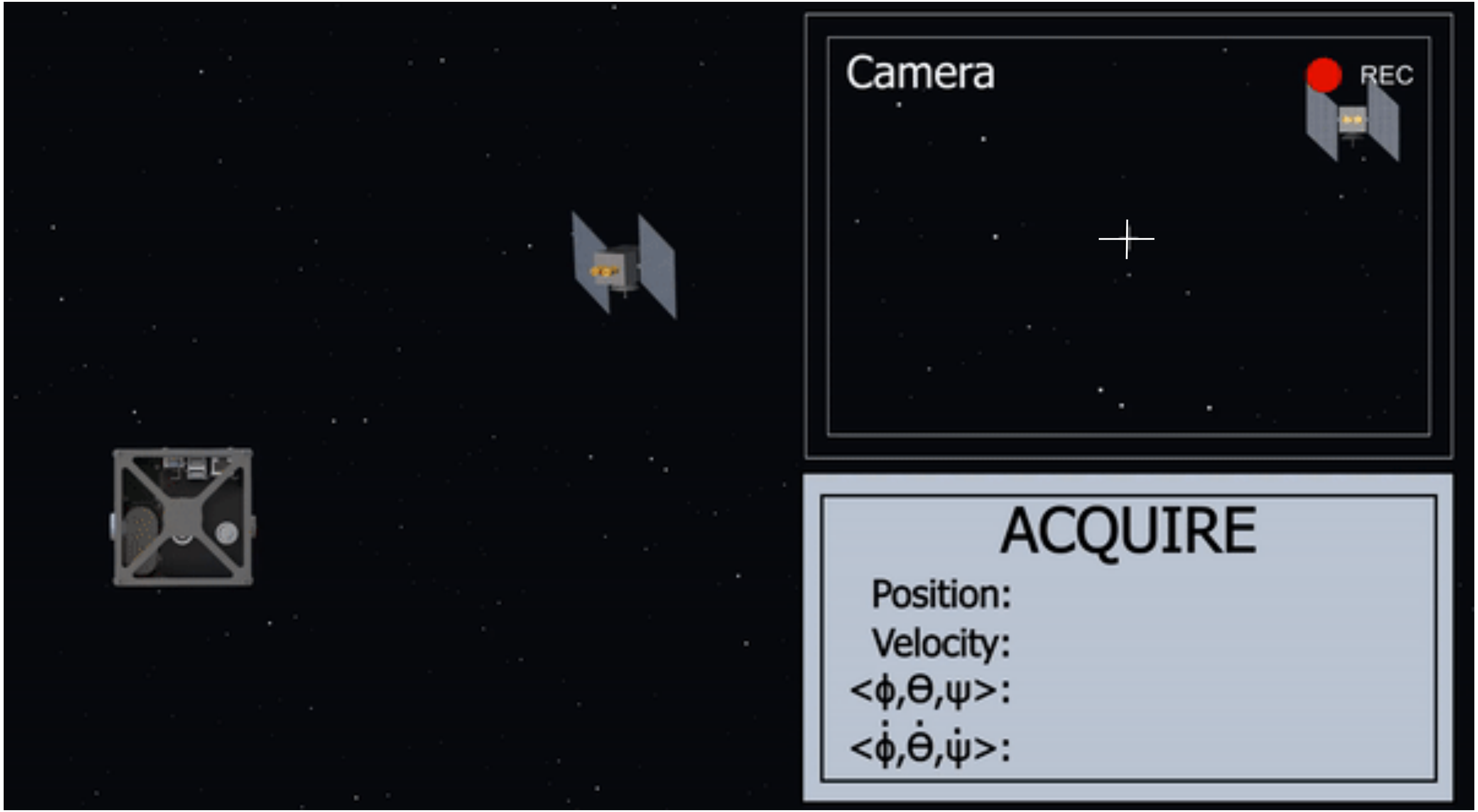
Level 2: Detect and return data outputs of a target satellite with no markers, but with a known 3-D model.

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

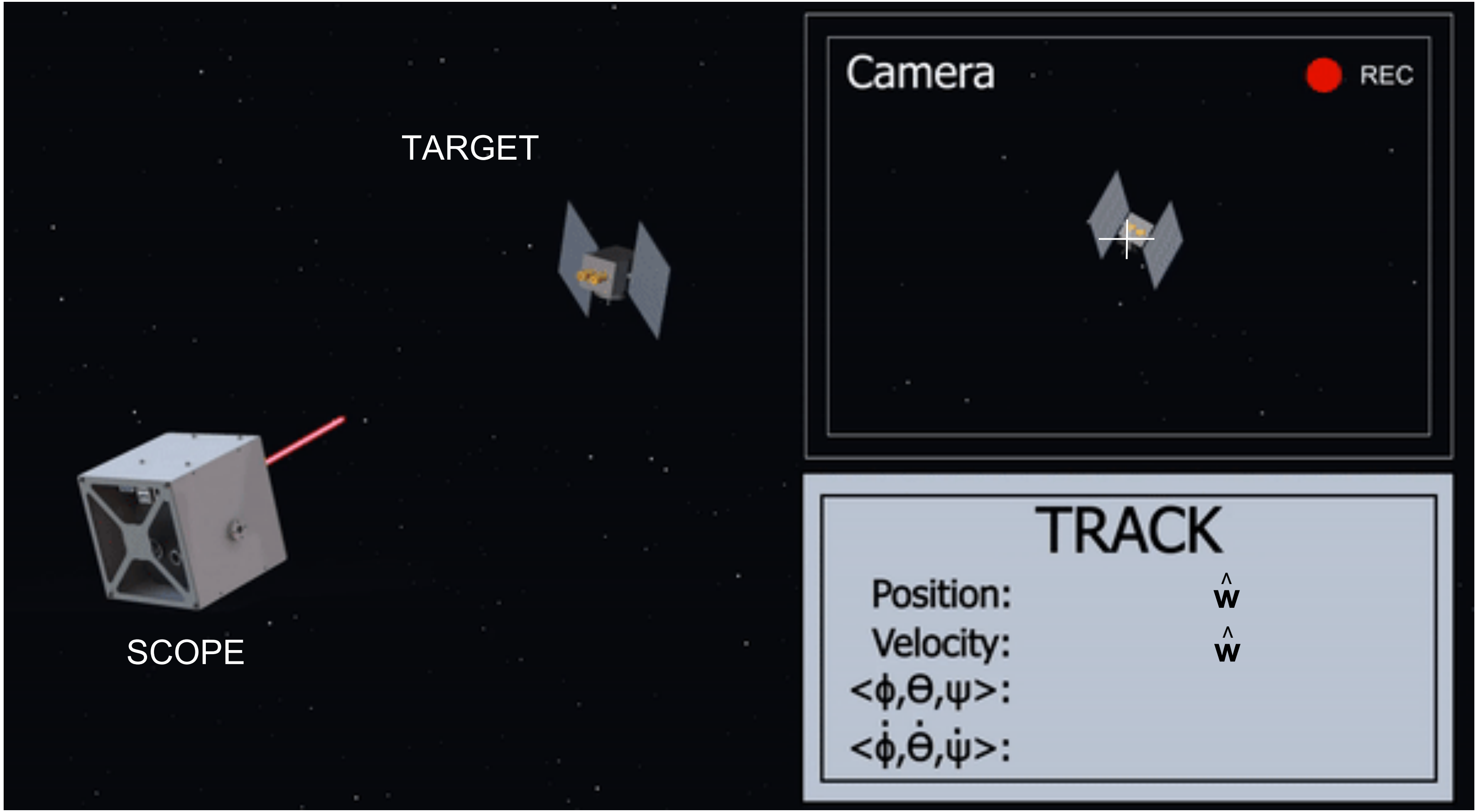
Mission CONOPS



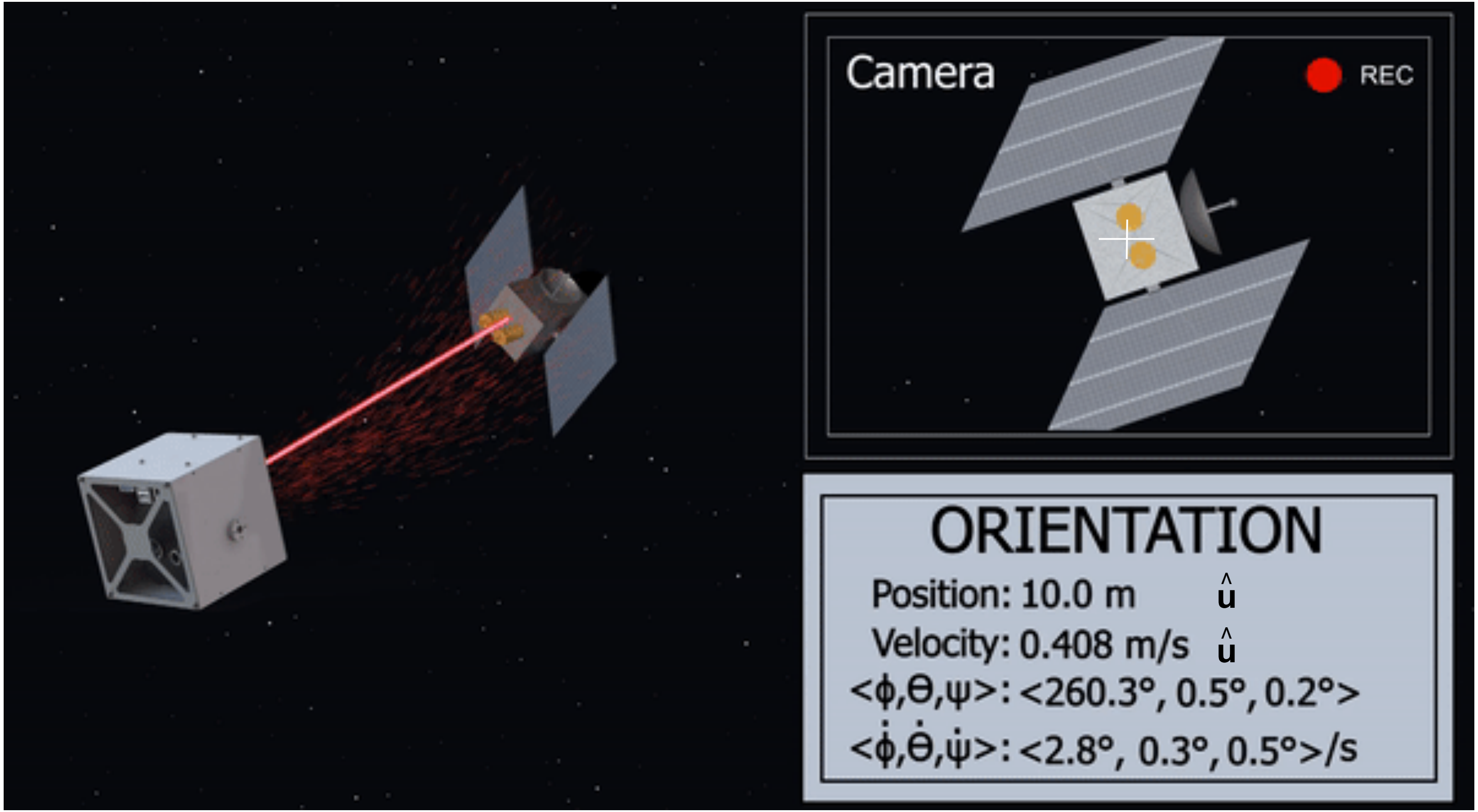
Mission CONOPS



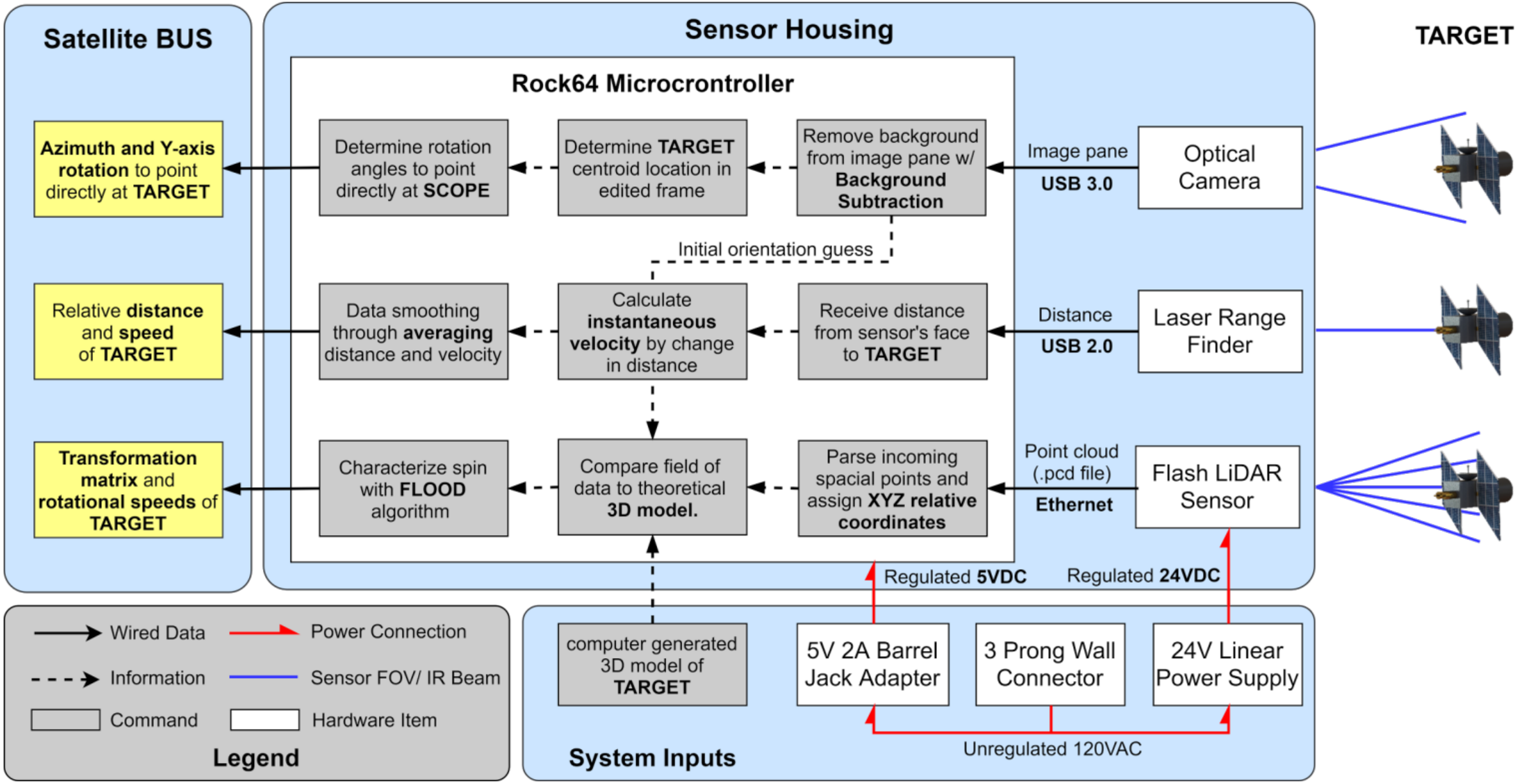
Mission CONOPS



Mission CONOPS



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

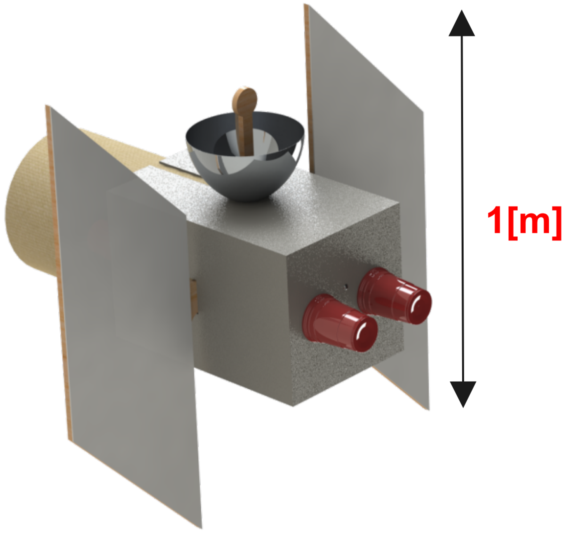
1. Return orientation of **TARGET** within 1 deg of actual.
2. Return angular rates of **TARGET** within 1% of actual.

