Preliminary Design Review

Team FLASH

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Presentation Layout

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- Objectives
- CONOPS
- FBD

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- LiDAR Sensor
- IMU Sensor
- Data Processing Software
- Mounting Mechanism

3. Baseline Feasibility

- LiDAR Feasibility
- IMU-LiDAR Integration Feasibility
- Mounting Mechanism Feasibility
- Power Availability Analysis

4. Status Summary and Strategy

- Plan for Future Studies
- Financial Outlook

Project Description

Motivation: Bridges

- 614,387 bridges in the US
- 200,000+ are over 50 years old
- 1 in 9 deemed structurally deficient
- Structurally deficient bridges are crossed 174 million times each day

Motivation: Bridge Infrastructure Analysis

- 17% of Bridges are inspected annually
- Cost of traditional inspection:
  - UBIV: up to $1M
  - Operational Cost: $3.5k p/d
- Infrastructure Monitoring Market valued at $1.78B in the U.S.
- Estimated to grow to $6.3B by 2029

Motivation: Current Innovations

- Manually operated drone imagery
  - Lower cost but similar manpower required, not always cheaper
- Higher precision, less time & manpower per bridge is the goal

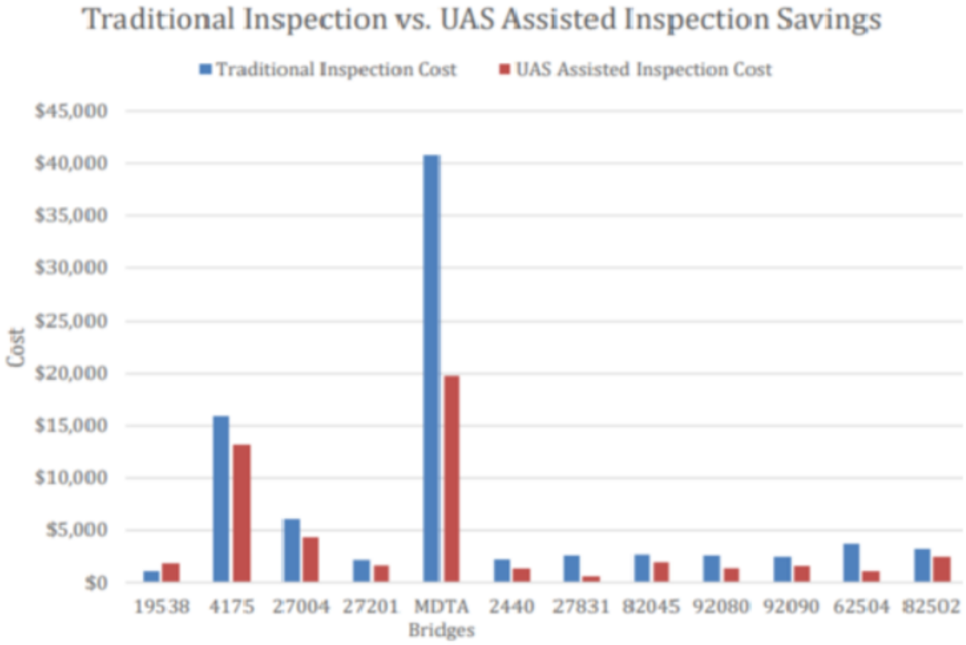
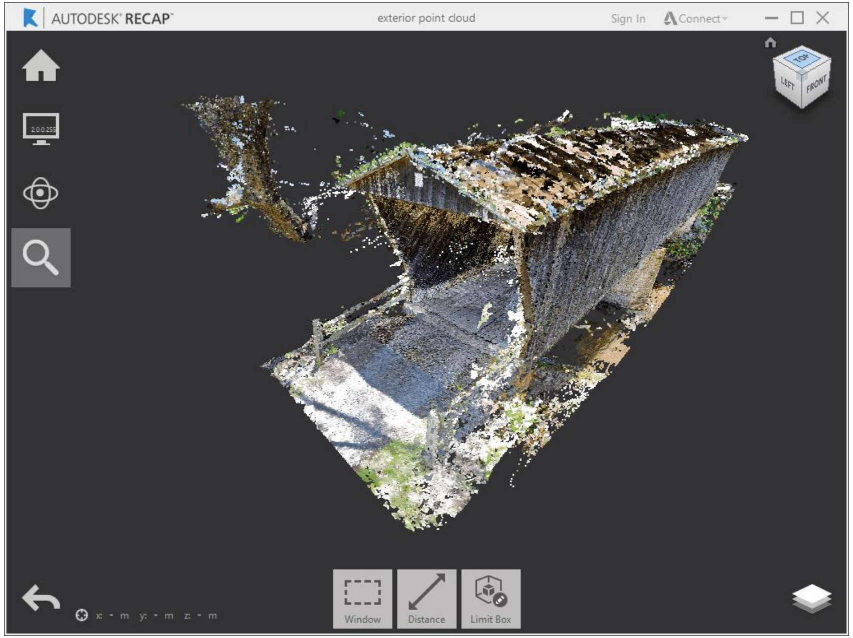


Figure 5.1 Traditional Inspection vs. UAS Assisted Inspection Savings

Objectives



Project Objective:

The system shall create an efficient and cheap way to analyze infrastructure.

Mission Statement:

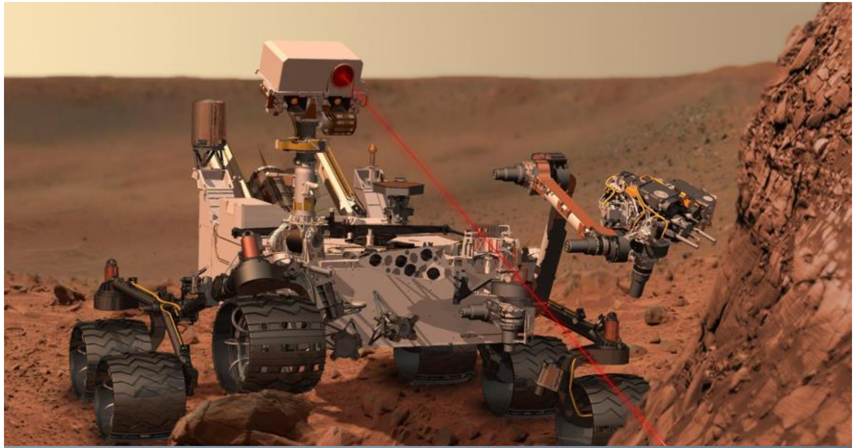
Design, build, and deploy a dynamic, vehicle-based **infrastructure analysis** sensor package using **LiDAR**.

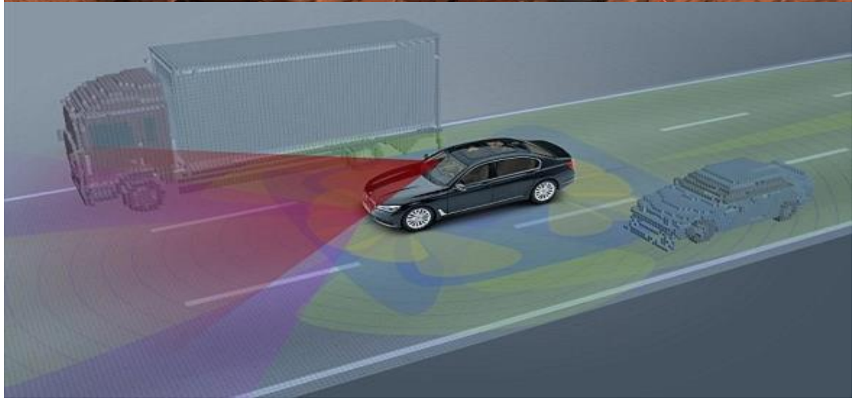
- The system shall **scan** its surroundings while in motion to produce a **3D map/model** that can be used by structural engineers to assess infrastructure.

Further Applications

3D Map creating system uses:

- Self-Driving Cars
- Mapping Planetary bodies
- Cave inspection
- Forest surveying
- Underwater exploration
- Battlefield mapping

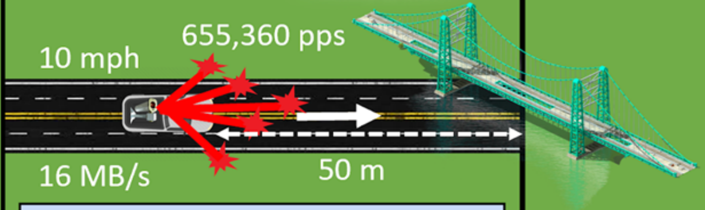




FLASH Concept of Operations

Single Infrastructure Inspection

Data Collection



1. **Activate and deploy system**

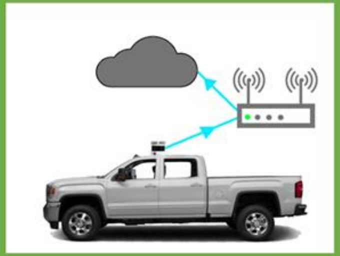
2. **Scan infrastructure while in motion**
   - Raw point cloud and IMU data collected (< 0.5 GB)
   - Up to 24.5 m bridge height and 160 m stretch of bridge length

FLASH Concept of Operations

Single Infrastructure Inspection

Data Collection

Data Transfer



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2. **Scan infrastructure while in motion**
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3. **Transmit data to post-processing home base**

FLASH: Functional LiDAR Assessment of Structural Health

FLASH Concept of Operations

Single Infrastructure Inspection

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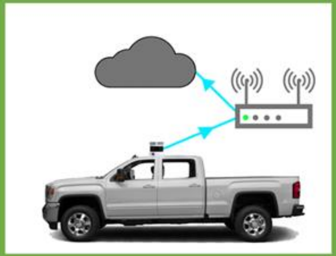
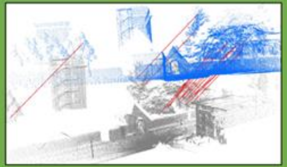
Data Transfer



