ASEN 4028: Senior Design Projects
Spring 2021

Manufacturing Status Review

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

February 4th, 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. Manufacturing
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

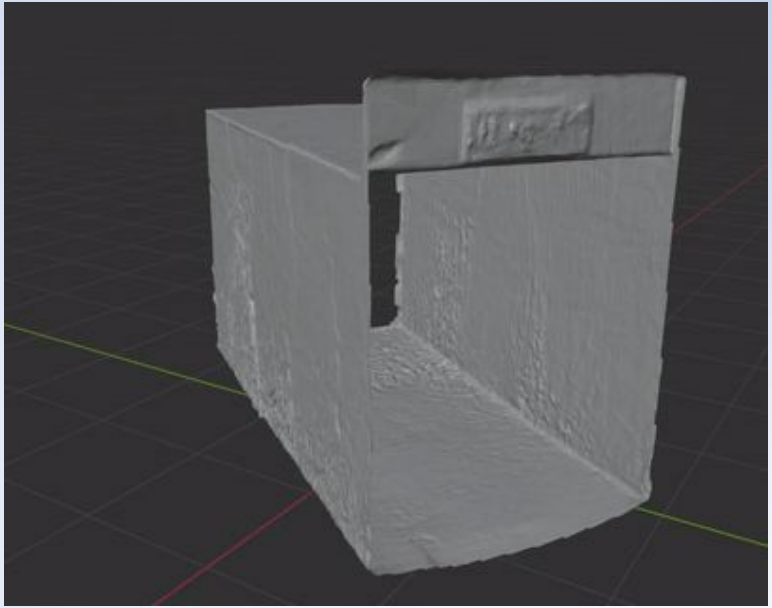
Objective & Mission Statement

Project Objective

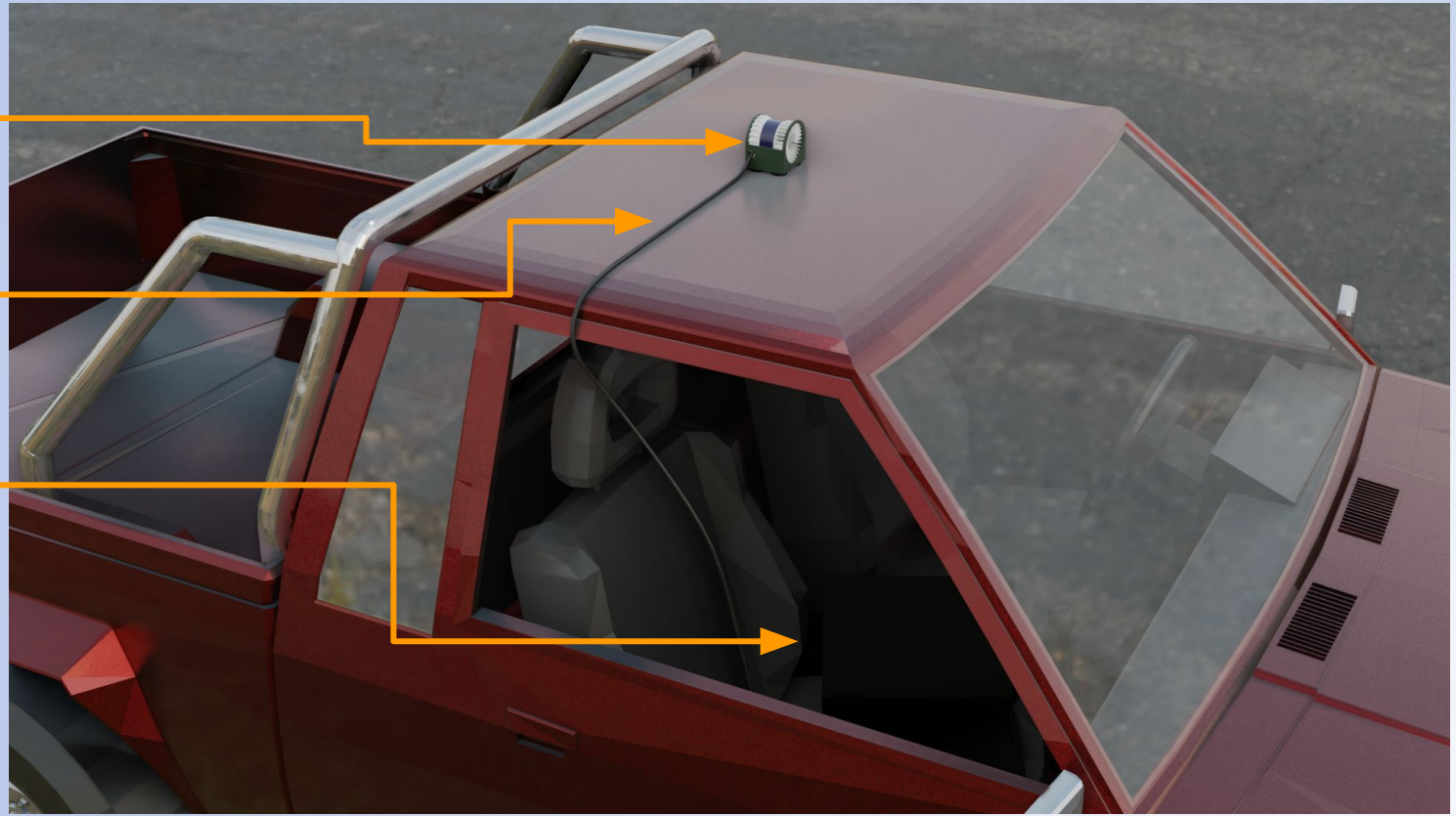
The system shall provide a low-cost and efficient way to monitor and assess infrastructure.

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**.



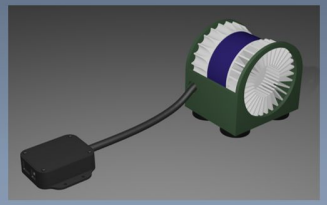
Top-Level Design Overview

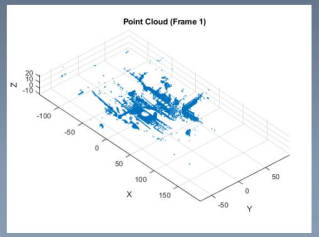


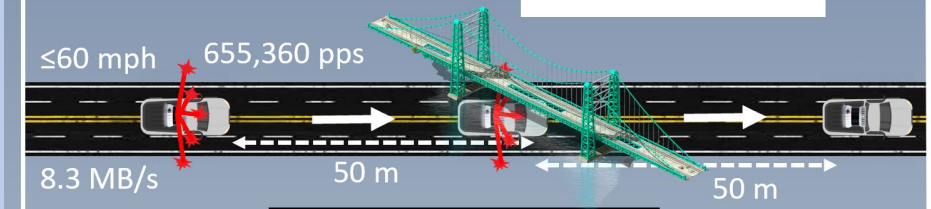
FLASH Concept of Operations

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

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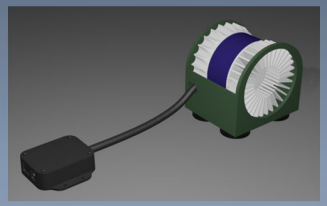

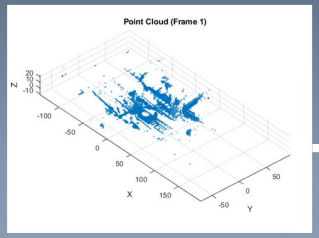

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2. **Scan infrastructure while in motion**
   - Raw point cloud and IMU data collected (< 0.5 GB)
   - Standard 5.1 m bridge height
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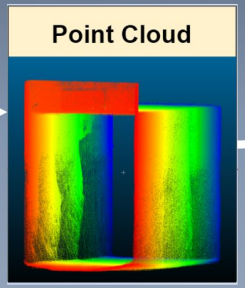
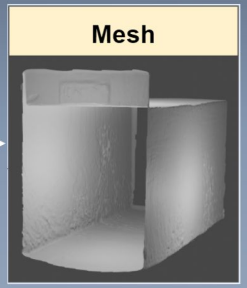
3D Map/Model Generation