1-U Satellite Constraints

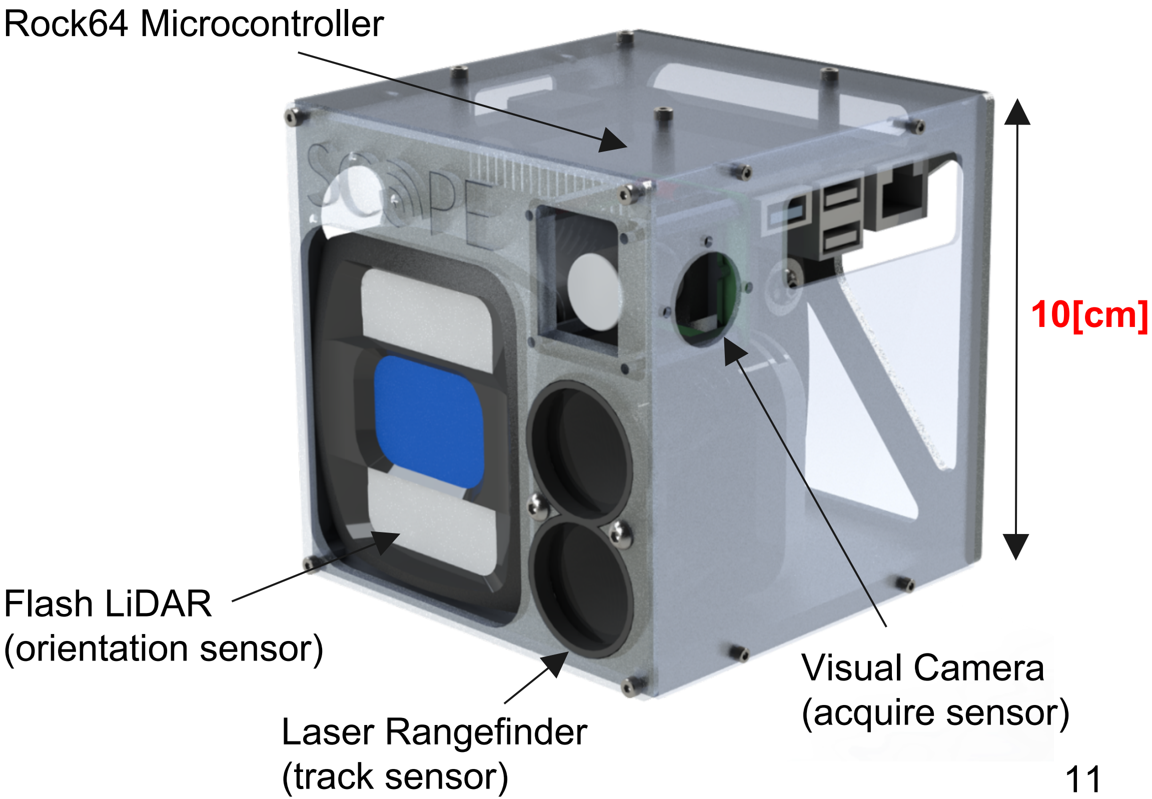
1. Mass is less than **1.33[kg]**
2. Dimensions fit within **10x10x10[cm]**
3. Data is written at a rate faster than **2[Hz]**
4. Average power remains below **20W**

Baseline Design

Target Satellite



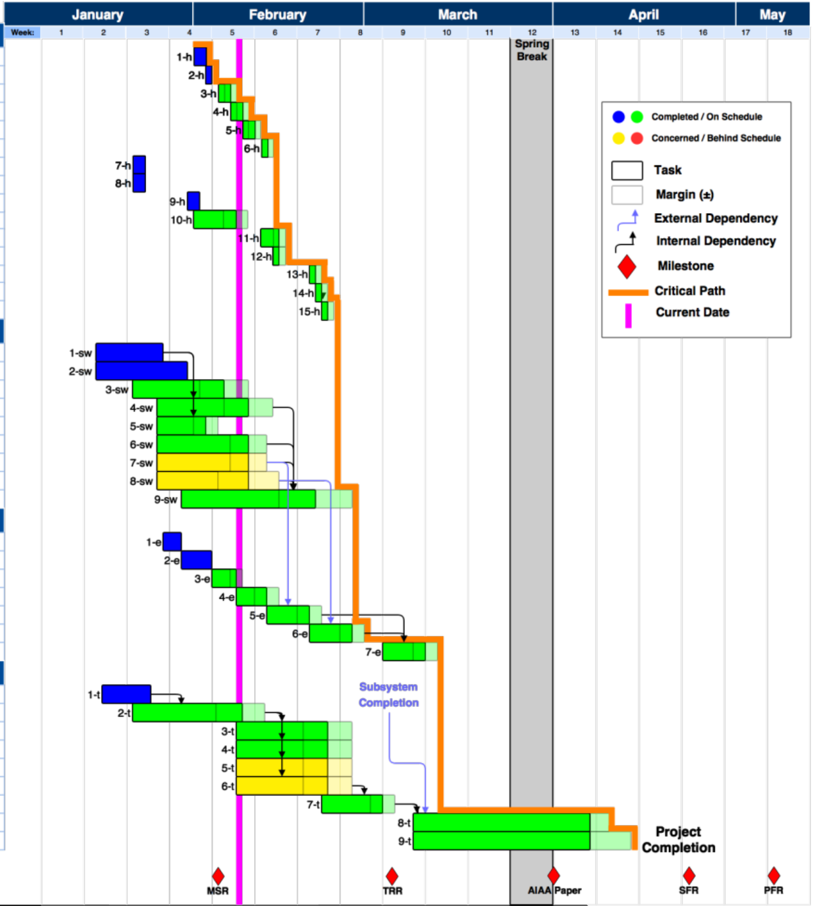
SCOPE Sensor Package



Project Schedule

Manufacturing 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
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
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 | Manufacturing | Budget

SCOPE/TARGET Hardware Schedule

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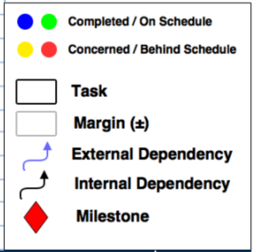

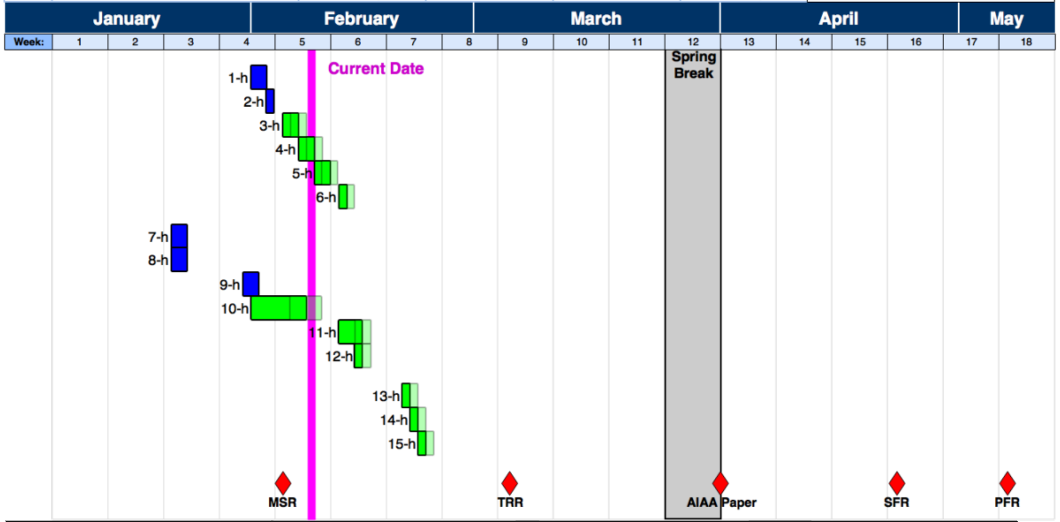

Overview | **Schedule** | Manufacturing | Budget

Software Schedule

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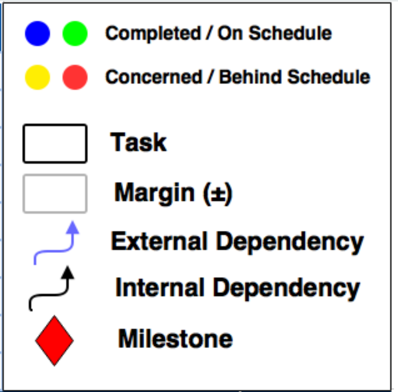
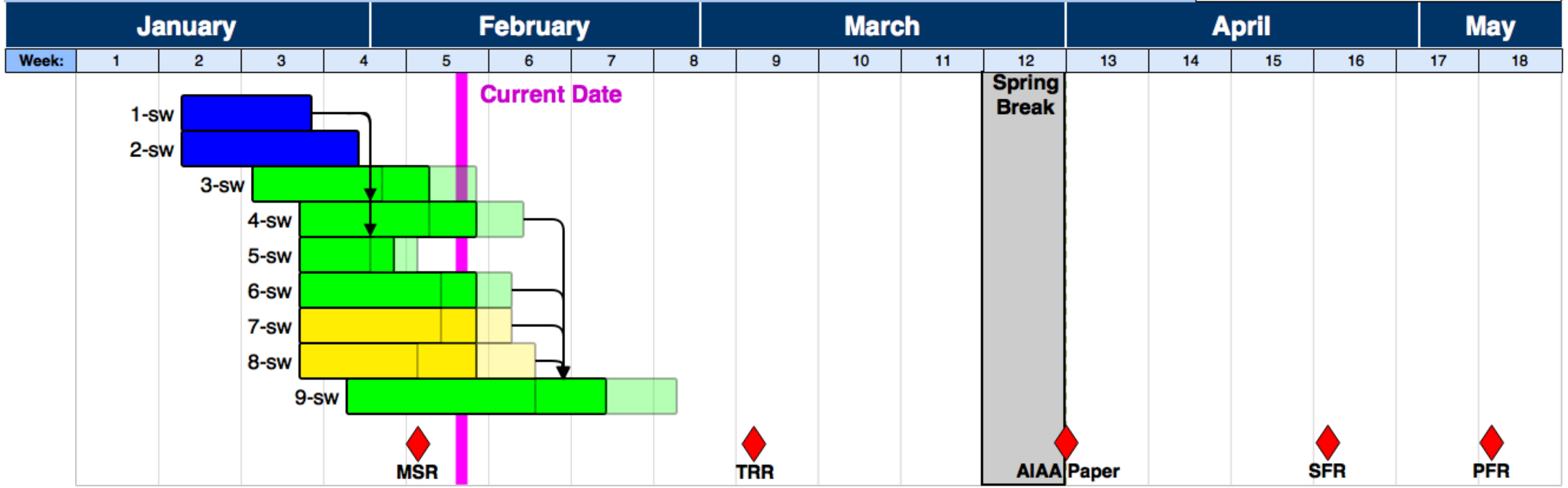
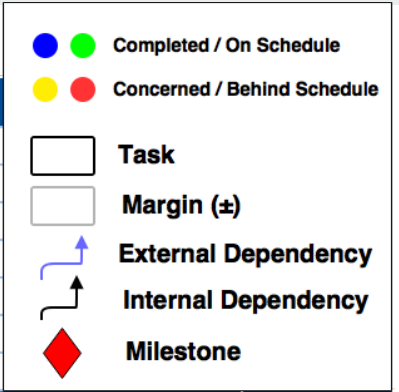




Electrical Schedule



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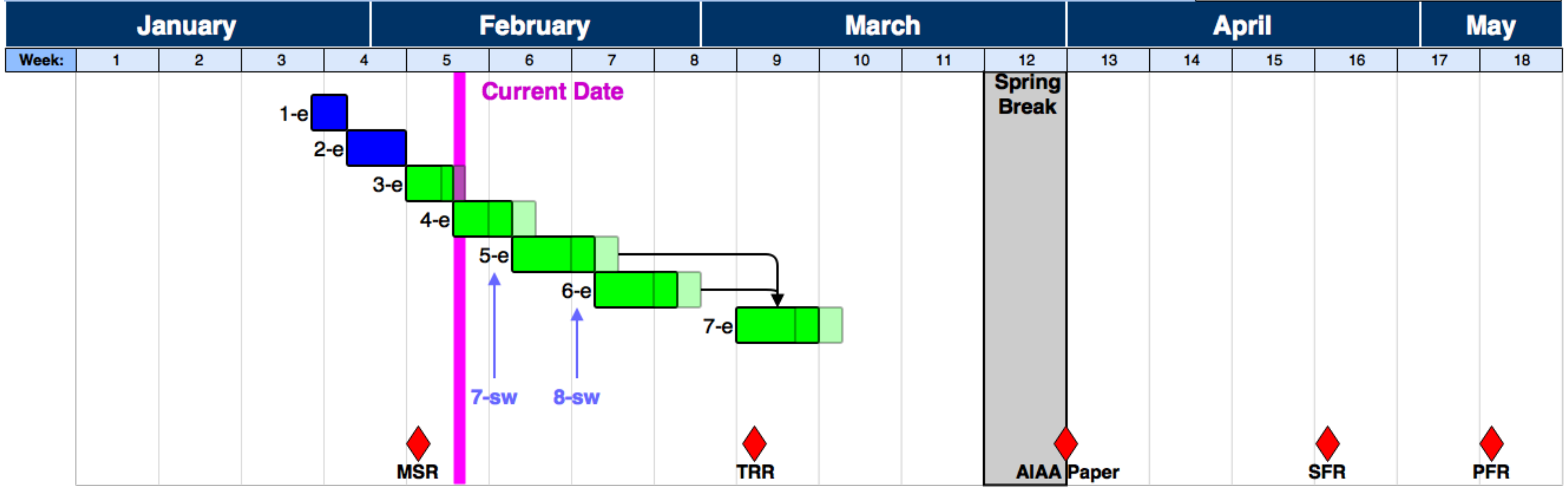

Testing Schedule

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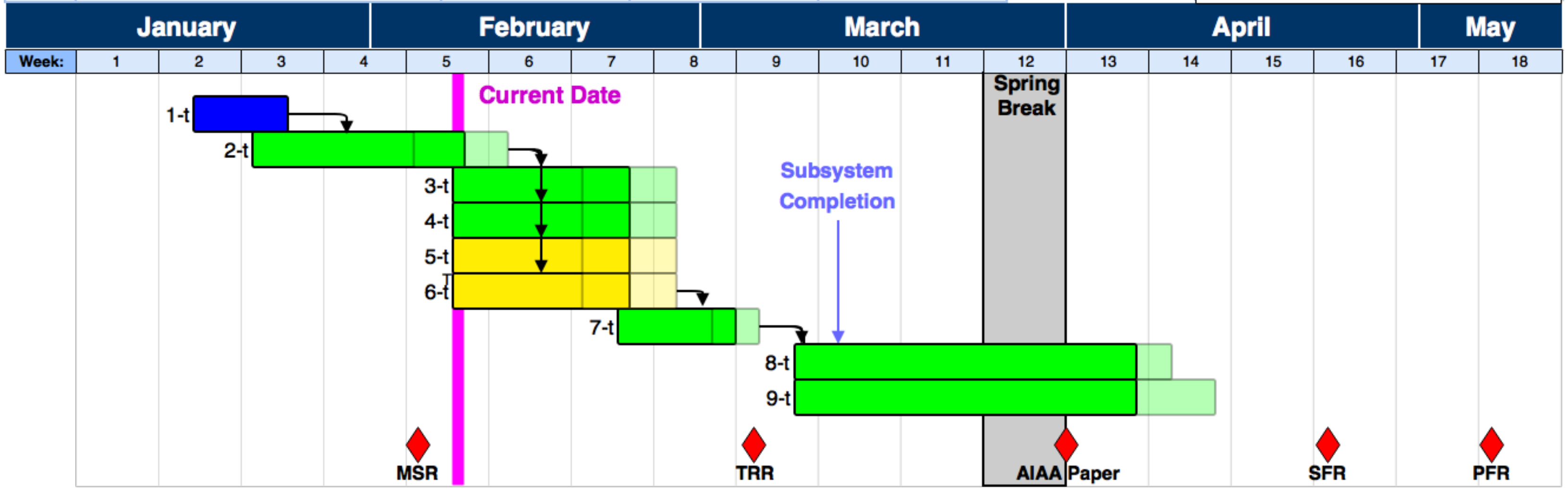
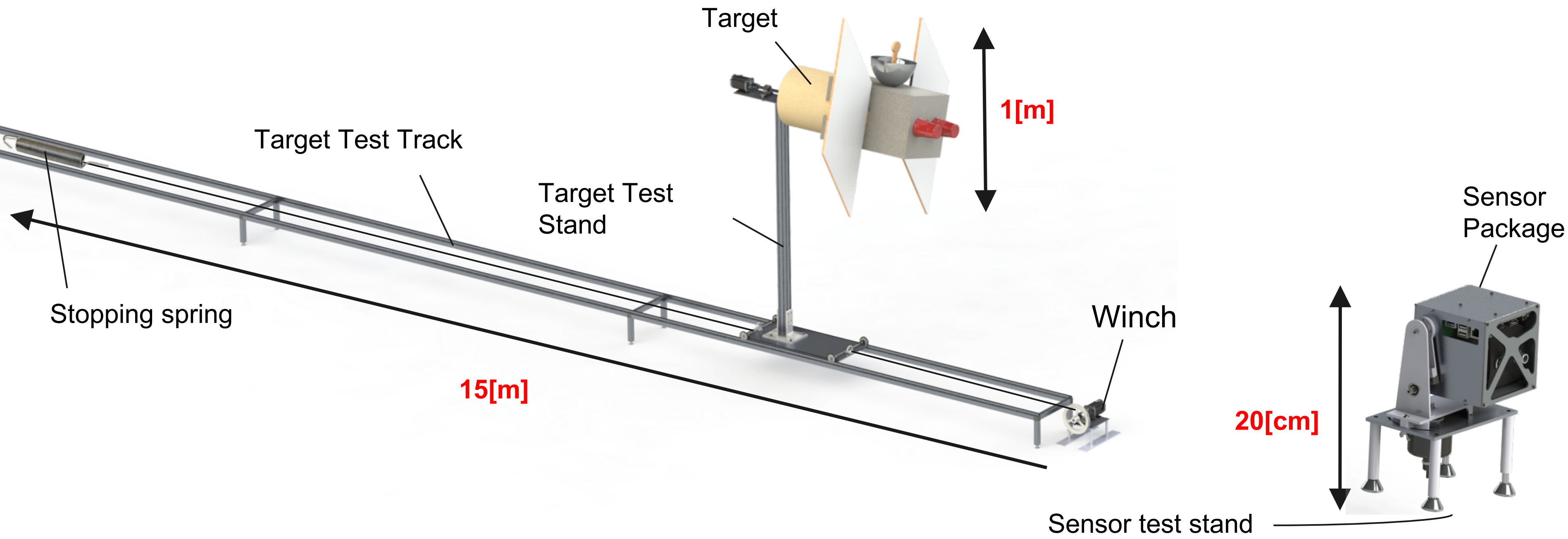
Completed / On Schedule
Concerned / Behind Schedule
Task
Margin (±)
External Dependency
Internal Dependency
Milestone



Overview | Schedule | Manufacturing | Budget

Manufacturing

Manufacturing Overview



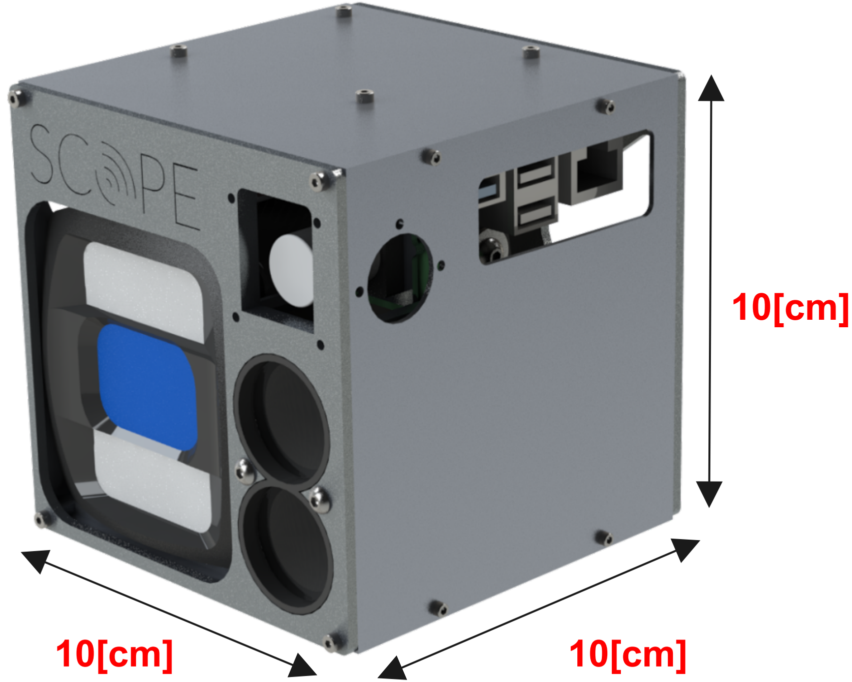
Manufacturing of SCOPE Shell	18/40 hr
Manufacturing of Testing Hardware	7/50 hr
Software Implementation and Optimization	22/60 hr
Electronics/Software Integration	15/60 hr

