ASEN 4028: Senior Design Projects
Spring 2021

Test Readiness Review

FLASH: **F**unctional **L**iDAR **A**ssessment of **S**tructural **H**ealth

March 4, 2021

Team: Kunal Sinha, Ishaan Kochhar, Ricky Carlson, Fiona McGann, Jake Fuhrman, Shray Chauhan, Erik Stolz, Julian Lambert, Courtney Kelsey, Andrew Fu

Customer: ASTRA — Andrew Gisler, Chris Prince, Erik Stromberg

Advisor: Professor Dennis Akos

Presentation Outline

1. Overview
2. Schedule
3. Test Readiness
4. Budget

Overview

Motivation: Infrastructure Analysis

Statistics

- 614,387 bridges in the US
- 200,000+ are over 50 years old
- 17% of bridges are inspected annually
- Infrastructure monitoring market valued at $1.78B in the U.S.

Motivation

- More precision, efficiency, and less manpower required per bridge is the goal

Source: Cormid Maintenance

Source: Metro.co.uk

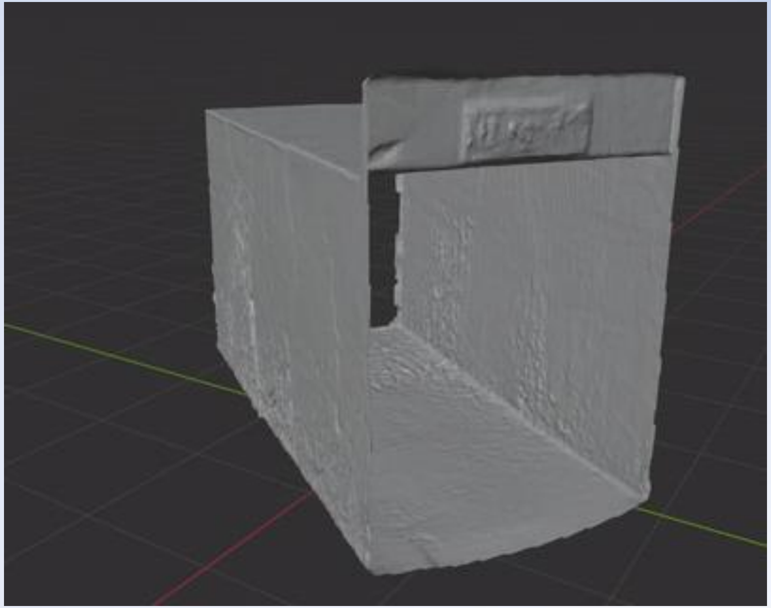
Objective & Mission Statement

Project Objective

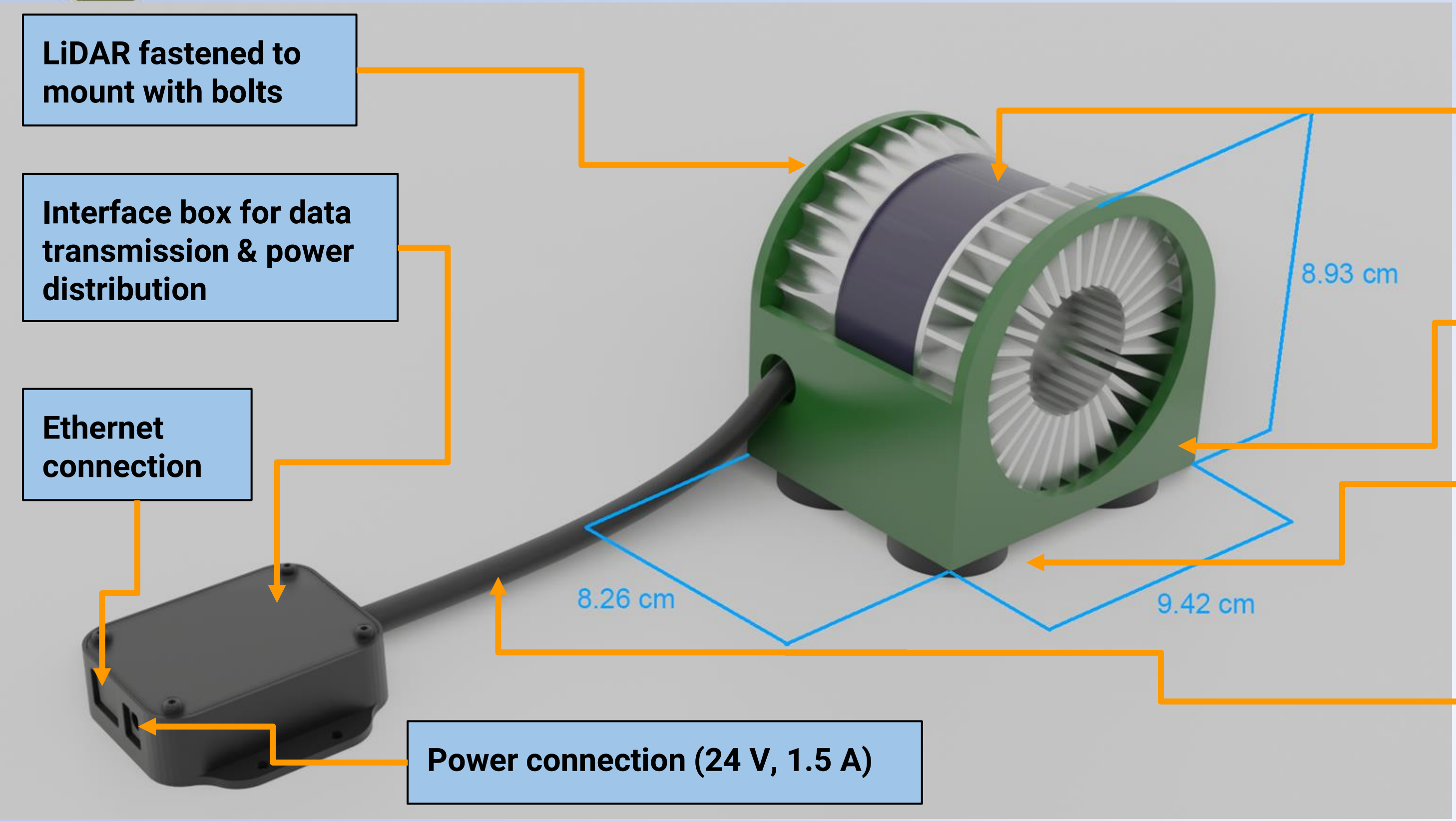
The system shall provide a low-cost and efficient way to monitor and assess infrastructure.

Mission Statement

Design, build, and deploy a dynamic, vehicle-based **LiDAR sensor package** which will **scan infrastructure** while in motion to produce a high-quality **3D map/model** that can be used by engineers to **assess structural health**.



LiDAR Hardware Overview

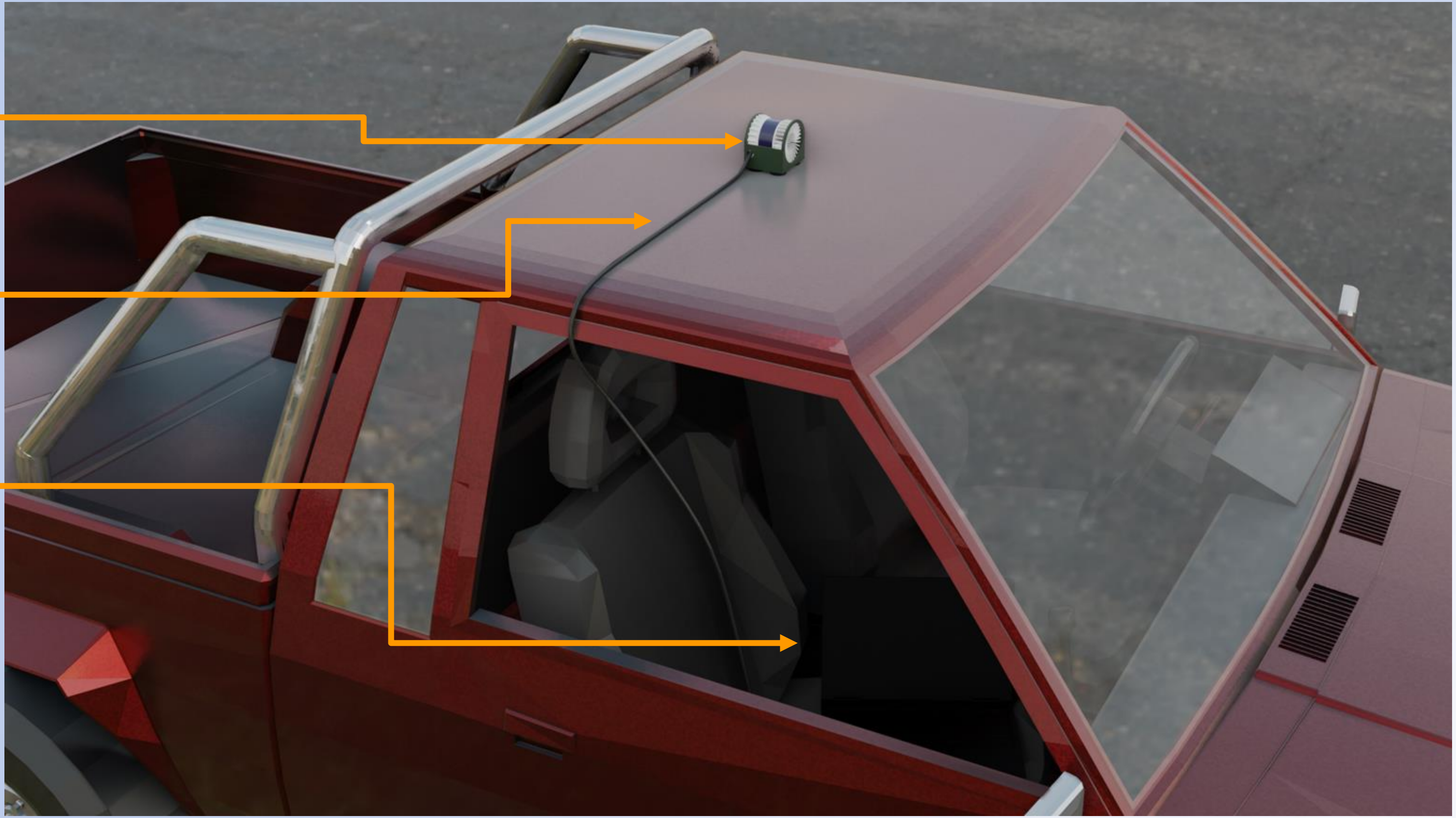


Top-Level Design Overview

LiDAR & Housing

Ethernet & Power

Onboard Laptop & Power Source

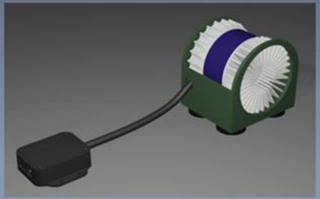


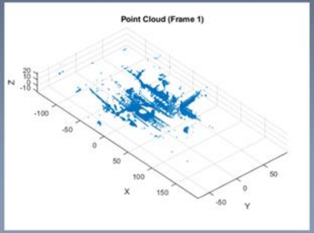
Overview | Schedule | Test Readiness | Budget

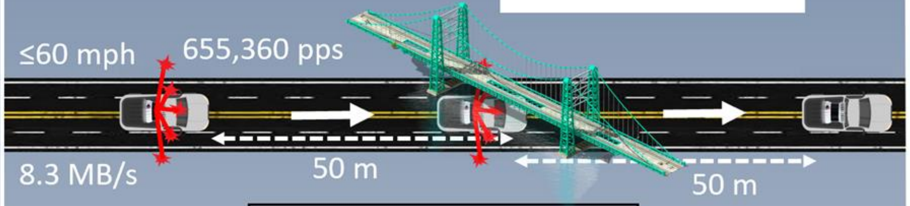
FLASH Concept of Operations

Single Infrastructure Inspection

Data Collection







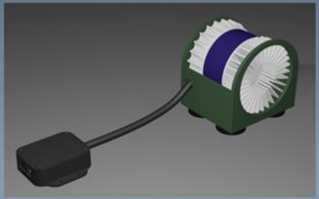
1. **Activate and deploy system**

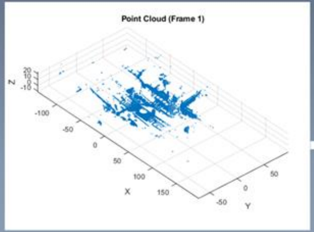
2. **Scan infrastructure while in motion**
   - Raw point cloud and IMU data collected (< 0.5 GB)
   - Standard 5.1 m bridge height
   - ~1000 pts/m^2 point density

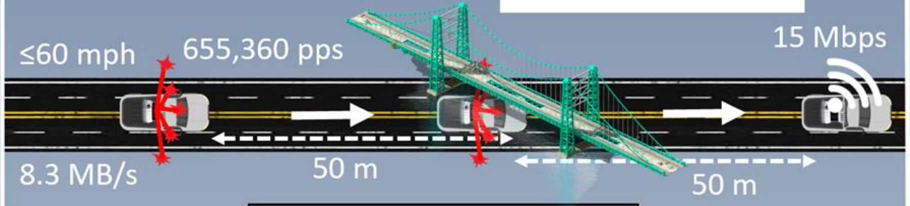
FLASH Concept of Operations

Single Infrastructure Inspection

Data Collection





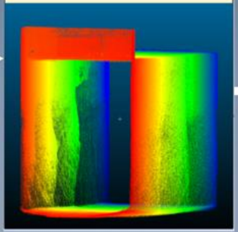


1. **Activate and deploy system**

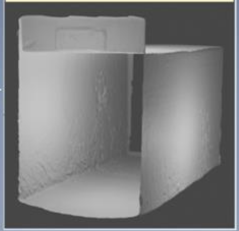
2. **Scan infrastructure while in motion**
   - Raw point cloud and IMU data collected (< 0.5 GB)
   - Standard 5.1 m bridge height
   - ~1000 pts/m^2 point density