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**

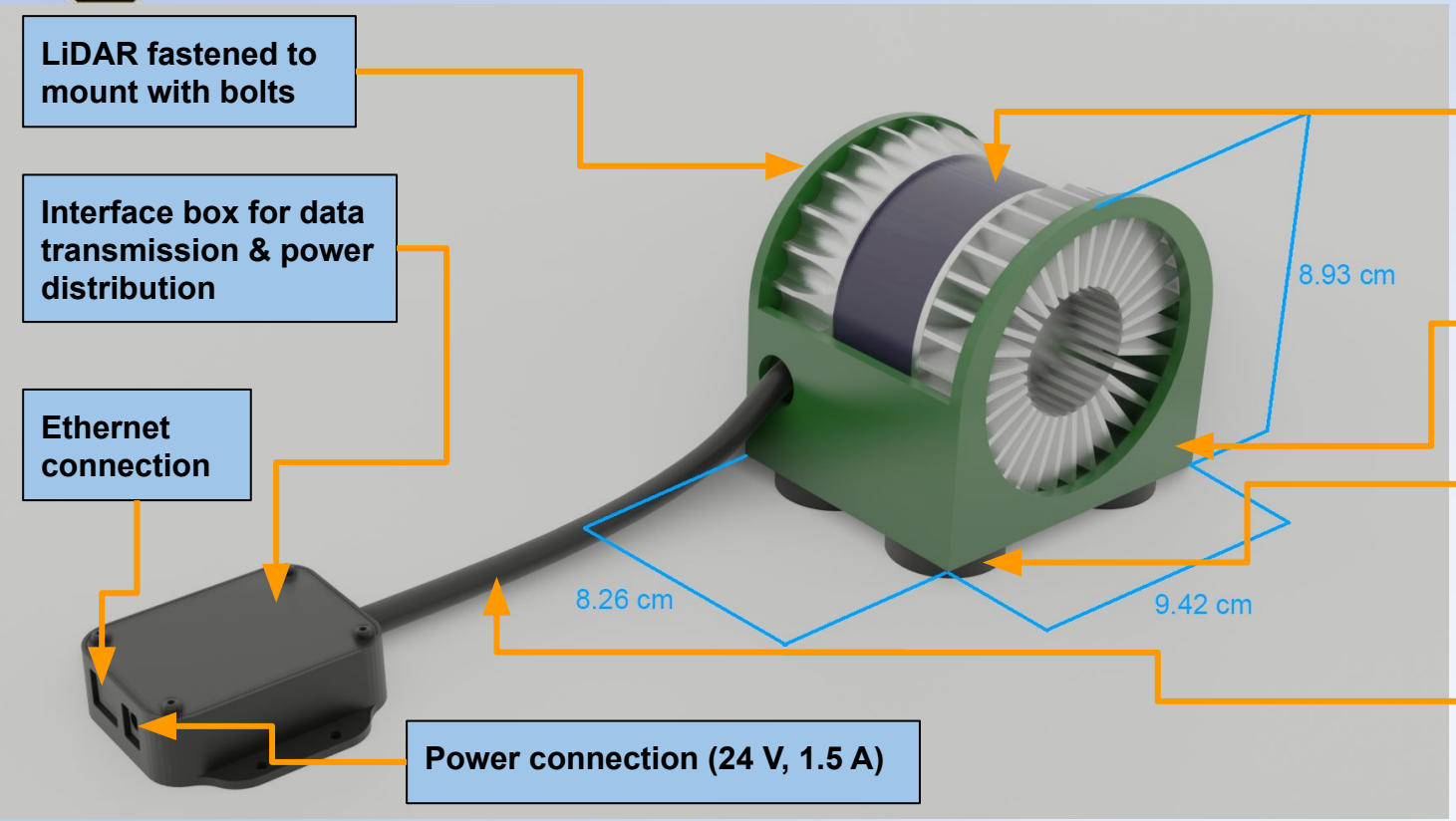
Critical Project Elements

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

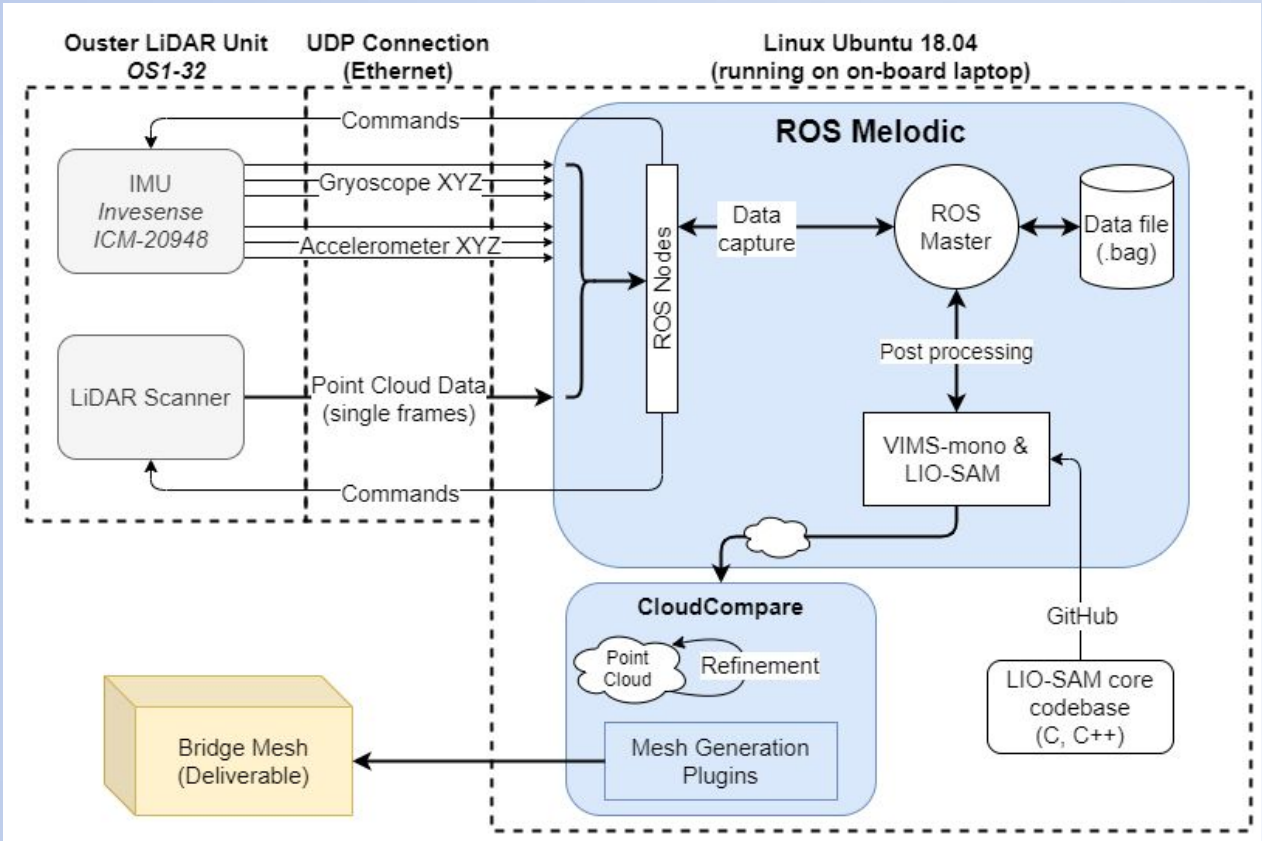
*ROS = Robot Operating System

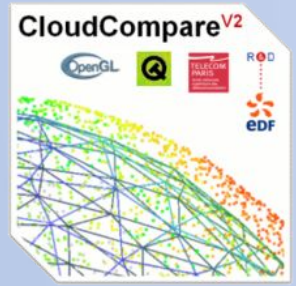
*SLAM = Simultaneous Localization and Mapping