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

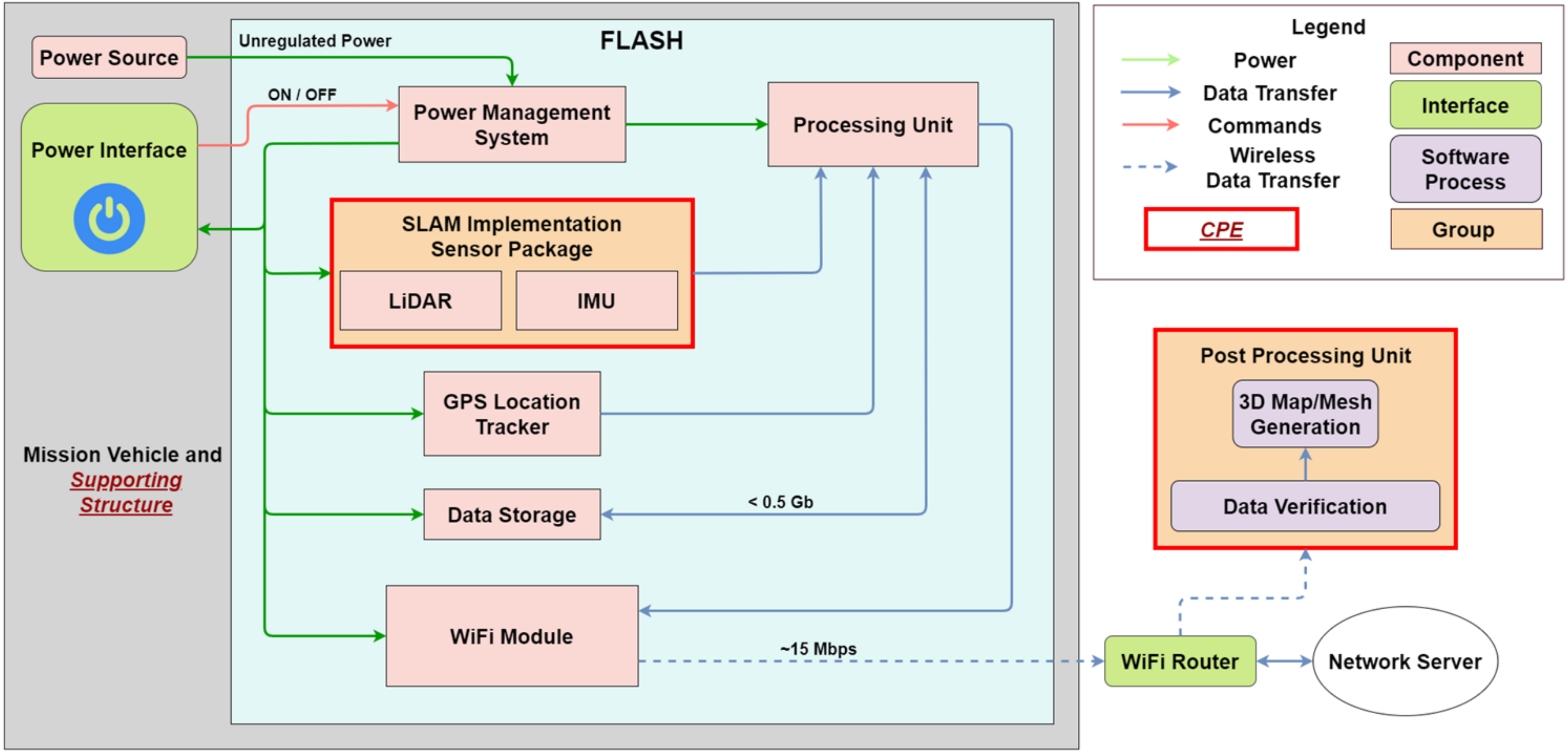
3D Map/Model Generation



4. **Process point cloud and IMU data**

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

Functional Block Diagram (FBD)

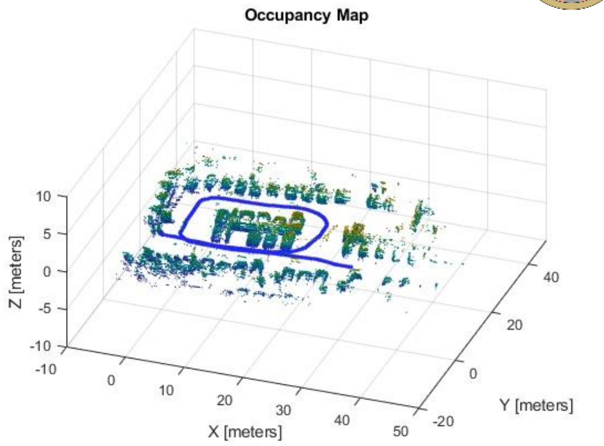


Baseline Design

Baseline Design

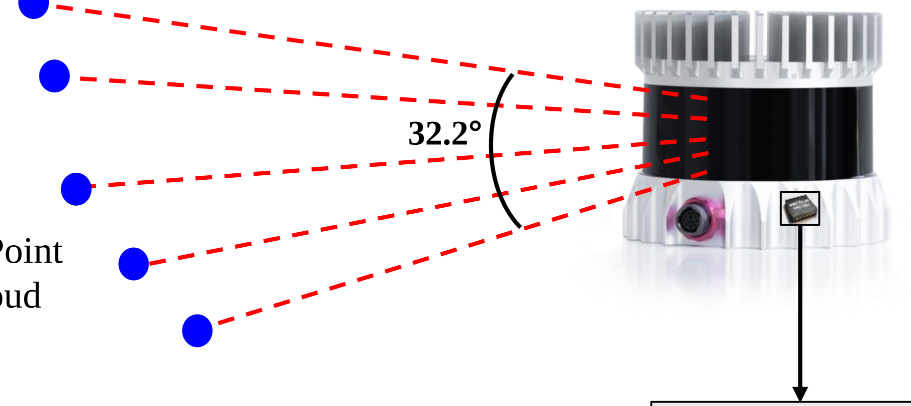
Critical Project Elements (CPEs)

- Sensor Package
  - LiDAR Sensor
  - IMU System
- Data Processing Software
  - Point cloud registration (CloudCompare)
  - SLAM Algorithm
- Vehicle Platform
  - Mounting Mechanism



Baseline Design – Sensor Package (LiDAR+IMU)

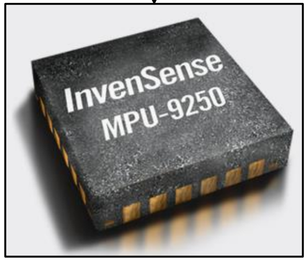
Ouster OS1-32 (Gen 1)



3D Point Cloud

Gyroscope + Accelerometer + Compass

9-axis motion tracking device



Key Specifications (LiDAR)	
Range	120 m (for target reflectivity of 80%)
Precision	+/-1.5 - 10 cm
Horizontal Resolution	1024 channels
Vertical Resolution	32 channels
Field of View	33.2° (V), 360° (H)
Cost	$3500 (customer-purchased)
Data Output	16.1 MB/s (129 Mbps) 655,360 points per sec
Power Consumption	14 - 20 W (Steady State)

Data Processing - Point Cloud Registration

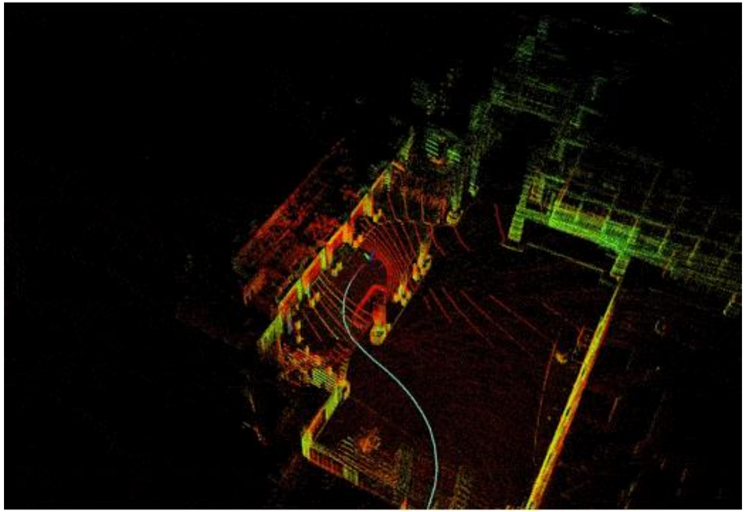
- Raw LiDAR and IMU data must be correlated to common coordinate frame, known as registration
  - Simultaneous Localization and Mapping (SLAM)used to improve pose estimates
  - LiDAR measurements outputted separately to IMU
  - Kalman filter combines signals in iterative process
- CloudCompare: open-source registration and visualization software package
  - Input: raw LiDAR files (.LAZ, .xyz)
  - Output: registered point cloud and/or 3D model (many file formats

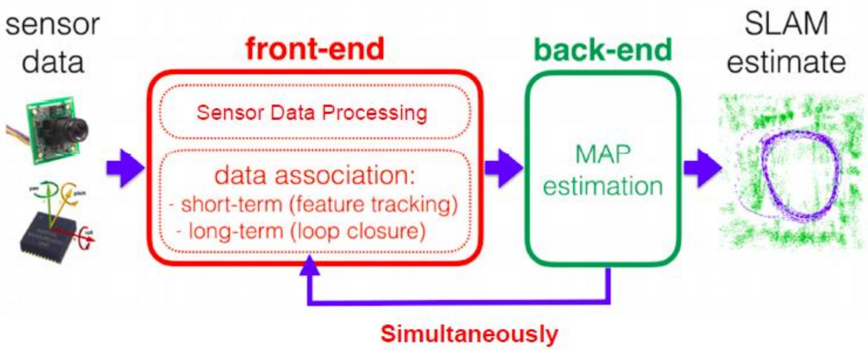
CloudCompare

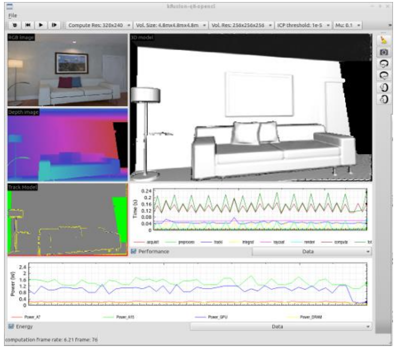
SLAM Algorithms

Simultaneous **L**ocalization **A**nd **M**apping

- Constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it.