Completed
On Schedule
Concerned
Behind Schedule

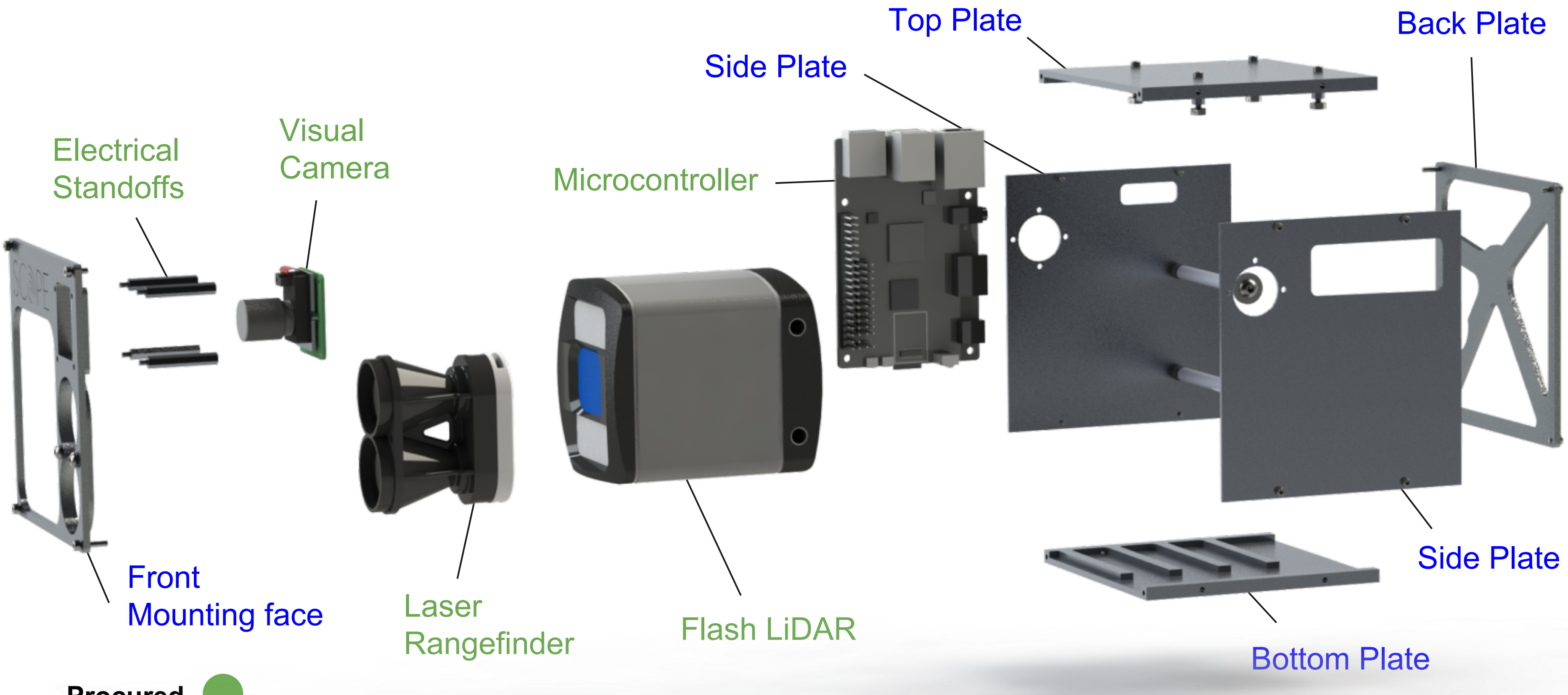
SCOPE Shell Design

Driving Requirements
DR 7.1 The sensor package shall not exceed **10**x**10**x**10[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

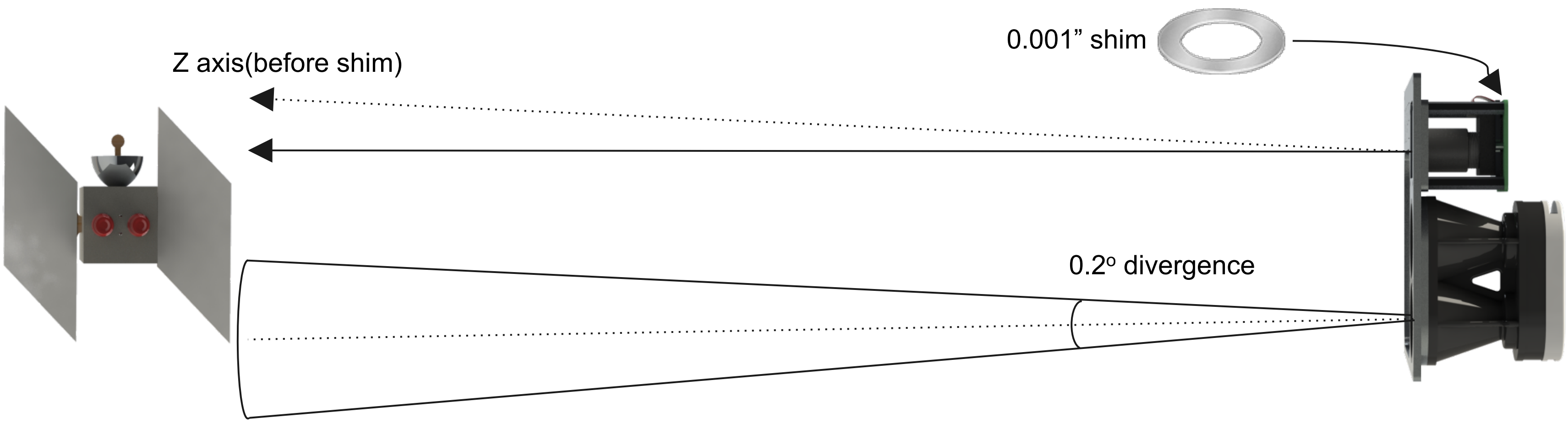


Procured

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.

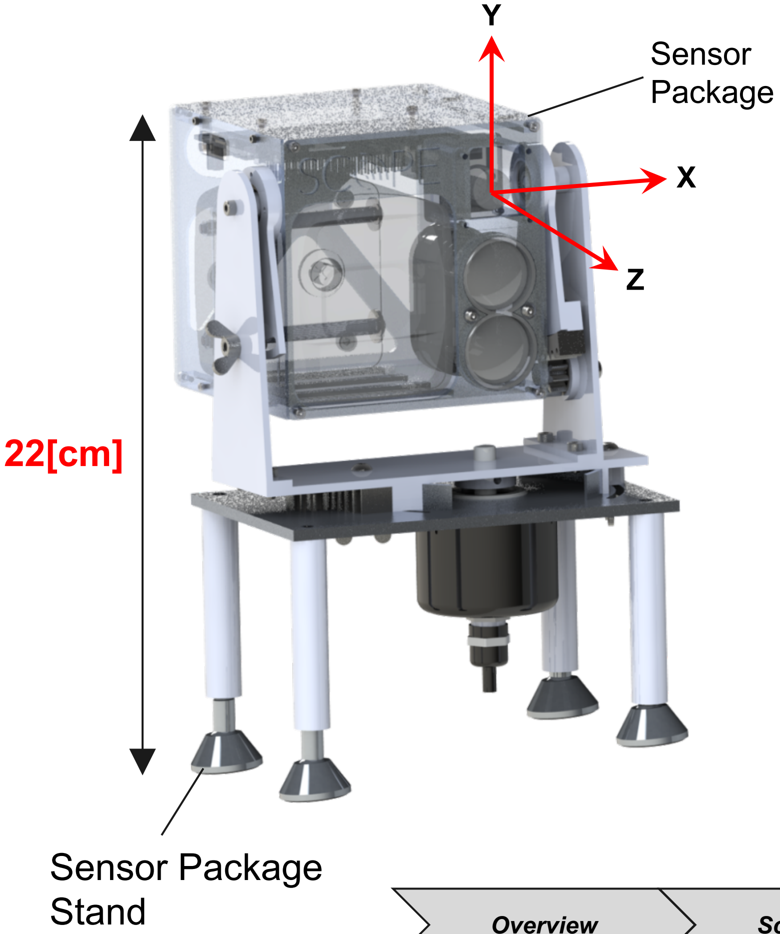


Completed
On Schedule
Concerned
Behind Schedule

SolidWorks Model → Machining Programs (3/5 hr) → Manufacturing (4/15 hr) → Assembly/Tuning (0/6 hr) → Testing (0/12 hr)

Overview | *Schedule* | *Manufacturing* | *Budget*

SCOPE Test Stand

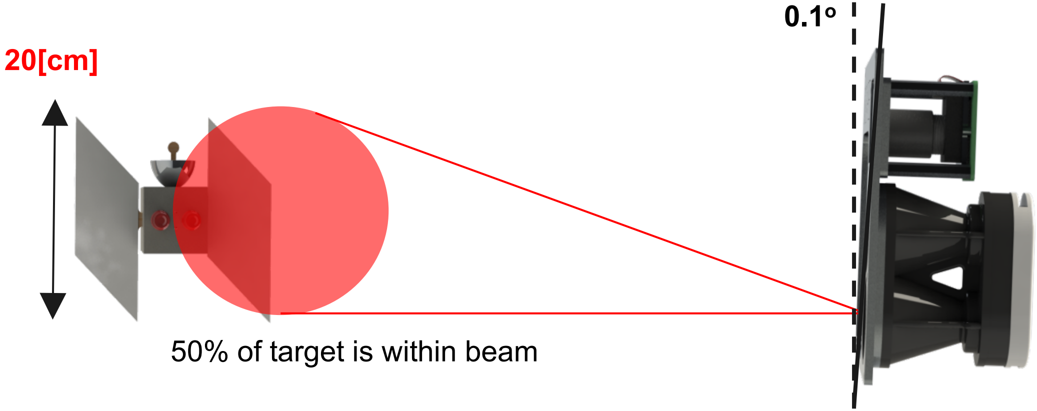


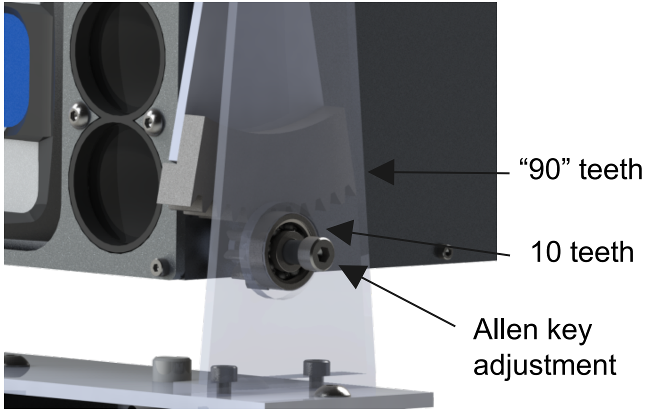
Driving Requirements
DR 1.1 The sensor shall be able to detect a target satellite with volumetric dimensions between **20x20x30 [cm]** and **1x1x1 [m]**.
DR 1.2.1 The sensor shall be able to detect a target satellite at a range of **100 [m].**

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.

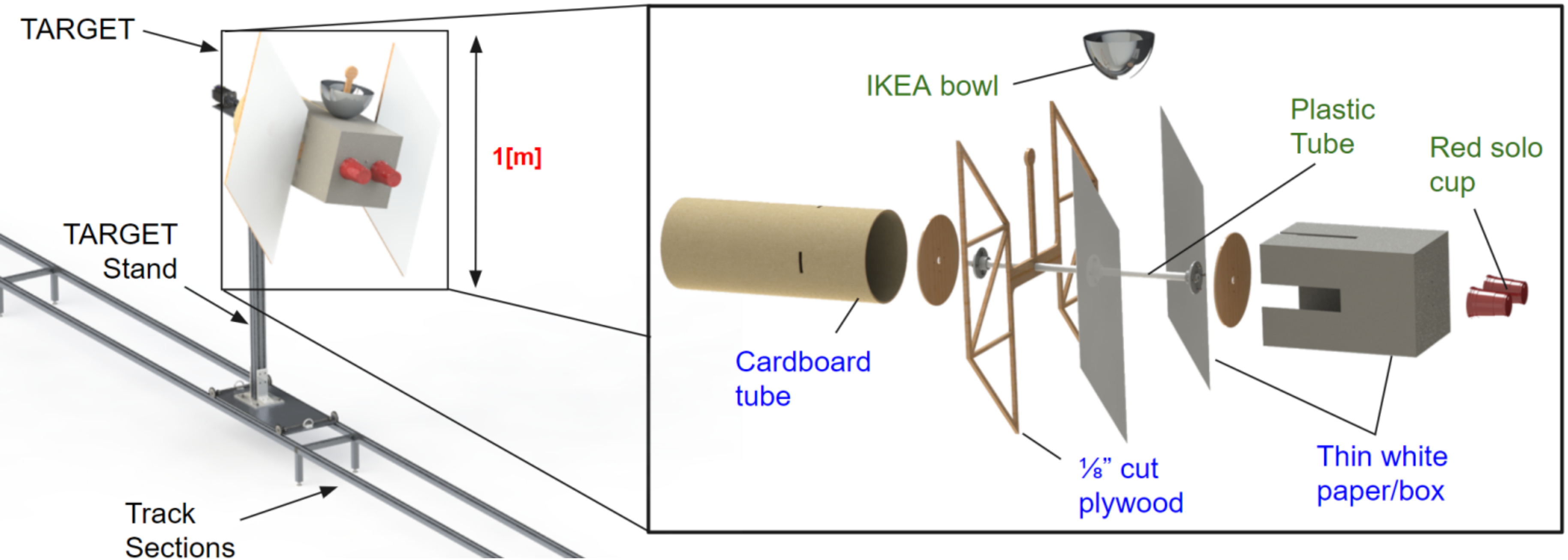


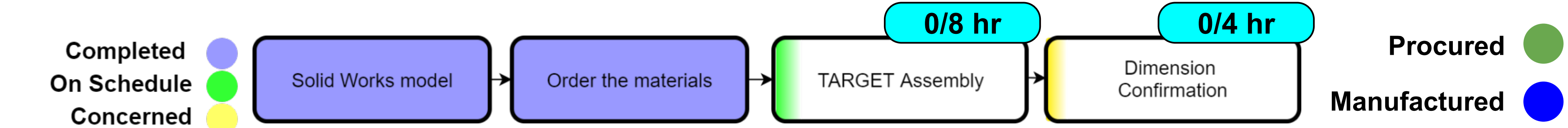


Completed
On Schedule
Concerned
Behind Schedule

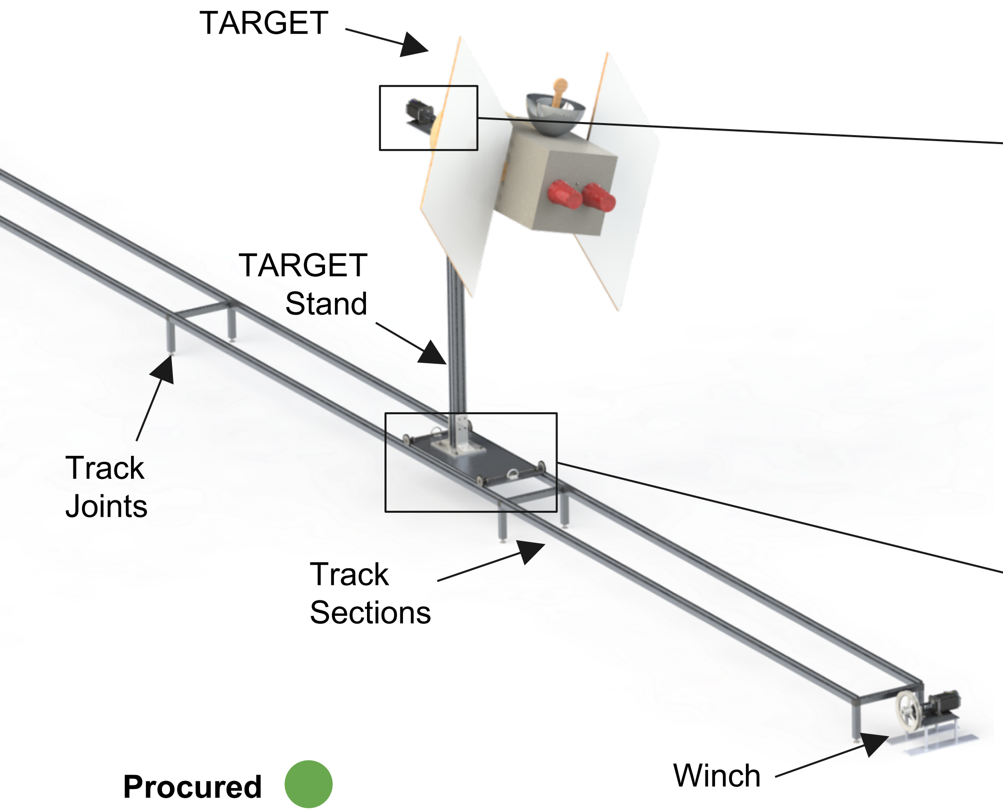
Solid Works model → Machining Programs (2/6 hr) → Manufacturing (4/17 hr) → Assembly/Tuning (0/3 hr) → Testing (0/12 hr)