LiDAR Hardware Overview



Software Design Overview

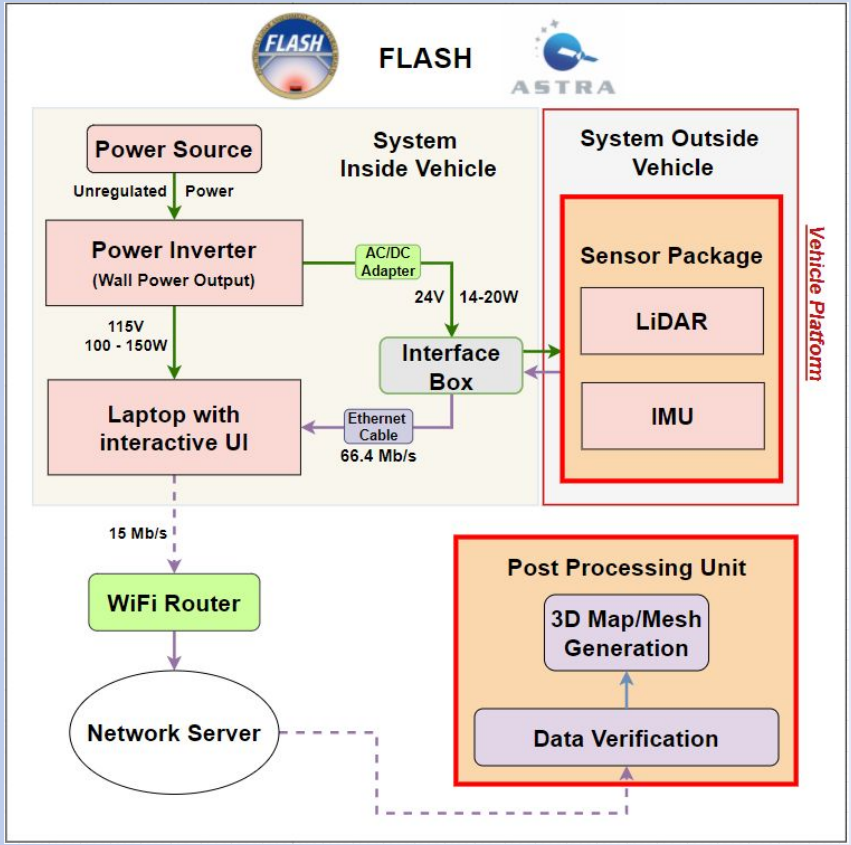


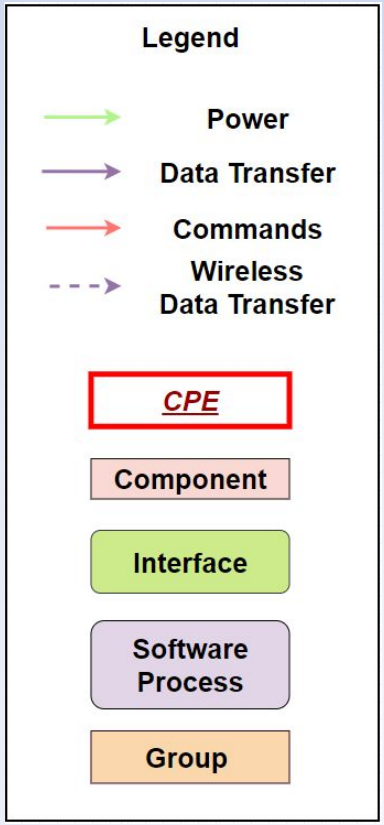


ROS
Robot Operating System

ROS
Robot Operating System

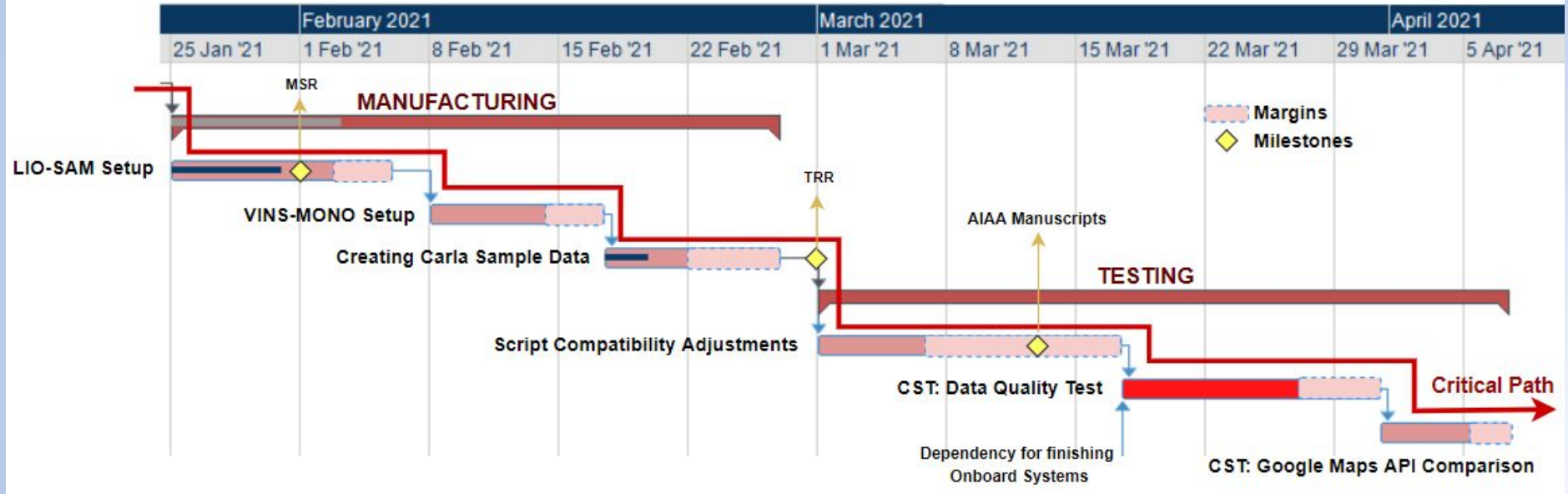
Functional Block Diagram (FBD)



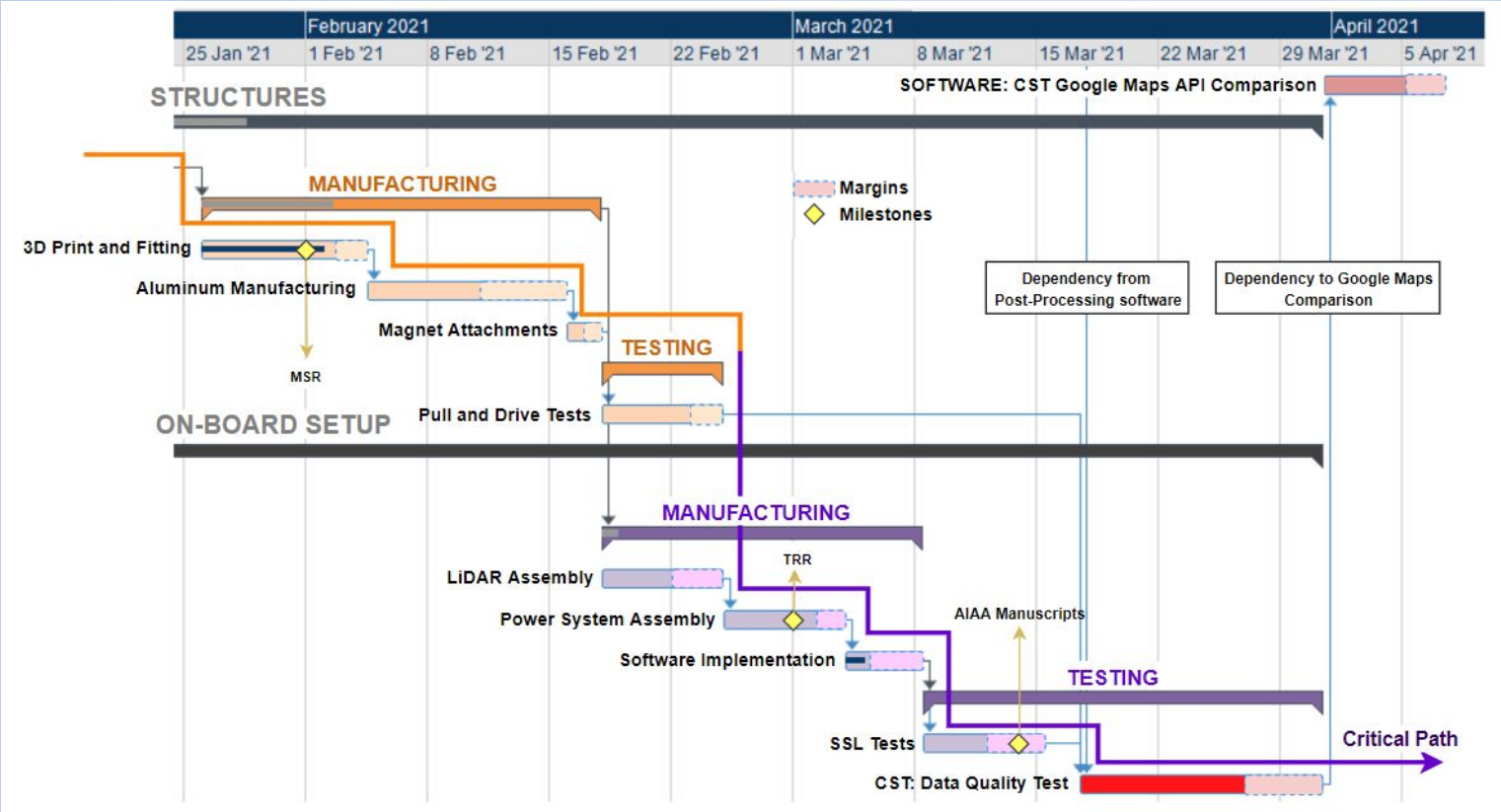


Schedule

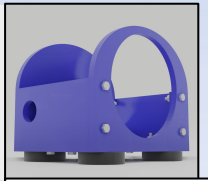
Team Schedule: Software

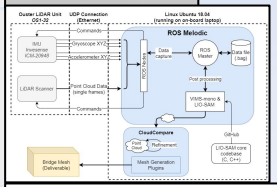
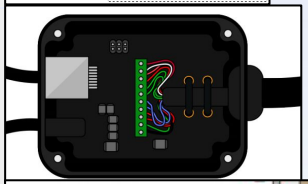
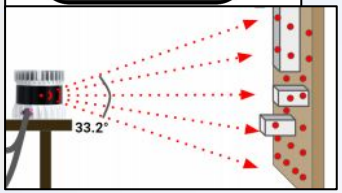


Schedule: Structures and On-Board Setup



Manufacturing Overview

01	Structures	• LiDAR Sensor Housing
		  ○ 3D-Printed Prototype (SLA)
		  ○ CNC Al-6061
			

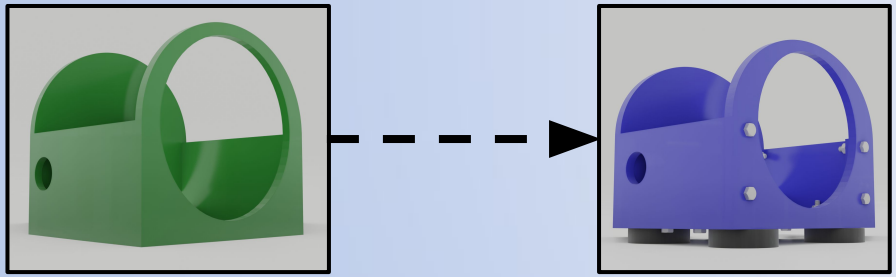
02	Software	• Sensor Communication • ROS Core • SLAM (Lio-SAM) • Mesh Generation	
03	Electronics	• Electrical Interfacing	
04	Test Setup	• CARLA Simulation • Small-Scale LiDAR Operational Test	