Baseline Design - Mounting Mechanism

- System mounted through magnetic attachments
- Holds housing structure onto roof of vehicle

Key Specifications	
Mass	0.52 kg (1.15 lb)
Cost	$14.15 (per 5 magnets)
Size	720 cm^3 (73.9 in^3)
Diameter	60 mm (2.4 in)
Carrying Capacity	22.7 kg (50 lb)

Baseline Design - Housing Structure

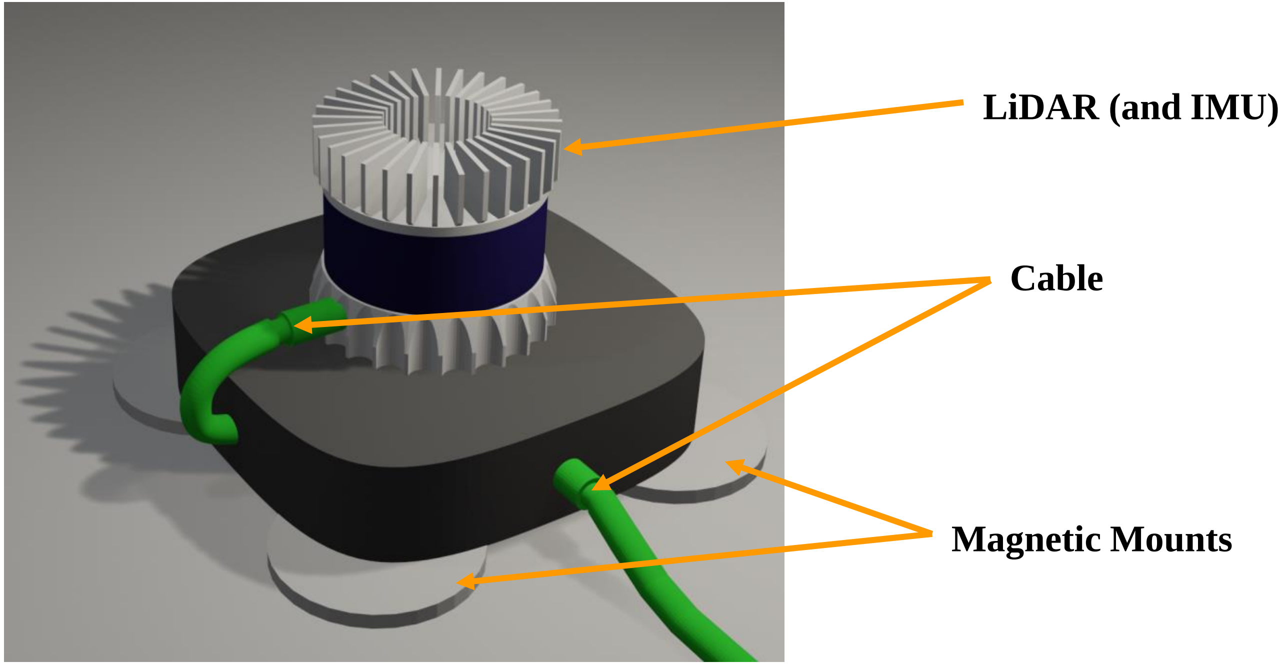
Conceptual Design

Items to be included inside housing:

- Power Management System
- GPS Sensor
- Processing Unit
- WiFi Module
- Data Storage
- Computer

Items to be included inside vehicle:

- Power Source



Baseline Feasibility

LiDAR Feasibility Overview

- LiDAR is the centerpiece of FLASH and overall project success depends upon collection of high-quality 3D point cloud data
- Key LiDAR feasibility elements are **scanning coverage**, **point spacing,** and **measurement error**

Governing Requirements

FR 1	The system shall utilize a 3D LiDAR sensor to survey infrastructure of interest.	• Customer-specified requirement • Associated DRs (1.1, 1.2) address measurement range and scanning coverage
FR 2	The system shall collect and output usable 3D point cloud data (x,y,z).	• Will be critical for 3D map/model creation • Associated DRs (2.1 - 2.3) address data accuracy, resolution, and output quantity

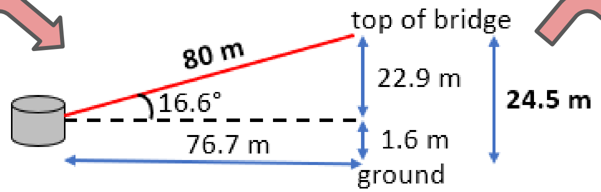
LiDAR Feasibility: Scanning Coverage

Typical grey concrete reflectivity is 35%

Sensor range is 80 m @ 35% target reflectivity

DR 1.1 (range ≥ 50 m) **Feasible** ✅

Sensor vertical FoV is 33.2º (16.6º up)



Can scan bridge up to 24.5 m in height

Sensor horiz. FoV is 360º

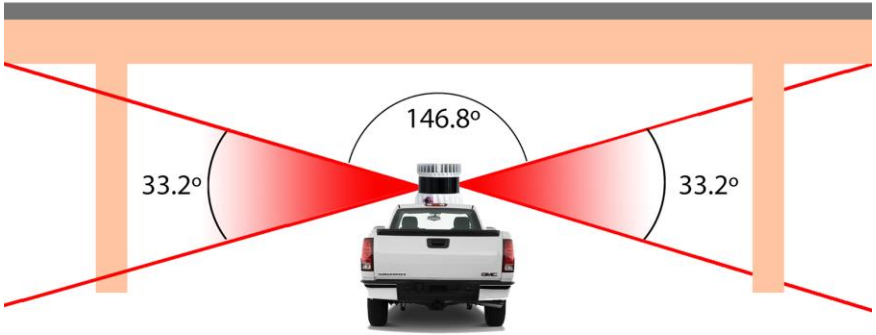
Sensor range is 80m

Can scan up to 160 m stretch of bridge length

DR 1.2 (full coverage) **Feasible** ✅

LiDAR Feasibility: Scanning Coverage (cont.)

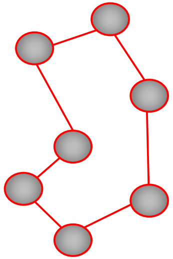
- As the vehicle passes directly under infrastructure, there will be a 146.8° "blind spot" due to limited vertical FoV
- Data for this "blind spot" will be captured as the vehicle approaches or leaves the infrastructure



LiDAR Feasibility: Point Spacing

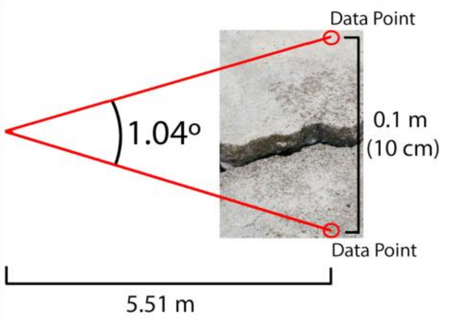
Vertical Resolution

32 laser channels
32.2° vertical FoV
} 1.04° angular resolution



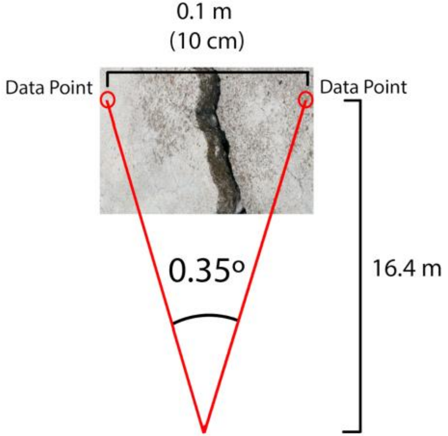
Horizontal Resolution

1024 laser channels
360° horizontal FoV
} 0.35° angular resolution



Sensor must be within 5.5 m of target to achieve 10 cm point spacing vertically

Sensor must be within 16.4 m of target to achieve 10 cm point spacing horizontally



DR 2.2 (resolution ≤ 10 cm)
Feasible ✅
BUT contingent upon being within range!

LiDAR Feasibility: Measurement Error

- **Accuracy** → How close are the measured points to the true/actual position of the structure being scanned?