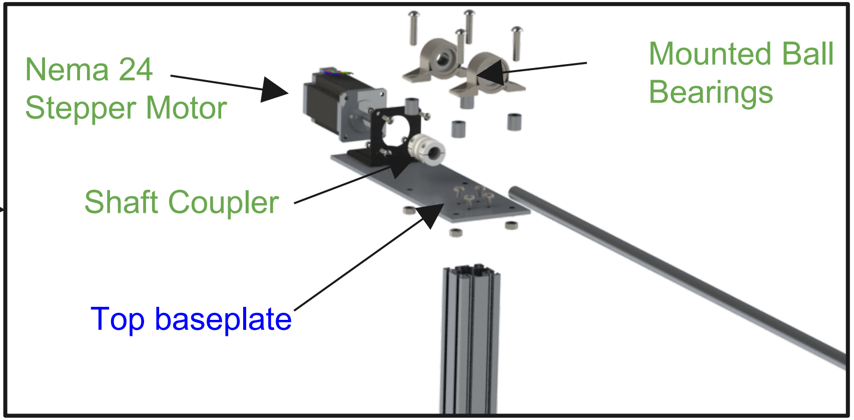
Target Satellite Progress

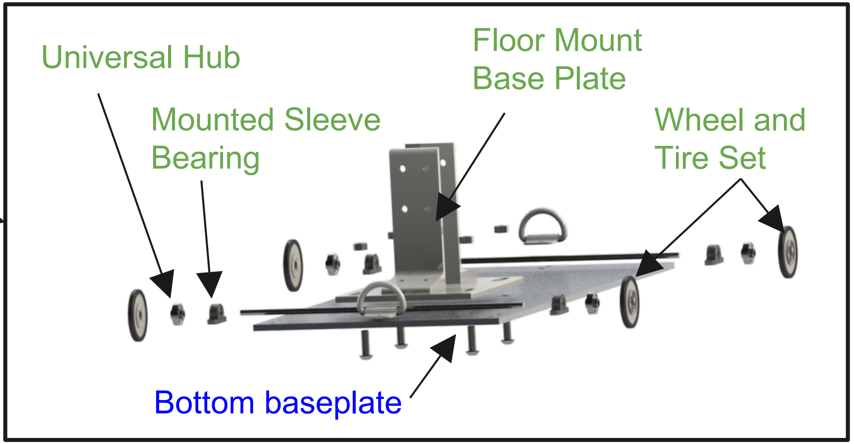




Target Test Stand Design - 2 Machined Parts





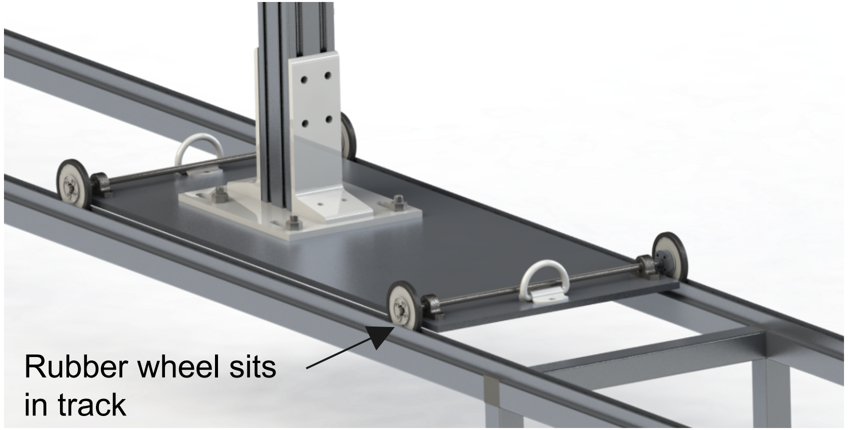


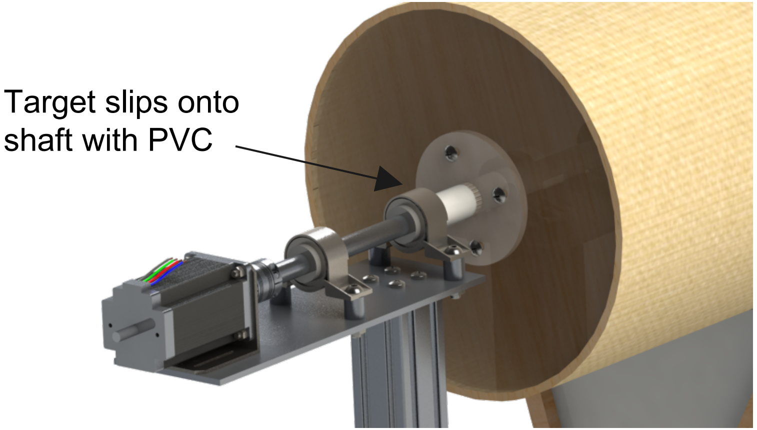
Procured

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.

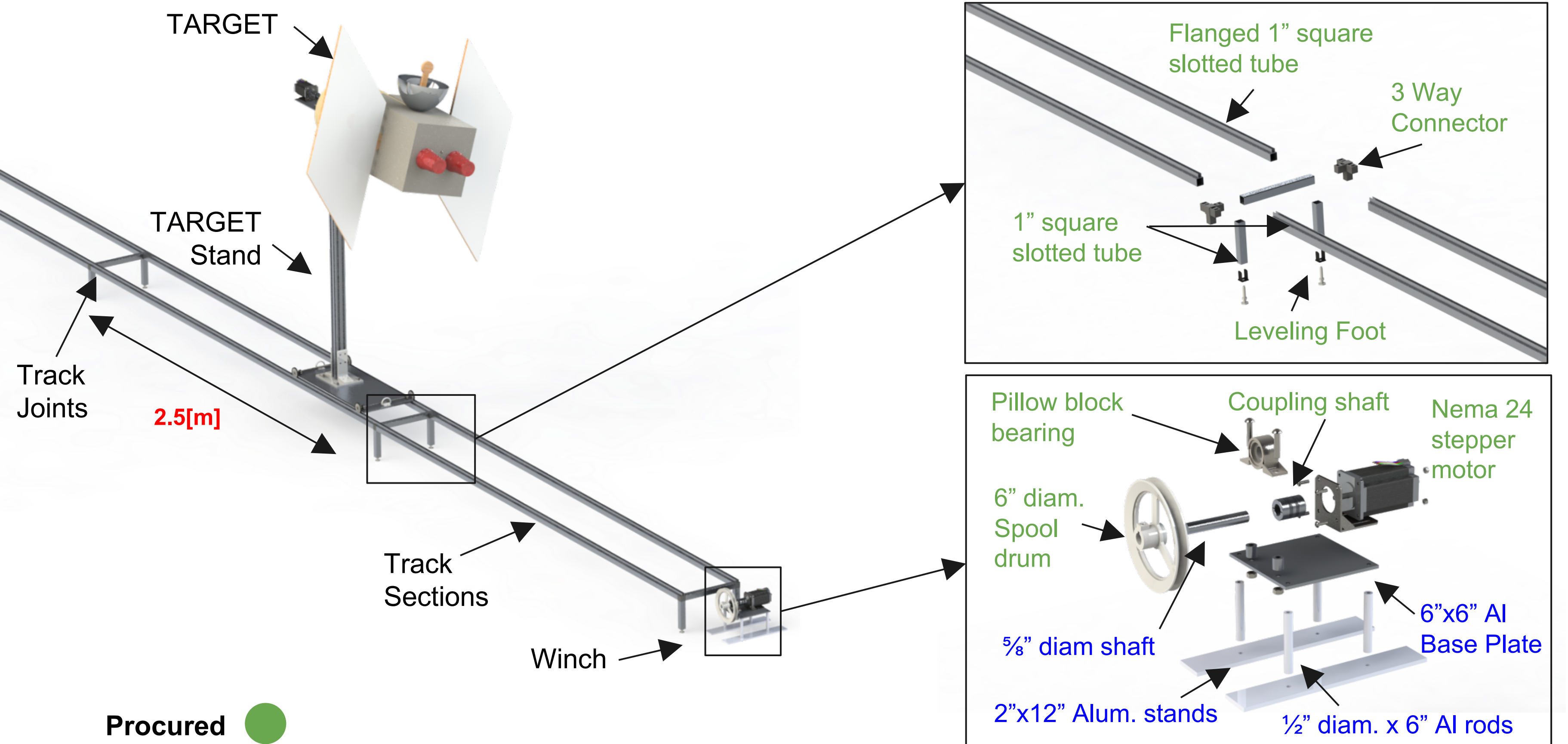




Completed
On Schedule
Concerned
Behind Schedule

Solid Works model → Order the materials → Stand Manufacturing and Assembly (0/12 hr) → Track and TARGET Integration (0/12 hr)

Track System - COTS Components

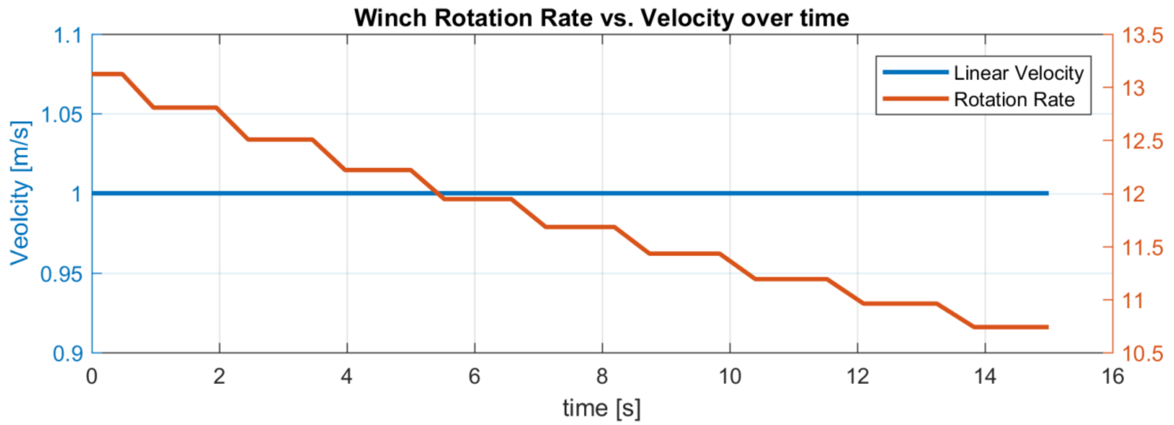


Procured

Manufactured

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.

Completed
On Schedule
Concerned
Behind Schedule

Solid Works model → Order the materials → Winch Speed Control through BigEasyDrive (**2/3 hr**) → Testing (**0/4 hr**)

Overview ***Schedule*** ***Manufacturing*** ***Budget***

Software Optimization and Implementation

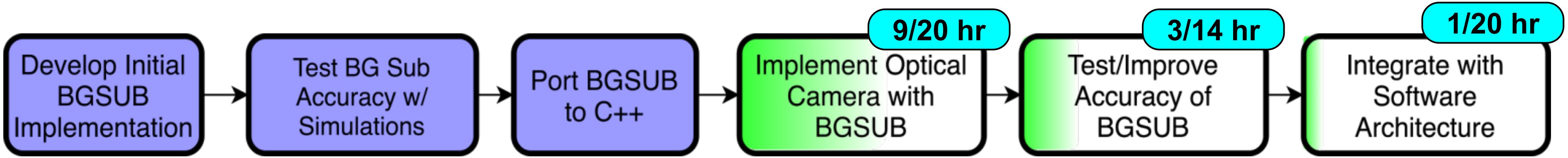
Background Subtraction

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

Background Subtraction On Schedule

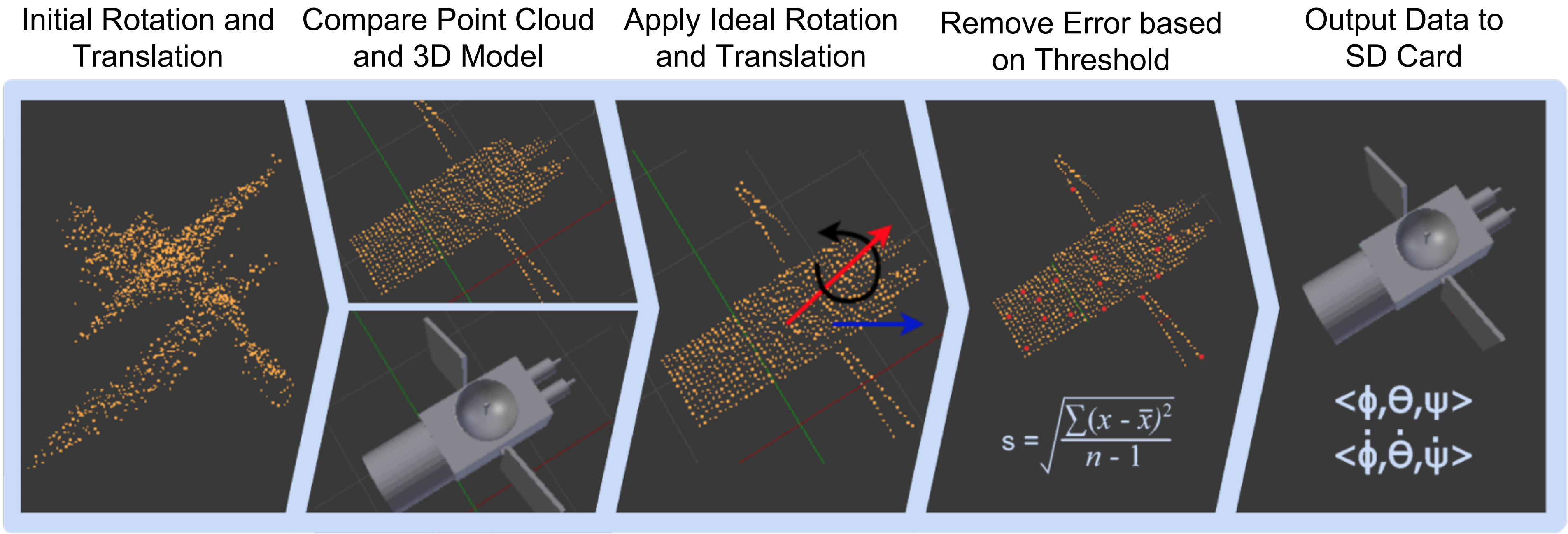
Task	Critical Elements	Next Steps
Optical Camera with Background Subtraction	Computation Time	Improve for higher resolutions
Test Background Subtraction Script	Camera auto focus and algorithm accuracy	Determine accuracy with testing model
Integrate into Software Hierarchy	Computation Time and Accuracy of Turning Angles	Automate the process within the hierarchy



Completed
On Schedule
Concerned
Behind Schedule

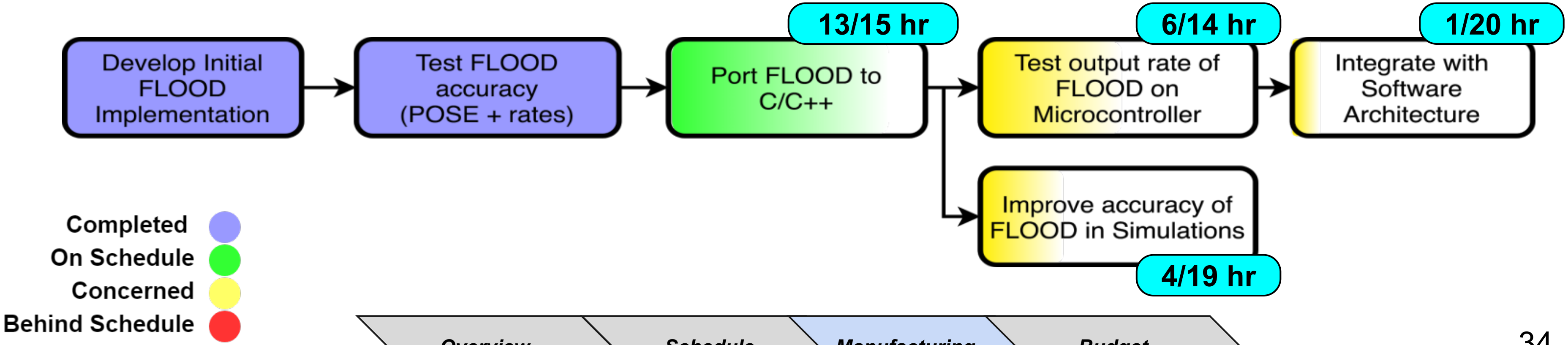
Iterative Closest Point ~ FLOOD

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



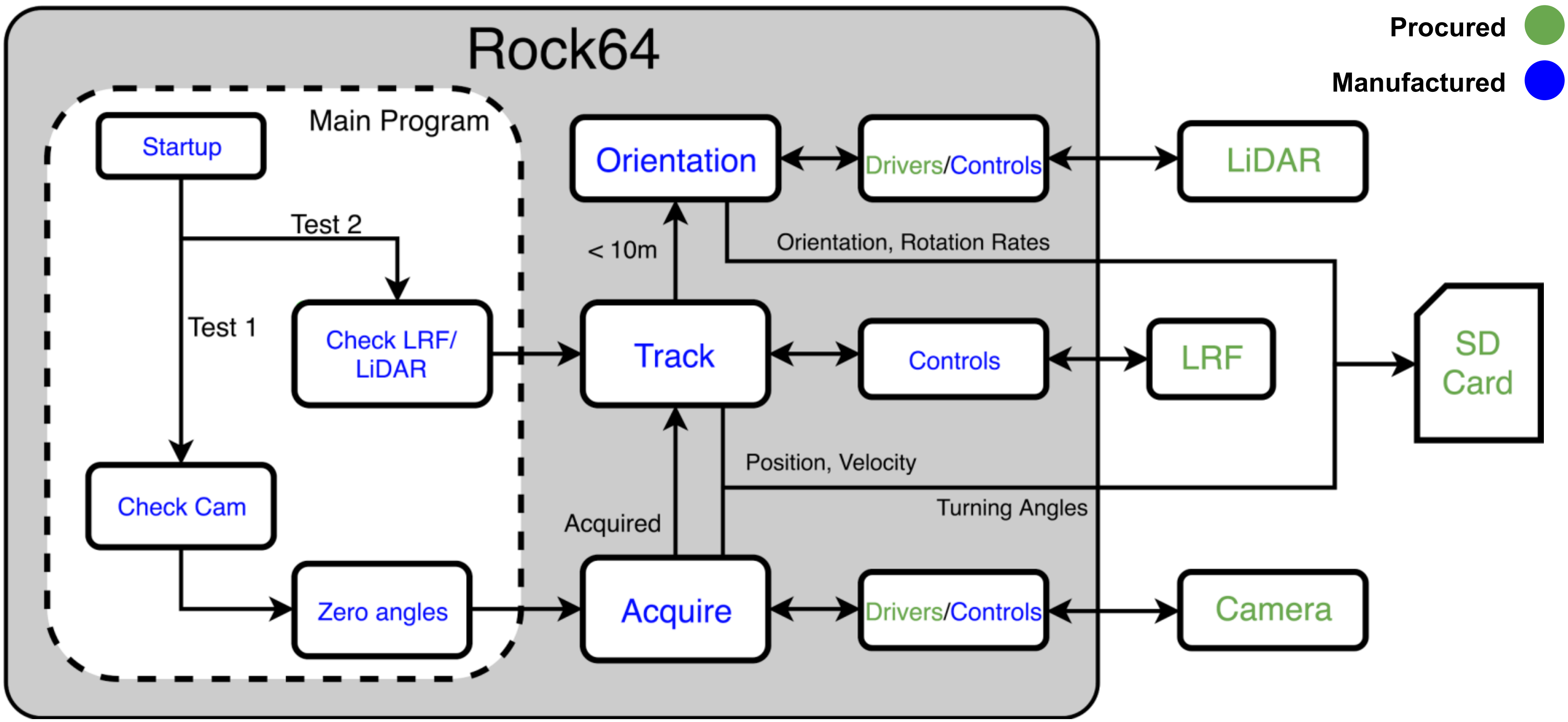
FLOOD On Schedule

Task	Status	Next Steps
Test Output rate of FLOOD on microcontroller	Output rate drops to ~1.5 Hz in some cases	Limit number of points analyzed at close range
Improve accuracy of FLOOD	POSE inaccurate at close range	Change TARGET model/Consider known limitations
Integrate orientation software	Waiting for LiDAR driver	Test algorithm using hardware and miniature model