Manufacturing: Structures

Hardware Scope & Status

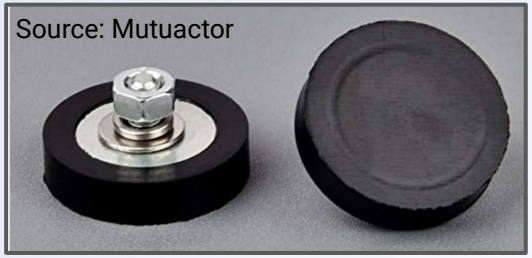
To-Be Manufactured

- **3D-Printed Prototype**
  - Assess fitting of LiDAR sensor, cable, and magnets + adjust design
  - Request for printing by: *2/4/2021*
- **Finalized Aluminum CNC Structure**
  - Request for CNC by: *2/15/2021*



COTS Items

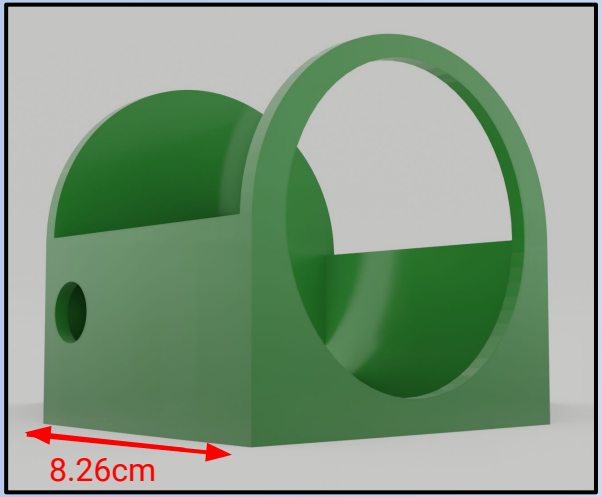
- **Magnets**
  - Purchase by: *2/16/2021* ✔
- **Attachment Screws**
  - Purchase by: *2/15/2021*



✔ = complete as of MSR

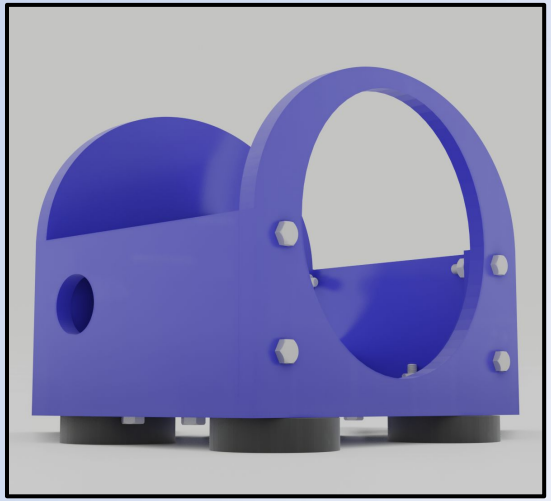
Housing Fabrication

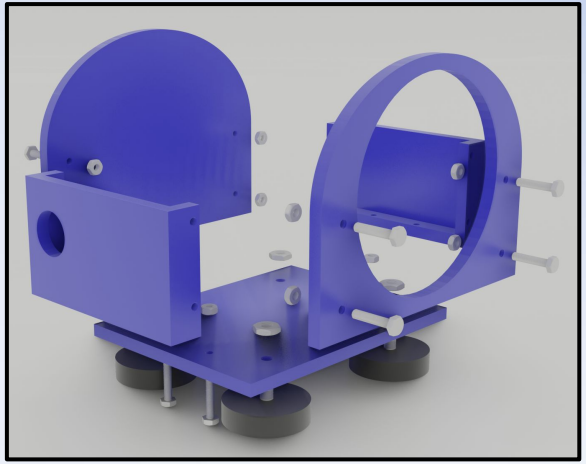
3D-Printed Prototype



3D Print Structure Complete:
2/6 - 2/7

Preliminary CNC Model (before fit check)

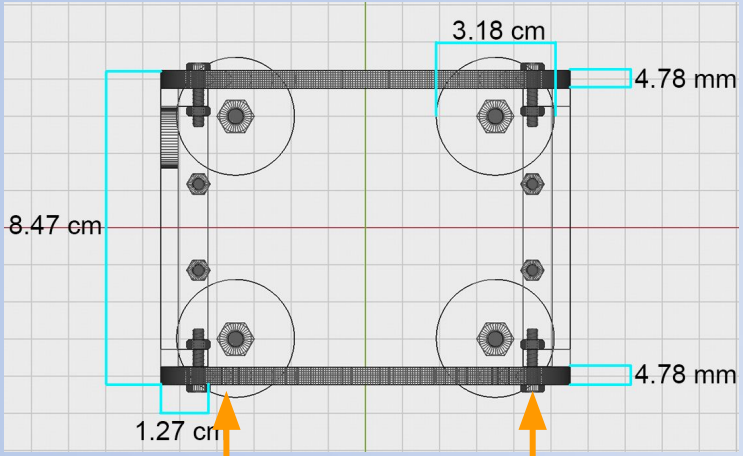




Final CNC Structure Assembly Complete: 2/17 - 2/18

Housing Dimensions

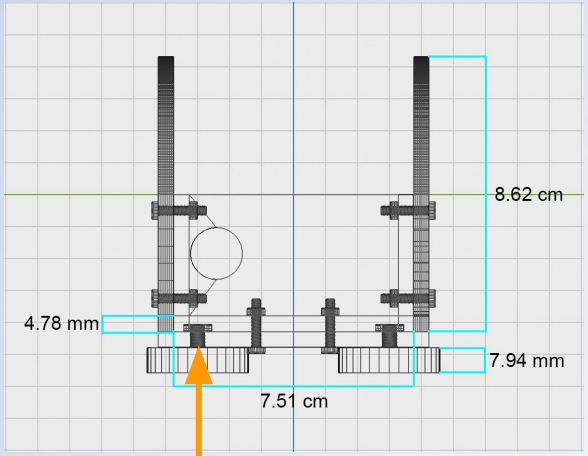
Top View



32 mm ∅
Magnet (4x)

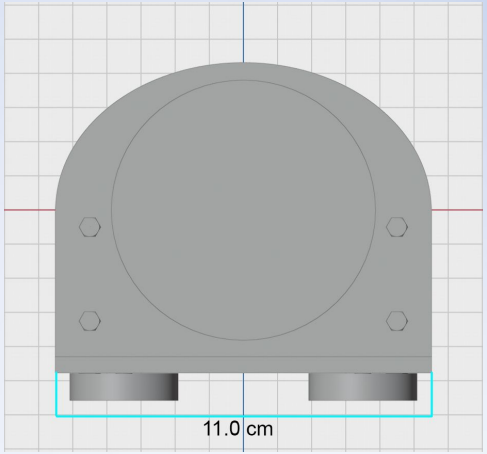
16 mm M3 Bolt (12x)

Side View



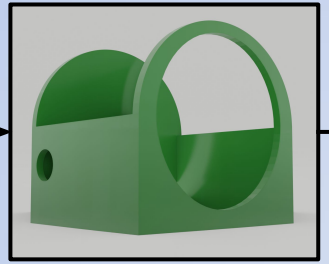
Bolts (5 mm x 9.5 mm)
Integrated with Magnets