- LiDAR point accuracy depends on external conditions → not necessarily a datasheet spec

- Typical accuracy for mobile mapping LiDAR units is 2-4 cm ($5,000 - $10,000)

- **Future Testing Plan** → Once the Ouster OS1-32 LiDAR is obtained:
  - LiDAR sensor will be used to scan a specific surface with known position
  - Processed point cloud data will be compared to known measurement
  - LiDAR measurement error (average and standard deviation) will be computed

DR 2.1 (error ≤ 15 cm)
Feasibility to be proven

IMU/LiDAR Integration Feasibility Overview

- It is crucial that the system is able to localize itself to a high level of accuracy without the aid of GNSS services.
- This ensures that GPS data is not required to construct the 3D model

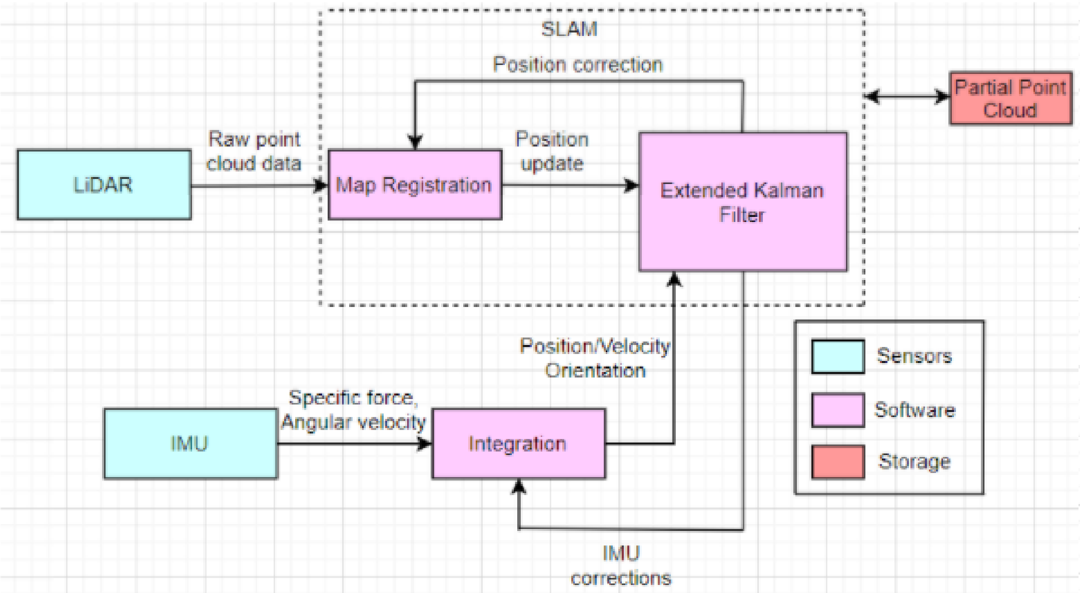
FR 3

The system shall be capable of localizing itself even when GNSS services are not readily available.

IMU (DR 3.1)
GPS Receiver (DR 3.4)

IMU/LiDAR Integration Feasibility

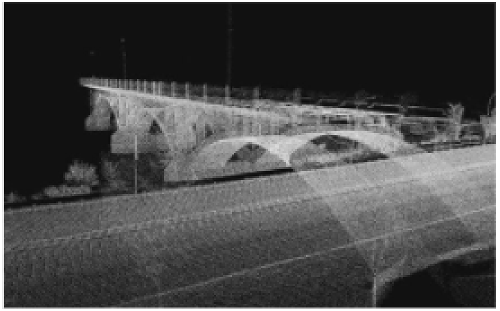
- Kalman filter - Linear quadratic estimation algorithm
  - Combines sensor data from multiple sources to reduce noise/uncertainty
  - Input - series of measurements observed over time
  - Output - estimated state as well as associated uncertainty



DR 3.1 and 3.4
Feasible ✅

Feasibility Analyses -- Data Processing

FR 2 | 2 The LiDAR sensor shall collect and output usable 3D point cloud data. | Accuracy Requirements (DR 2.1)



- Point cloud must be outputted to useable 3D model
- Compare 3D model to ground truth data collected by manual surveying and Google Maps API
- Organize point cloud and models into larger selectable maps via geotags

DR 2.1 (Error <15cm)
Feasibility to be proven

Feasibility Analysis -- Mounting Mechanism

FR 5 — The system shall be capable of mounting onto a vehicle and operating while the vehicle is in motion.

- Customer-specified requirement
- Associated DRs (5.1, 5.2, 5.3) address holding capacity, withstanding drag forces, road vibration tolerance

- Magnet mechanism fulfills this FR:
  - Can easily **attach/detach** from any vehicle with metal roof
  - Designed for car top signs / ski racks
    - Tested at high speeds
    - Widespread COTS usage
  - High customer reviews (average: 4.4 / 5 stars)

Feasibility Analysis -- Mounting Mechanism

FR 5 The system shall be capable of mounting onto a vehicle and operating while the vehicle is in motion.

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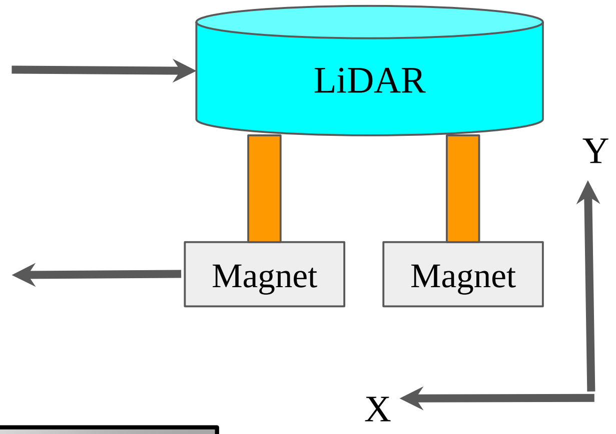
- Constraints:
  - Each magnet has a holding capacity of **50 lbs (222.4 N)**
    - **16.66 lbs (74.1 N)** in horizontal direction
  - LiDAR area exposed to oncoming wind: **0.0062 m^2**
  - Factory of safety of 1.5 **(49.3 N)**
- Maximum:
  - Force exerted by **67 mph** relative wind is **9.6 N**
    - (Well below FOS)



$\Sigma F_x = 0$

DR 5.2 (withstand ≥ 35 mph relative wind)
Feasible ✅

Status Summary

Status Summary of Feasibility Studies

	Sensor Package (LiDAR+IMU)	Software	Mounting Structure
Aspects shown to be feasible	• Scanning range and coverage • Point spacing (resolution)	• Preliminary IMU-LiDAR data integration plan • 3D model from point cloud	• Mounting mechanism
Remaining studies	• Testing to determine point accuracy (measurement error)	• Choose a SLAM algorithm (trade study) compatible with CC • Study algorithm accuracy dependencies	• Component housing design • Test protocol

Preliminary Financial Outlook

Subsystem	Cost
LiDAR/IMU	$3,500** ($0)
Structures	(~$200)
Communications	(~$300)
Power	(~$100)
Data Storage	(~$400)
Miscellaneous	(~$50)
Margin	25%
Total Cost	**($1312.50)**

- **Total Project Budget**: $5,000.00
- **Total Cost w/ Margin**: ($1,312.50)
- **Remaining Budget**: $3,687.50
- Loaned Hardware:
  - **ASTRA has verbally agreed to purchase and loan this LiDAR system to the team for the duration of the project
- Margin Percentage: 25%
  - Will be refined after PRR
  - Defines worst case scenario


Thank You!
Smead Aerospace
UNIVERSITY OF COLORADO BOULDER
FLASH
FUNCTIONAL LIDAR ASSESSMENT of STRUCTURAL HEALTH
Questions?

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Backup Charts

Functional Requirements

FR 1: The system shall utilize a 3D LiDAR sensor to survey infrastructure of interest.
FR 2: The LiDAR sensor shall collect and output usable 3D point cloud data.
FR 3: The system shall be capable of localizing itself even when GNSS services are not readily available.
FR 4: The on-board processing unit shall be capable of data storage, handling, and interfacing between components.
FR 5: The system shall be capable of mounting onto a vehicle and operating while the vehicle is in motion.
FR 6: The system shall incorporate a power source that is capable of continuously supplying power to all applicable components.
FR 7: The point cloud and localization data shall be consolidated and post-processed into an interactive digital 3D map/model to quickly identify structural faults.
FR 8: The on-board communications unit shall be capable of wirelessly transferring point cloud and localization data directly to a designated headquarters.
FR 9: The system shall be capable of initiating and terminating data collection with minimal driver interaction.
FR 10: The system shall conform to all relevant safety regulations and guidelines.

Design Requirements

DR 1.1	The system shall have a measurement range of no less than 50 meters.
DR 1.2	The system shall provide scanning coverage for bridges up to 30 meters in height and 30 m in length.
DR 2.1	The point cloud data shall have an average measurement error no more than 15 cm.
DR 2.2	The point cloud resolution shall be no less than 10 cm.
DR 2.3	The sensor shall output no less than 150,000 data points per second.
DR 3.1	The system shall incorporate an inertial navigation device with bias instability of less than 2°/hr.
~~DR 3.2~~	~~The system shall incorporate a Global Positioning System (GPS) module with a positional error of less than 5 cm.~~
~~DR 3.3~~	~~The system shall utilize a GNSS sensor to assign geographic coordinates to collected data.~~

Design Requirements

DR 3.4	The system shall operate during GNSS service outages of no more than 10 seconds.
DR 4.1	The system shall accommodate a cumulative data size of at least 5 GB.
DR 4.2	The memory unit shall be compatible with a UDP connection over gigabit ethernet.
DR 4.3	The processing unit shall provide an interface between the LiDAR sensor, auxiliary sensors, and a hard drive.
DR 5.1	The mounting structure shall be capable of supporting a LiDAR sensor up to 5 pounds in mass.
DR 5.2	The mounting structure shall withstand drag forces associated with a vehicle speed of at least 35 mph.
DR 5.3	The mounting structure shall secure all components of the system up to a vehicle vibration frequency of 50 Hz.
DR 6.1	The power system shall supply no less than 30 V.

Design Requirements

DR 6.2	The power system shall be capable of supplying 25W of continuous steady-state power.
DR 7.1	The point cloud data shall be stitched together to create a 3D map using localization data.
DR 8.1	The system shall be capable of transmitting data at a range of 70 meters.
DR 8.2	The system shall be capable of transmitting data at a minimum rate of 15 Mbps.
DR 9.1	The system shall automatically begin data collection 50 m away from the infrastructure of interest, and shall automatically terminate 50 m after infrastructure of interest.
DR 9.2	The system shall provide a means of manual data collection initiation and termination.
DR 10.1	The system shall adhere to all applicable Federal Motor Vehicle Safety Standards (FMVSS).
DR 10.2	The LiDAR sensor shall adhere to laser safety regulations under IEC 60825-1:2014.

