Test Readiness Review

FLASH: Functional LiDAR Assessment of Structural Health

March 4, 2021

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

Advisor: Professor Dennis Akos
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

Overview Schedule Test Readiness Budget
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

- LiDAR fastened to mount with bolts
- Interface box for data transmission & power distribution
- Ethernet connection
- Power connection (24 V, 1.5 A)
- Ouster OS1-32 Gen 2 LiDAR sensor
- Aluminum mount
- 4 magnets to secure structure to vehicle
- Cable routed through window (length not to scale)

Overview Schedule Test Readiness Budget
Top-Level Design Overview

- LiDAR & Housing
- Ethernet & Power
- Onboard Laptop & Power Source
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/m² point density

Overview  Schedule  Test Readiness  Budget
FLASH: Functional LiDAR Assessment of Structural Health

FLASH Concept of Operations

Overview

Data Collection

3D Map/Model Generation

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/m² point density
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

Schedule

Test Readiness

Budget
## Critical Project Elements

<table>
<thead>
<tr>
<th>Designation</th>
<th>Element</th>
<th>Components</th>
<th>Why critical?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPE-1</td>
<td>Sensor Package</td>
<td>Scanning LiDAR sensor + integrated IMU</td>
<td>High-resolution, precise, and accurate data collection is key to insightful 3D mapping and model generation</td>
</tr>
<tr>
<td>CPE-2</td>
<td>Data Processing Software</td>
<td>ROS* and SLAM*-based pipeline + commercial software package (CloudCompare)</td>
<td>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</td>
</tr>
<tr>
<td>CPE-3</td>
<td>Vehicle Platform</td>
<td>Magnetic mounts + custom-fabricated housing</td>
<td>Sensor package must be secure up to highway speeds and must not pose a safety concern</td>
</tr>
</tbody>
</table>

*ROS = Robot Operating System  
*SLAM = Simultaneous Localization and Mapping
Software Design Overview
Software Design Overview

Overview

Schedule

Test Readiness

Budget

Ouster LiDAR Sensor

On-Board Passenger Laptop
Software Design Overview

Overview

1. **Ouster LiDAR Unit OS1-32**
   - Commands
   - Gyroscope XYZ
   - Accelerometer XYZ

2. **UDP Connection (Ethernet)**
   - Point Cloud Data (single frames)

3. **Linux Ubuntu 20.04 (running on on-board laptop)**
   - Data capture
   - ROS Master
   - Data file (.bag)
   - Post processing

4. **ROS Noetic**
   - VINS-Mono & LIO-SAM

5. **CloudCompare**
   - Bridge Mesh (Deliverable)
   - Point Cloud
   - Cloud Comparison
   - Mesh Generation Plugins
   - LIO-SAM core codebase (C, C++)

6. **GitHub**

1 Point Cloud Frame

Stitched Point Cloud Map
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
Schedule: Structures and On-Board Setup

Overview

Schedule

Test Readiness

Budget
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

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

- **Schedule:**
  - Structures: Pull Test: 1 week
  - Small Scale LiDAR Test: 1 week
  - CARLA Simulation Test: 20 days
  - Comprehensive System Test: 2 weeks
  - Google Maps API Comparison: 2 weeks

- **Test Readiness:**
  - Structures: Pull Test: Complete
  - Small Scale LiDAR Test: In Progress
  - CARLA Simulation Test: Not Started
  - Comprehensive System Test: Not Started
  - Google Maps API Comparison: Not Started
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| 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)                          |
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: $F_{\text{mag}} >> 1.6 \text{ lbf}$

Verifying DR 5.1
Withstanding drag forces associated with relative wind
Validated through Pull Test

Overview  Schedule  Test Readiness  Budget
Structures: Pull Test

32 mm Ø Magnet (4x)

Bolts (5 mm x 9.5 mm) Integrated with Magnets
Structures: Pull Test

Overview

Vehicle Roof

3D-printed Structure with Magnets and Dummy Weight

Belt with Hook Scale

Hook Scale Measurement

Schedule

Test Readiness

Budget
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

<table>
<thead>
<tr>
<th>Hook Scale Reading</th>
<th>Observations</th>
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<tr>
<td>5 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>10 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>20 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>30 lb</td>
<td>Earliest observed slipping</td>
</tr>
<tr>
<td>35+ lb</td>
<td>Steady, consistent slipping as load increases</td>
</tr>
</tbody>
</table>
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.
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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.
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Software: Pipeline Validation Tests

- Overview
- Schedule
- Test Readiness
- Budget
**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.

**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.

Validation Method

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

Screen capture of map to be imported onto CARLA
Software: CARLA Simulation

Overview

Schedule

Test Readiness

Budget

Test Schedule

In Progress (to end by 3/22)

Expected Result (Pass Criteria)

Generated LiDAR mesh from simulated asset with 10cm accuracy and precision

Risk Reduction

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

Screen capture from ROS - CARLA integration tutorial
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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)

Overview

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.