Front View



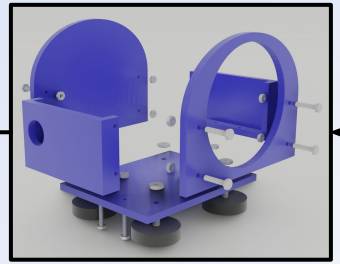
Assembly/Manufacturing Sequence

3D-Printed Model Fabrication

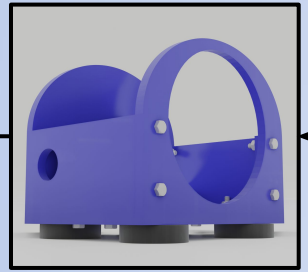


Fit Check with LiDAR Sensor and Magnets

Design Adjustment as Necessary and CNC Request Submission



CNC Housing Fabrication and Assembly

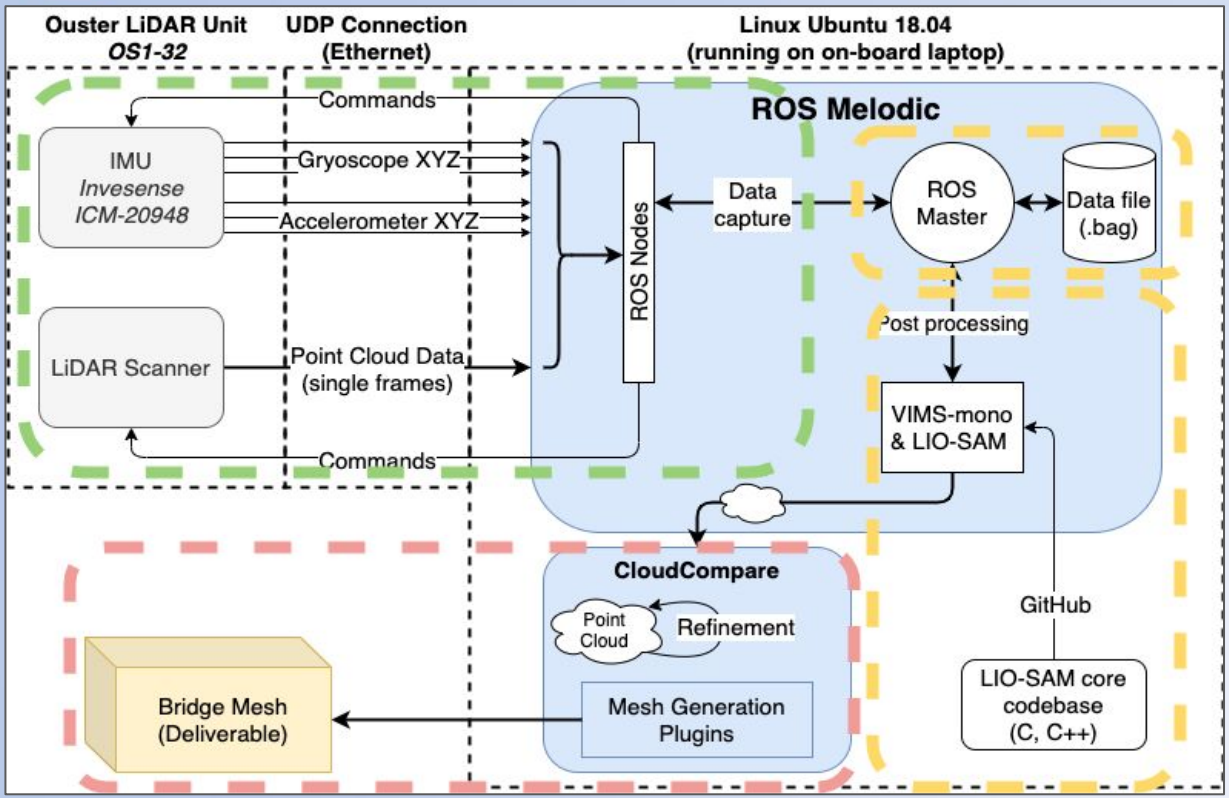


Magnet Attachment and Vehicle Mounting

LiDAR Sensor Attachment

Manufacturing: Software

Software: Overview



Development Status:

Completed*

* Ready for immediate testing once hardware is received

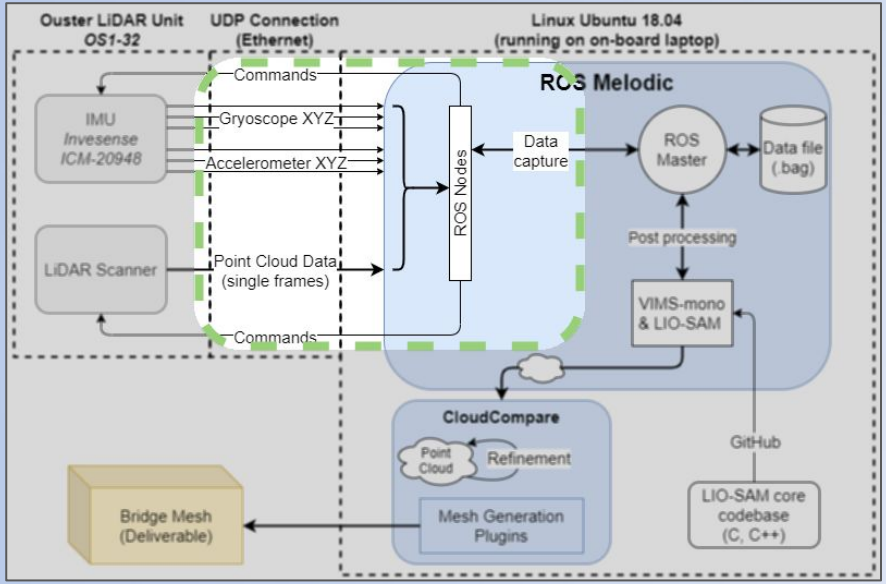
In Progress

On Deck

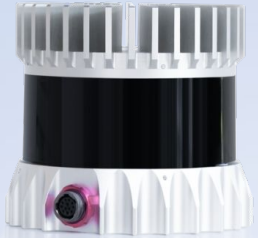
Software: Sensor Communication

STATUS: **Completed*** ✓

- ROS Node structure pre-defined by Ouster
- Codebase on laptop, awaiting hardware for testing



The area outlined in **green** is where all data acquisition and communication with the sensor package occurs.



OS1-32 Sensor Package
LiDAR + IMU

ROS

ROS Melodic
Connected via Ethernet

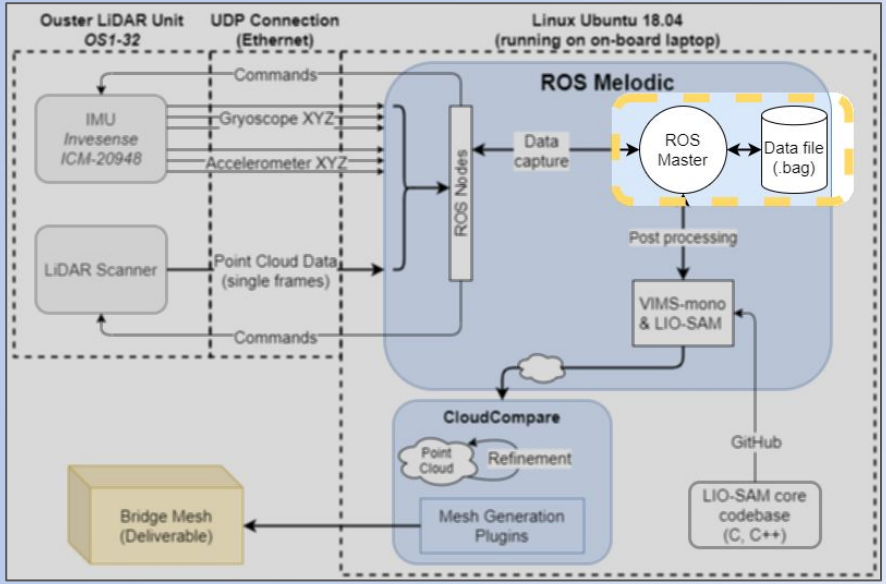
Ubuntu 18.04
Installed on On-Board Laptop

Overview | Schedule | Manufacturing | Budget

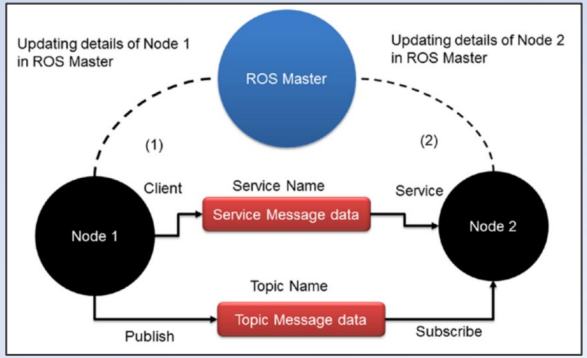
Software: ROS Core

STATUS: **In Progress**

- ROS Melodic and Linux 18.04 distro installed on Laptop
- Final bag file structure **in development**



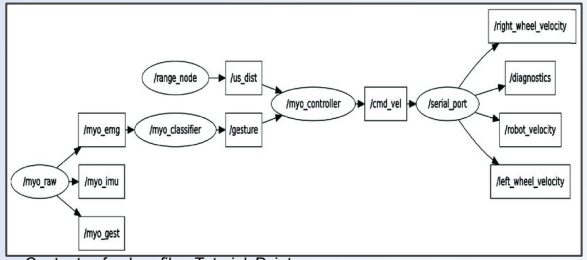
The area outlined in **yellow** is the core of our ROS build, where commands are issued and raw data is stored.



Basic overview of ROS Melodic - Understanding ROS Master Process
https://www.frontiersin.org/articles/10.3389/fict.2018.00002/full January 2021

ROS Master

Handles all topics and node, stores messages into .bag



Contents of a .bag file - TutorialsPoint
https://www.frontiersin.org/articles/10.3389/fict.2018.00002/full January 2021

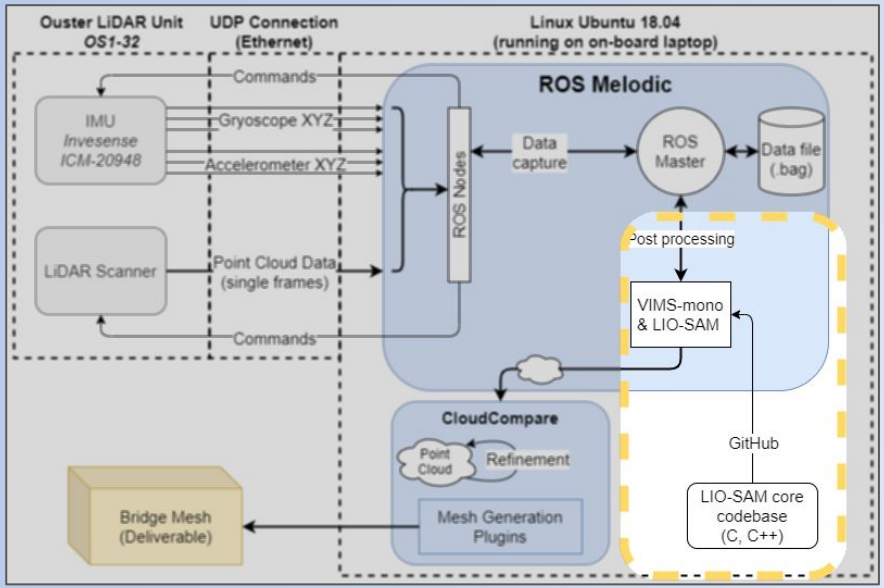
Bag File

Stores all recorded topics in a tree structure

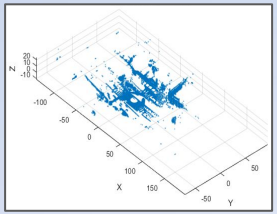
Software: SLAM (LIO-SAM)

STATUS: **In Progress**

- Algorithm fully developed and tested with OS1-32
- Awaiting hardware for **integration & param tuning**



The area outlined in **yellow** are the algorithms executed during post-processing to generate the 3D point cloud.