3D Map/Model Generation

Point Cloud



Mesh



3. **Transmit data to post-processing home base**

4. **Process point cloud and IMU data (ROS + SLAM)**

5. **Generate 3D map/model for infrastructure assessment**

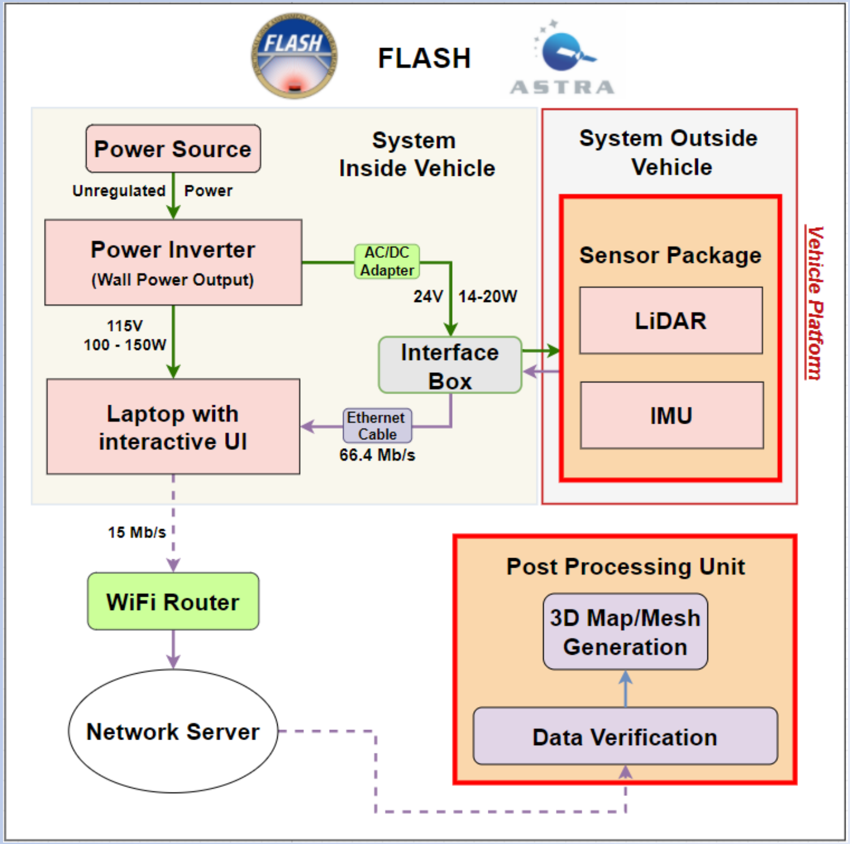
Critical Project Elements

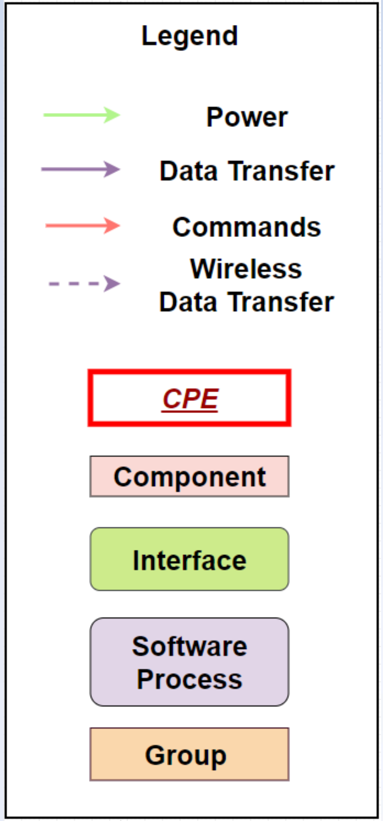
Designation	Element	Components	Why critical?
CPE-1	Sensor Package	Scanning LiDAR sensor + integrated IMU	High-resolution, precise, and accurate data collection is key to insightful 3D mapping and model generation
CPE-2	Data Processing Software	ROS* and SLAM*-based pipeline + commercial software package (CloudCompare)	Will require the most time and effort; consolidation of LiDAR and IMU data into a high-quality point cloud or mesh is not a straightforward process
CPE-3	Vehicle Platform	Magnetic mounts + custom-fabricated housing	Sensor package must be secure up to highway speeds and must not pose a safety concern

*ROS = Robot Operating System

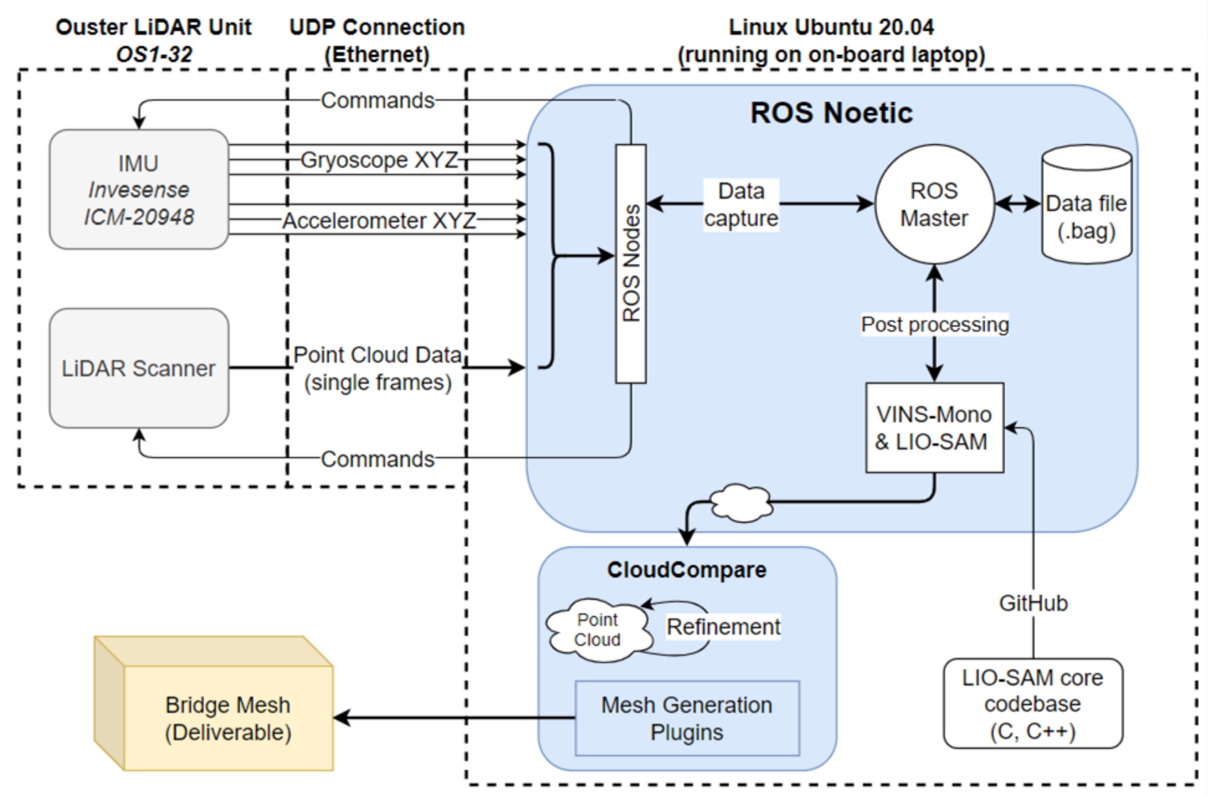
*SLAM = Simultaneous Localization and Mapping

Functional Block Diagram (FBD)