LiDAR Sensor Trade Study Results

		Velodyne Puck Hi-Res	Ouster OS0-32	Ouster OS1-16 (Gen 1)	SICK MRS1000	Livox Mid-100	Velodyne Puck
Criteria	**Weight**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
Accuracy	7.5%	4	3	2	1	5	4
Range	7.5%	4	1	2	3	5	4
Field of View	30%	3	5	4	2	1	3
Cost	20%	1	2	4	3	5	3
Data Output	20%	3	5	4	2	3	3
Platform Integration	5%	4	3	3	5	3	4
Mass	5%	3	4	5	2	1	3
Power	5%	5	3	3	4	1	5
Total	100%	2.9	**3.7**	3.65	2.45	2.9	3.3

Table 28: *Trade Study of LiDAR Sensors*

Navigation Sensor Trade Study Results

		Advanced Navigation SPATIAL	Vectornav 200	Vectornav 300	Trimble BD992-INS	Gladiator Tech Landmark 60
Criteria	**Weight**	**Score**	**Score**	**Score**	**Score**	**Score**
IMU Performance	25%	5	4	4	4	5
GNSS Performance	25%	4	3	5	3	4
Additional Sensors	10%	5	4	4	4	4
Cost	20%	3	1	1	5	1
Platform Integration	10%	4	4	4	4	5
Mass	5%	5	5	5	5	4
Power	5%	4	4	4	5	3
Total	100%	**4.2**	3.2	3.7	4.05	3.7

Table 30: *Trade Study of Navigation Sensors*

Data Processing Trade Study Results

		PointFuse	ArcGIS	CloudCompare	AutoDesk	TerraSolid	MATLAB
CRITERIA	WEIGHT	Score	Score	Score	Score	Score	Score
Cost	35%	1	4	5	3	2	4
Tools/Capabilities	25%	3	2	4	5	4	3
Compatibility	20%	4	2	5	3	1	2
User Engagement, Ease of Use	20%	5	2	3	4	3	1
Total	100%	2.9	2.7	4.35	3.7	2.5	2.75

Table 32: *Trade study of Data Processing Softwares*

Mounting Mechanism Trade Study Results

		Fixed Attachment	Magnetic Attachment	Clamping Attachment
Criteria	Weight	Score	Score	Score
Ease of Attach/Detach	30%	2	5	4
Stability Risk	25%	5	3	4
Mass	20%	1	5	3
Cost	10%	1	5	4
Manufacturability	10%	2	5	4
Size	5%	2	5	2
Total	100%	2.45	4.5	3.7

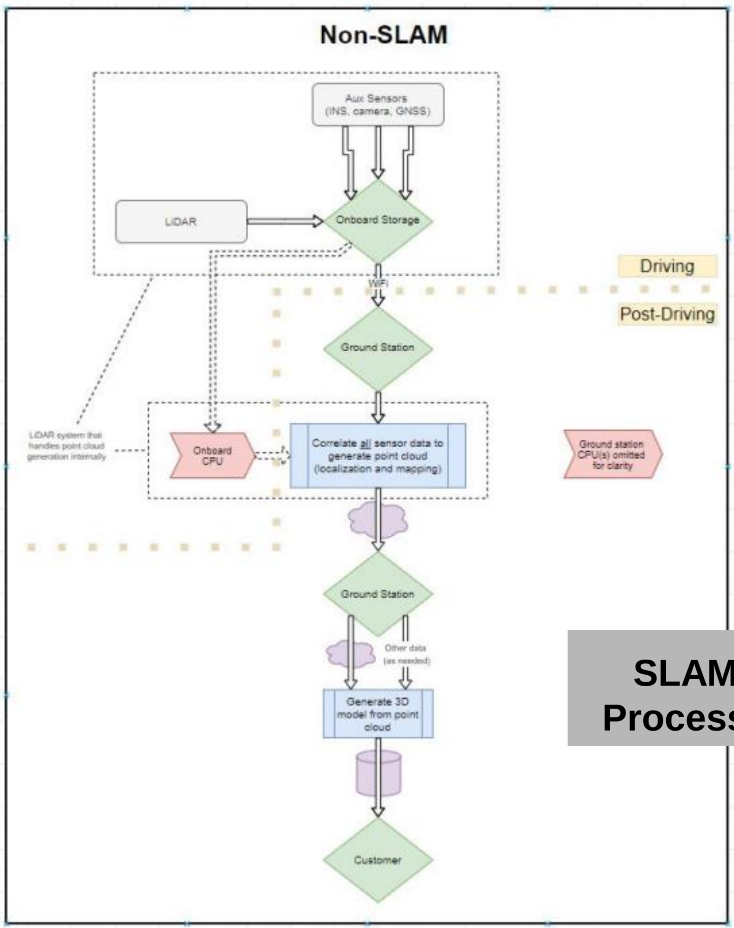
Table 34: *Trade study of Mounting Structure*

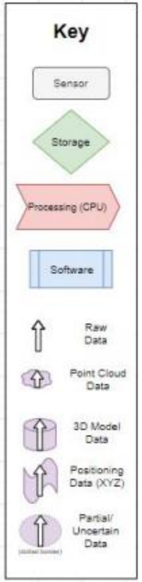
Communication Protocol Trade Study Results

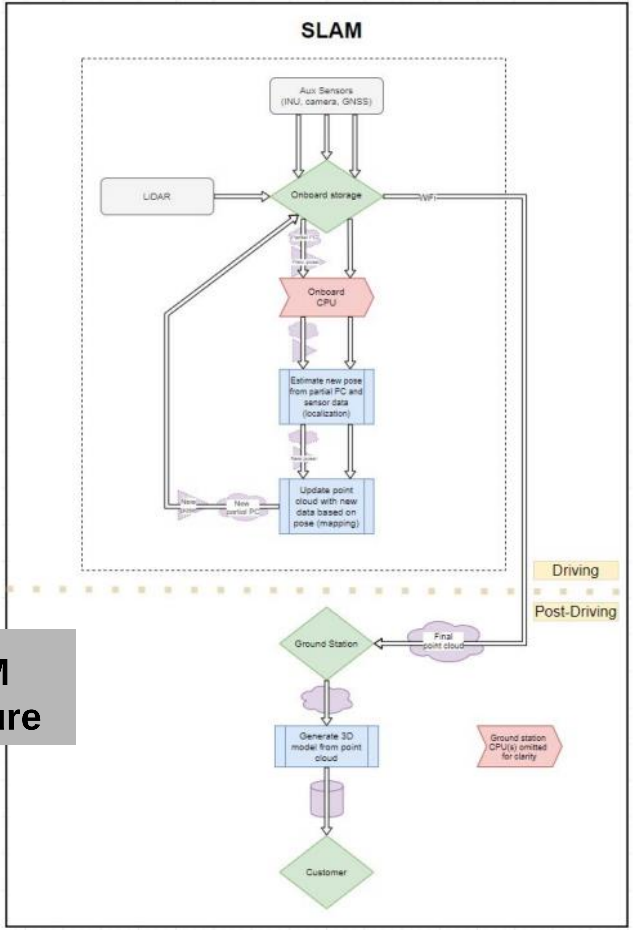
		Wi-Fi	4G LTE	Bluetooth LE
Criteria	**Weight**	**Score**	**Score**	**Score**
Range	10 %	5	5	5
Data Rate	30 %	5	5	4
Hardware constraints	35 %	3	3	3
Power	5 %	3	3	5
Cost	10 %	3	1	5
Internet Accessibility	10 %	5	5	1
Total	100%	4	3.8	3.6

Table 36: *Trade Study of Communication Protocols*

SLAM vs. Non-SLAM Processing Architecture







Sensor Package - Sensor Package (LiDAR/IMU)

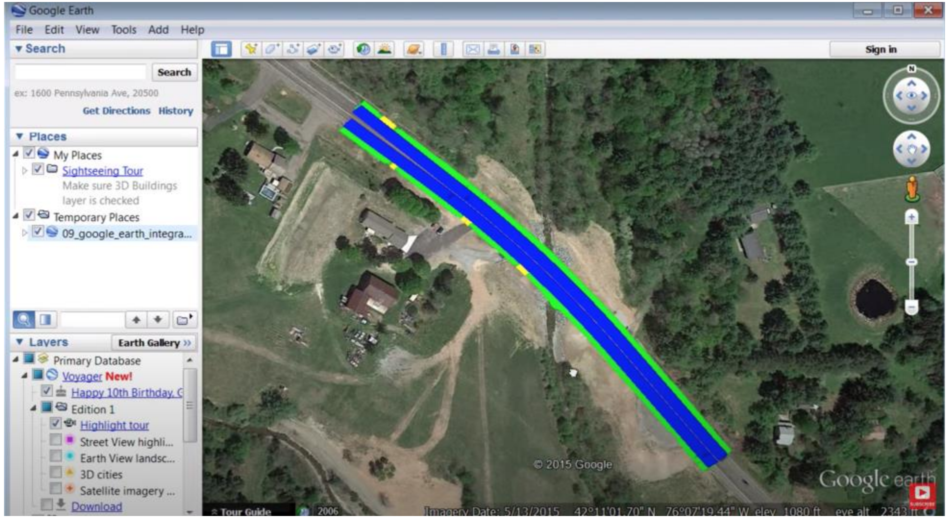
- Ouster OS1-32 comes with built-in IMU, **InvenSense MPU-9250**

Sensor Package - Global Positioning System (GPS)

- Update rate: 1-5 Hz
- Small and cheap
- Mainly used for documenting approximate location of infrastructure
- If GPS is available during scanning it will aid in localization