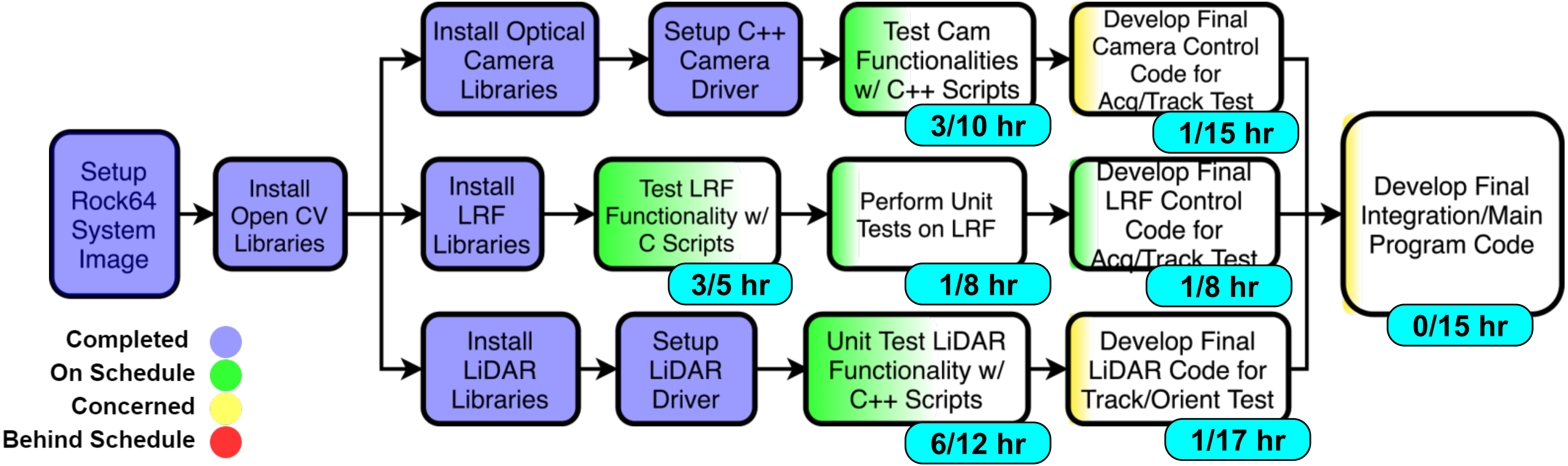


Electronics/Software Integration

Final Test Software Architecture



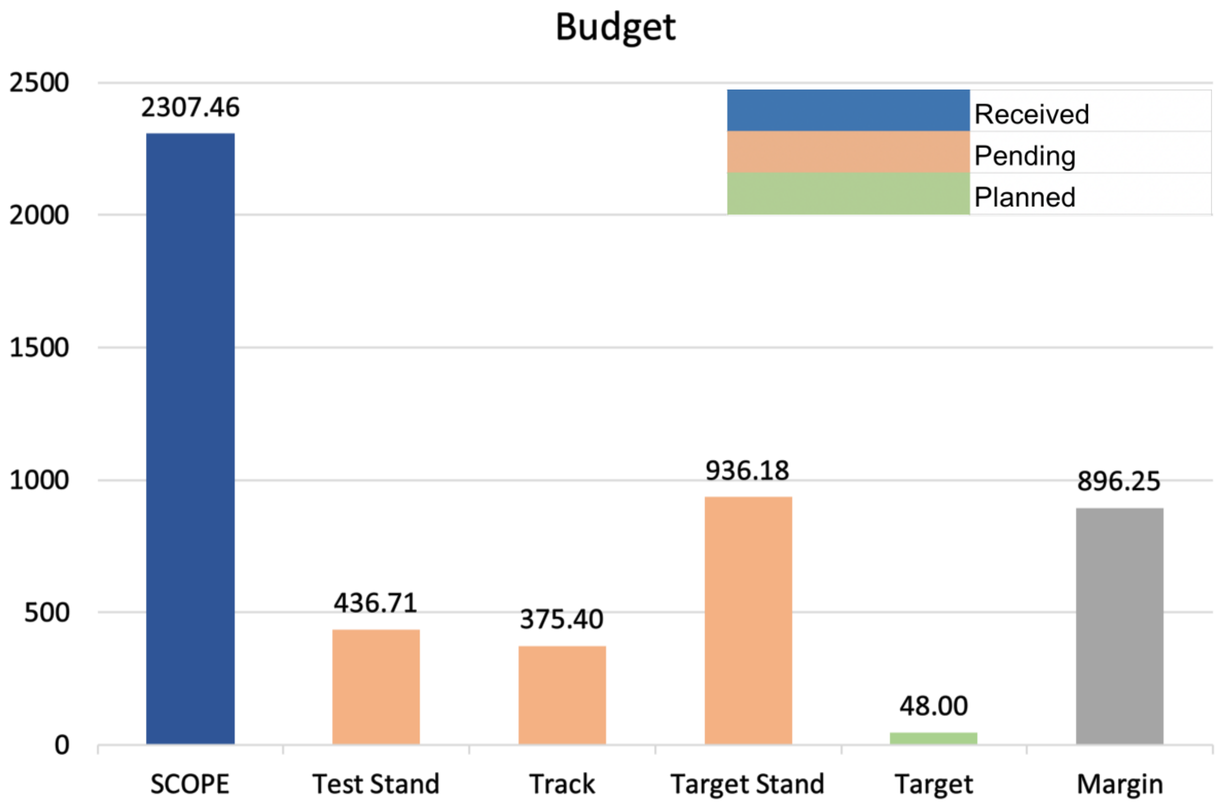
Electrical/Software Integration Tasks On Schedule



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

Updated Cost Plan

Cost Plan



Item	Lead time
Test Stand Encoder	2-3 Week Lead time
Test Stand Bearings	2 Week lead time

Used	$4055.75
Planned	$48.00
Total	$5,000
Margin	$896.25

Acknowledgments

We would like to thank **Trudy Schwartz, Bobby Hodgkinson**, and **Matt Rhode** 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.

Questions?

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Backup Slide Index

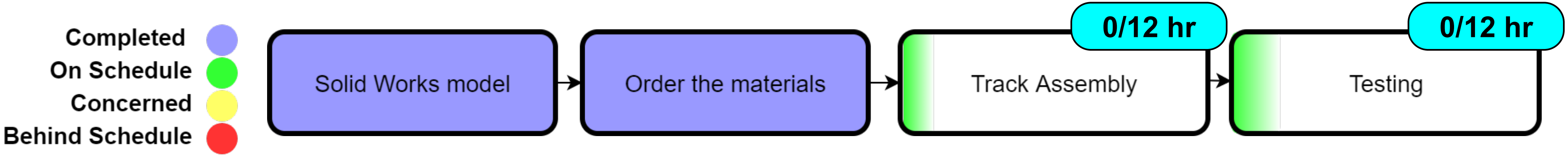
Error Analysis	Derivations	Simulations	Software	Testing
1Km Infeasibility Distribution of LRF Mean Position Error Propagation Behavior of STD of Sample Mean OpC w/ Background subtraction	Sensor Calibration Sensor face offset Error due to face offset 1km infeasibility	Thermal conditions Power Outputs Operational temperatures Static load analysis	Autofocus capabilities Flash LiDAR resolution FLOOD explained KD tree FLOOD timing	Functional Requirements Fulfilled Test Plan Test 1 Testing Hardware Flowchart The Target Satellite Encoder Quadrature

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

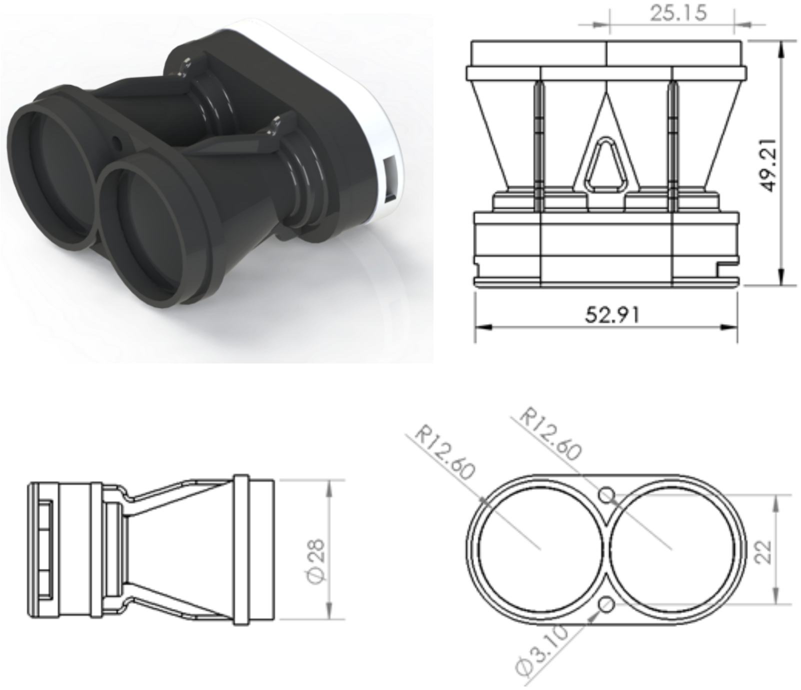
Track Progress and Critical Elements

Task	Critical Elements	Next Steps
Track Assembly	Level all the track feet properly so that the track is as flat as possible	Use digital level on all joints of the track
Balance Analysis	Study the forces acting on the target stand and ensure dynamic stability	Implement winch and spring systems