Schedule

Test Readiness

Budget
**Comprehensive System Test (CST)**

**Overview**

**Schedule**

**Test Readiness**

**Budget**

---

**Expected Result (Pass Criteria)**

Creation of a **3D mesh** which meets all Design Requirements when compared to ground truth data

**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**

**Software Outputs**

---
Budget
<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Total Cost</th>
<th>Procurement Status</th>
<th>Lead Time</th>
<th>Criticality to Project Success**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lenovo Legion V Laptop</td>
<td>1</td>
<td>$999.99</td>
<td>Received</td>
<td>N/A</td>
<td>Desirable</td>
</tr>
<tr>
<td>Rubber Magnets (for Mounting)</td>
<td>4</td>
<td>$59.40</td>
<td>Received</td>
<td>N/A</td>
<td>Important</td>
</tr>
<tr>
<td>Power Inverter</td>
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<td>Desirable</td>
</tr>
<tr>
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<td>1</td>
<td>$3,585.00*</td>
<td>Received</td>
<td>N/A</td>
<td>Critical</td>
</tr>
<tr>
<td>Mounting Structure (3D Printed - Plastic)</td>
<td>1</td>
<td>$20.00</td>
<td>Received</td>
<td>N/A</td>
<td>Important</td>
</tr>
<tr>
<td>Mounting Structure (CNC 6061 Aluminum)</td>
<td>1</td>
<td>N/A</td>
<td>On Order</td>
<td>~2 weeks</td>
<td>Important</td>
</tr>
</tbody>
</table>

*ASTRA has purchased

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

### Total Funds Spent:
- Total Funds Spent: $1,171.83
- Pilot Deposit: $200.00
- Remaining Funds: $3,628.17

### Overview

#### Schedule

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Updated Cost Plan

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

- 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)**

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Package</td>
<td>$0*</td>
</tr>
<tr>
<td>Software</td>
<td>$0</td>
</tr>
<tr>
<td>Structures</td>
<td>($134.40)</td>
</tr>
<tr>
<td>Electronics/Communications</td>
<td>($1035.95)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>($1170.35)</td>
</tr>
<tr>
<td>Cost Margin</td>
<td>10%</td>
</tr>
<tr>
<td>Pilot Deposit</td>
<td>($200.00)</td>
</tr>
<tr>
<td><strong>Total w/ Margin</strong></td>
<td>($1487.39)</td>
</tr>
</tbody>
</table>
Thank You!

Questions?

FUNCTIONAL LIDAR ASSESSMENT of STRUCTURAL HEALTH

FLASH
Backup Charts
Pull Test: Full Procedure

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.

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

Equipment:
Belt
Structural Housing
Dummy Weight
2 Vehicles

Belt attached to around the rear two magnets for the pull test.
# Pull Test: Take 1

<table>
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<tr>
<th>Hook Scale Reading</th>
<th>Observations (PT 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>10 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>20 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>30 lb</td>
<td>Noise indicated slippage was starting to occur</td>
</tr>
<tr>
<td>35 lb</td>
<td>Slow, but steady slipping around 35 lbs</td>
</tr>
</tbody>
</table>
## Pull Test: Take 2

<table>
<thead>
<tr>
<th>Hook Scale Reading</th>
<th>Observations (PT 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>10 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>20 lb</td>
<td>Sturdy (No slippage)</td>
</tr>
<tr>
<td>&gt; 30 lb*</td>
<td>Steady slippage occurred</td>
</tr>
</tbody>
</table>

* slippage occurred after 30 lbs of force, but before 35 lbs of force
Magnaflux 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): \( \rho \) = 1.14 kg/m\(^3\)
- Surface Area of Structural Housing: \( A \) = 99.9 cm\(^2\)

@ 65 mph \( \rightarrow \) \( F_w = 4.8079 \text{ N} = 1.0809 \text{ lbf} \)

w/ FOS = 1.5 \( \rightarrow \) \( F_w = 7.2119 \text{ N} = 1.6213 \text{ lbf} \)

Magnets must withstand at least 1.6213 lbf from a vertical pull test.
Small-Scale LiDAR (SSL) Test Board

Hole & Protrusion Sizes: 2.5 cm, 5 cm, 7.5 cm, 10 cm

Protrusion Depth: 4.75 cm

Interchangeable Paper Panels
Small Scale LiDAR Test: Full Procedure

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.

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

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

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

1m

2m

3m

4m
Small Scale LiDAR Test: Shaded, 2nd Papers
Small Scale LiDAR Test: Sun, 2nd Papers
Software: Carla Simulation

Simulated Physical Environment
- Create simple test environment within simulated carla
- LiDAR sensor specifications and locations inputted
- Automatically add levels of noise or uncertainty to give more realistic outputs

Realistic 3D LiDAR and IMU Outputs
- Enables rapid testing and development of post-processing software pipeline

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

CARLA Simulator - 3D LiDAR data plot
https://www.youtube.com/watch?v=Mt08Ag57Vel January 2021
Software: Carla Simulation

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.

- LiDAR: 32 channel, 10Hz, 50m range
- Vehicle speed: (10 to 60mph), height: 1.6m
- Model: Simulated infrastructure

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

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

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.

- Generated point cloud of chosen infrastructure using Lio-SAM method
- API map of chosen infrastructure
LiDAR data will be collected as required by subteam tests, transmitted, and processed to generate a 3D point cloud and mesh.

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
Comprehensive System Test: Locations

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

I-70 over Kipling Street (Built 1967)

I-70 over Harlan 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
- 32 mm Ø Magnet (4x)
- 16 mm M3 Bolt (12x)
- 4.78 mm
- 3.18 cm
- 1.27 cm

Side View
- 4.78 mm
- 7.51 cm
- 7.94 mm
- 8.62 cm

Front View
- 11.0 cm

Bolts (5 mm x 9.5 mm)
Integrated with Magnets