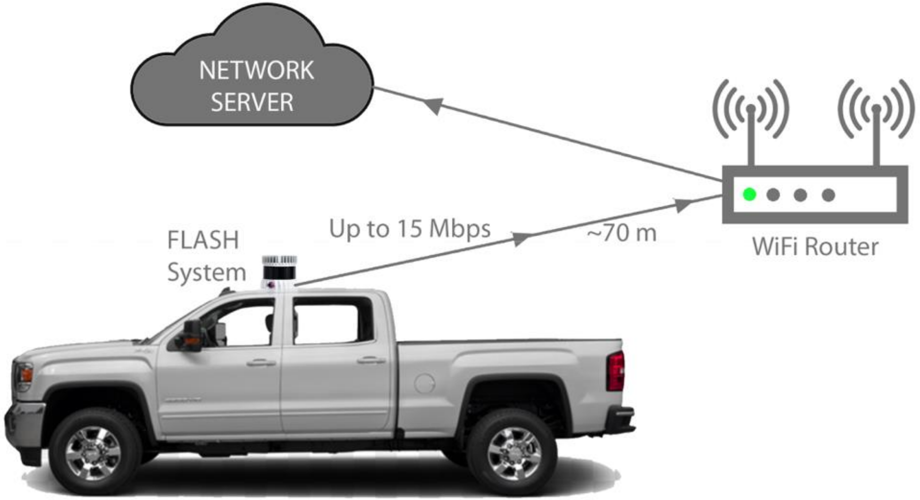
Data Processing - Geotagging

- Models will be exported with geotags
  - Large scale visualization
  - Ease of cataloging and organizing multiple scans
- Google Earth used for visualization
  - Free software
  - Model verification with data from Google Maps API
  - Keyhole Markup Language (KML) support



Communications Protocol

- WiFi (IEEE 802.11 Family of standards)
- Average data upload rate ~ 5 to 15 Mbps
- WiFi is commonly used and reliable
- Data is readily available once uploaded,
  from anywhere



Structures Feasibility: Off-The-Shelf Products

Ski Racks Show Magnetic Attachments

1. Are Weather Resistant
2. Functions properly at highway speeds
3. Reliably Hold Significant Weight
   a. 4-6 skis (up to 80lbs)
4. Does Not Harm Car
5. Cost Range: $50 - $260

Example Companies:

Inno Ski Racks: https://www.innoracks.com/

Structures Feasibility: Force Analysis

<u>Variables:</u>

Force From Wind: $\mathbf{F_w}$

Relative Wind (Car Speed): $\mathbf{v}$

Air Density (STD ATM) : $\boldsymbol{\rho}$

Area of Ouster: $\mathbf{A_o}$*

Area of Legs: $\mathbf{A_l}$ *

Hold Capacity (Vertical) : $\mathbf{F_v}$

Hold Capacity (Horizontal) : $\mathbf{F_h}$

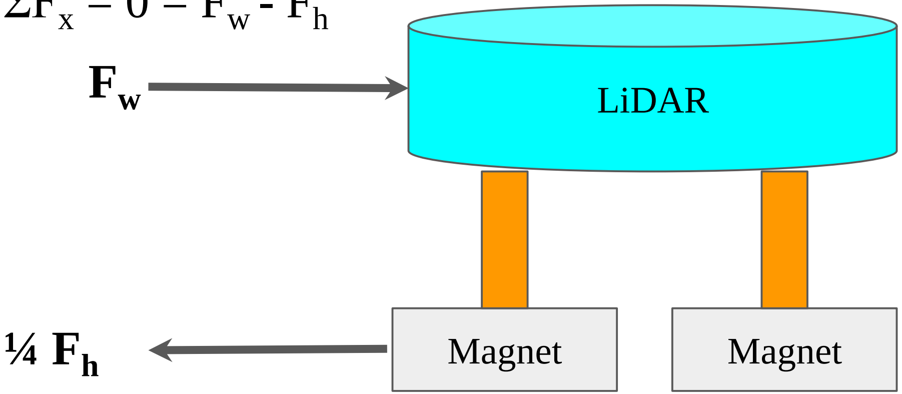
* : Indicates unknown variables

<u>Equations:</u>

$F_w = (A_o + A_l) \times (\rho) \times (v)^2$

$F_h = 4 \times (\frac{1}{3}\ F_v)$

$\Sigma F_x = 0 = F_w - F_h$



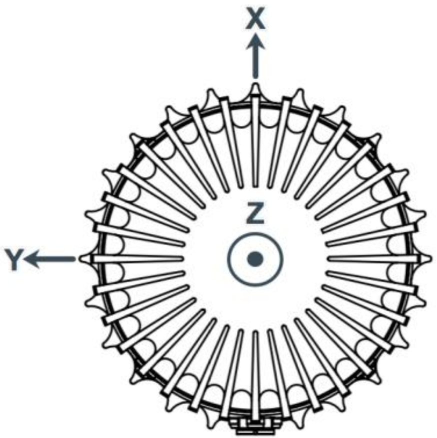
Note: Similar to a static cantilever beam (sum of forces is valid)

Structures Feasibility: Other Considerations

1. Vibration Test
   a. Car Vibrations → FEM Analysis and Vibe Table in the PILOT
2. Shock / Impulse Test
   a. Potholes
   b. Slamming on Brakes → FEM Analysis and Physical Tests
3. Separation of Magnets and Electronics → Build into Design
4. Detachability
   a. Individual LiDAR
   b. Full Structural Mount → Build into Design

LiDAR Data – Coordinate Frame Transformation

- The Ouster OS1-32 outputs data in the form of **range**, **beam_altitude_angle**, and **beam_azimuth_angle**
- Must be transformed into 3D Cartesian x,y,z coordinates in a common "sensor frame"



$$r = \texttt{range mm}$$

$$\theta = 2\pi\left(\frac{\texttt{encoder\_count}}{90112} + \frac{\texttt{beam\_azimuth\_angles[i]}}{360}\right)$$

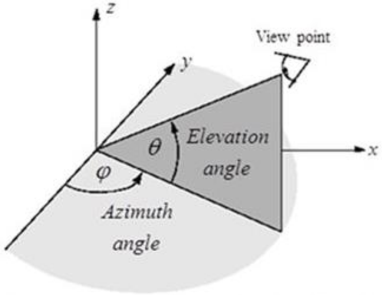
$$\phi = 2\pi\frac{\texttt{beam\_altitude\_angles[i]}}{360}$$

$$x = r\cos(\theta)\cos(\phi)$$

$$y = -r\sin(\theta)\cos(\phi)$$

$$z = r\sin(\phi)$$

This constitutes a **point cloud**



Ouster OS1-32 (Gen 1) Specs

OPTICAL PERFORMANCE

Range (80% Reflectivity)	0.8 m - 120 m @ 80% reflective lambertian target, 100 klx sunlight, >50% detection probability, false positive rate of 1/10,000 0.8 m - 105 m @ 80% reflective lambertian target, 100 klx sunlight, >90% detection probability, false positive rate of 1/10,000
Range (10% Reflectivity)	0.8 m - 60 m @ 10% reflective lambertian target, 100 klx sunlight, >50% detection probability, false positive rate of 1/10,000 0.8 m - 40 m @ 10% reflective lambertian target, 100 klx sunlight, >90% detection probability, false positive rate of 1/10,000
Range Accuracy	Zero bias for lambertian targets, slight bias for retroreflectors
Range Resolution	0.3 cm
Range Repeatability (1 sigma / standard deviation)	0.8 - 2 m: ± 3 cm; 2 - 20 m: ± 1.5 cm; 20 - 60 m ± 3 cm; > 60 m: ± 10 cm
Vertical Resolution	16, 32, or 64 channels
Horizontal Resolution	512, 1024, or 2048 (configurable)
Field of View	Vertical: +16.6° to -16.6° (33.2°) Horizontal: 360°
Angular Sampling Accuracy	Vertical: ±0.01° / Horizontal: ±0.01°
Rotation Rate	10 or 20 Hz (configurable)
# of Returns	1 (strongest)

LASER

Laser Product Class	Class 1 eye-safe per IEC/EN 60825-1: 2014
Laser Wavelength	850 nm
Beam Diameter Exiting Sensor	10 mm
Beam Divergence	0.13° (FWHM; 16, 32, and 64 channel)

LIDAR OUTPUT

Connection	UDP over gigabit ethernet
Points Per Second	327,680 (16 channel) 655,360 (32 channel) 1,310,720 (64 channel)
Data Per Point	Range, intensity, reflectivity, ambient, channel, azimuth angle, timestamp
Time Stamp Resolution	< 1 µs
Data Latency	< 10 ms

IMU OUTPUT

Connection	UDP over gigabit Ethernet
Samples Per Second	100
Data Per Sample	3 axis gyro, 3 axis accelerometer
Time Stamp Resolution	< 1 µs
Data Latency	< 10 ms
Additional Details	InvenSense MPU9250; datasheet for more details: https://www.invensense.com/download-pdf/mpu-9250-datasheet/

CONTROL INTERFACE

Connection	TCP and HTTP APIs
Time Synchronization	Input sources: • IEEE1588 Precision Time Protocol (PTP) • gPTP • NMEA $GPRMC UART message support • External PPS • Internal 10 ppm drift clock Output sources: • Configurable 1 - 60 Hz output pulse
LIDAR Operating Modes	Hardware triggered angle firing (guaranteed fixed resolution per rotation): • x 2048 @ 10 Hz • x 1024 @ 10 Hz or 20 Hz • x 512 @ 10 Hz or 20 Hz
Additional Programmability	Multi-sensor rotation phase tuning Queryable intrinsic calibration information: • Beam angles • IMU pose correction matrix