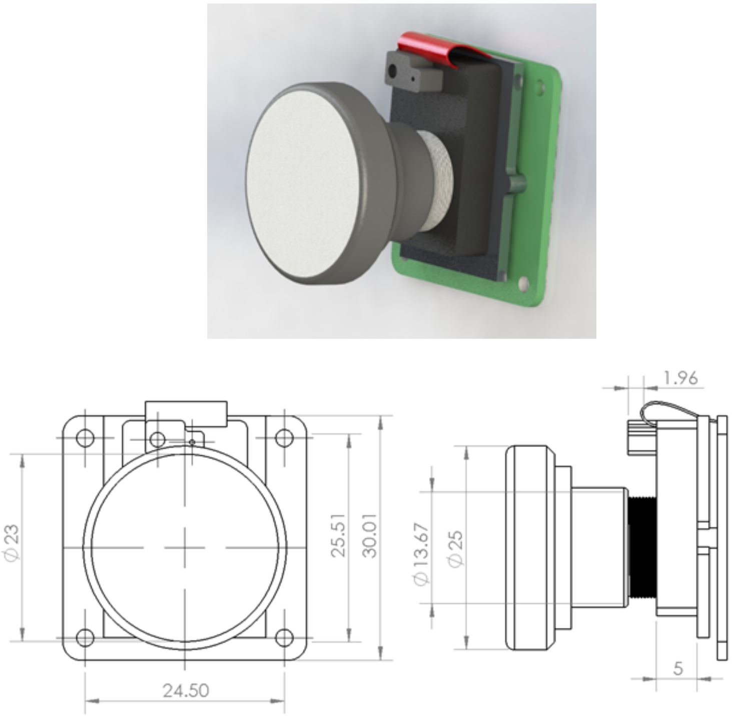


Sensors and Rock64 Diagrams

Laser Rangefinder

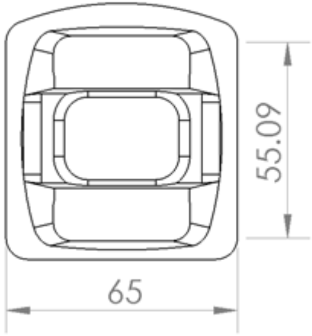


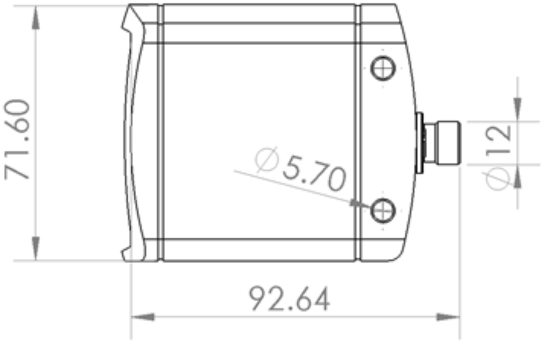
Visual Camera



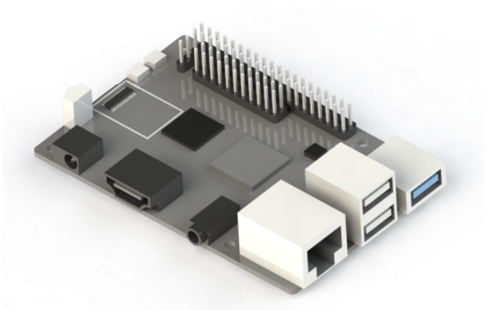
Sensors and Rock64 Diagrams

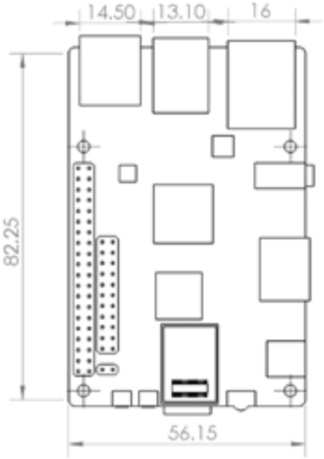
Flash LiDAR

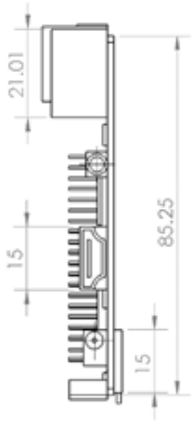




Rock64 Microcontroller

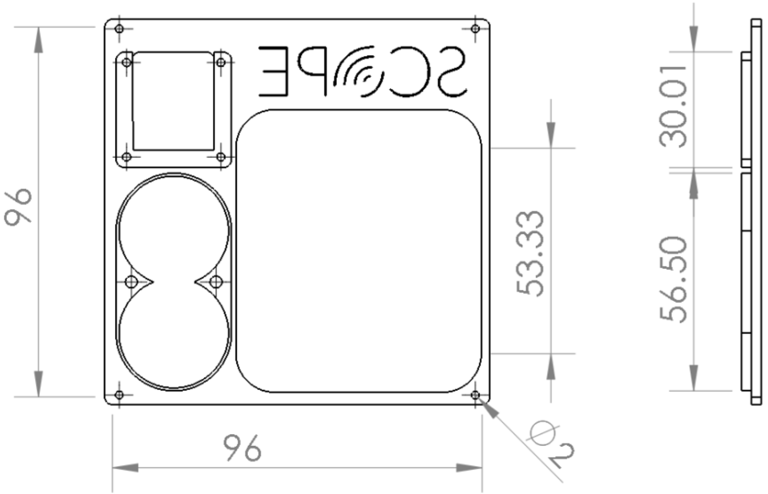




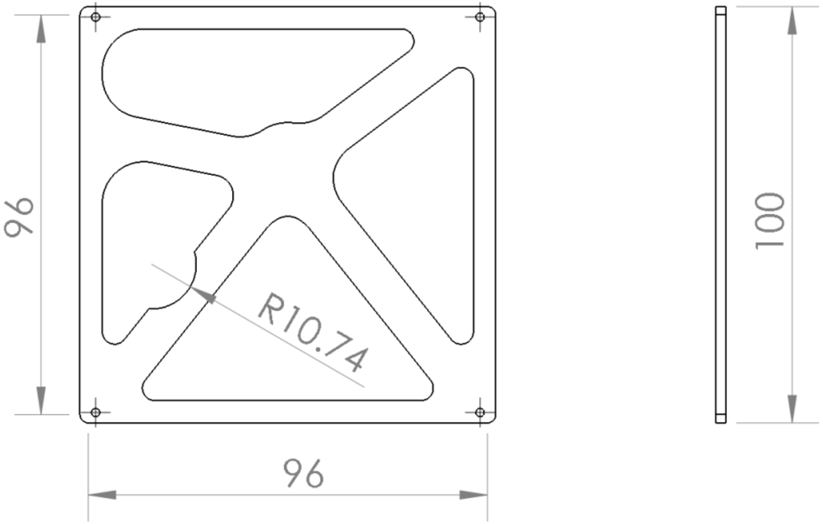


Shell Diagrams

Mount Face

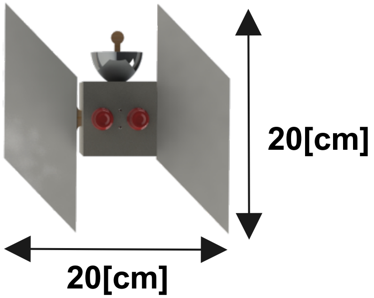


Back Plate



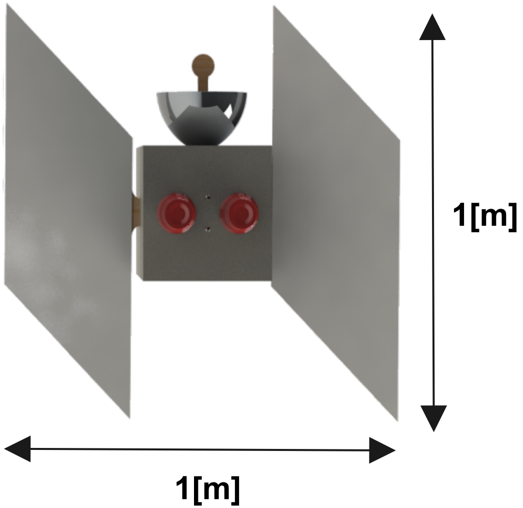
TARGET Model

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

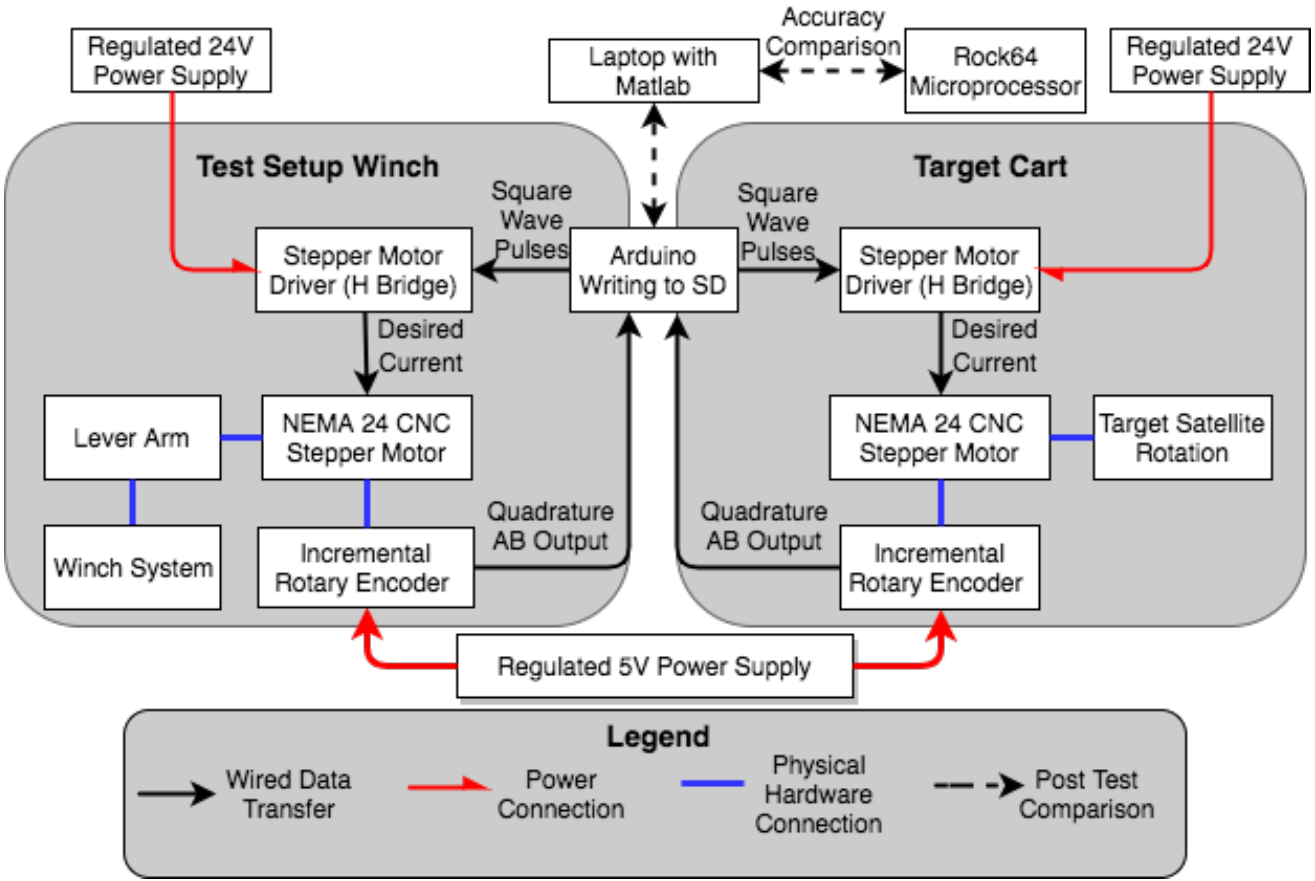
Phases:

- 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>

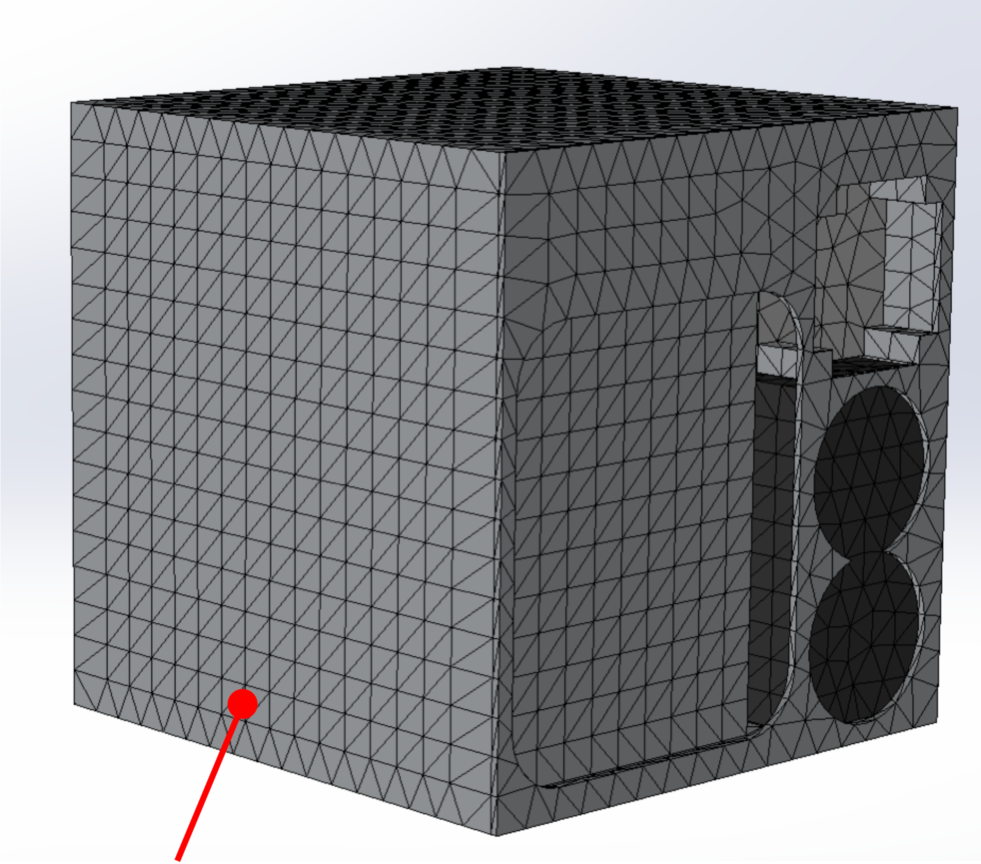
Component(s): Shell
Material: 6061 Aluminum Alloy
Thermal Conductivity: 170 W/(m*K)

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

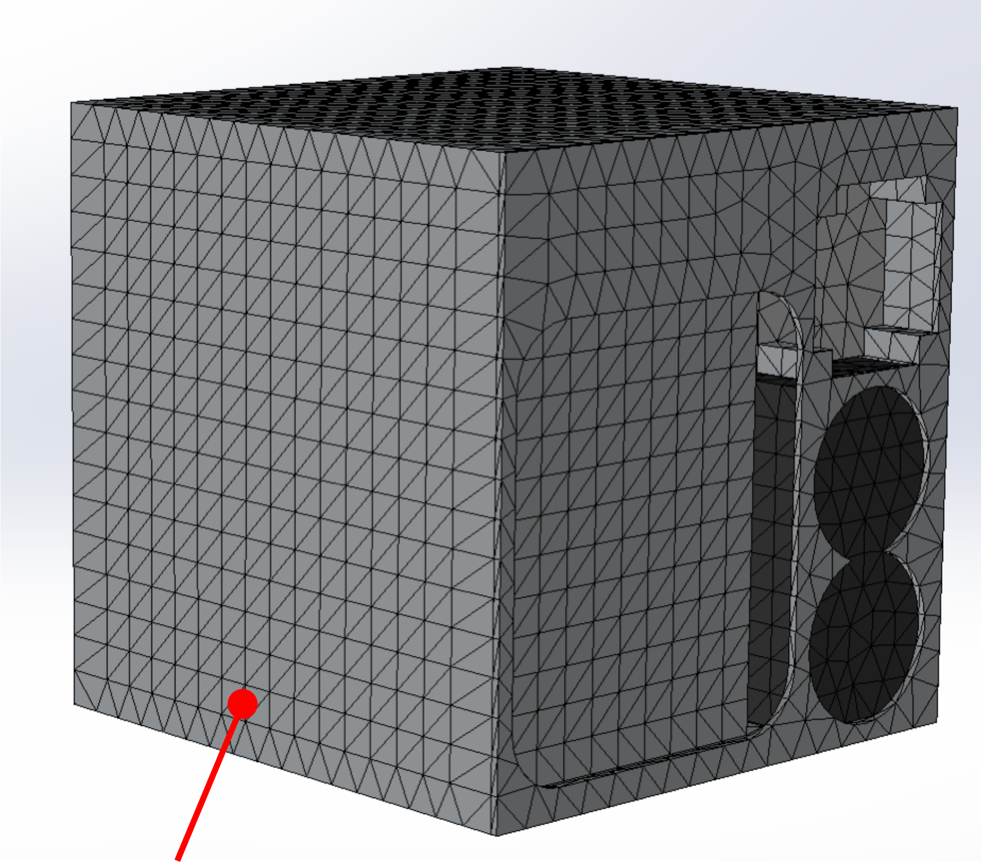
FEA Mesh and Parameters (thermal)

<u>Model uses the following conditions:</u>

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**

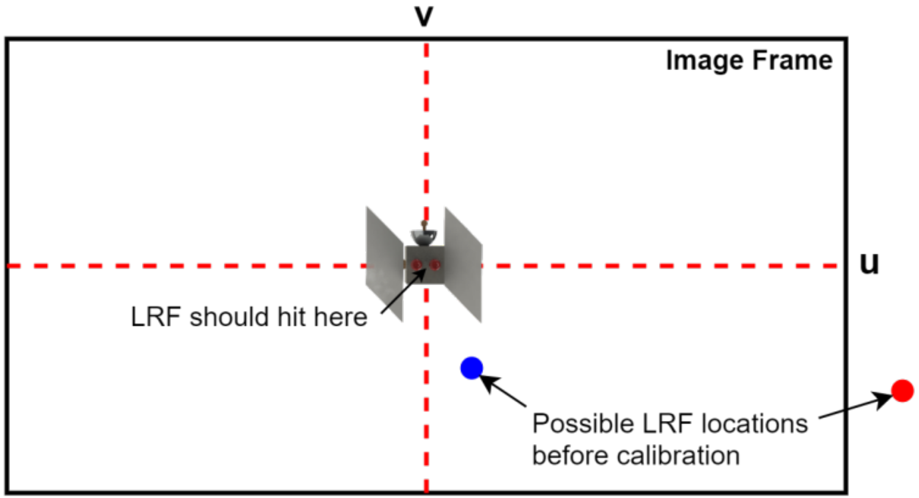
Sources
Rock64: https://forum.pine64.org/showthread.php?tid=1220
AFUJ003: https://www.theimagingsource.com/products/autofocus-cameras/usb
-3.0-color/dfkafuj003m12/
SC30-C: https://www.parallax.com/product/28058
03D301: https://www.ifm.com/hu/en/product/O3D301

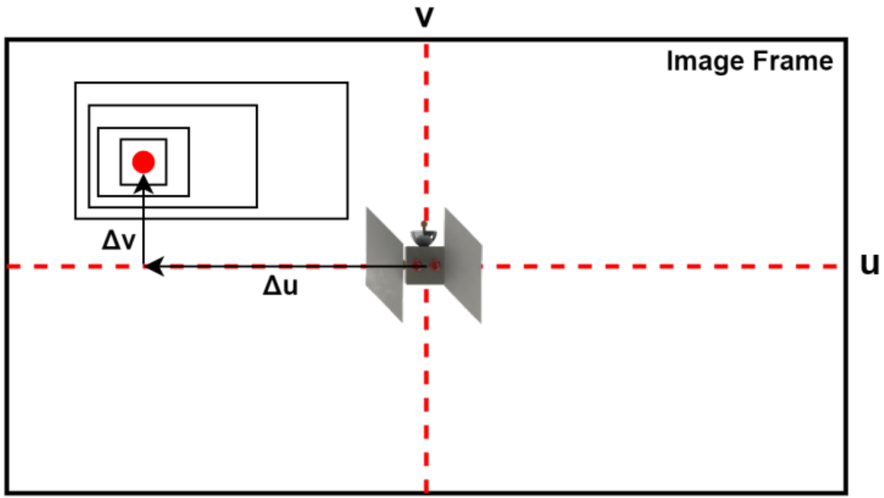
Various Operational Temperatures

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.

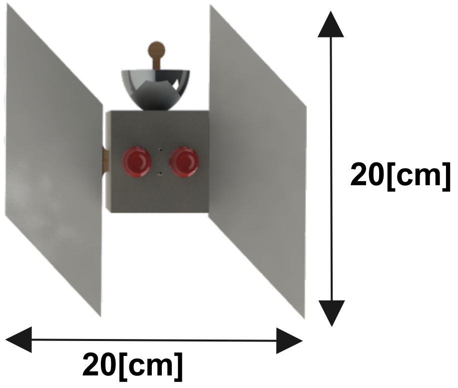
Minimum Pointing Accuracy

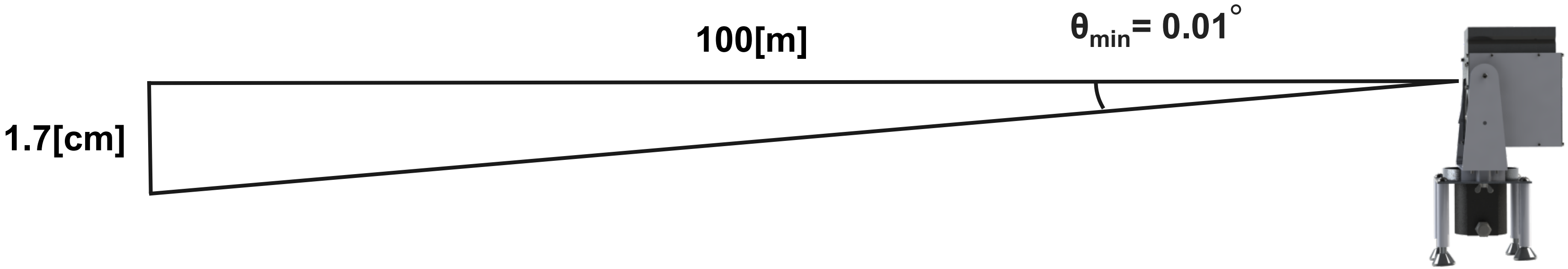
The minimum sized model defines the pointing accuracy to be required as a **20[cm]** vertical and horizontal resolution.

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

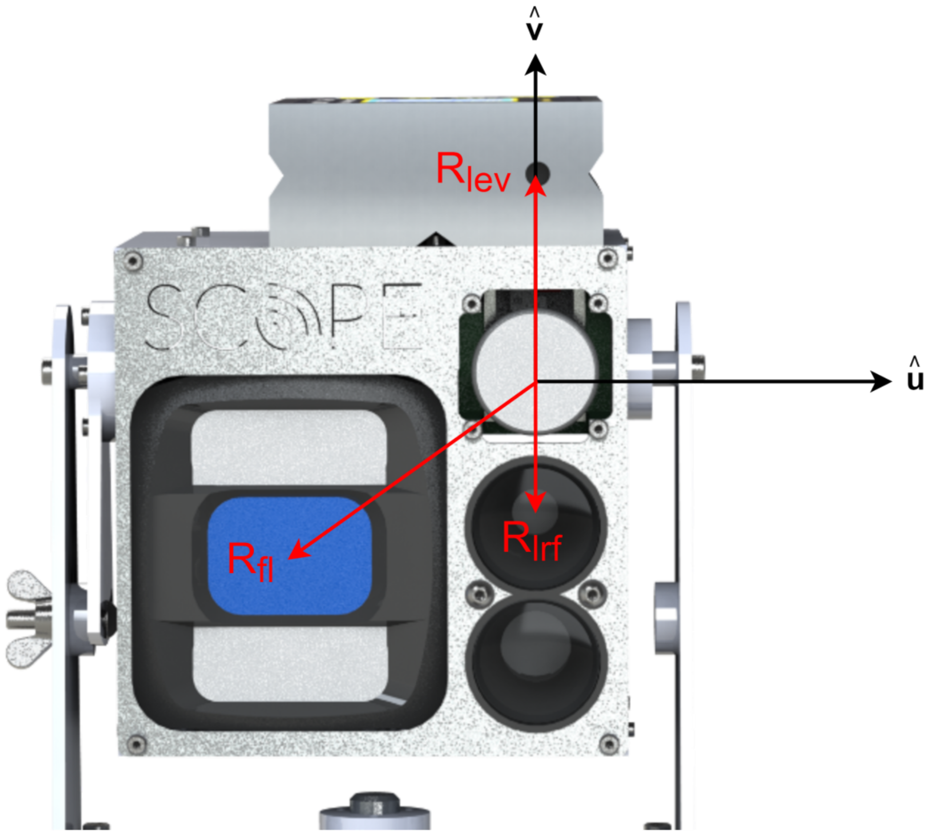
The resolution of our **sensor test stand encoders and digital level** give a resolution of **0.01[deg].**