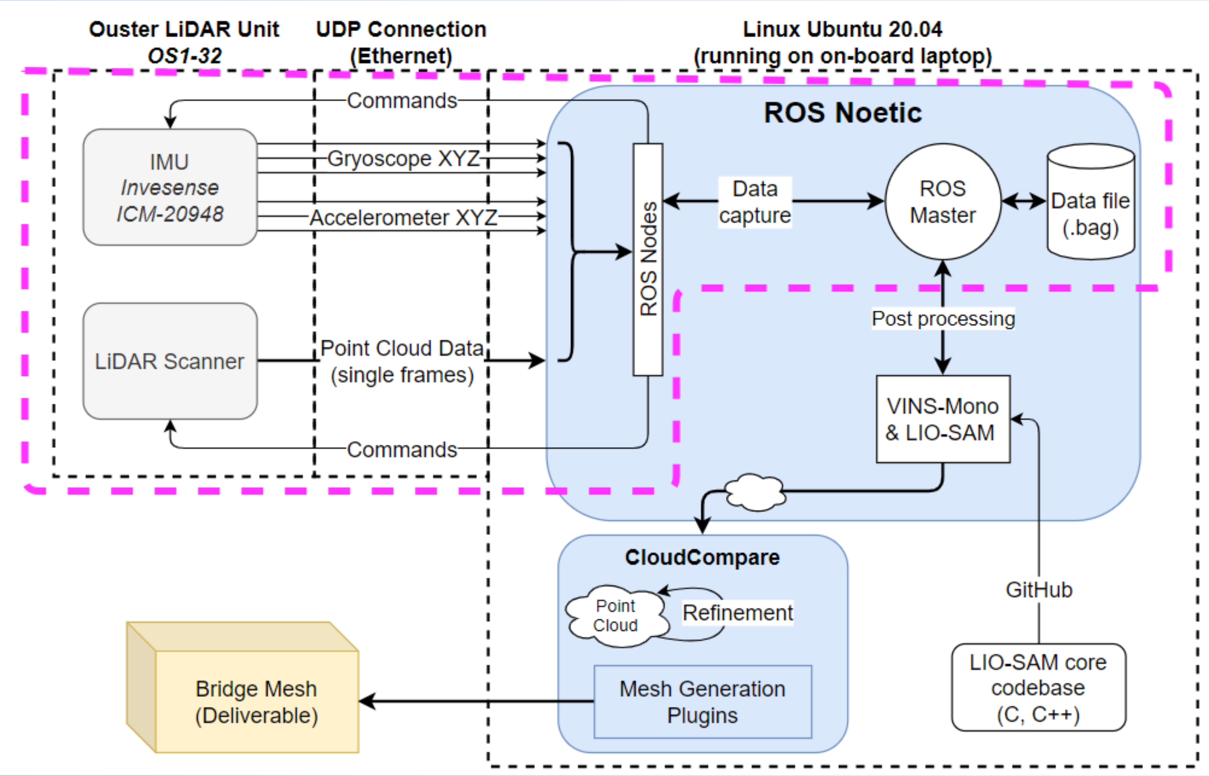


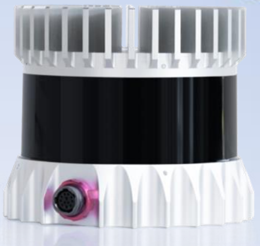


Software Design Overview



Software Design Overview

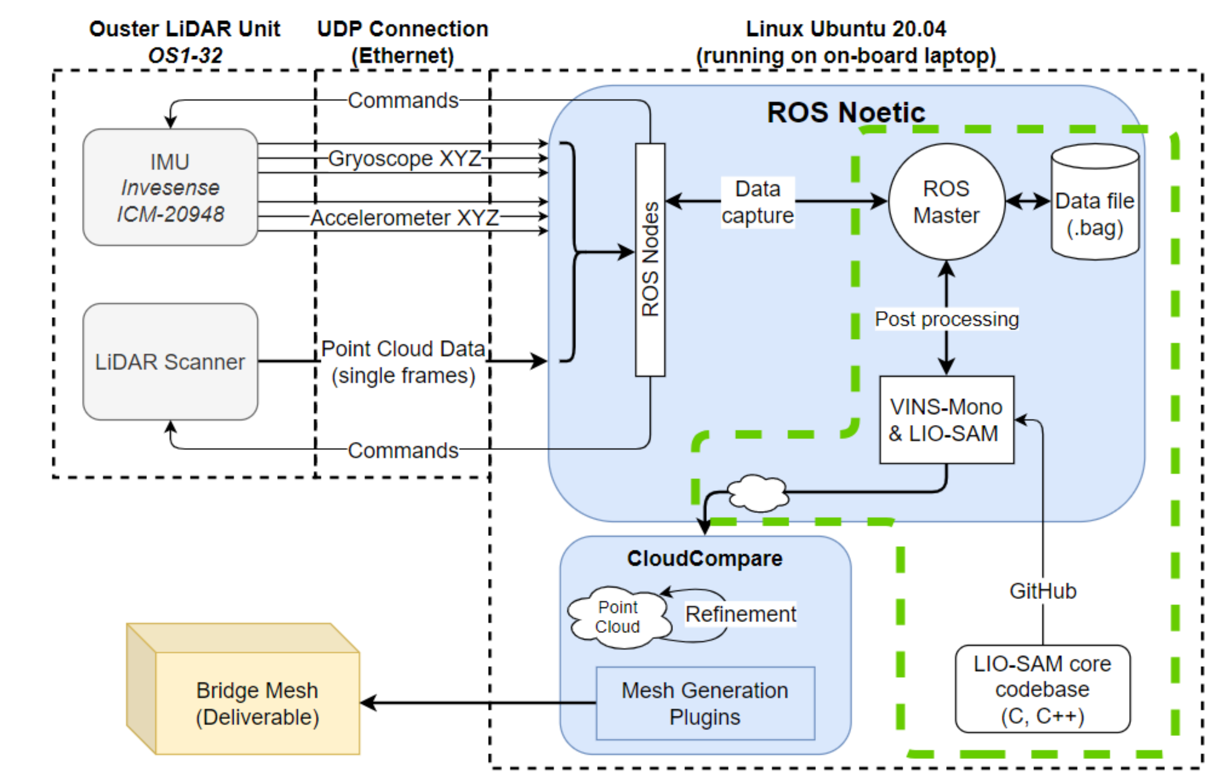




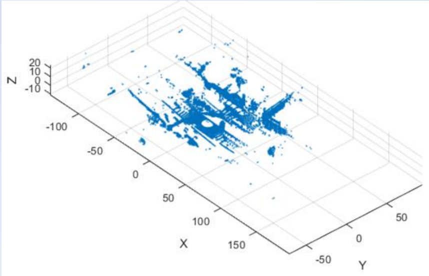
Ouster LiDAR Sensor

On-Board Passenger Laptop

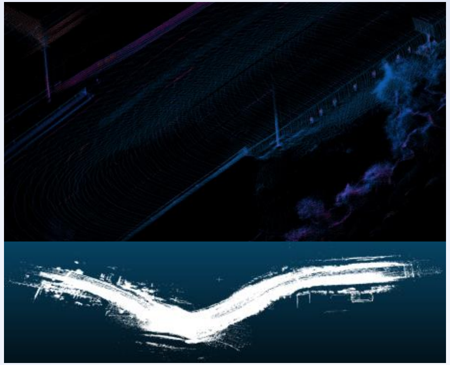
Software Design Overview



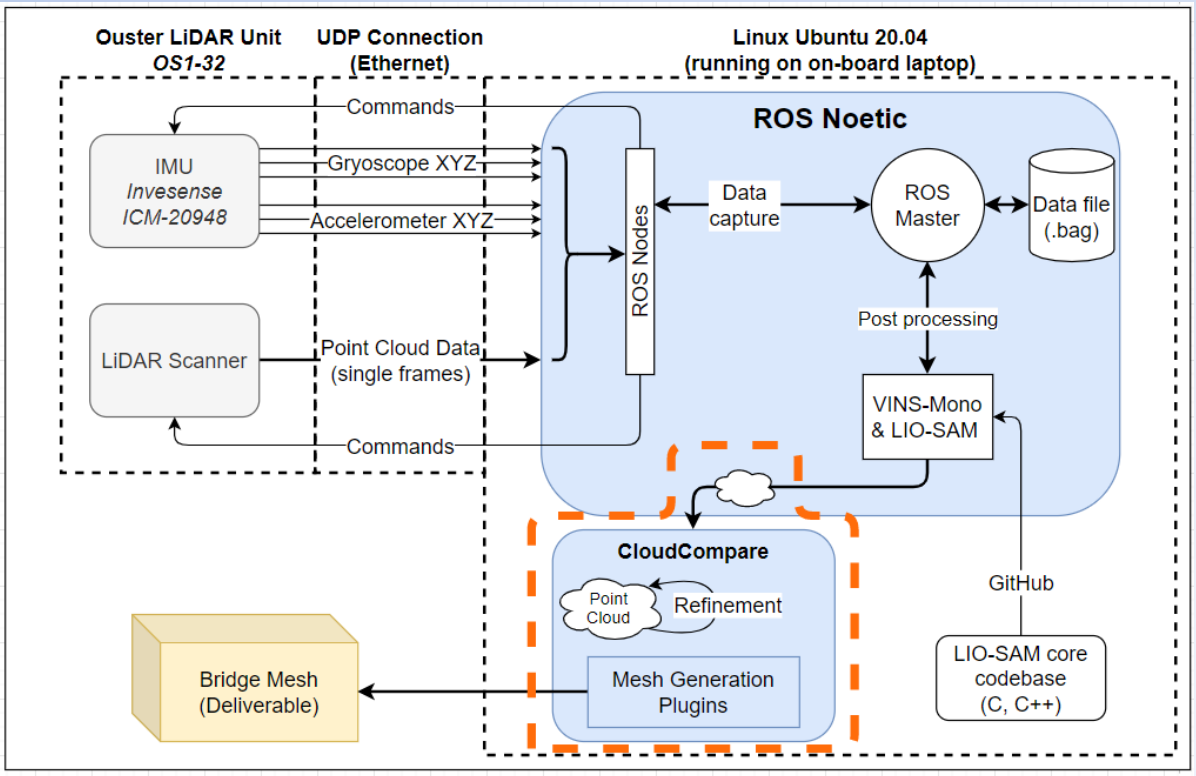
1 Point Cloud Frame



Stitched Point Cloud Map

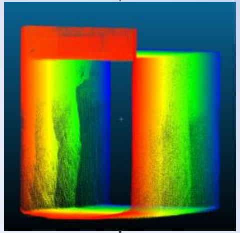


Software Design Overview

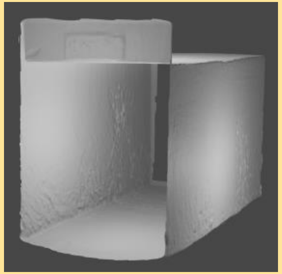


Infrastructure

Point Cloud



Mesh



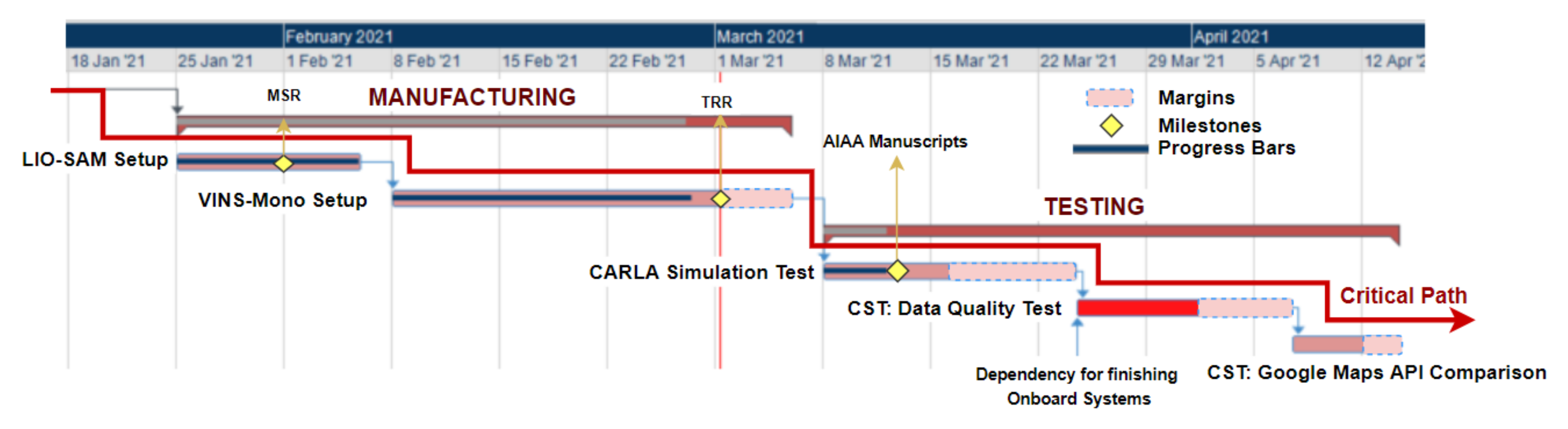
Project Updates Since MSR

Hardware
- Received LiDAR unit from ASTRA
- Fit check performed with 3D-printed mount
- Ordered aluminum mount
- Successfully performed Pull Test

Software
- Completed ROS Master and startup scripts
- Finalized data file (.bag) structure
- Collected preliminary data (SSL test)
- Successfully installed LIO-SAM
- Finalized VIMS-Mono sub-components required for Ouster/LIO-SAM bridge

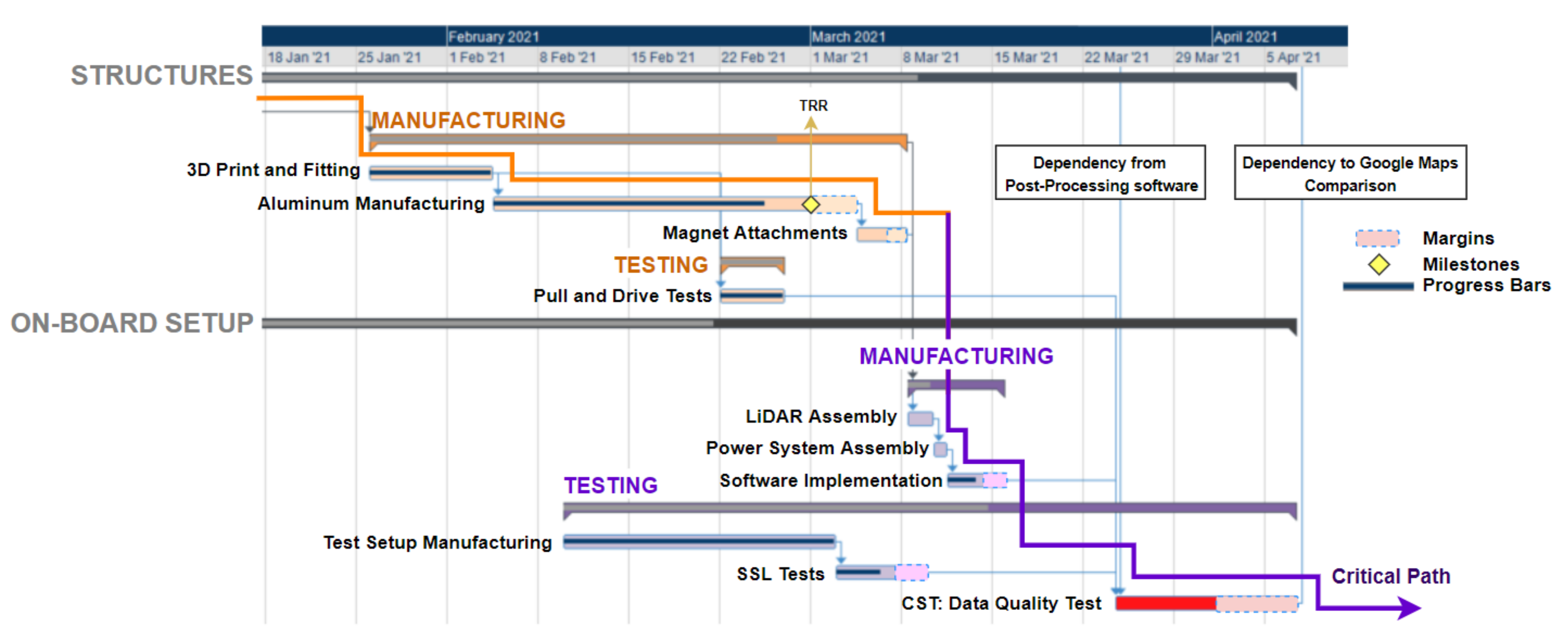
Schedule

Team Schedule: Software



Overview | Schedule | Test Readiness | Budget

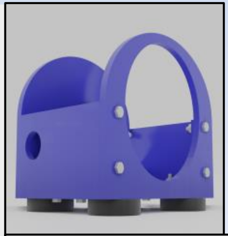
Schedule: Structures and On-Board Setup



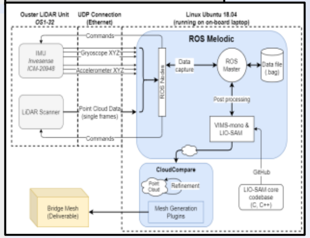
Test Readiness

Test Readiness Overview

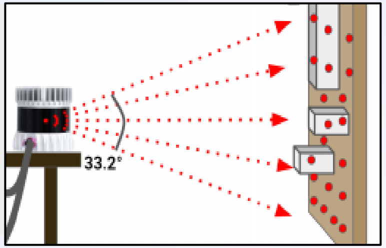
01 **Structures**
- Fit Check
- Pull Test



02 **Software**
- ROS Scripts
- Carla Simulation
- Google Maps Comparison



03 **Full System**
- Small Scale LiDAR Test
- Comprehensive Data Quality Test



Test Overview

Complete	In Progress	Not Started
Green	Yellow	Red

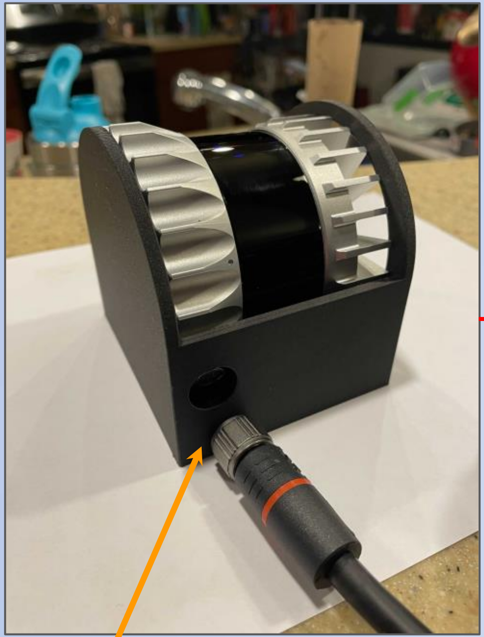
Test Name	Duration	Pre	Status	Equipment	Location
Structures: Pull Test	1 week	NA	Complete (green)	• Hook scale • Mount + magnets	Open parking space
Small Scale LiDAR Test	1 week	2	In Progress (yellow)	• Test board • LiDAR sensor + laptop	Controlled indoor + outdoor environment
CARLA Simulation Test	20 days	NA	In Progress (yellow)	• Processing computer	Homebase (with WiFi)
Comprehensive System Test	2 weeks	2	Not Started (red)	• LiDAR sensor + laptop • Mount + magnets • Vehicle • Electrical hardware	Low-traffic road with a highway underpass
Google Maps API Comparison	2 weeks	4	Not Started (red)	• Processing computer	Homebase (with WiFi)

Test Overview

Complete	In Progress	Not Started
(green)	(yellow)	(red)

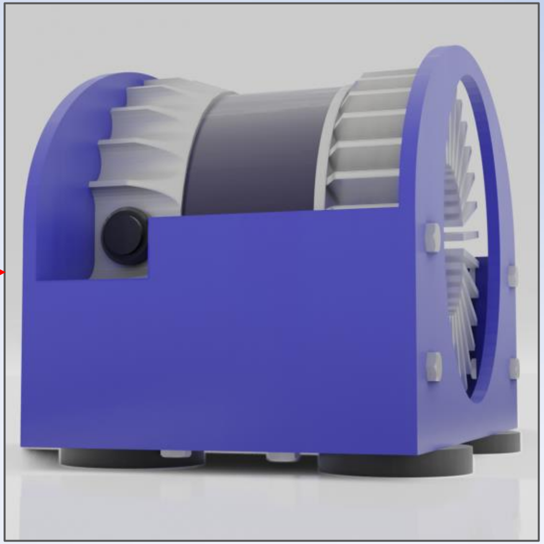
Test Name	Duration	Pre	Status	Equipment	Location
Structures: Pull Test	1 week	NA	Complete (green)	• Hook scale • Mount + magnets	Open parking space
Small Scale LiDAR Test	1 week	2	In Progress (yellow)	• Test board • LiDAR sensor + laptop	Controlled indoor + outdoor environment
CARLA Simulation Test	20 days	NA	In Progress (yellow)	• Processing computer	Homebase (with WiFi)
Comprehensive System Test	2 weeks	2	Not Started (red)	• LiDAR sensor + laptop • Mount + magnets • Vehicle • Electrical hardware	Low-traffic road with a highway underpass
Google Maps API Comparison	2 weeks	4	Not Started (red)	• Processing computer	Homebase (with WiFi)

Structures: Fit Check



LiDAR fits perfectly but the cable does not

Adjustments were made to accommodate cable



Fit check informed changes on future aluminum mount design

Structures: Pull Test

Objective/Rationale

Determine experimental “maximum” that the magnetic mounting can withstand to verify what the structure will be able to withstand during CST.