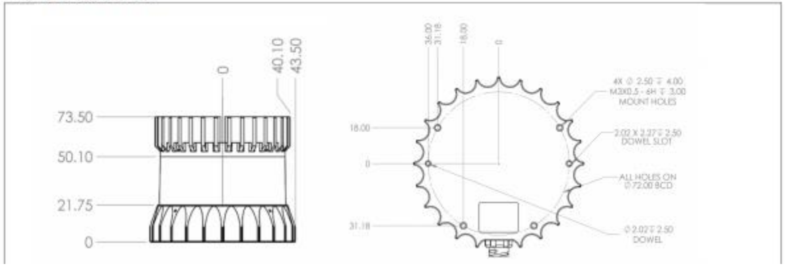
MECHANICAL/ELECTRICAL

Power Consumption	14 - 20 W (22 W peak at startup)
Operating Voltage	22 - 26 V, 24 V nominal
Connector	Proprietary pluggable connector (Power + data + DIO)
Dimensions	Diameter: 85 mm (3.34 in) Height: • Without cap: 58.35 mm (2.3 in) • With thermal cap: 73.5 mm (2.9 in)
Weight	For fixed cap sensors: 396 g (14.0 oz); For modular cap sensors: 425 g (15.0 oz) with fin cap, 348 g (12.3 oz) without cap
Mounting	4 M3 screws / 2 locating 3 mm pins

ACCESSORIES

Included Interface Box	PolyCarb/FR4, 100 g, 75 mm x 50 mm x 25 mm (LxWxH), 2 m CAT6 cable, 24 V power adapter, 5 m sensor cable
Optional Mount	Aluminum, 530 g, 110 mm x 110 mm x 20.5 mm (LxWxH), 4 x M8 thru holes

EXTERIOR DIMENSIONS

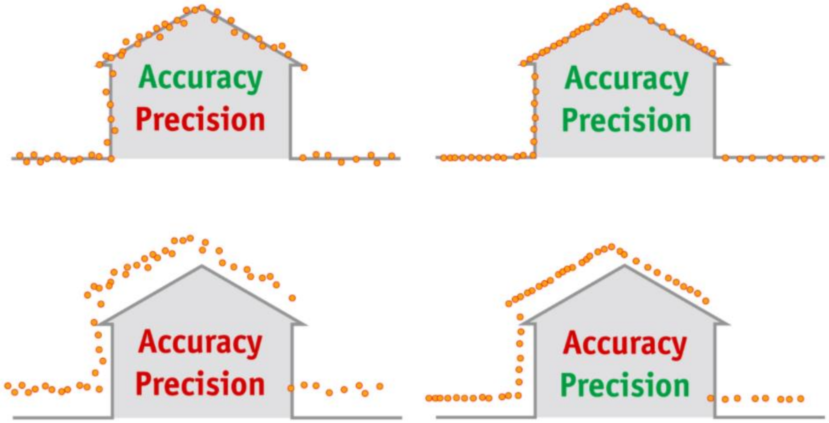


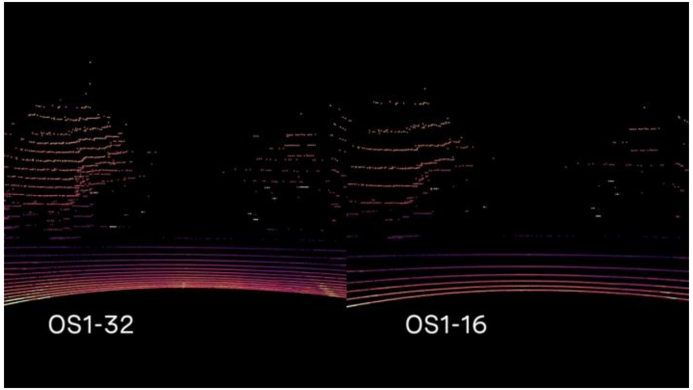
LiDAR Accuracy vs. Resolution vs. Precision

Accuracy → How close are the measured points to the true/actual position of the structure being scanned?

Resolution → How far apart are the measured points? How dense is the point cloud?

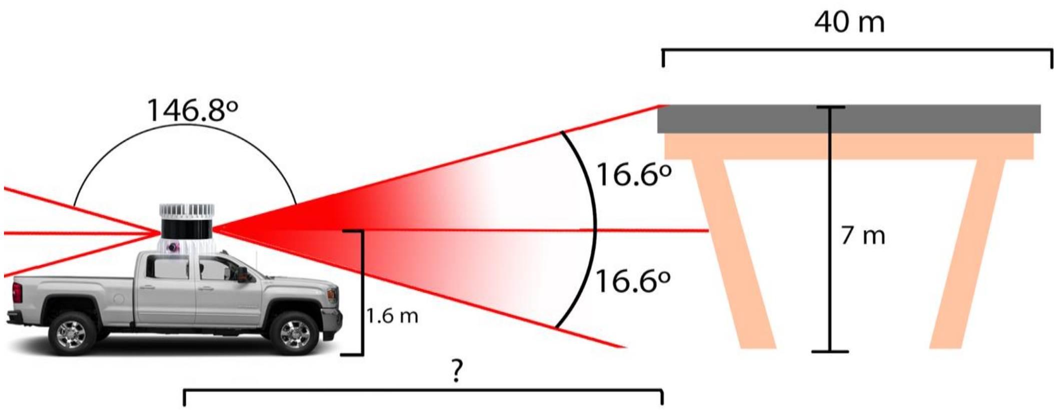
Precision → How repeatable are the measurements? How much noise is observed in the point cloud?





LiDAR Feasibility: Scanning Coverage

- Given the vertical sensor field of view (33.2°) and the vertical distance between LiDAR sensor and top of bridge (5.4 m), the system will be able to achieve **full vertical coverage** as long as scanning begins at least **18.11 meters ahead** of the bridge → this falls within range spec of sensor
- Given a constant vehicle speed of 10 mph (4.47 m/s) and an active data collection distance of 76.22 meters (see calculation below), scanning will last approximately **17 seconds**
- Given the horizontal sensor field of view (360°), the sensor rotation rate (10 Hz), and the estimated scanning time (17 seconds), the system will be able to achieve **full horizontal coverage** up to a range of 60 meters (sensor spec)
- Fulfillment of **DR 1.1** (>50m range) and **DR 1.2** (complete coverage) are feasible with current configuration



Assumptions:

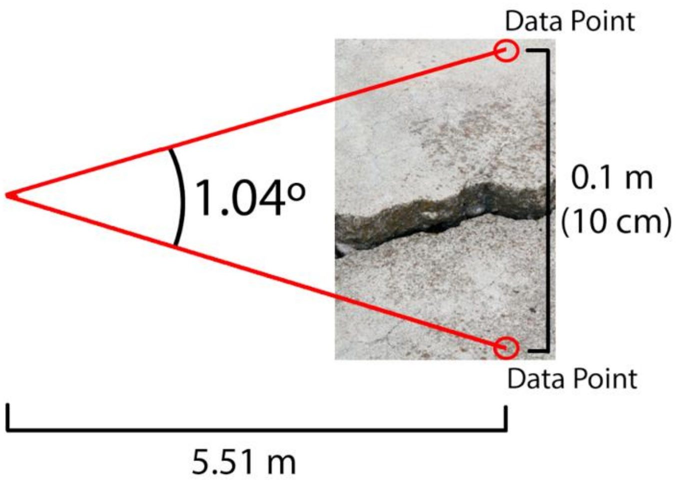
- Bridge height: 7 meters
- Bridge width: 40 meters
- LiDAR height above ground: 1.6 meters

Distance traversed before and after bridge

18.11 m + 18.11 m + 40 m = 76.22 m

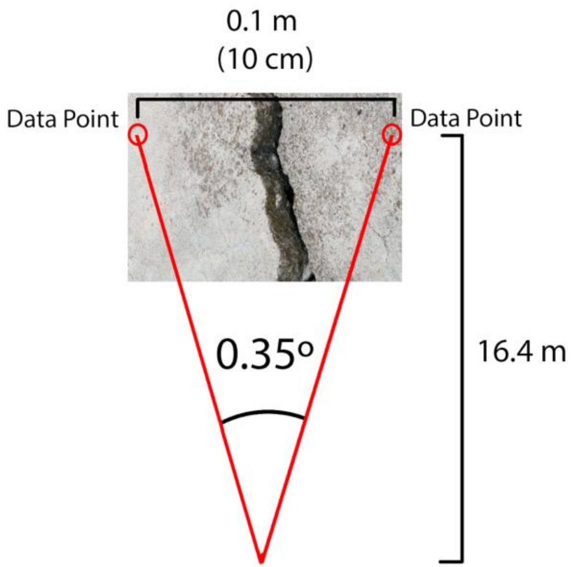
Distance traversed underneath bridge

LiDAR Feasibility: Vertical Point Spacing



- The OS1-32 (Gen 1) has 32 emitter/receiver pairs, or lasers, aligned on a vertical axis
- The LiDAR has a 33.2° vertical field of view (FOV)
- The associated angle between each laser and where it strikes the inspected surface is derived from dividing the vertical FOV by the number of lasers
- This calculation yields 1.04° of vertical spacing between consecutive measured points
- The resolution distance depends on the distance between the LiDAR and the infrastructure
    - To achieve **0.1 m of resolution**, the LiDAR must be **5.51 m** away from the measured point
- **DR 2.2** (resolution of <10 cm) is satisfied when within 5.51 m range

LiDAR Feasibility: Horizontal Point Spacing



- The OS1-32 (Gen 1) has 1024 horizontal channels (lasers)
- The LiDAR has 360° horizontal field of view (FOV)
- To determine the horizontal angular resolution, the FOV is divided by the number of horizontal channels
- This calculation results in a horizontal angular resolution of **0.35°**
- To achieve a horizontal resolution distance of 0.1 m, the LiDAR would have to be **16.4 m** away
- For a distance of 5.51 m away, the horizontal resolution would be **0.034 m**
- **DR 2.2** (resolution <10 cm) is satisfied when within 16.4 m range
  - Vertical resolution (within 5.51 m) is the limiting factor

Feasibility Analyses -- Communications Protocol

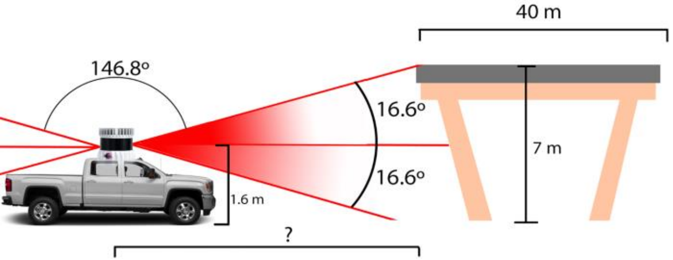
Governing Requirements

FR 8 — **The on-board communications unit shall be capable of wirelessly transferring point cloud and localization data directly to a designated headquarters**