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





Sensor Face Offset



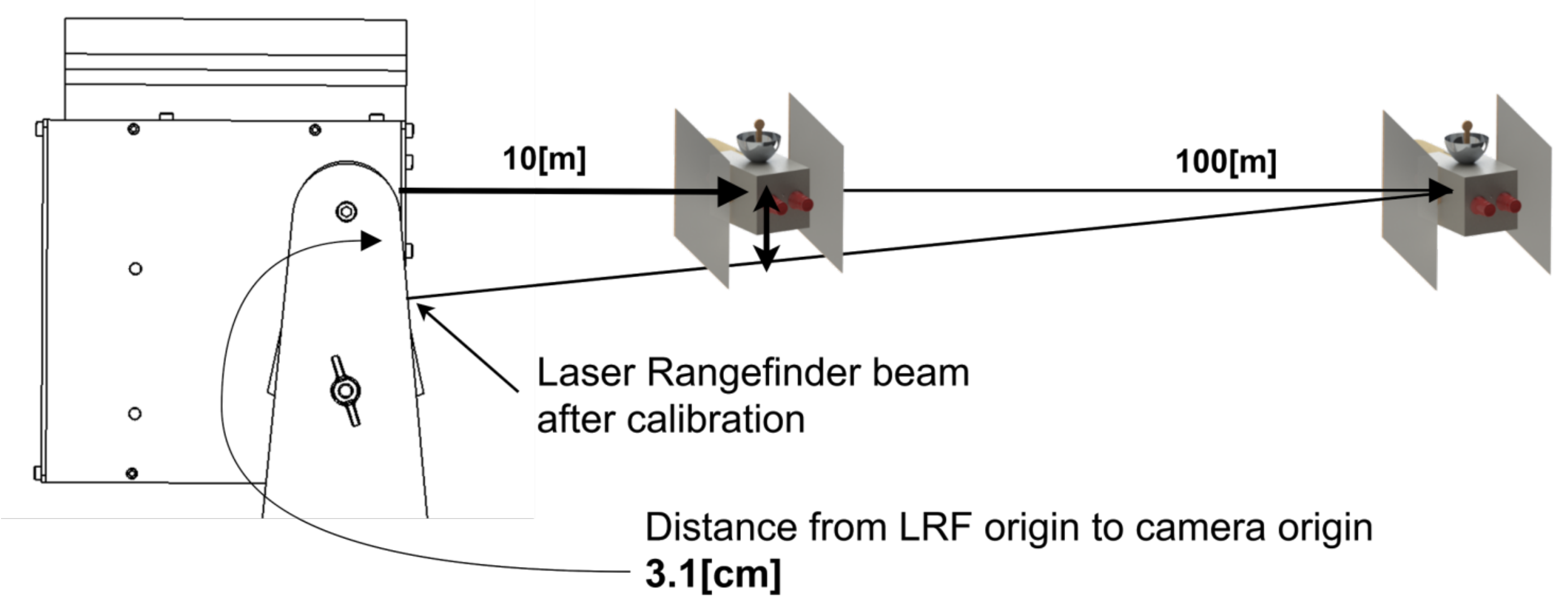
All offsets are accounted for in software

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

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

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

Error Due to Face Offset



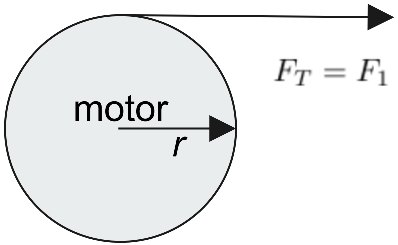
This offset causes error in pointing as the object gets closer.

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

Beam Divergence

Laser Rangefinder has a beam divergence of 0.2 degrees.

Track Motor math



$F_T = F_1 + F_2$

Givens:

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

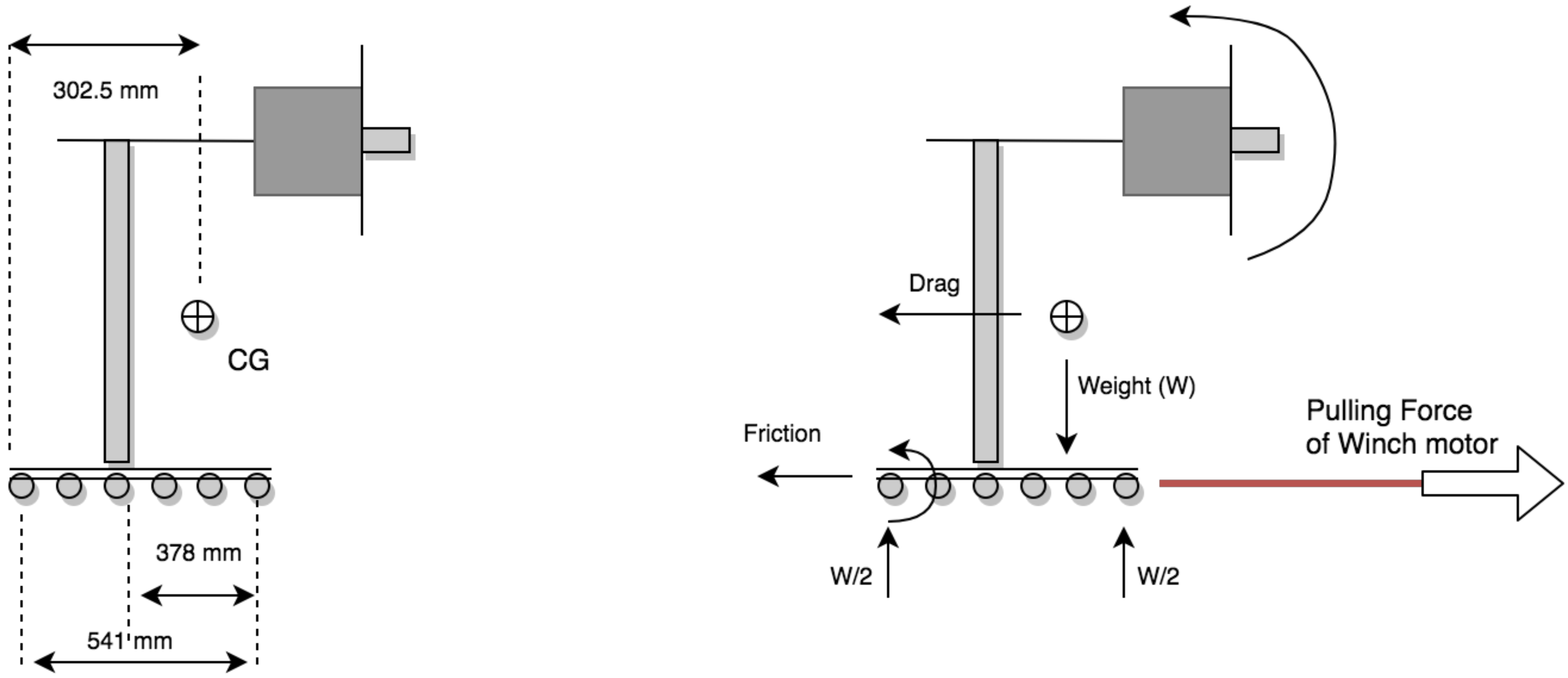
Analysis:

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

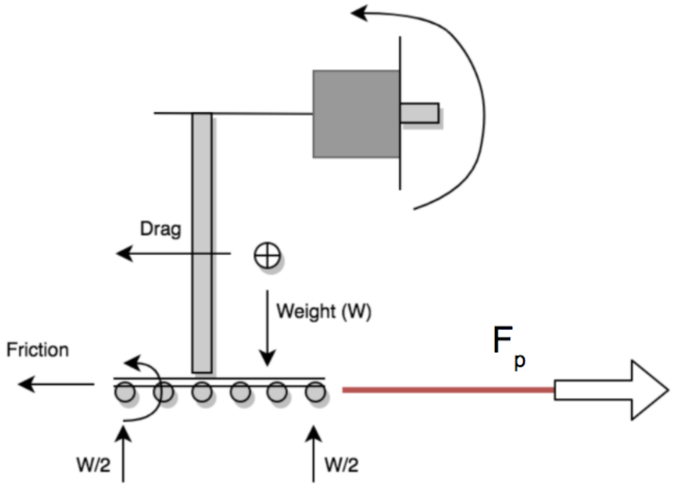
Conclusions:

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:

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

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

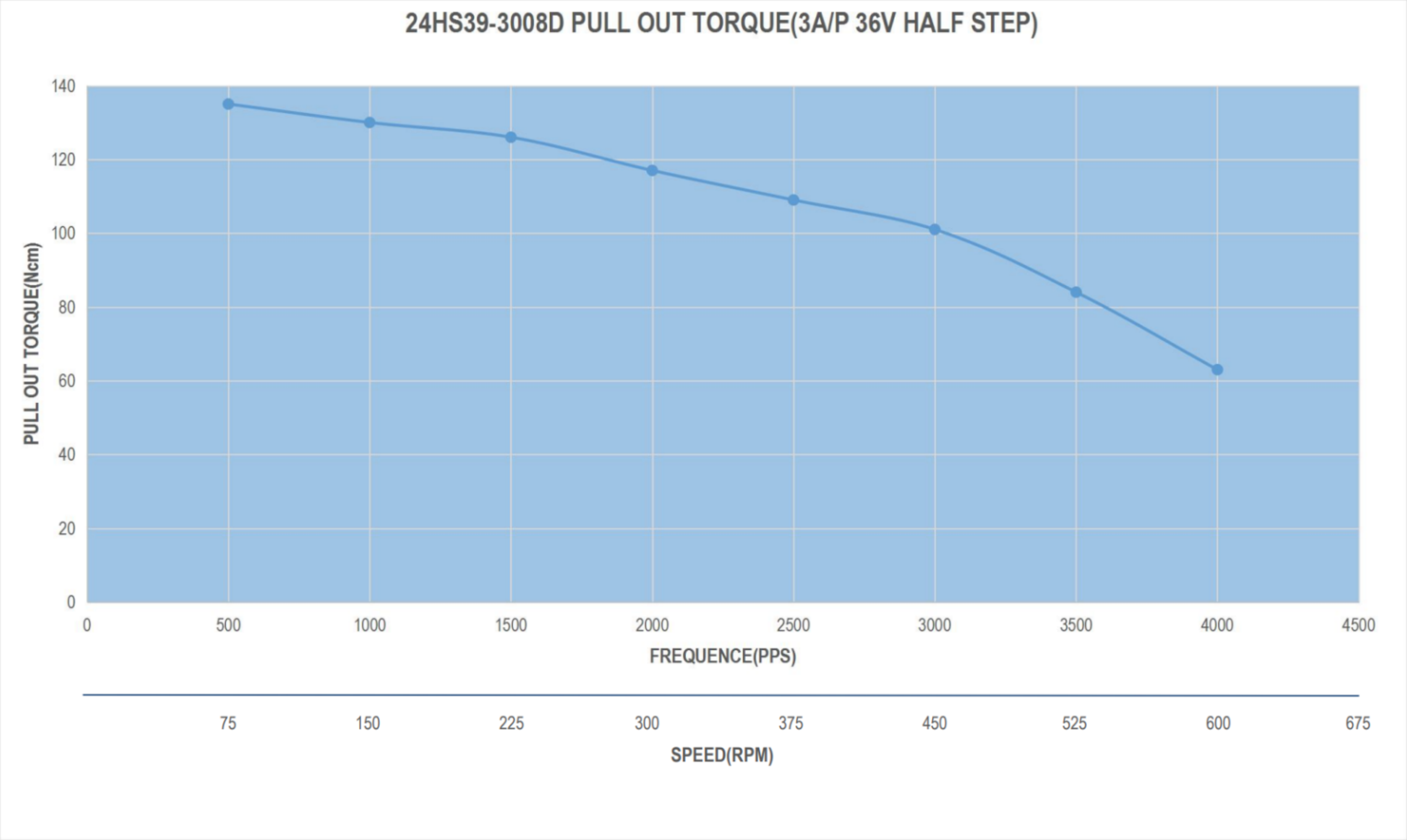
$$T = F_p * r = 1.19Nm$$

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

Conclusions:

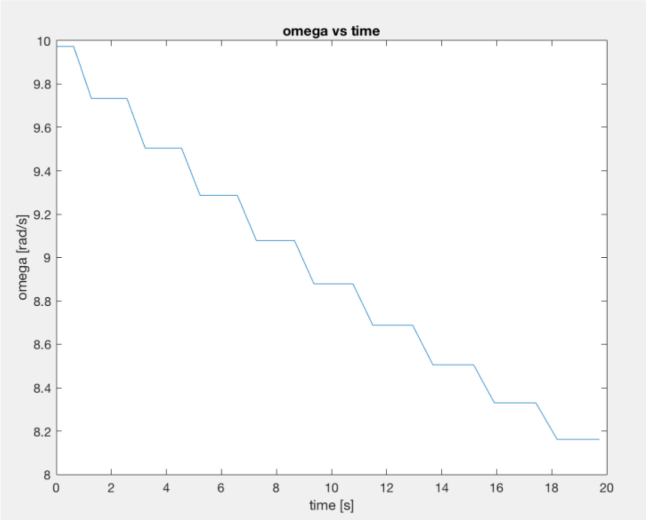
The needed Torque at 125 RPM is 1.19Nm. Looking at the Pullout torque curve one the next slide, it is possible to conclude that the motor will provide sufficient torque for the test stand to move as needed

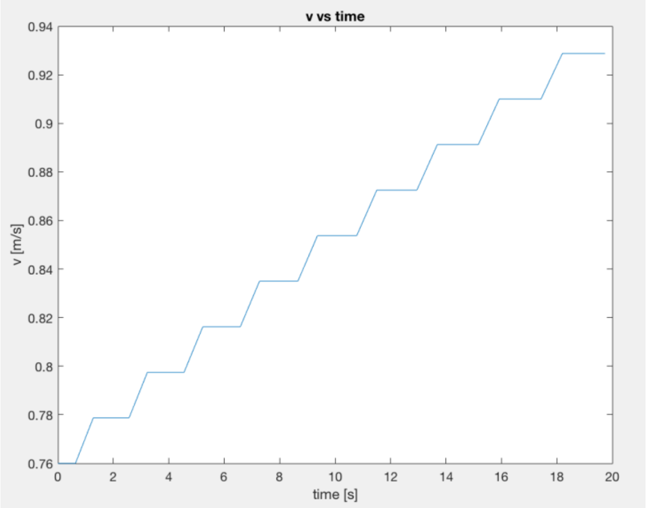
Torque vs RPM



Velocity Changes of Target Test Stand

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

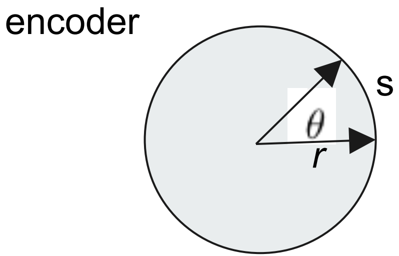




If we had to maintain a constant velocity when v_0 = 0.7 m/s, this is how we should decrease the angular velocity for the winch

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



Givens:

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

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

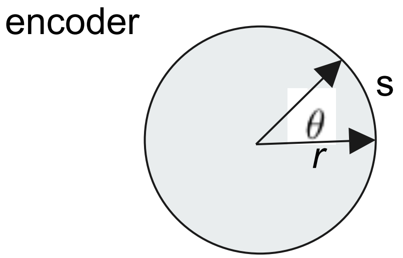
Analysis:

$$\boxed{ppr = 2\pi/\theta = 314.159}$$
$$\boxed{f_{max} = \omega_{max}/\theta = 1000Hz}$$
$$\boxed{f_{min} = \omega_{min}/\theta = 100Hz}$$

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:

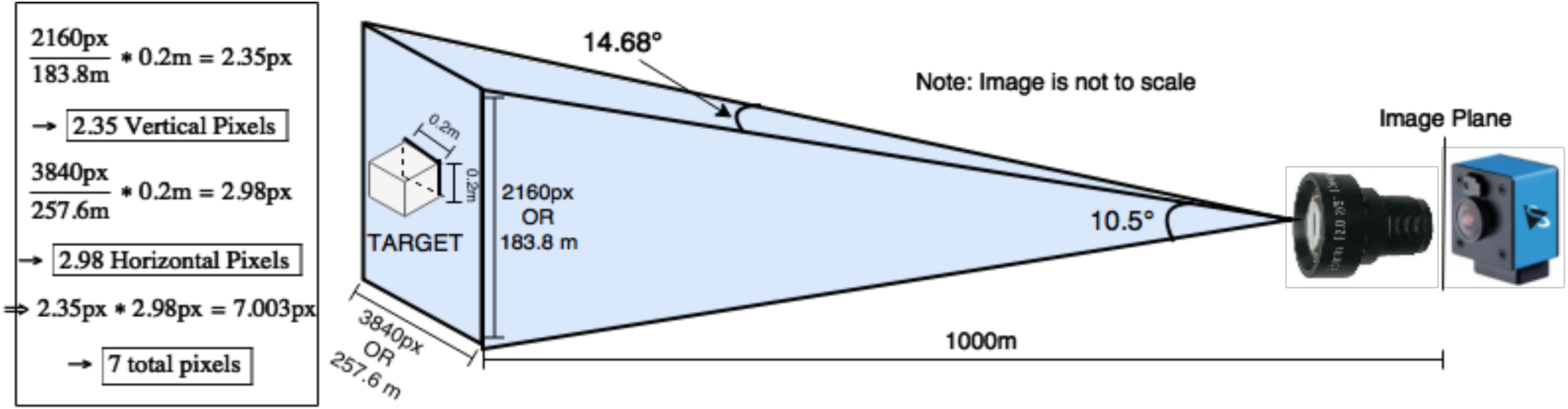
Choose detection angle to be 0.1 deg (one order of magnitude greater than functional requirement)

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

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

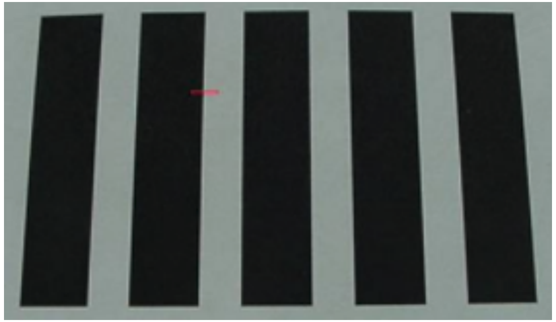
Two types: Passive and Active

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

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

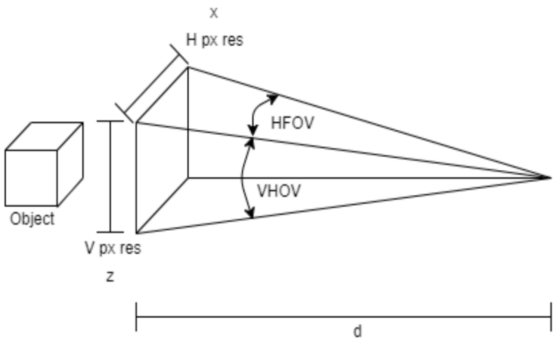
- Determines blurriness by contrast of edge pixels