Validation of Model

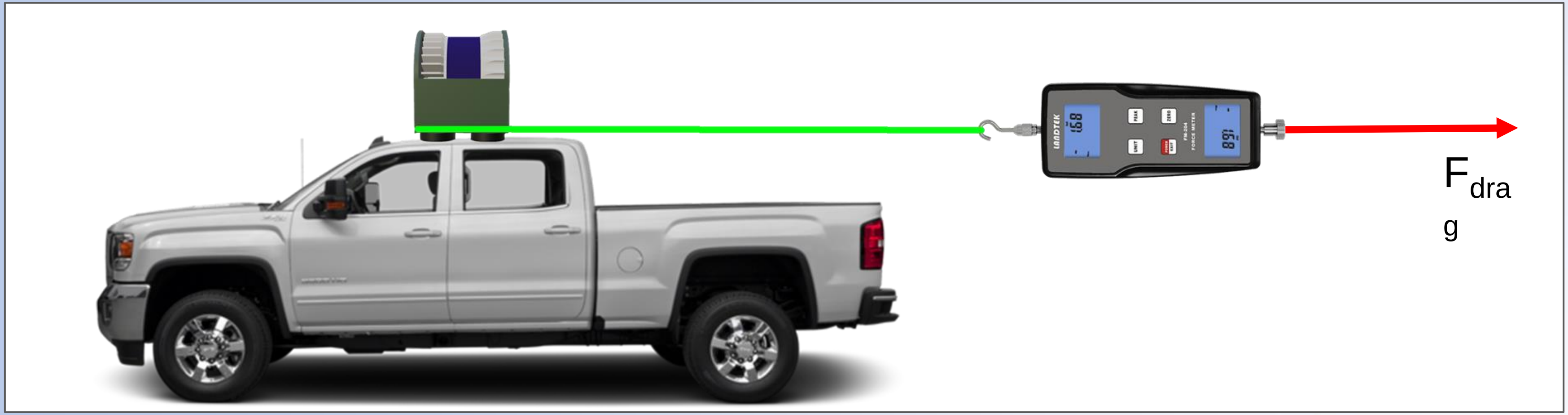
Holding capacity tested with hook scale

Expected result: $\mathbf{F_{mag} >> 1.6\ lbf}$

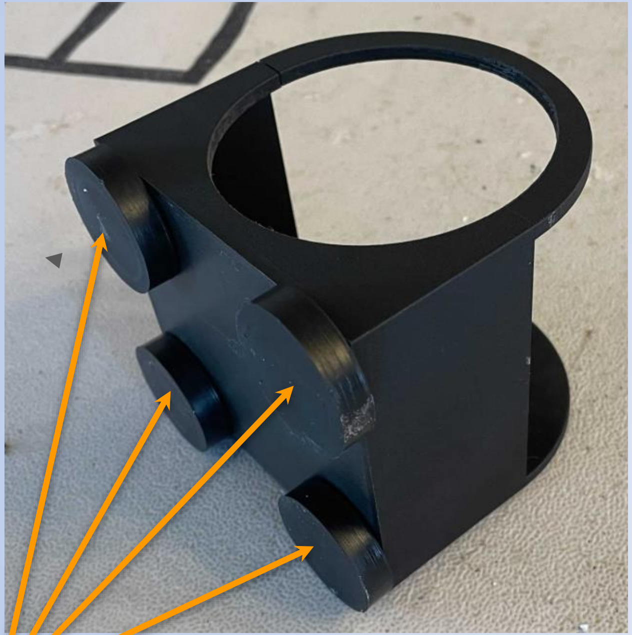
Verifying DR 5.1

Withstanding drag forces associated with relative wind

Validated through Pull Test



Structures: Pull Test



32 mm Ø
Magnet (4x)

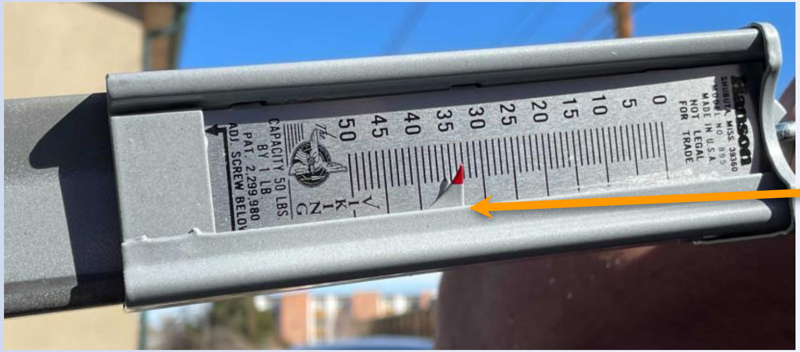
Bolts (5 mm x 9.5 mm)
Integrated with Magnets

Structures: Pull Test

Vehicle Roof

Belt with Hook Scale

3D-printed Structure with Magnets and Dummy Weight



Hook Scale Measurement

Structures: Pull Test

Requirement (DR 5.1)

Magnet horizontal holding capacity ≥ $1.5F_{drag} = 1.6$ lbf

Validating DR 5.1

Withstanding drag forces associated with relative wind

FOS achieved = ~30 ☑

Validated through Pull Test

Aggregate Trial Summary	
Hook Scale Reading	**Observations**
5 lb	Sturdy (No slippage)
10 lb	Sturdy (No slippage)
20 lb	Sturdy (No slippage)
30 lb	**Earliest observed slipping**
35+ lb	Steady, consistent slipping as load increases

Structures: Pull Test

Risk Reduction

Risk of LiDAR falling off vehicle proven to be extremely low

Test Importance

System Safety: LiDAR sensor proved to be safe against drag forces associated with driving at 65 mph.

V&V: Critical importance for project success.

Test Schedule

Completed

Test has been completed and was successful in proving structural capability.

Test Overview

Complete	In Progress	Not Started
(green)	(yellow)	(red)

Test Name	Duration	Pre	Status	Equipment	Location
Structures: Pull Test	1 week	NA	Complete	• Hook scale • Mount + magnets	Open parking space
Small Scale LiDAR Test	1 week	2	In Progress	• Test board • LiDAR sensor + laptop	Controlled indoor + outdoor environment
CARLA Simulation Test	20 days	NA	In Progress	• Processing computer	Homebase (with WiFi)
Comprehensive System Test	2 weeks	2	Not Started	• LiDAR sensor + laptop • Mount + magnets • Vehicle • Electrical hardware	Low-traffic road with a highway underpass
Google Maps API Comparison	2 weeks	4	Not Started	• Processing computer	Homebase (with WiFi)

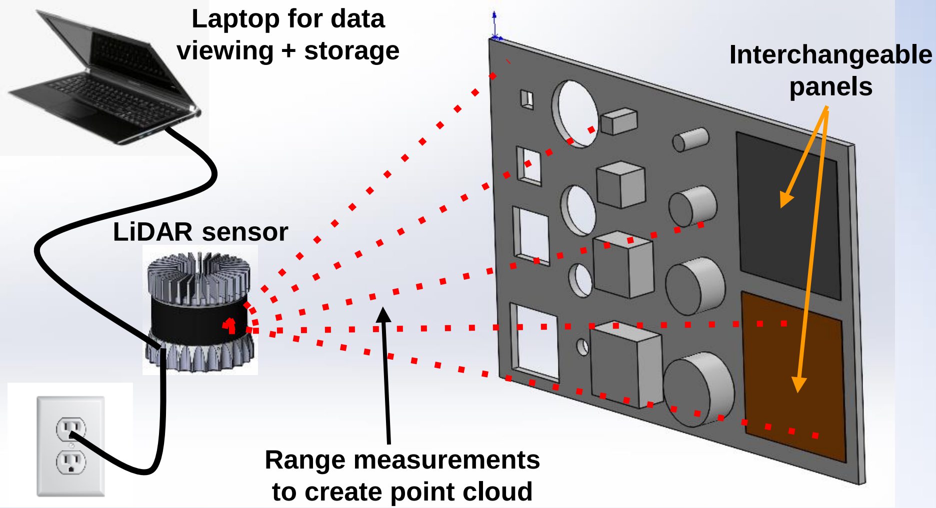
Small-Scale LiDAR (SSL) Operational Test

Objective/Rationale

Baseline verification of stationary sensor performance and operation

General Procedure

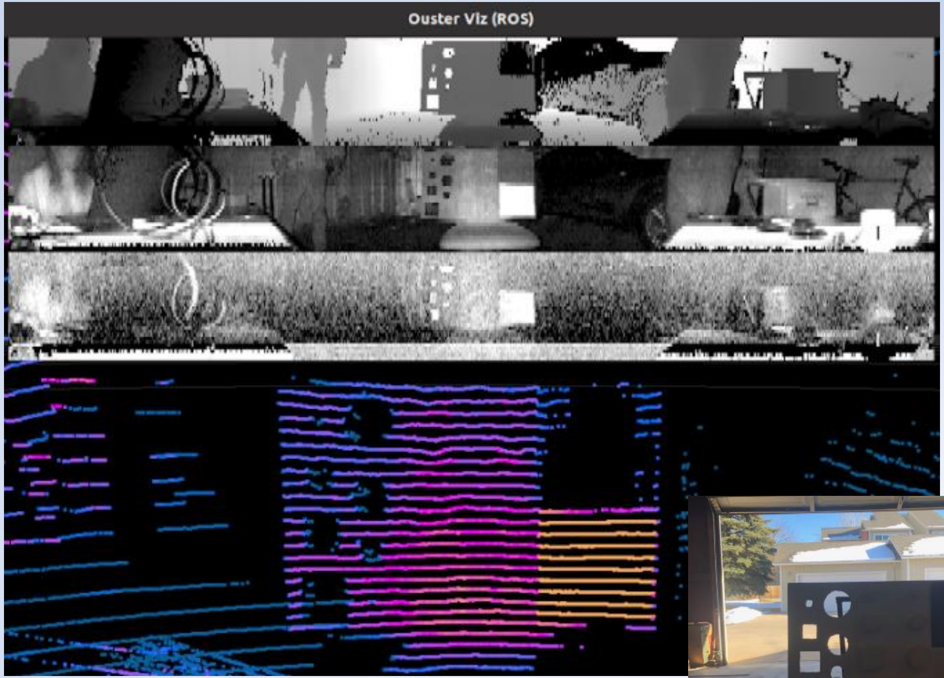
1) Scan test board at incremental distances (1 to 4 m) in shaded environment ☑
2) Repeat in direct sunlight environment ☑
3) Extract individual point cloud frames from saved data file for each test case (TBD)
4) Evaluate correspondence between point cloud data and true test board features/dimensions (TBD)



Small-Scale LiDAR (SSL) Operational Test

Risk Reduction

- LiDAR performance characterization before field deployment
- Ensure that data can be collected, stored, and viewed reliably
- Ensure that features can be discerned



Expected Result (Pass Criteria)

Identification of features at least 5 cm in size from distances up to 4 meters in shaded condition

Small-Scale LiDAR (SSL) Operational Test

Test Importance

Relevant Requirements:

- DR 2.2: Accuracy ≤ 10 cm (for range only)
- DR 2.3: Precision ≤ 10 cm
- FR 4: The on-board computer shall be capable of data storage, handling, and interfacing between components

V&V: Moderate importance for project success

Test Status: In Progress

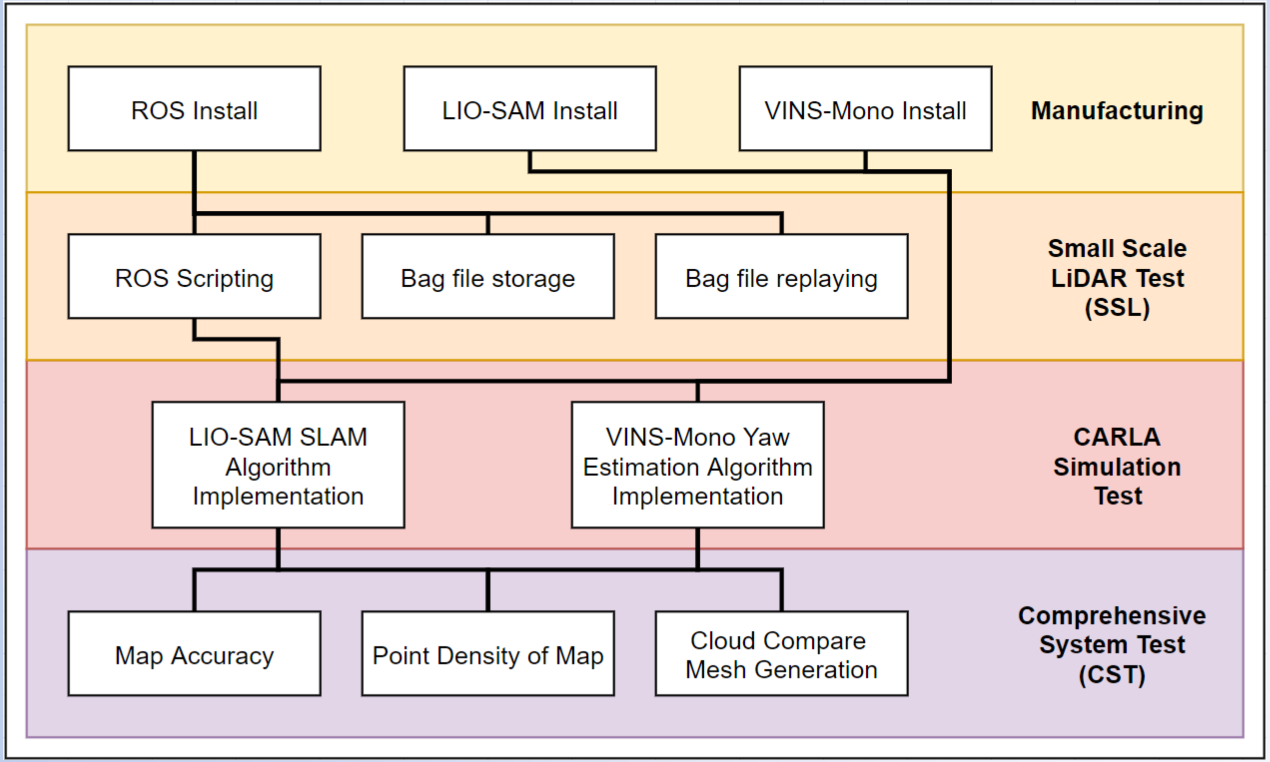
Data has been collected on test board. Waiting on software pipeline for data assessment.