- Customer-specified requirement
- Associated DRs (8.1, 8.2) address transmission range and upload speed

Feasibility Analyses -- Communications Protocol

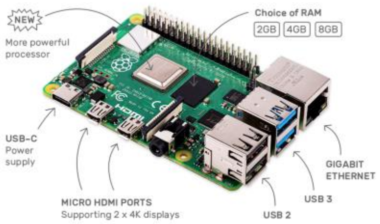
- At 5 mph and 76.22 m ~ 35s
- At 129 mbps and 35s = 4515 Mb ~ **0.56 GB**
- Data Packets will be 0.56 GB or less on average
- With a 5 Mbps upload speed it will take 15 minutes
- Google Drive offers 15 Gb of free storage (or Github)



Feasibility Analyses -- Communications Protocol

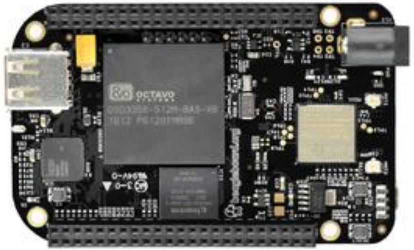
Single board processing units are a solution to data storage and transmission

- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless
- Micro-SD card slot for loading operating system and data storage
- Includes Gigabit Ethernet port which can connect to Ouster
- Feasibility Issue, board may not be able to accept throughput of 129 Mbps (16 MB/s)



Raspberry pi 4
~ $35

Arduino Uno WiFi REV2
~ $44.80



Beaglebone Black Wireless
~ $80

Feasibility Analyses -- Communications Protocol

Mini PCs are a solution to data storage and transmission

- Capable of integrating classic WiFi adapter card - Fast data rate capabilities.
- Can handle data throughput of 129 Mbps.
- Storage capabilities far exceed ~0.5 GB estimated file size.
- Can install common operating systems.
- Feasibility Issue, Costs will be ~ $400 which is much greater than single board computers.

Feasibility Analyses -- Power

FR 6

The system shall incorporate a power source that is capable of continuously supplying power to all applicable components.

- Customer-specified requirement
- Associated DRs (6.1, 6.2) address power requirements of project

Power Solutions for Lidar System

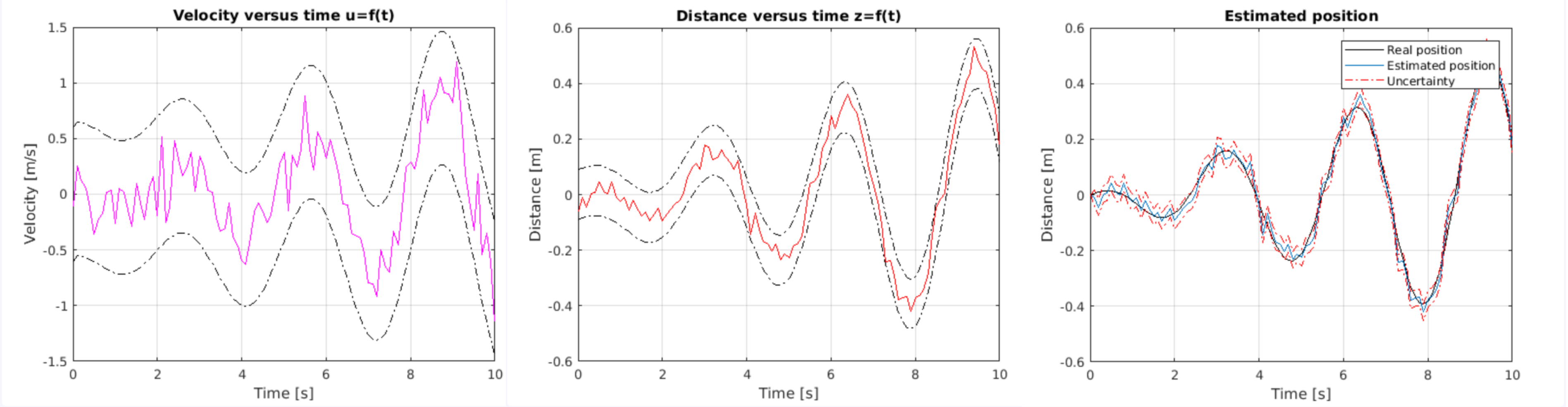
- External Power (from vehicle)
  - Routed from 12V DC power outlet
  - Or directly from Battery
- Advantages
  - Reduces project weight
  - Constant supply during operation
- Drawbacks
  - Inconsistent running voltage (8-14V)
  - PMS needed to regulate

- Internal Power (battery)
  - Li-Ion Battery within system
- Advantages
  - Versatility independent of vehicle
- Drawbacks
  - BMS needed to regulate power
  - Increases weight and complexity
  - Limited Supply

Status Summary: Structures

- Attachment mechanism determined
- Structural housing material and shape to be determined
  - Requires final parts list
  - Determine best configuration/layout
- Structural housing test protocol
  - Construct prototype
  - Fill with approximate weight of system and dummy camera
  - Walking tests: ensure secure structure
  - Driving tests: ensure secure mounting at increasing speeds to determine speed limit
  - Rigorous driving condition scenarios:
    - Sharp turns, steep incline/decline, breaking, etc.

Kalman Filter Example



Gantt Chart

ASTRA

FLASH LiDAR Senior Project

University of Colorado, Boulder

Company: ASTRA

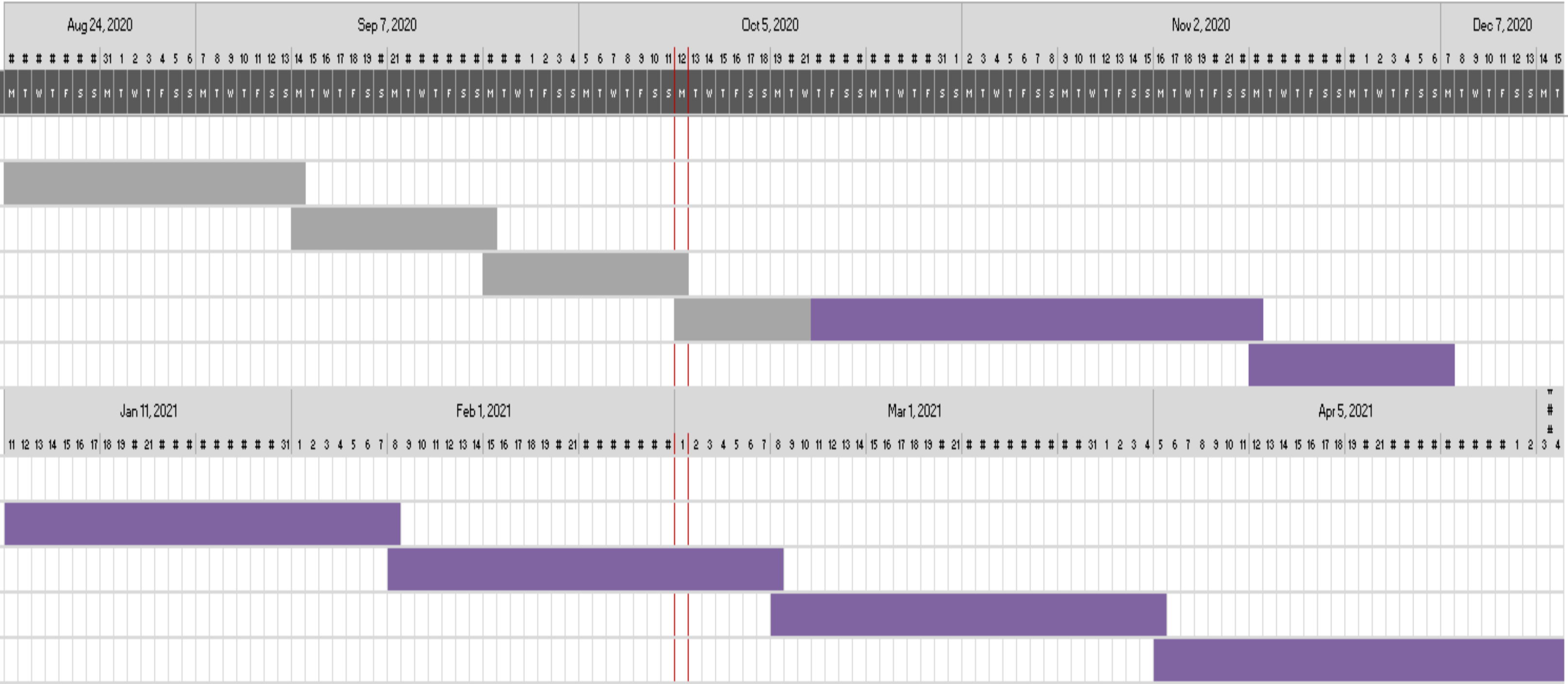
SIMPLE GANTT CHART by Vertex42.com

https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project Start: Mon, 8/24/2020

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Phase 1 Fall 2020				
PDD	All Members	100%	8/24/20	9/14/20
CDD	All Members	100%	9/14/20	9/28/20
PDR	All Members	100%	9/28/20	10/12/20
CDR	All Members	25%	10/12/20	11/23/20
FRR	All Members	0%	11/23/20	12/7/20
Project Start:	Mon, 1/11/2021			
Phase 2 Spring 2020				
MSR	All Members	0%	1/11/21	2/8/21
TRR	All Members	0%	2/8/21	3/8/21
SFR	All Members	0%	3/8/21	4/5/21
PFR	All Members	0%	4/5/21	5/3/21



Team Organization

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