Out-of-focus image



In-focus image

Flash LiDAR Resolution



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

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

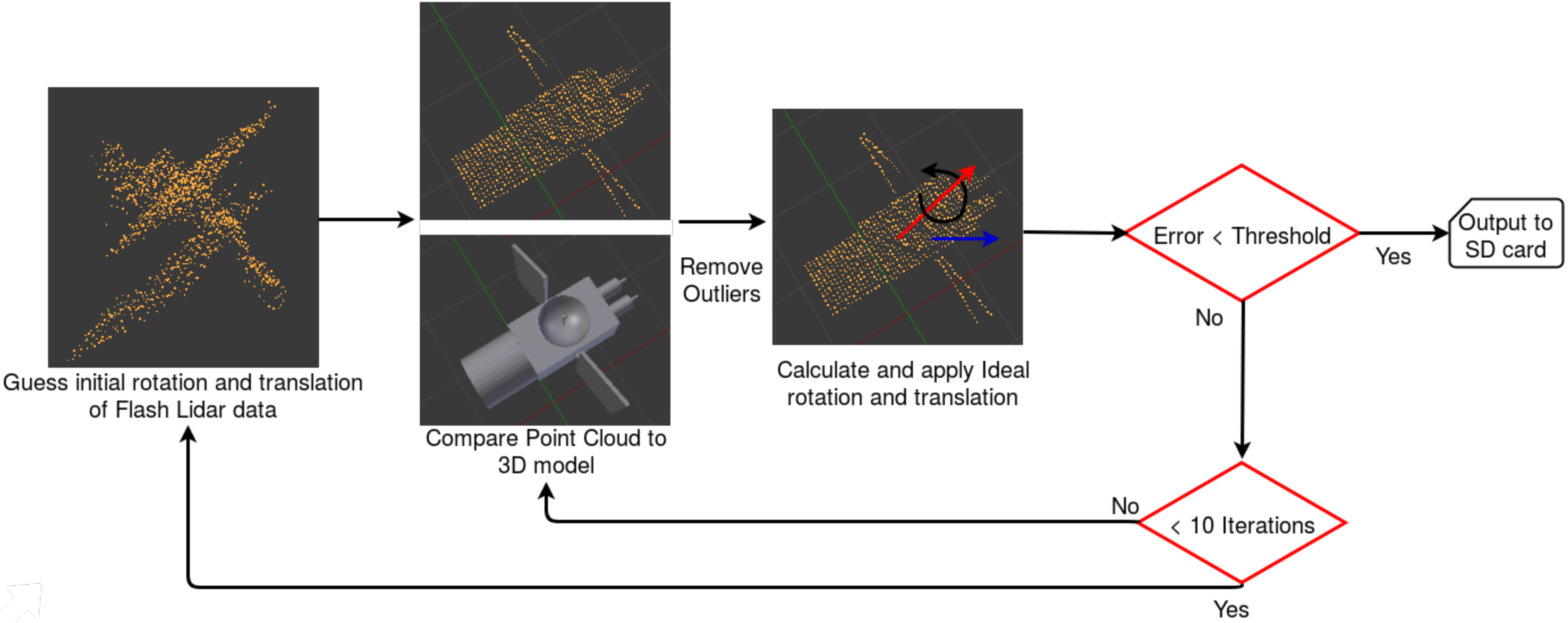
$$horizontalpix/m = \frac{HpxRes}{x}$$

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

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

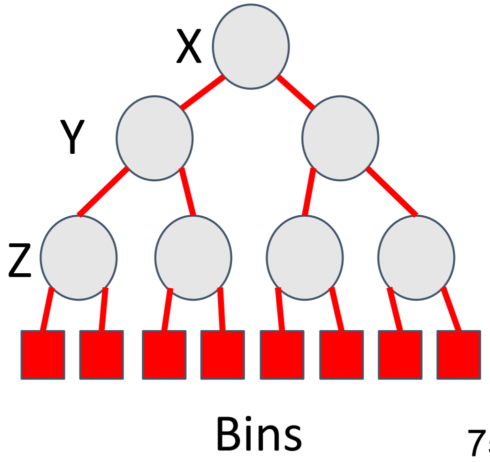
IFM O3D301	FOV:40X30	RES:176X132	20 x 20 cm	1 x 1 m
Distance (m)	total (px/m^2)	(cm^2/pixel)	Pixel per object	Pixel per object
11	492	20.32	20	492
10	596	16.79	24	596
9	735	13.60	29	735
8	931	10.75	37	931
7	1215	8.23	49	1215
6	1654	6.04	66	1654
5	2382	4.20	95	2382
4	3722	2.69	149	3722
3	6617	1.51	265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

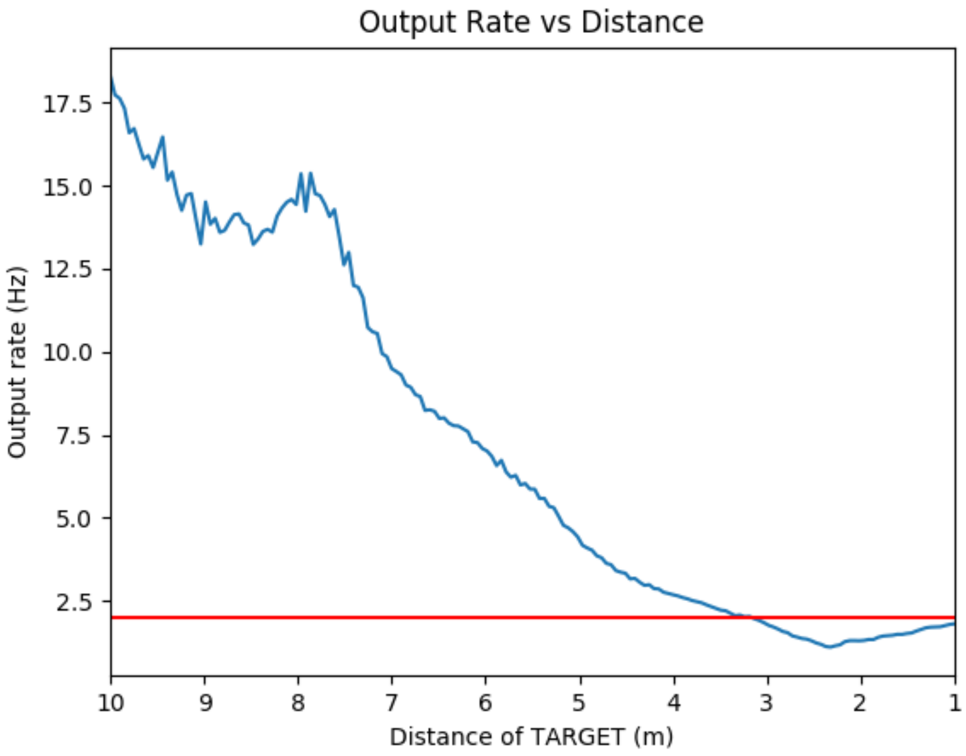
Given the two point cloud sets M and D, where D is the set produced by the LiDAR scan, and M is the set derived from the model. For each point $d_i \in \mathbb{R}^3$ in D, and a rotation R and translation t, there is a point c_i such that.

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

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

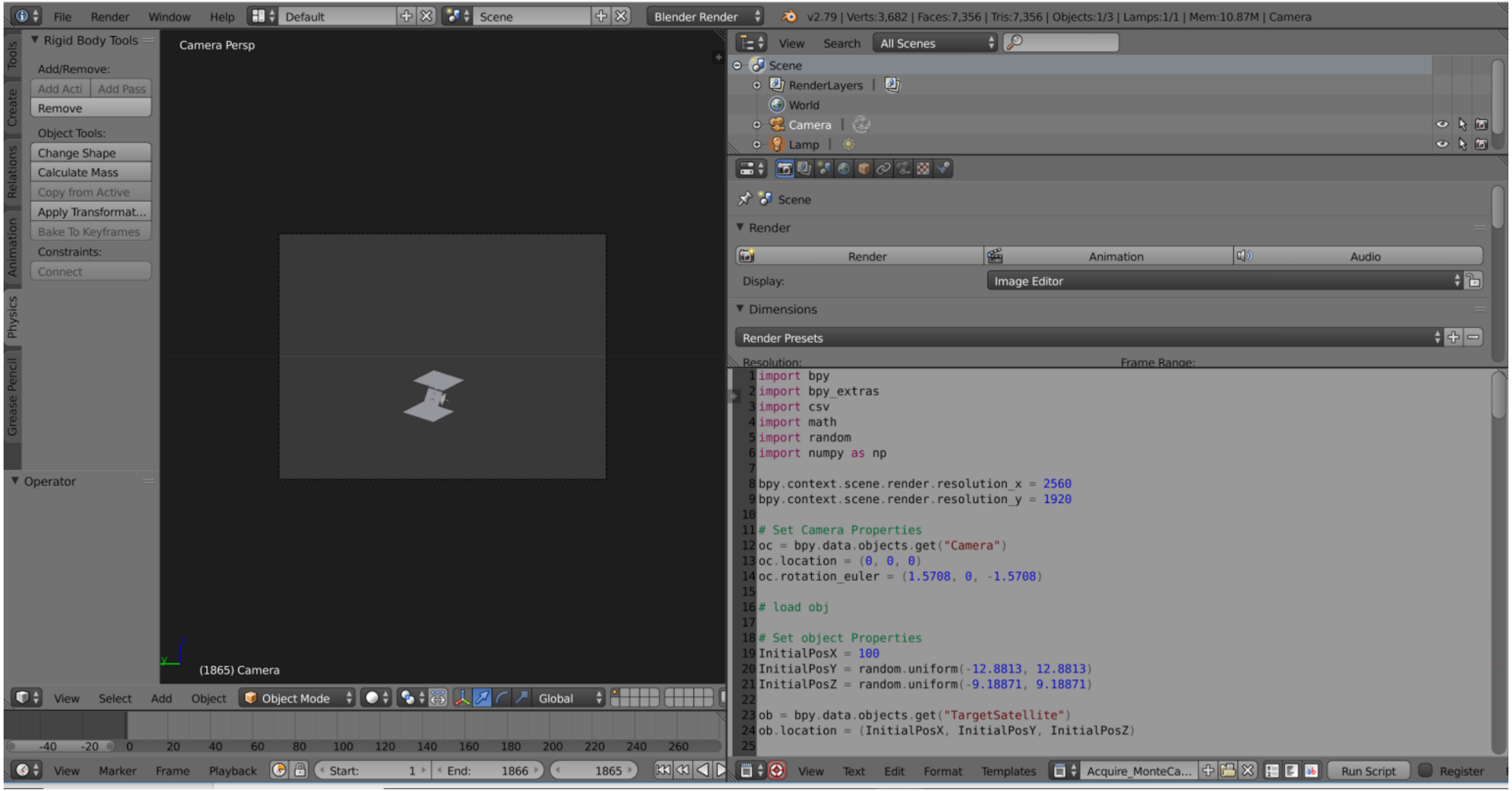
$$\epsilon = \frac{1}{m} \min_{t,R} \sum_{i=1}^{m} \| Rd_i + t - c_i \|^2 \tag{2}$$

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
Tools
Create
Relations
Animation
Physics
Grease Pencil
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
Camera Persp
(1865) Camera
View
Select
Add
Object
Object Mode
Global
-40 -20 0 20 40 60 80 100 120 140 160 180 200 220 240 260
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, $Z_{\alpha/2} = 2.575$.

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

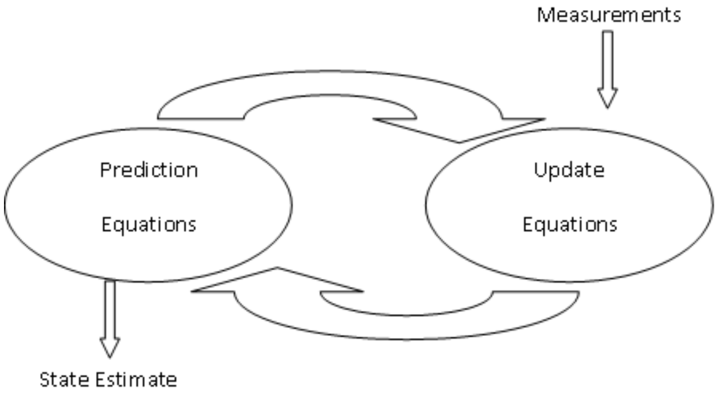
Use of Kalman Filtering

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.

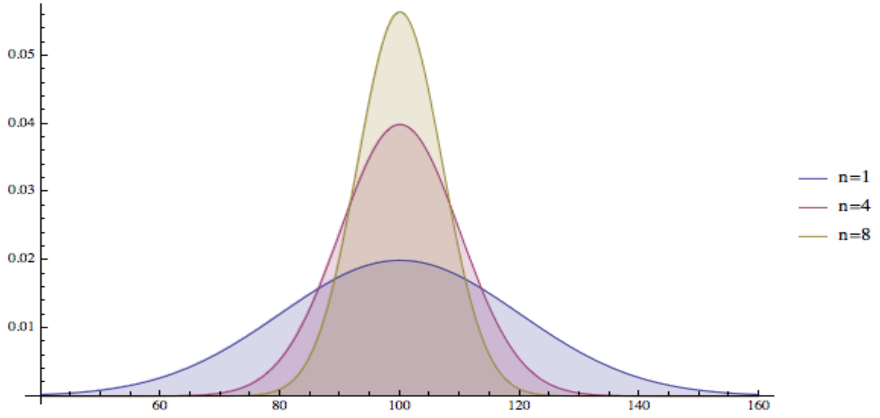
$$\sqrt{2}\sigma_{pos} \leq \sqrt{n}(0.003883)d \rightarrow \sigma_{pos} \leq \sqrt{n/2}(0.003883)d = \sqrt{5}(0.03883) = 0.0868$$

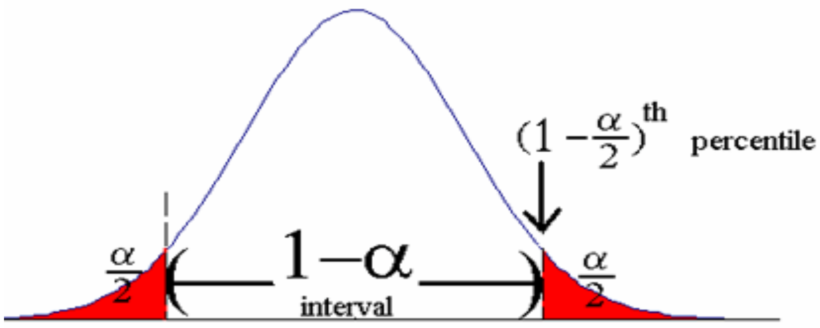
Therefore the 99% confidence interval can be calculated.

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

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.

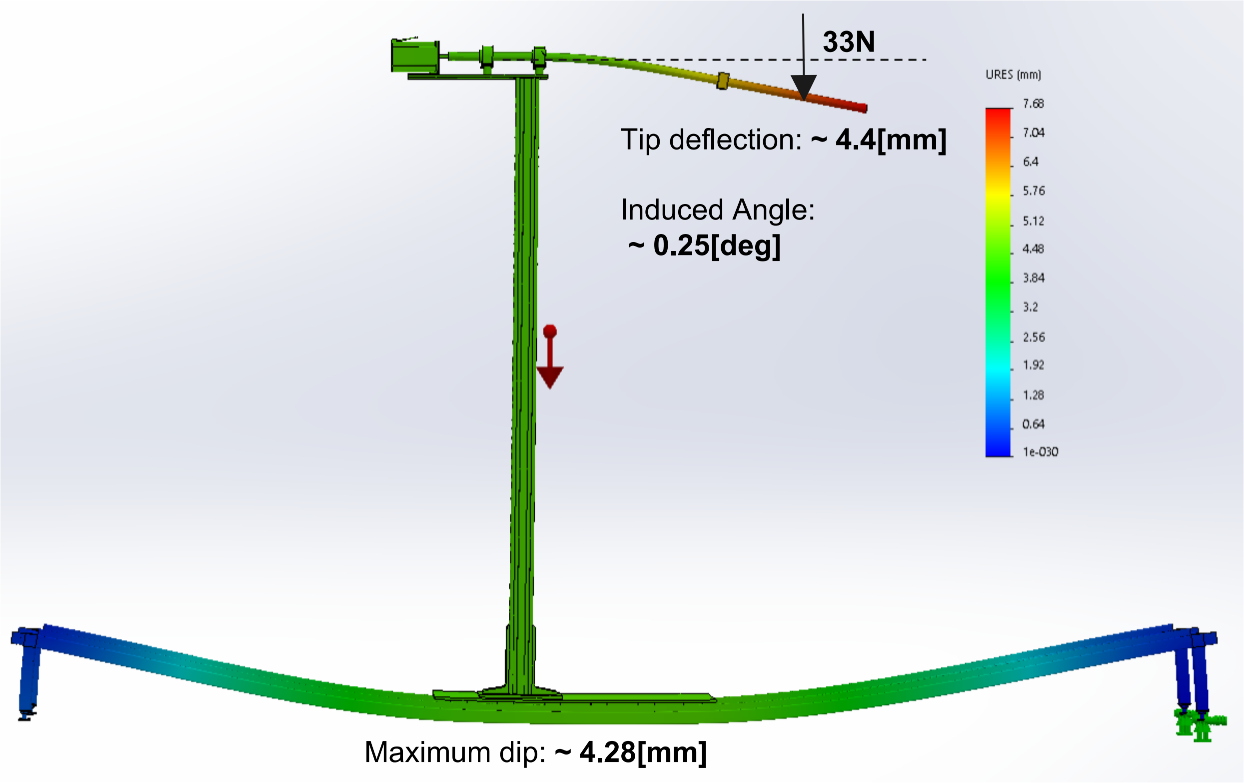
$$\sigma_\psi = \frac{2dtan(\frac{\alpha}{2})}{m}(\sigma_m) \quad \sigma_\theta = \frac{2dtan(\frac{\beta}{2})}{n}(\sigma_n)$$

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.

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

Static Load Analysis



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