Raw data from sensor
Single LiDAR data frame shown

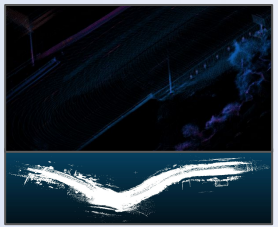
ROS

VINS-mono & LIO-SAM

VINS-mono
Initializes IMU data for LIO-SAM

LIO-SAM
Merges data frames using SLAM implementation

ROS

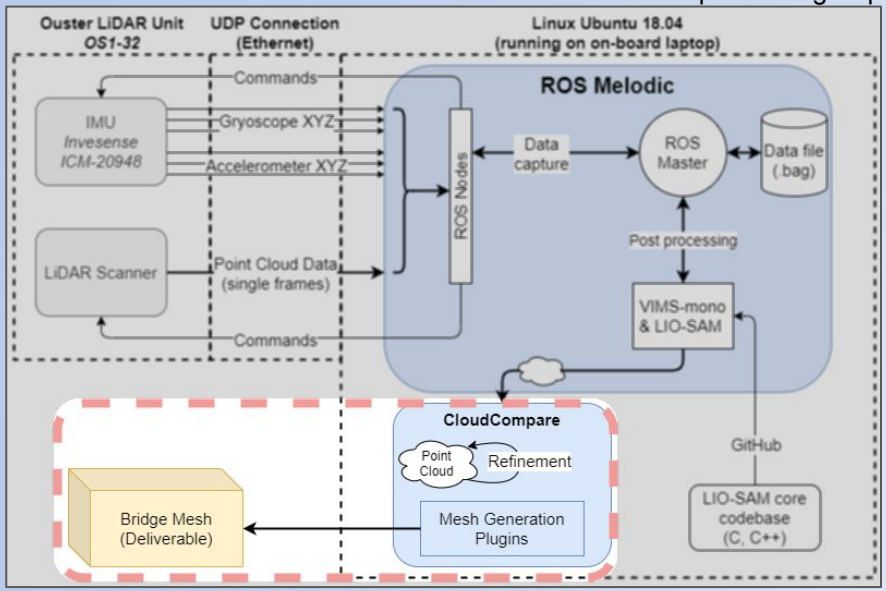


Completed point cloud
All data points share common coordinate frame

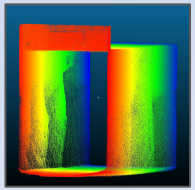
Software: Mesh Generation

STATUS: **On Deck**

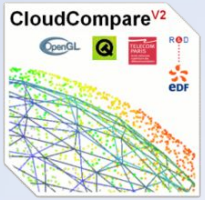
- Successfully generated mesh using sample data (pictured)
- **Awaiting test data to begin development** of finalized CC workflow and processing reqs



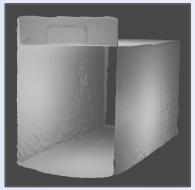
The area outlined in **red** are the external tools used to refine the point cloud and generate the final solid mesh.



3D point cloud data
Output generated by LIO-SAM



Review data in CloudCompare
Visualize data, apply outlier filters, categorize points



Generate smooth mesh object
Final output to be passed on to customer for structural analysis

Manufacturing: Electronics

Electrical Interfacing

12 VDC Vehicle Output

12 VDC

Power Inverter (Received)

AC/DC Inverter

120 VAC

24 VDC

Ouster Interface Box (On Order)

Ouster OS1-32 Gen 2 (On Order)

Lenovo Legion V Laptop (Received)

WiFi (15 Mbps)

20 VDC

UDP Ethernet

INSIDE VEHICLE

OUTSIDE VEHICLE

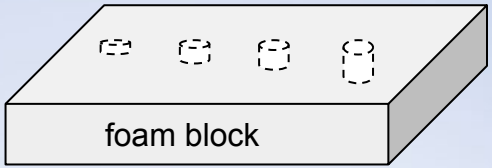
Remaining Manufacturing: N/A ✔️

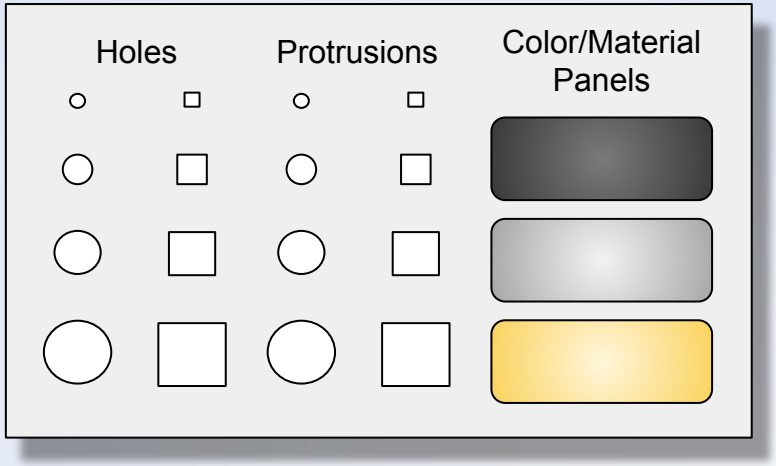
Team FLASH will *verify* all electrical/communicative interfaces during the **Small-Scale LiDAR Operational Test** and **Comprehensive System Test**

Manufacturing: Test Setup

Small-Scale LiDAR Operational Test

- Objective: Baseline verification of stationary sensor operation
  - Data collection/transfer, point cloud visualization, and feature discernment
- How is the sensor output (point cloud) affected when these factors are varied:
  - Feature size and shape
  - Feature depth
  - Target distance
  - Target color/material (for reflectivity)
  - Ambient lighting (night vs. day)
- **Items to be acquired and modified:**
  - 24” x 36” poster board
  - Craft foam block



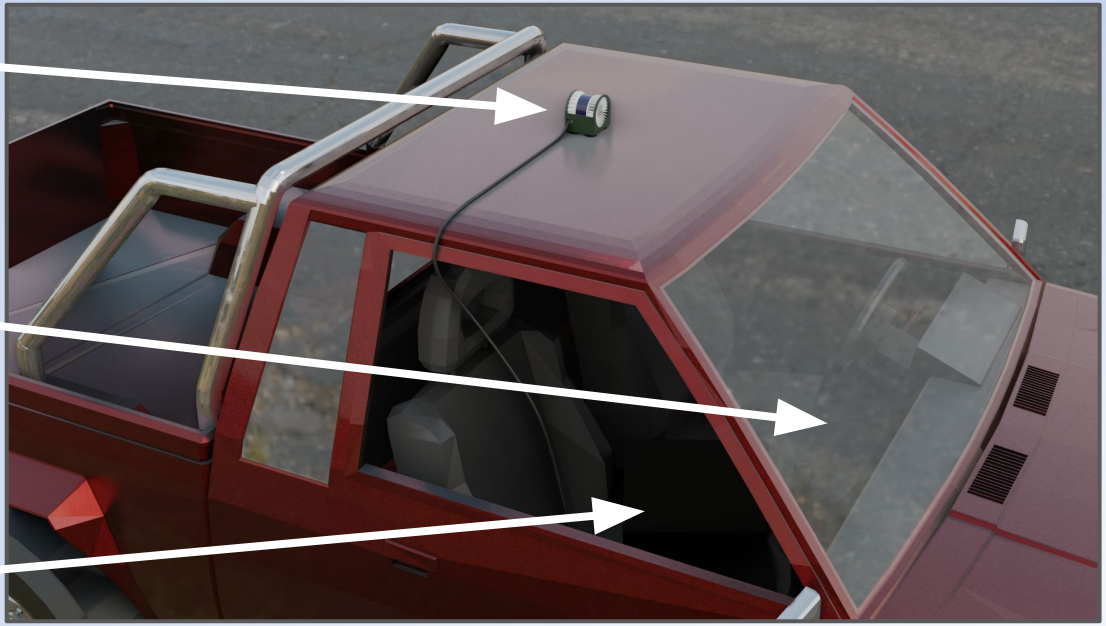


System Integration Plan

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

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

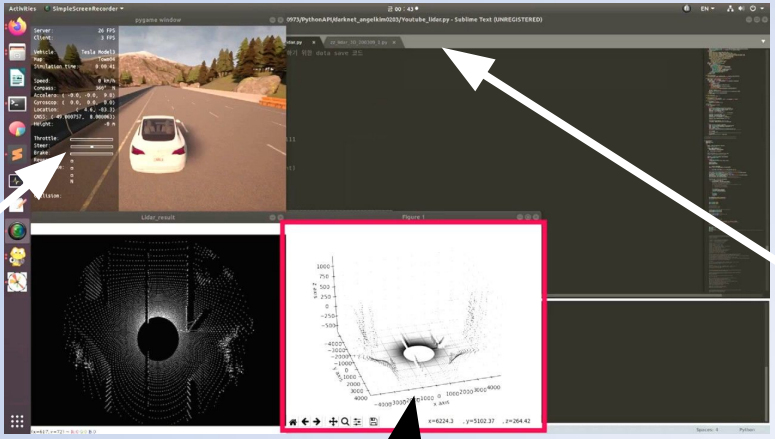
Software
- UDP Ethernet connection from LiDAR interface box to laptop
- WiFi-enabled for data transfer