Test Overview

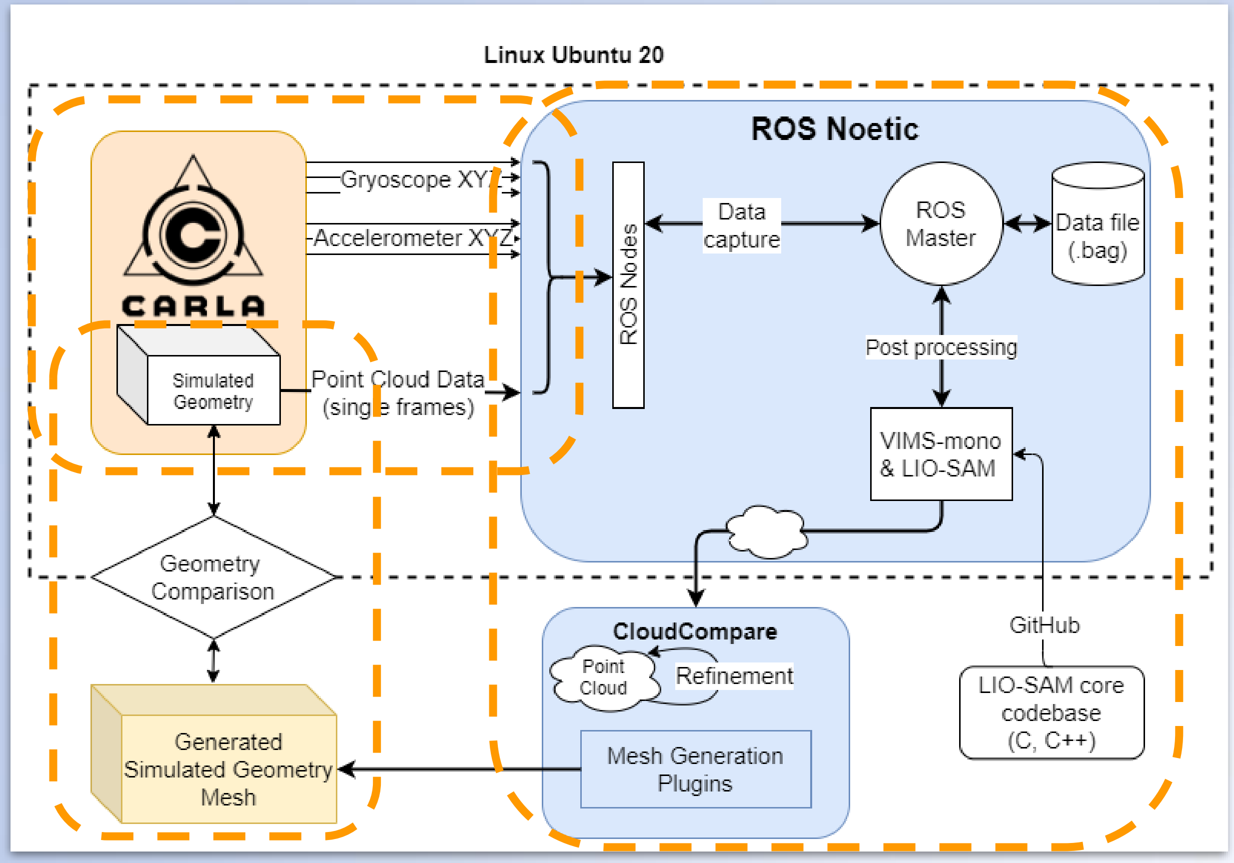
Complete	In Progress	Not Started
(green)	(yellow)	(red)

Test Name	Duration	Pre	Status	Equipment	Location
Structures: Pull Test	1 week	NA	Complete (green)	• Hook scale • Mount + magnets	Open parking space
Small Scale LiDAR Test	1 week	2	In Progress (yellow)	• Test board • LiDAR sensor + laptop	Controlled indoor + outdoor environment
CARLA Simulation Test	20 days	NA	In Progress (yellow)	• Processing computer	Homebase (with WiFi)
Comprehensive System Test	2 weeks	2	Not Started (red)	• LiDAR sensor + laptop • Mount + magnets • Vehicle • Electrical hardware	Low-traffic road with a highway underpass
Google Maps API Comparison	2 weeks	4	Not Started (red)	• Processing computer	Homebase (with WiFi)

Software: Pipeline Validation Tests



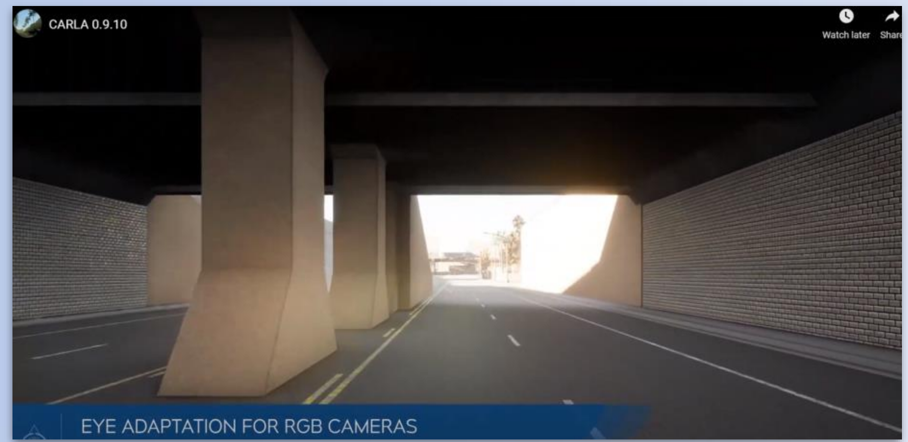
Software: CARLA Simulation Flow Diagram



Software: CARLA Simulation

Objective/Rationale

Rapid test of software pipeline by providing raw LiDAR and IMU data of a virtual environment with the exact parameters of our sensor package.



Screen capture of map to be imported onto CARLA

General Procedure

1) Import map from CARLA Asset library of a bridge/structure to sample data
2) Set up simulation LiDAR Parameters to match Ouster's (from data sheet and orientation)
3) Connect simulated LiDAR to ROS Nodes in our script, record bag file
4) Play bag file in LIO-SAM and VINS-Mono algorithm to get Mesh
5) Take note of parameters to be changed and repeat from step 4

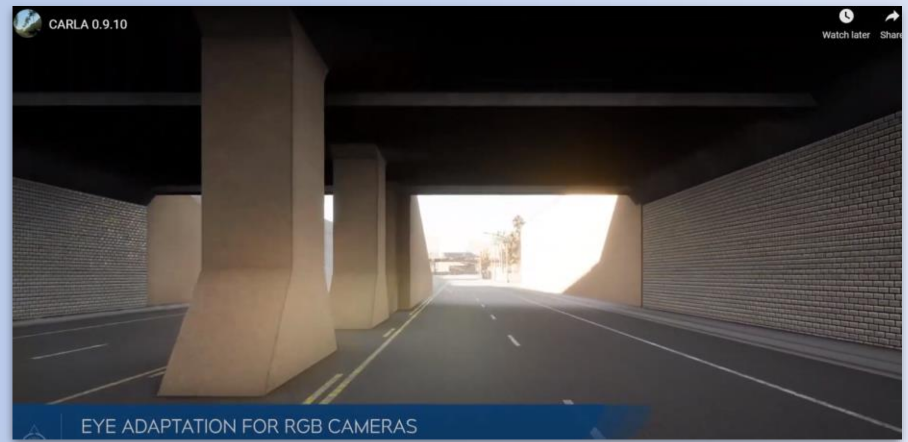
Software: CARLA Simulation

Test Importance

SLAM Functionality: a CARLA Simulation will prove that the output of SLAM can match ground truth data.

Verifying DR 3.1 and DR 7.1

Post processing efforts will be able to produce a useable 3D model outside of GNSS services.



Screen capture of map to be imported onto CARLA

Validation Method

Measurements of output will can be taken on Cloud Compare, will be compared with CARLA SImulated Map

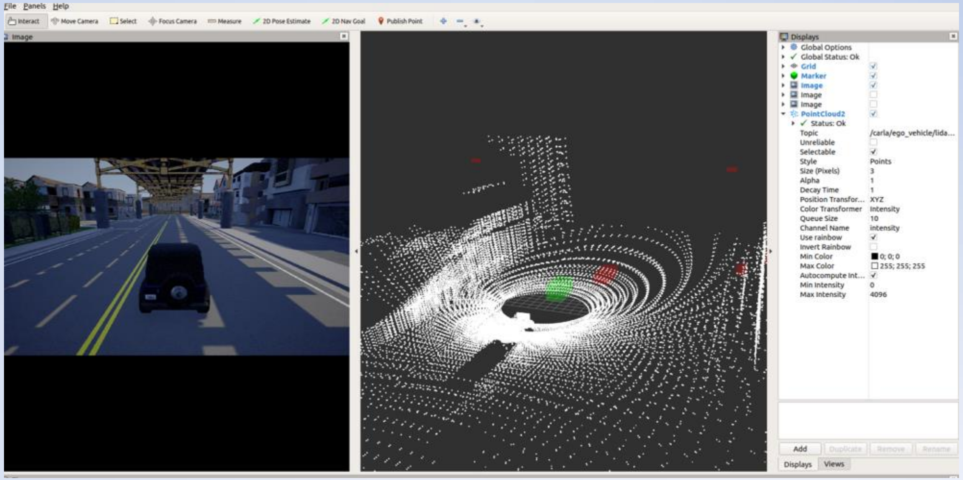
Software: CARLA Simulation

Expected Result (Pass Criteria)

Generated LiDAR mesh from simulated asset with <u>10cm accuracy and precision</u>

Risk Reduction

- Give confidence in algorithm implementations
- Quick modifications to code without taking real data every time



Screen capture from ROS - CARLA integration tutorial

Test Schedule

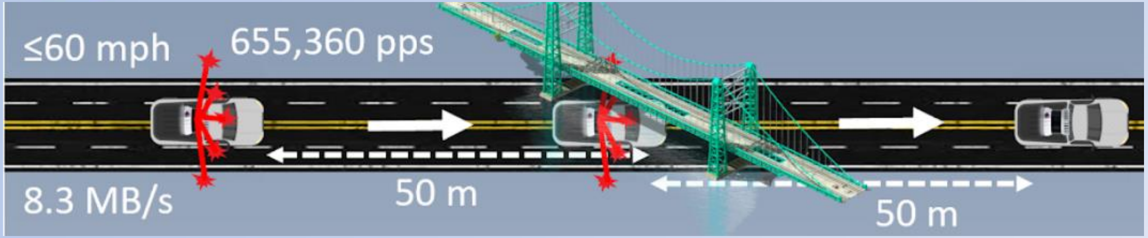
In Progress (to end by 3/22)

Test Overview

Complete	In Progress	Not Started
Green	Yellow	Red

Test Name	Duration	Pre	Status	Equipment	Location
Structures: Pull Test	1 week	NA	Complete (green)	• Hook scale • Mount + magnets	Open parking space
Small Scale LiDAR Test	1 week	2	In Progress (yellow)	• Test board • LiDAR sensor + laptop	Controlled indoor + outdoor environment
CARLA Simulation Test	20 days	NA	In Progress (yellow)	• Processing computer	Homebase (with WiFi)
Comprehensive System Test	2 weeks	2	Not Started (red)	• LiDAR sensor + laptop • Mount + magnets • Vehicle • Electrical hardware	Low-traffic road with a highway underpass
Google Maps API Comparison	2 weeks	4	Not Started (red)	• Processing computer	Homebase (with WiFi)

Comprehensive System Test (CST)



Objective/Rationale

Complete system integration from real, raw 3D point cloud data to a deliverable 3D mesh. Project elements to be validated here include:

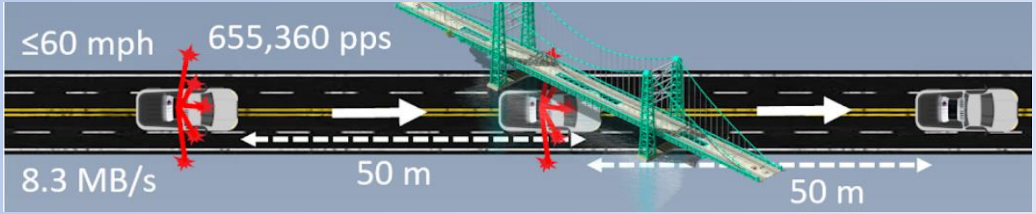
- ❑ Magnetic Attachment of Mount
- ❑ All Electrical Interfacing
- ❑ LiDAR 3D Point Cloud Collection
- ❑ Saving/Registering 3D Point Cloud Data
- ❑ Generating a Deliverable 3D Mesh

Test Environment: 6th Ave + Wadsworth, 3/23/21 at 1:00 PM
Equipment: Complete system + vehicle

General Procedure (CONOPs)

1) Secure system to vehicle and verify power to all systems
2) Pass under the bridge/infrastructure of interest with LiDAR powered on
3) Collect, save, and register 3D point cloud data
4) Post-process data through custom pipeline to create a 3D mesh model of the infrastructure

Comprehensive System Test (CST)



Test Importance

Relevant Requirements:

- All Design Requirements

V&V: Critical importance to project success.

Validation Method

Resolution: Density will be calculated via tool within CloudCompare software.