Software: Carla Simulation

Simulated Physical Environment

- Create simple test environment from physical world (open, straight road)
- 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=Mt08Ag57Vel January 2021

Seamless Integration with ROS Melodic

- 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

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*	On Order	~2 weeks	Critical
Mounting Structure (3D Printed - Plastic)	1	$40.00	On Order	~2 weeks	Important
Mounting Structure (CNC 6061 Aluminum)	1	~$50.00	Planned	~2 weeks	Desirable

*ASTRA to purchase

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

Procurement Updates

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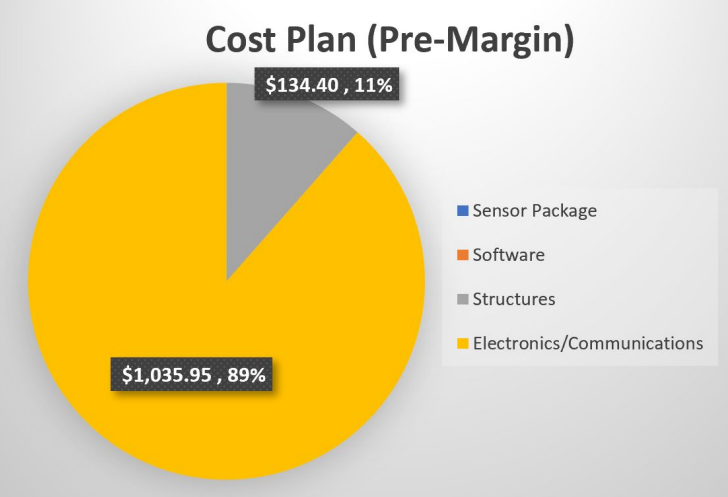
Total Funds Spent: $1,135.35 + Pilot Deposit: $200.00 → Remaining Funds: $3,664.65

Updated Cost Plan

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

- **ASTRA has agreed to purchase our OS1-32 LiDAR sensor ($3585.00)**



*Option to include External IMU ($1,495.00) if deemed necessary after testing

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)**

Backup Charts

Evaluation of Infrastructure

FLASH data should be able to exhibit the following structural failure points:

Spalling

Delamination

Destructive Losses

Corrosion

Collecting a database of these failure points can...

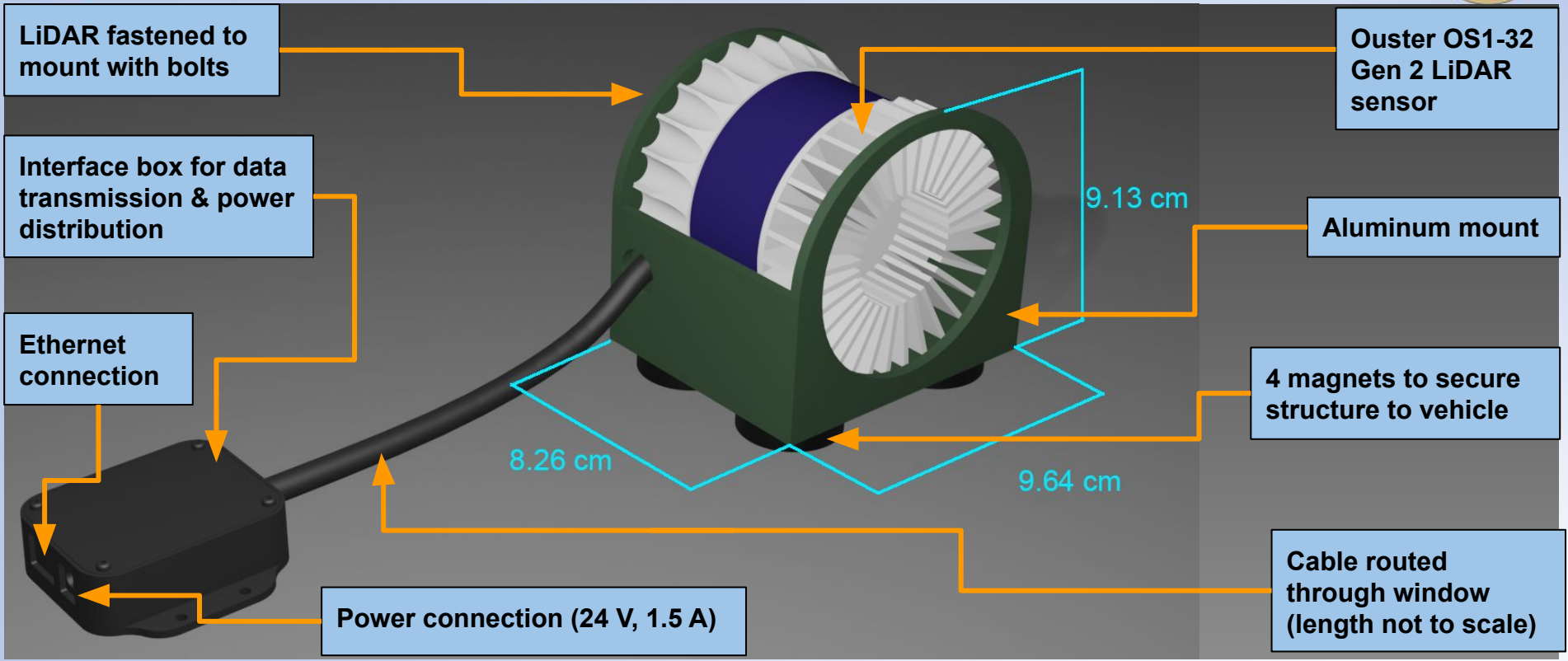
Decrease Length of Routine Inspection

Track Defect Propagation

Give Context for Damage Inspections

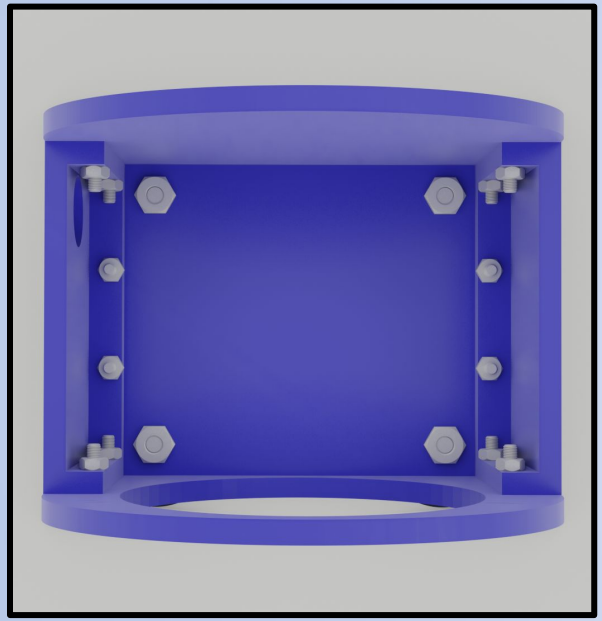
Cheaper and faster than traditional inspection!

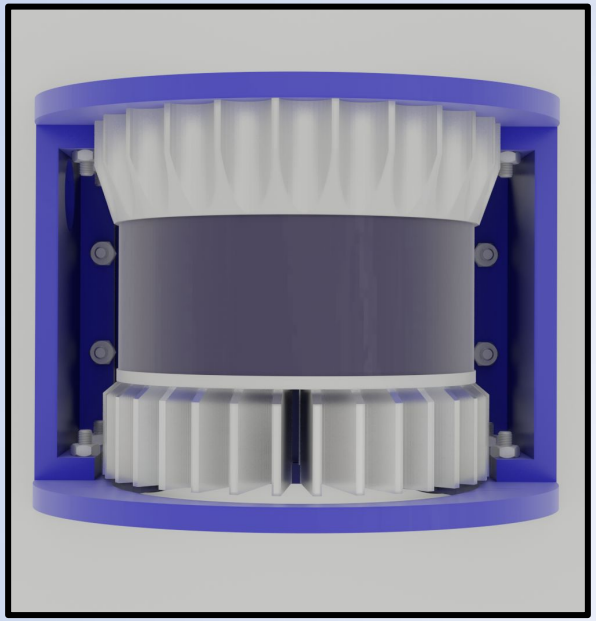
Top-Level Design Overview (Hardware)

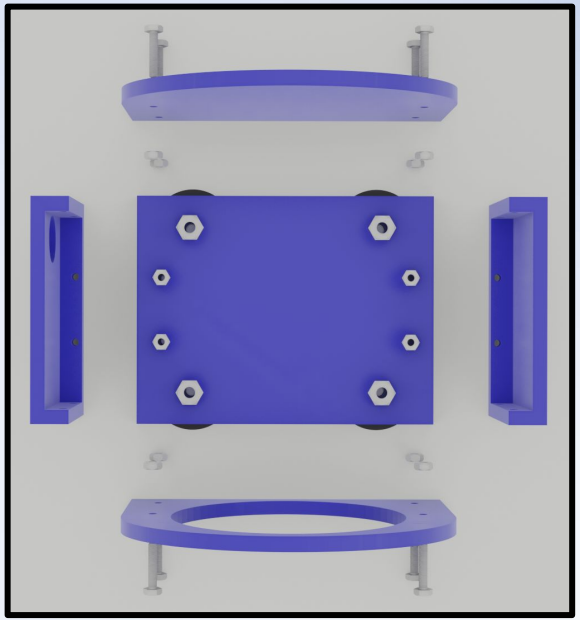


Housing Fabrication

Preliminary CNC Model (before fit check)