Accuracy: Point cloud will be checked against stationary data and bridge clearance values from CDOT database (OTIS).

Test Schedule

Not Started

Requires all subteams to be ready and all other tests to be completed first.

Comprehensive System Test (CST)

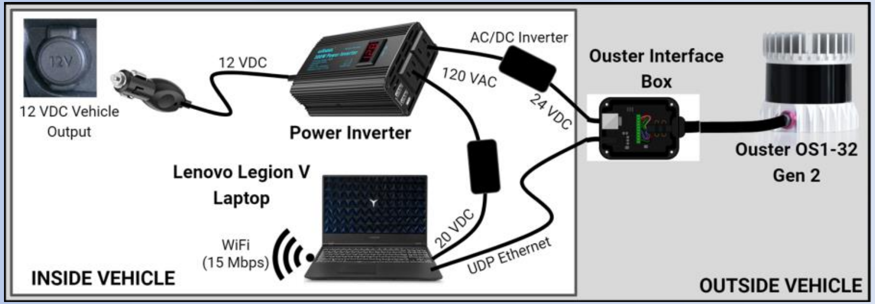
Expected Result (Pass Criteria)

Creation of a <u>3D mesh</u> which meets <u>all</u> <u>Design Requirements</u> when compared to <u>ground truth data</u>

Risk Reduction

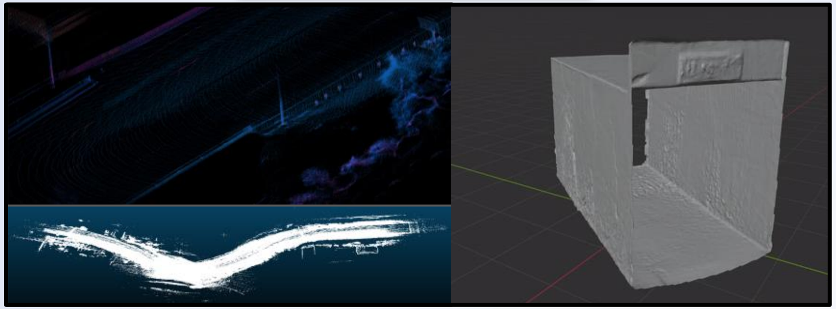
- Ensure that data can be collected, stored, and viewed
- Ensure system compatibility without error on a moving vehicle platform
- "Day-in-the-life" simulation of full system deployment as to be used by customer

Hardware Inputs



CST

Software Outputs



Budget

Procurement Updates

Item	Quantity	Total Cost	Procurement Status	Lead Time	Criticality to Project Success**
Lenovo Legion V Laptop	1	$999.99	Received	N/A	Desirable
Rubber Magnets (for Mounting)	4	$59.40	Received	N/A	Important
Power Inverter	1	$35.96	Received	N/A	Desirable
Ouster OS1-32 Gen 2 LiDAR	1	$3,585.00*	Received	N/A	Critical
Mounting Structure (3D Printed - Plastic)	1	$20.00	Received	N/A	Important
Mounting Structure (CNC 6061 Aluminum)	1	N/A	On Order	~2 weeks	Important

*ASTRA has purchased

**Criticality to upcoming testing schedule (all will be critical to project completion)

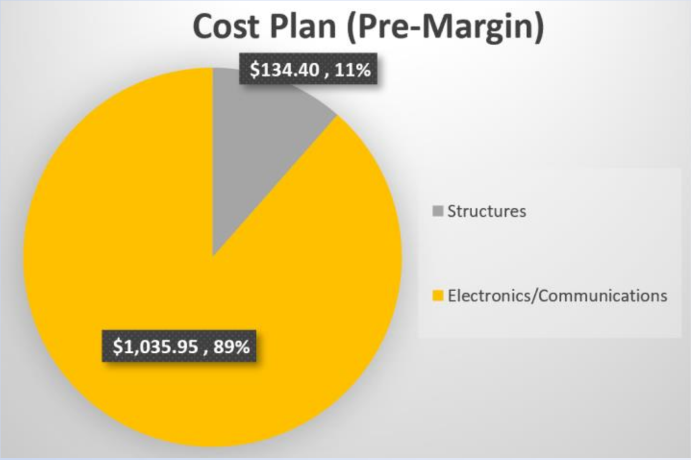
Procurement Updates

Item	Quantity	Total Cost	Procurement Status	Lead Time	Criticality to Project Success**
Lenovo Legion V Laptop	1	$999.99	Received	N/A	Desirable
Rubber Magnets (for Mounting)	4	$59.40	Received	N/A	Important
Power Inverter	1	$35.96	Received	N/A	Desirable
Ouster OS1-32 Gen 2 LiDAR	1	$3,585.00*	Received	N/A	Critical
Mounting Structure (3D Printed - Plastic)	1	$20.00	Received	N/A	Important
Mounting Structure (CNC 6061 Aluminum)	1	N/A	On Order	~2 weeks	Important

Total Funds Spent: $1,171.83 + Pilot Deposit: $200.00 → Remaining Funds: $3,628.17

Updated Cost Plan

- Current Budget Estimate:
  - $1,487.39
- Total Budget Allocated:
  - $5,000.00
- Remaining Budget:
  - $3,512.61



Subsystem	Total Cost ($)
Sensor Package	$0*
Software	$0
Structures	($134.40)
Electronics/ Communications	($1035.95)
Total	**($1170.35)**
Cost Margin	10%
Pilot Deposit	($200.00)
Total w/ Margin	**($1487.39)**

- **ASTRA has purchased our OS1-32 LiDAR sensor ($3585.00)**

*Option to include External IMU ($1,495.00) if deemed necessary after testing (*Decision Deadline: 3/11/21*)

Thank You!

Questions?

Backup Charts

Pull Test: Full Procedure

Test Environment:
Parking Lot: 1055 Adams Cir
Date: 2/22/21
Time: 2:00 PM MST
Dry, Sunny Day (~50^{o}F)

Equipment:
Belt
Structural Housing
Dummy Weight
2 Vehicles

1. Park two cars of similar heights with trunks facing each other.
    a. Park as close as possible.
2. Sit on roof of one car and attach the structural housing to the top of the other. Load dummy weight into the structural housing.
    a. The back of the housing should be facing the tester.
3. Attach a rope/belt around the rear (closest to the tester) two magnets in between the car and the base of the structure.
4. Attach the hook scale to the rope/belt.
5. Apply force steadily, noting when slippage happens.

Belt attached to around the rear two magnets for the pull test.

Pull Test: Take 1

Hook Scale Reading	Observations (PT 1)
5 lb	Sturdy (No slippage)
10 lb	Sturdy (No slippage)
20 lb	Sturdy (No slippage)
30 lb	Noise indicated slippage was starting to occur
35 lb	Slow, but steady slipping around 35 lbs

Pull Test: Take 2

Hook Scale Reading	Observations (PT 2)
5 lb	Sturdy (No slippage)
10 lb	Sturdy (No slippage)
20 lb	Sturdy (No slippage)
> 30 lb*	Steady slippage occured

* slippage occurred after 30 lbs of force, but before 35 lbs of force

Pull Test: Model Verification

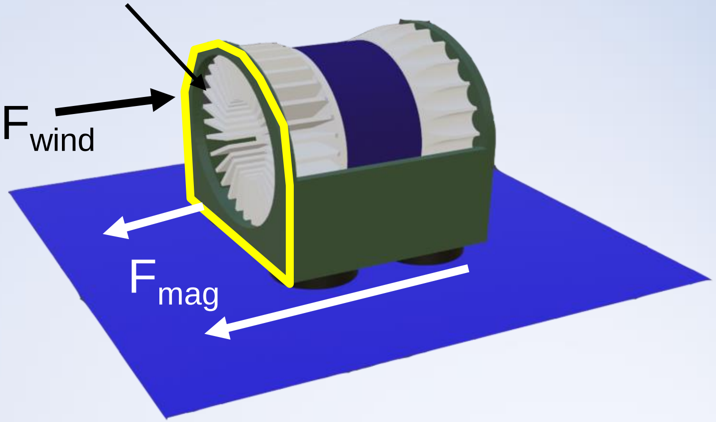
Magnets must withstand the force of the oncoming wind created by the motion of the vehicle.

Variables:

Force From Wind	F_w
Relative Wind (Car Speed)	v

Constants:

Air Density (typical)	ρ	1.14 kg/m^3
Surface Area of Structural Housing:	A	99.9 cm^2



$$F_w = \text{pressure} * \text{area} = (\tfrac{1}{2}\rho v^2)*(A)$$

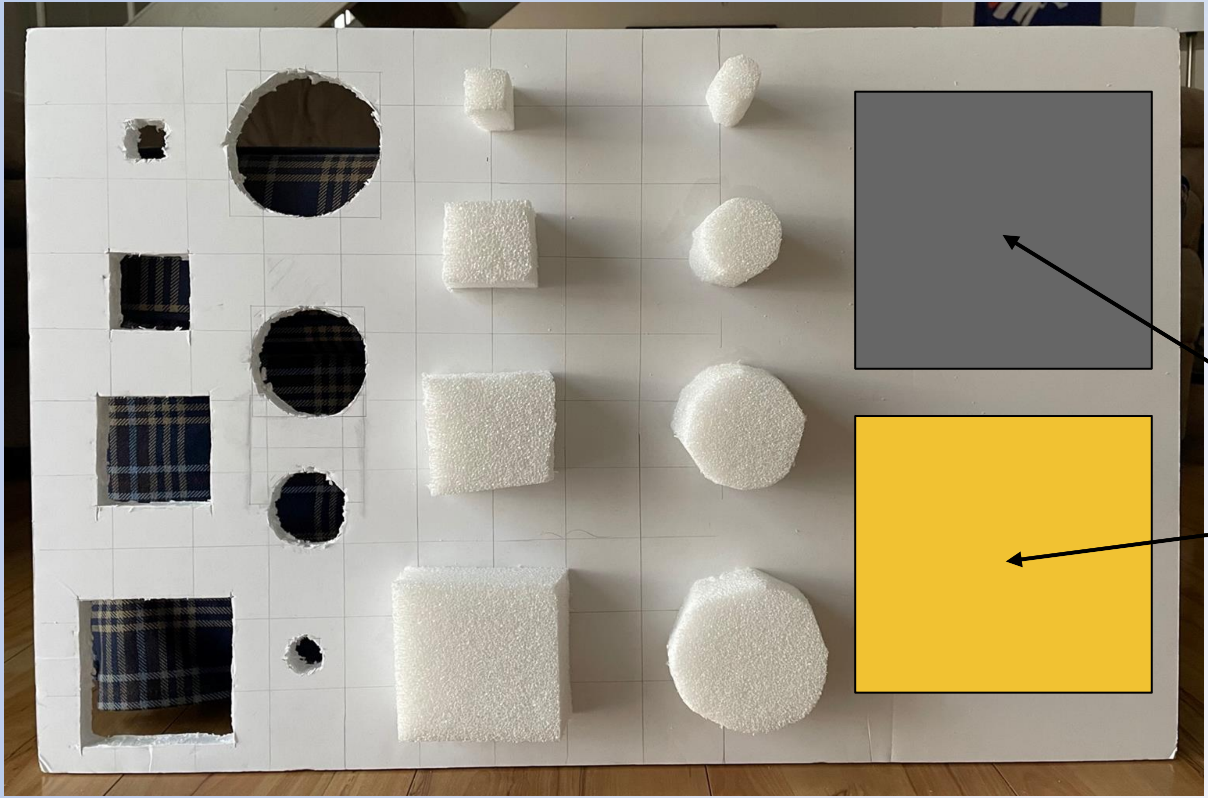
@ 65 mph → F_w = 4.8079 N = 1.0809 lbf

w/ FOS = 1.5 → F_w = 7.2119 N = 1.6213 lbf

Magnets must withstand at least 1.6213 lbf from a vertical pull test

Small-Scale LiDAR (SSL) Test Board

50.8 cm



76.2 cm

<u>Hole & Protrusion Sizes:</u>
2.5 cm, 5 cm, 7.5 cm, 10 cm

<u>Protrusion Depth:</u> 4.75 cm

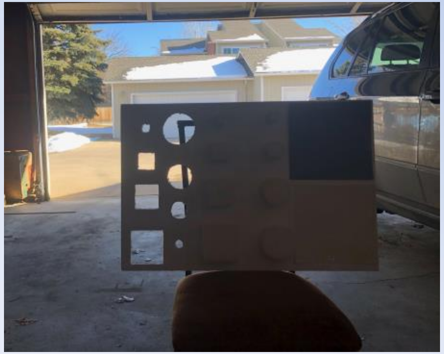
Interchangeable
Paper Panels

Small Scale LiDAR Test: Full Procedure

Test Environment:
Garage Area: 5550 Pennsylvania Ave
Date: 2/28/21
Time: 2:00 PM MST
Dry, Sunny Day (~30ºF)

Equipment:
LiDAR Sensor
LiDAR Data Cable
LiDAR Power Cable
Laptop
Test Board
Paper Panels + Tape
Tape Measure

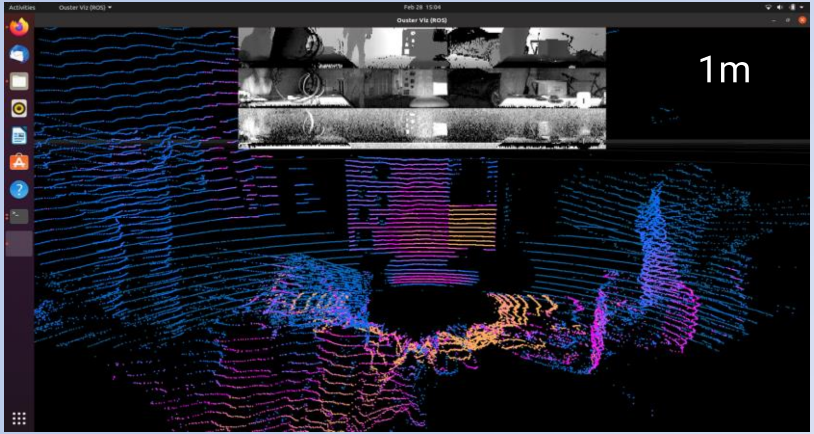
1. Set up test board (see previous slide).
2. Set up markers at 1, 2, 3, and 4 meters away from the front of the LiDAR.
3. Set up test board at 1 meter mark at the same height as the LiDAR.
4. Open ROS Noetic code in Ubuntu 20.
   a. Verify IP address of the LiDAR
   b. Check source
   c. Input .bag command
5. Run code to capture data for a small .bag file (~5 seconds).
6. Take screen capture of live stream (optional).
7. Repeat 5 and 6 at 2, 3, and 4 meters.
8. Repeat steps 1 - 7 in different lighting conditions with different paper panels as desired.