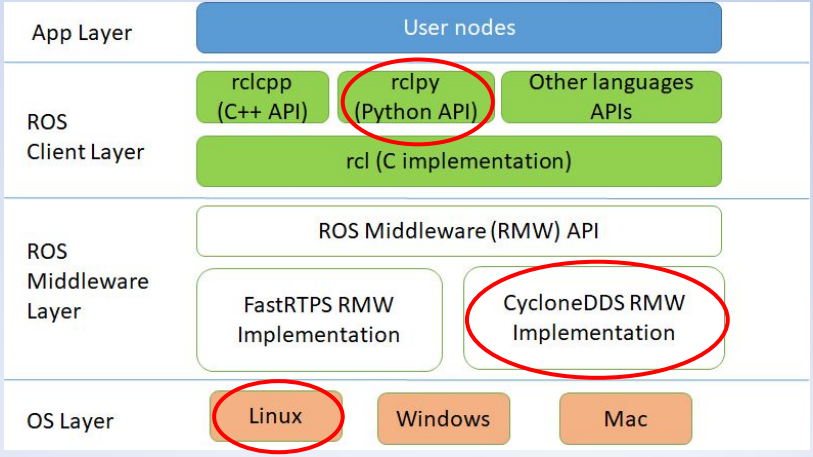






Software Pipeline - ROS

ROS provides a powerful framework for generically interfacing between OS and hardware systems
Primarily based off of networking protocols
We will be using TCP over ethernet
Industry standard, directly supported by Ouster
Outputs single *.bag* file which will be ingested by LIO-SAM automatically during post-processing



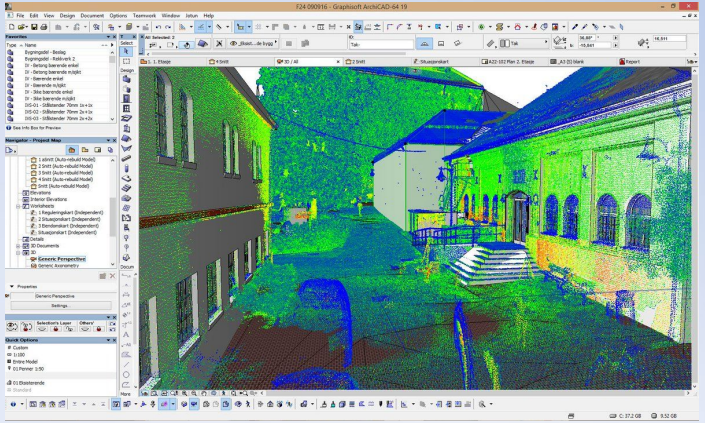
Data from LiDAR and IMU fed into ROS Kinetic nodes/topics ran on a Linux Ubuntu 18.04 native install on system laptop

DR 4.3 (Gather sensor data on-demand)
Satisfied ✔

(From CDR)

Software Pipeline - CloudCompare

CloudCompare will serve as primary software for point cloud visualization, refining, and mesh generation
Open source, industry standard
Easy framework for working with multiple scans
Currently used by our customer, ASTRA
Offers many built-in tools for modifying and refining data
Outlier filters
Point classification tools
...many, many more!
Runs mesh generation algorithm(s) as plugins
Highly configurable
Can write custom plugins if customer prefers alternative/proprietary mesh generation algorithm



CloudCompare offers open source tools for PC viewing and refining of data

DR 7.2 (Visualize mesh/PC)
Satisfied ✓

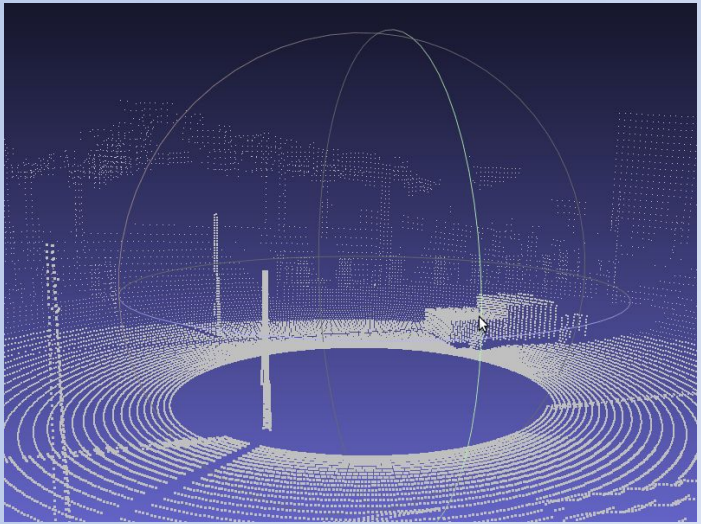
(From CDR)

Software: Google Maps API Comparison

- **Purpose**
  - Ground-truth data for infrastructure usually non-existent
  - Google Maps offers comprehensive freely available 2D positional data and visualization options
- **Description**
  - Completed point cloud and mesh data will be aligned to visual and numerical data outputted by Google Maps API
  - This will expose any large-scale flaws in infrastructure geometry in map, such as drift or discontinuities
- **Configuration**
  - Point cloud and mesh output from Data Quality Test will be aligned to corresponding Google Maps location
  - 2D projections will be made if necessary
- **Expected result**
  - X/Y drift errors quantified over duration of scan

(From CDR)

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.

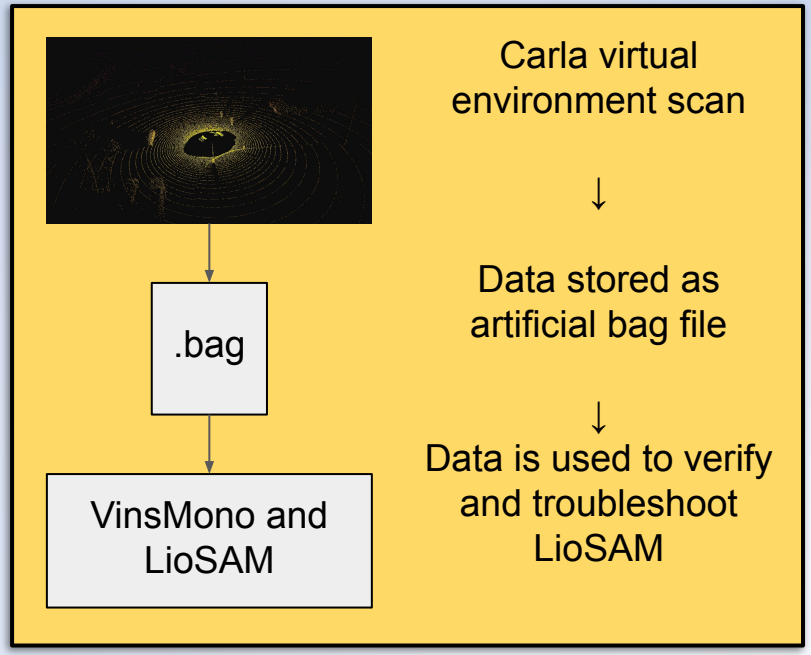
Expected Result

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

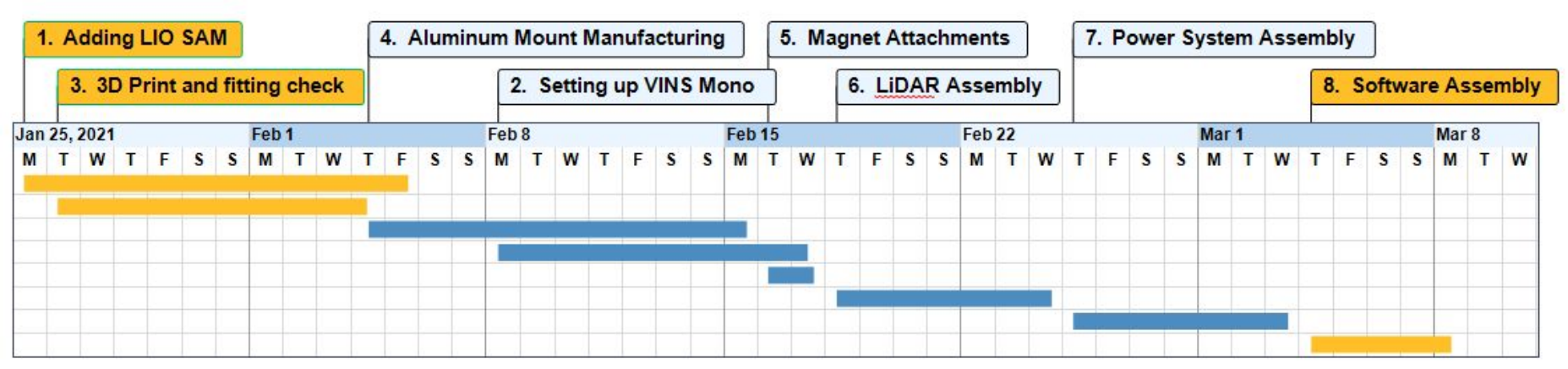
(From CDR)

Software - Carla Simulation

- Objective: Use carla to generate artificial lidar data to test software
  - Point cloud generation verification
- Variables to be controlled:
  - Custom virtual scanning environment
  - Lidar scan rate and orientation
  - Gyroscope output
  - Virtual vehicle speed
- **Items to be acquired and modified:**
  - Custom scanning environment in Carla



Manufacturing Schedule



In Progress