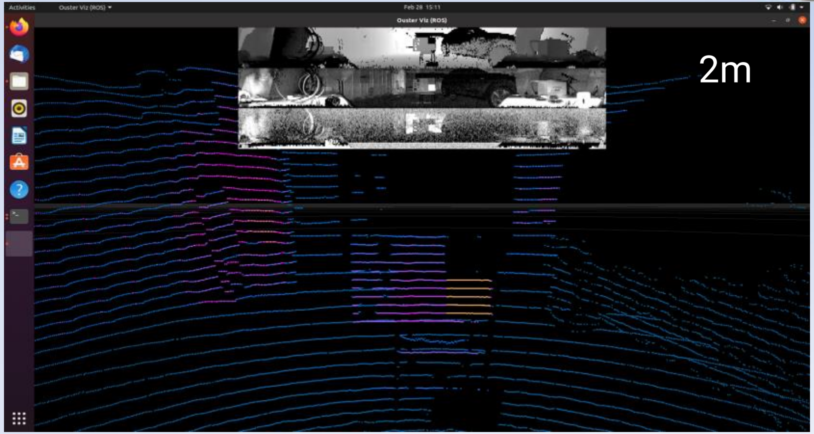


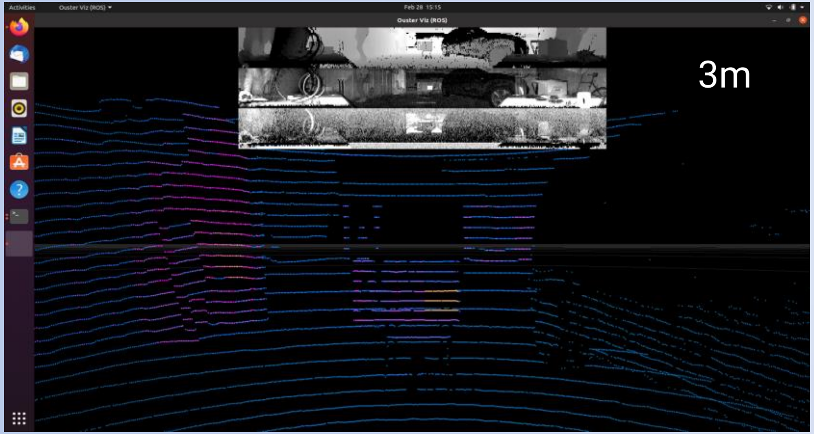
Lighting condition 1 with 1st set of paper panels.

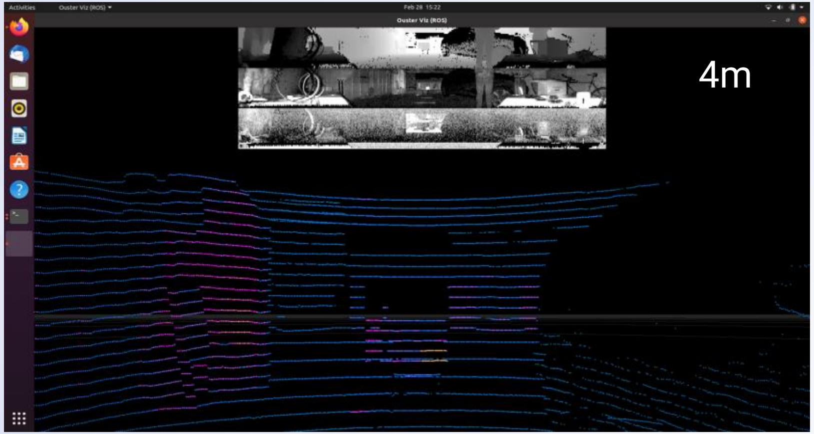
Lighting condition 2 with 2nd set of paper panels.

Small Scale LiDAR Test: Shaded, 1st Papers

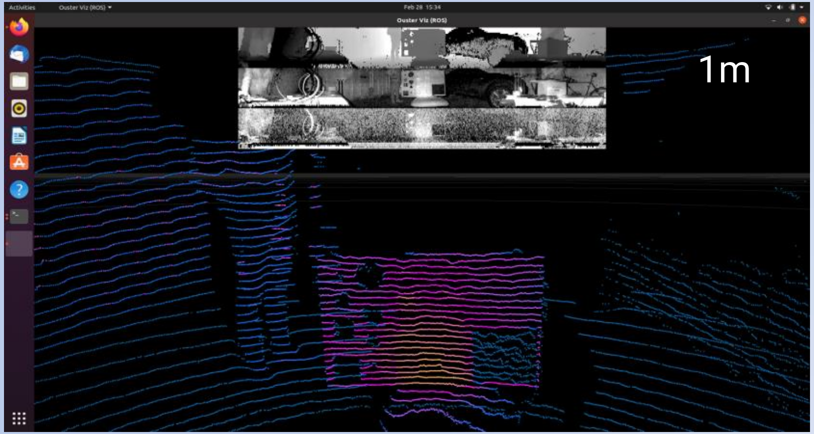


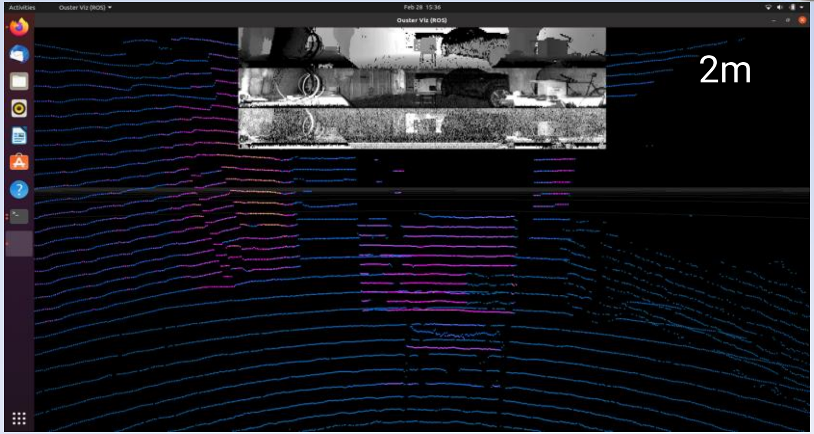


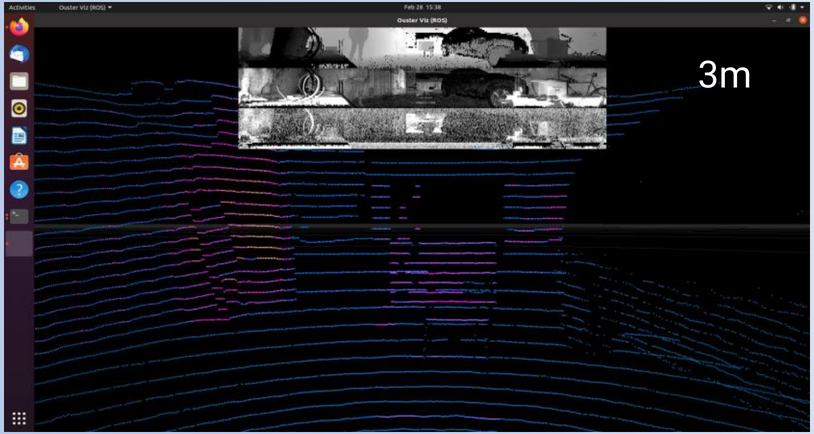


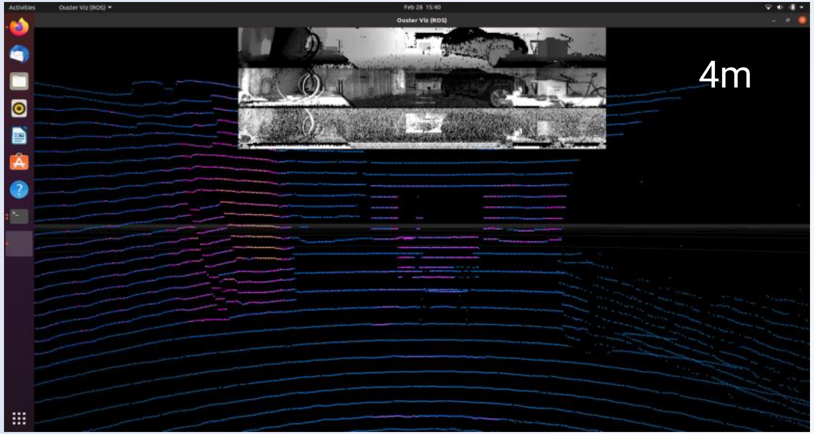


Small Scale LiDAR Test: Shaded, 2nd Papers

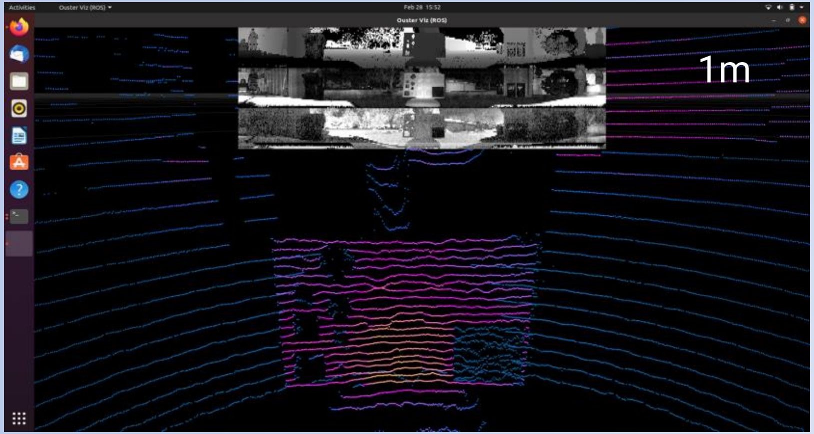


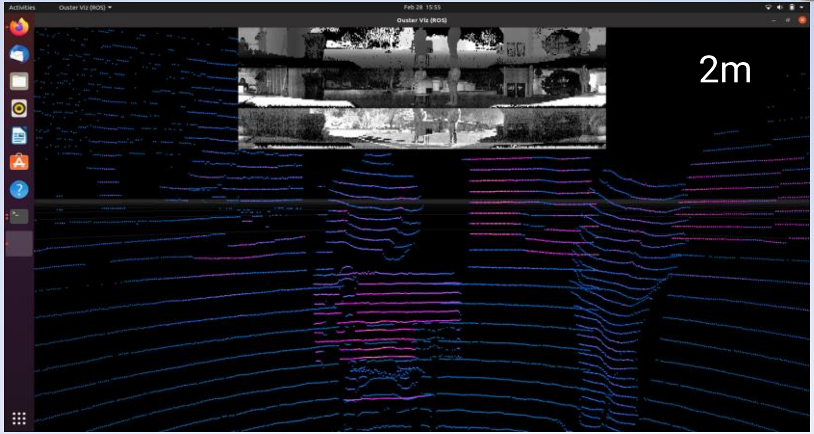


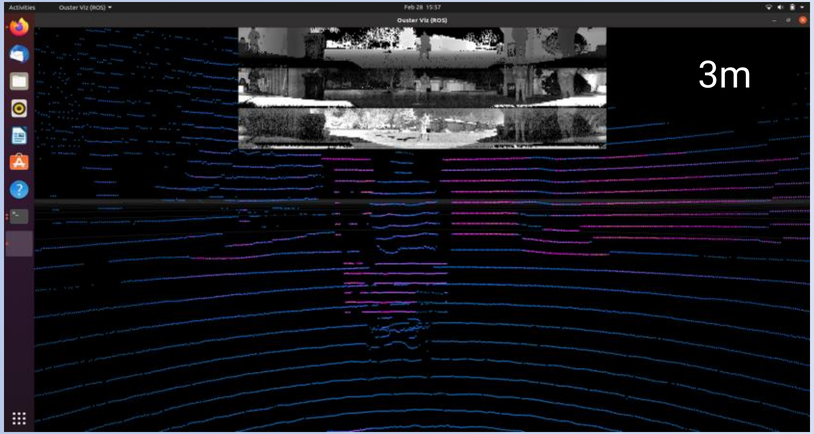


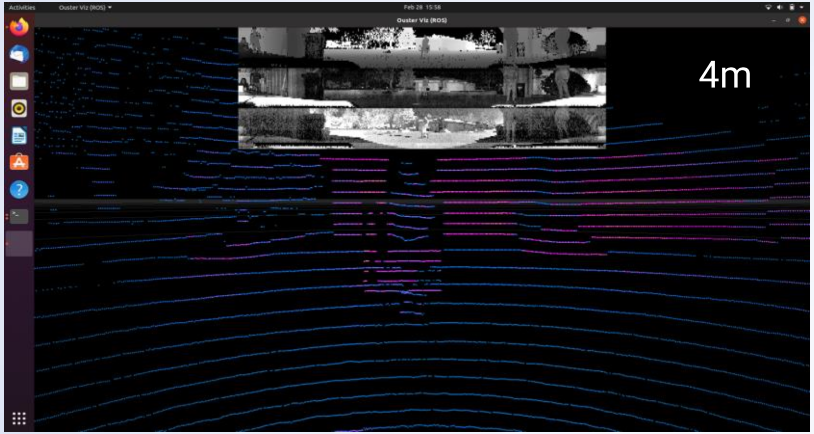


Small Scale LiDAR Test: Sun, 2nd Papers





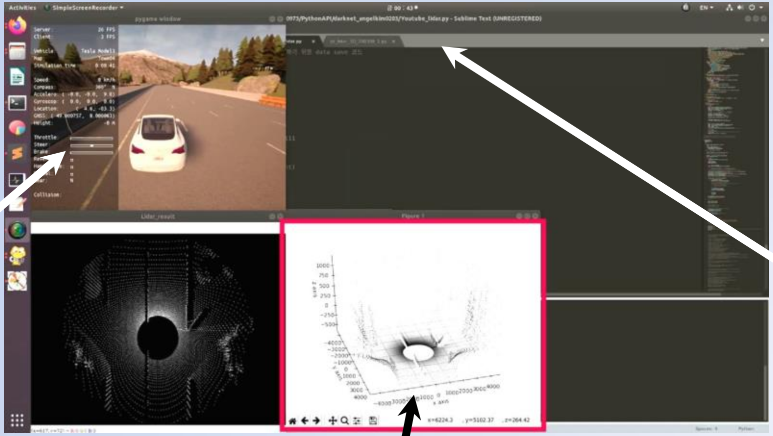




Software: Carla Simulation

Simulated Physical Environment

- Create <u>simple</u> test environment within simulated carla
- LiDAR sensor specifications and locations inputted
- Automatically add levels of noise or uncertainty to give more realistic outputs



CARLA Simulator - 3D LiDAR data plot
https://www.youtube.com/watch?v=Mt08Ag57VeI January 2021

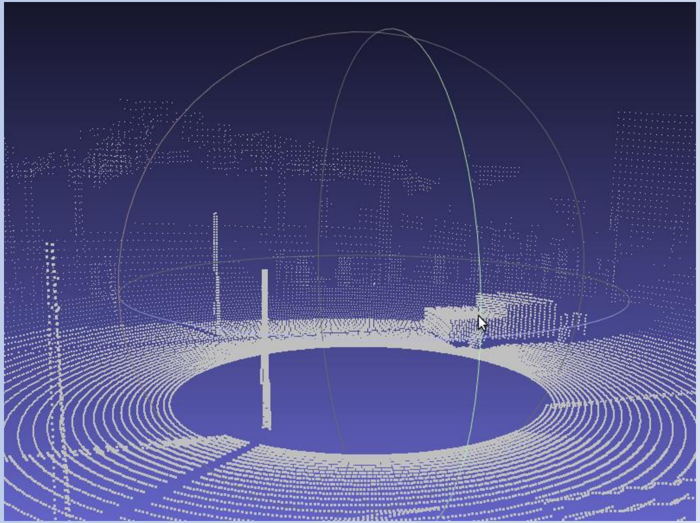
Seamless Integration with ROS Noetic

- Dev build of software tested in real-time
- No risk to LiDAR unit during testing
- ROS Master and .bag behave exactly same as physical tests

Realistic 3D LiDAR and IMU Outputs

- Enables rapid testing and development of post-processing software pipeline

Software: Carla Simulation



"lidar_point_cloud ", Cameras and Sensors, https://carla.readthedocs.io/en/stable/cameras_and_sensors/, Nov. 2020

- LiDAR: 32 channel, 10Hz, 50m range
- IMU: 6 axis, Accel. Gyro.
- Vehicle speed: (10 to 60mph), height: 1.6m
- Model: Simulated infrastructure

Requirement

A GNSS-independent post-processing technique shall be implemented to produce a point cloud from raw sensor data.

Validation Method

Carla will test our software pipeline by providing raw LiDAR and IMU data of a virtual environment with the exact parameters of our sensor package.

Expected Result

Lio-SAM registration and mapping will provide a point cloud that mirrors the virtual environment.

Comprehensive System Test: Full Procedure

Test Environment:
Bridge: 6th Ave + Wadsworth
Date: 3/21/21
Time: 1:00 PM MST (1300)

Equipment:
LiDAR Sensor
LiDAR Data Cable
LiDAR Power Cable
Structural Housing
Laptop
Power Inverter
Power Adapter

1. Secure system to vehicle and verify power to all systems.
    a. Secure structural housing to the top of testing vehicle.
        i. We will be using Jake’s car (2004 Chevrolet Trail Blazer)
    b. Insert LiDAR sensor into structural housing and connect the LiDAR cable to the Laptop and power source inside of the car.
    c. Turn on and verify power to Laptop
    d. Open ROS code and verify LiDAR is operational via live stream.
    e. Verify .bag files can be taken by capturing a small tester .bag file.

Continued on next slide →

Comprehensive System Test: Full Procedure

2. Pass under the bridge/infrastructure of interest with LiDAR powered on
   a. Drive to 6th Ave + Wadsworth Bridge
      i. Following all laws and not exceeding the speed limit.
3. Collect, save, and register 3D point cloud data
   a. Begin taking data approximately 50 meters from the desired bridge.
   b. Stop taking data approximately 50 meters from the desired bridge.
   c. Verify that .bag file has been saved.
4. Post-process data to create a 3D mesh model of the infrastructure.
   a. Return
   b. Load in .bag file to LIO-SAM and VINS Mono code.
   c. Load the resulting point cloud into Cloud Compare to create the desired 3D mesh

Notes

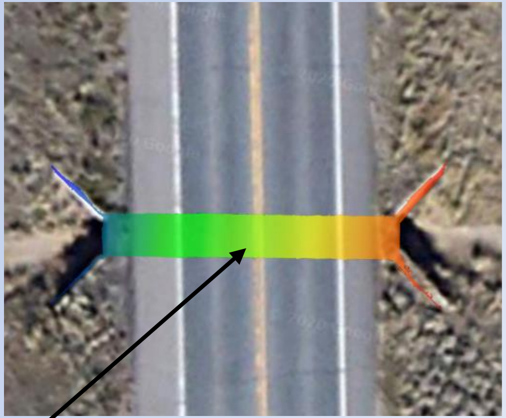
- Multiple passes are not needed because this is meant to verify the functionality of the system. This test will only have one pass under the bridge. Based on the results, the team may decide multiple passes are needed for future data collection.
- Verification of the LiDAR's accuracy will come from comparing our generated 3D mesh to CDOT data.
- Verification of the point cloud density will occur within the post processing phase by utilizing tools within the Cloud Compare software.

Test Overview

Complete	In Progress	Not Started
(green)	(yellow)	(red)

Test Name	Duration	Pre	Status	Equipment	Location
Structures: Pull Test	1 week	NA	Complete (green)	• Hook scale • Mount + magnets	Open parking space
Small Scale LiDAR Test	1 week	2	In Progress (yellow)	• Test board • LiDAR sensor + laptop	Controlled indoor + outdoor environment
CARLA Simulation Test	20 days	NA	In Progress (yellow)	• Processing computer	Homebase (with WiFi)
Comprehensive System Test	2 weeks	2	Not Started (red)	• LiDAR sensor + laptop • Mount + magnets • Vehicle • Electrical hardware	Low-traffic road with a highway underpass
Google Maps API Comparison	2 weeks	4	Not Started (red)	• Processing computer	Homebase (with WiFi)

Comprehensive System Test: Google Maps API Comparison



Google Maps API overlay

- Generated point cloud of chosen infrastructure using Lio-SAM method
- API map of chosen infrastructure

Requirements

The point cloud data shall be combined with the localization data to create a **3D mesh**.

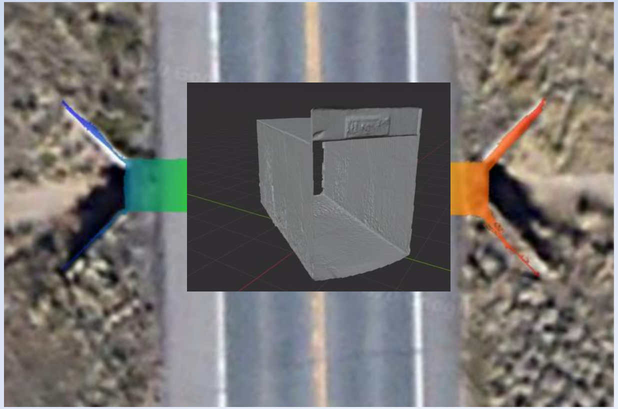
Validation Method

Google Maps API will provide true X/Y position that our mesh will be compared against.

Expected Result

Point cloud data from the Ouster will mirror X/Y of Google Maps API and any drift errors will be quantified

Google Maps API Comparison



Risk Reduction

This test will reduce the risk of project failure by verifying that the location data received from the LiDAR is accurate enough when compared to a control.

Test Importance

Data Quality: This test will give the team further confidence of the validity of the data received.

V&V: Mild Importance once successfully completed

Test Schedule

Not Started

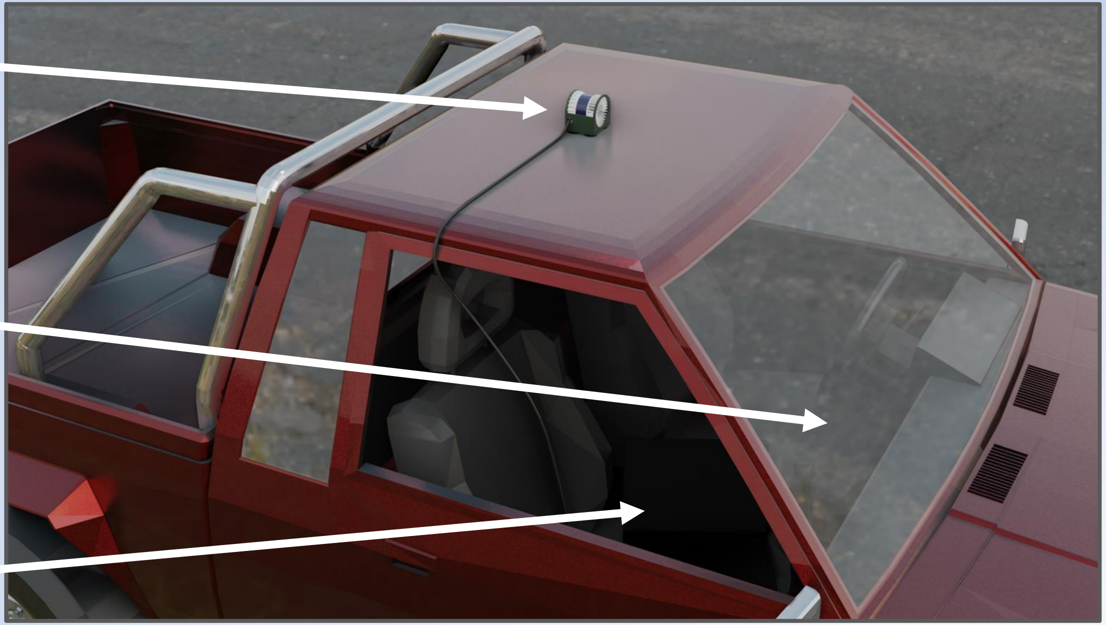
Requires usable data from the system of a comparable bridge or structure.

System Integration Plan

Structures
- Magnetic attachment to vehicle
- Provides thermoregulation
- Accommodates interface cable

Electronics
- Input power from the vehicle
- Inverter distributes power to all necessary components

Software
- UDP Ethernet connection from LiDAR interface box to laptop
- WiFi-enabled for data transfer



Overview | Schedule | Test Readiness | Budget

Comprehensive System Test: Locations

6th Ave. over Wadsworth Blvd. (Built 1972)

I-70 over Harlan Street (Built 1967)

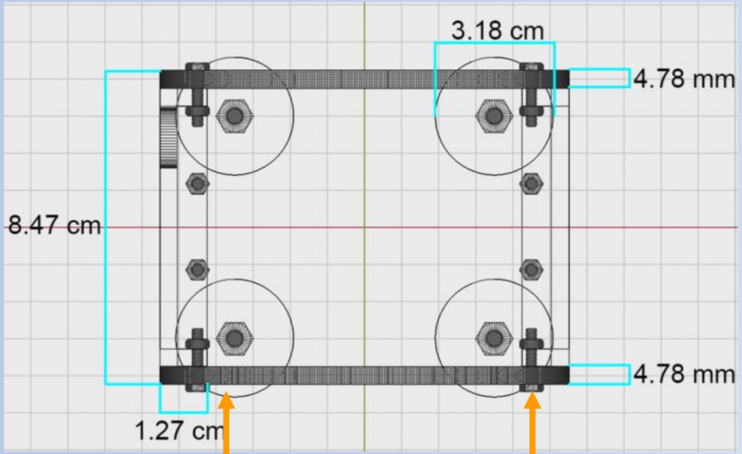
I-70 over Kipling Street (Built 1967)

These bridges clearly exhibit structural deficiencies in the form of cracking, spalling, corrosion, delamination, and deformation

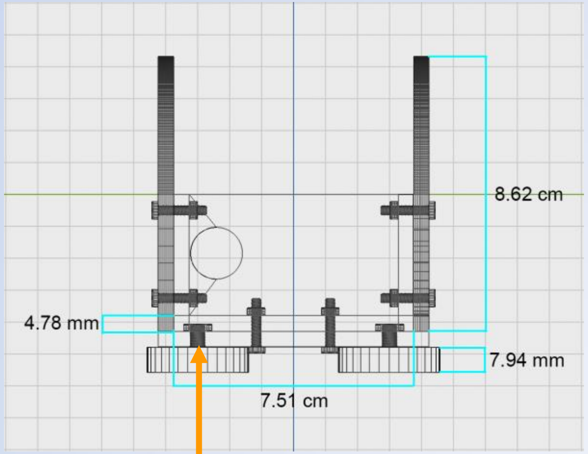
Source: Google Maps, Denver7 News

Housing Dimensions

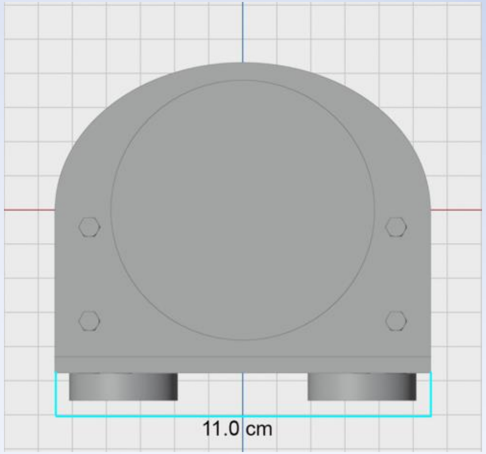
Top View



Side View



Front View



32 mm ⌀ Magnet (4x)

16 mm M3 Bolt (12x)

Bolts (5 mm x 9.5 mm) Integrated with Magnets