Motivation

Connected Vehicle applications require roadway feature representation and reference in the form of a map

What is a Connected Vehicle(CV) Application ?

CV applications enable enhanced safety, reduces emission, and greater mobility using map referenced location and short range communication and between vehicles and roadway infrastructure

- **FHWA estimates there are 300,000 signalized intersections in the US**
  - **Intersection models are detailed**
  - **Intersections are complex**

- **Manual survey and model construction would be prohibitively expensive**
- **Sensor based surveys are well underway, with largely manual feature extraction**
- **Sensor based surveys with automatic feature extraction is in its infancy**

Tasks and Schedule

Task 1: Mapping Methodology Assessment

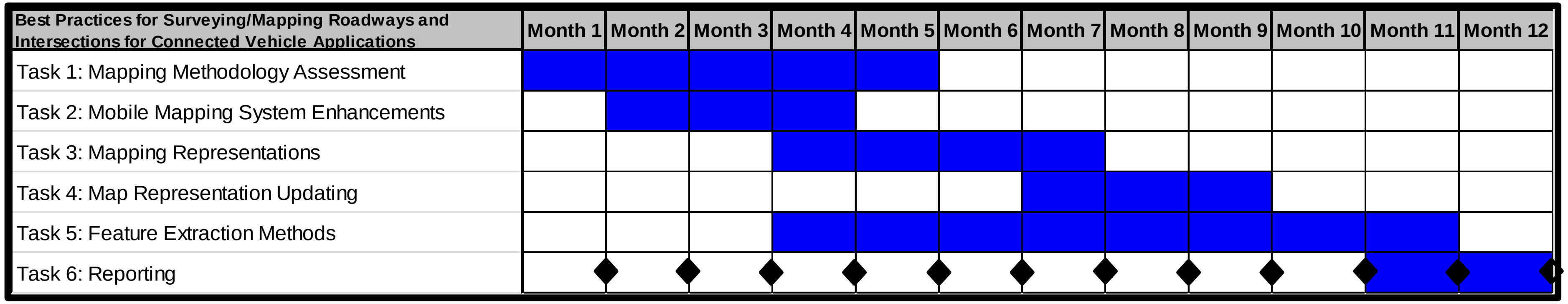
Task 2: Mobile Mapping System Enhancements

Task 3: Mapping Representations

Task 4: Map Representation Updating

Task 5: Feature Extraction Methods

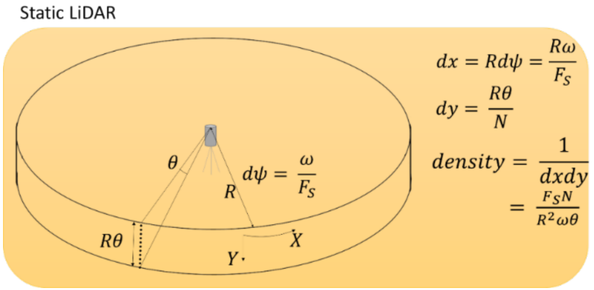
Task 6: Reporting

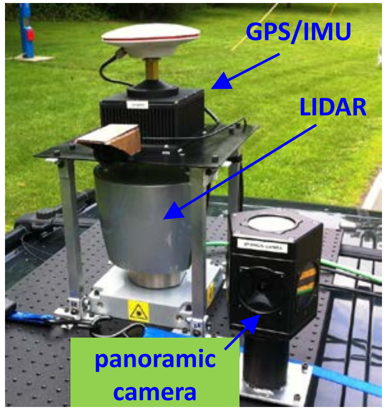


Task 1: Mapping Methodology Assessment

Summary:

- **Objectives:**
  - Interviewing People in mapping field to study current technology
  - Recommendation of Mapping Methodology
- **Implementations:**
  - Interviewed people from different educational institute and business company and visiting one research laboratory
  - Performing comparative study in different Lidar technology(STLS, MTLS, ALS) and recommending MTLS method as the most suitable one
  - Information about MTLS Process, Instruments, Software
  - CV Applications: Features and Accuracy Requirements
  - Overview of recent business model





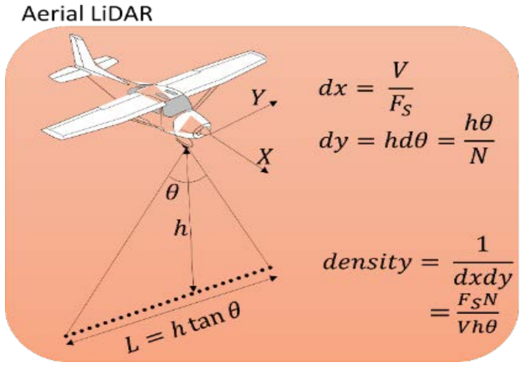


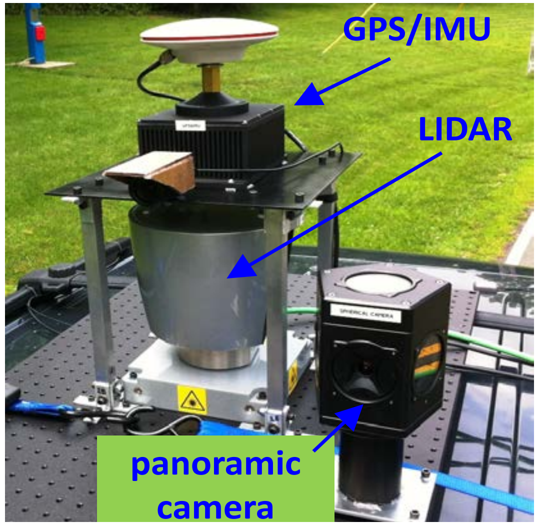
Table: Comparative Study of Different Mapping Technology

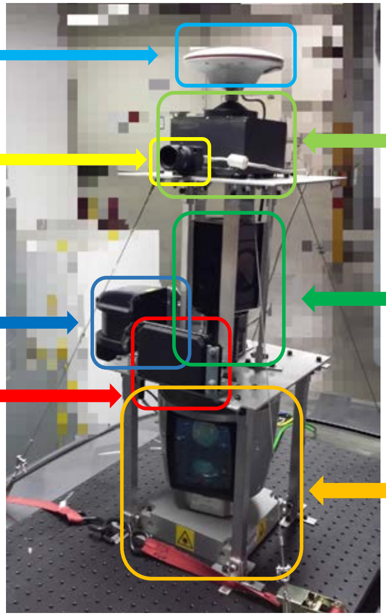
Technology	Accuracy (m/cm/sub meter level)	Feature Detection Capability(Road sign, markings, stop bars)	Coverage		Point Density
			Volume of Data	Feasibility of Map Development	
INS	N/A	No		×	
GNSS	cm	No		×	
Camera	N/A			×	
LiDAR	N/A			×	
STLS	cm	Yes	75m × 75m	×	High
MTLS	cm	Yes	100m × Trajectory length	√	High
ALS	sub meter	Yes	150m × Trajectory length	×	Low
Crowd Source Data	m	Inferred	Full road	Detecting Map Updates	N/A

Task 2: Mobile Mapping System Enhancements

Summary:

- **Objectives:**
  - Mobile Positioning and Mapping System enhancement
  - Data Collection Procedure Enhancement
- **Implementations:**
  - Hardware architecture aligned along vertical axis with sensor offset calibration
  - Streamlined software data collection sequence and improved data formatting
  - Improved wiring and sensor connections
  - Enhanced data collection procedures
  - Improved data integration
  - Improved base station interoperability utilizing CORS/NTRIP





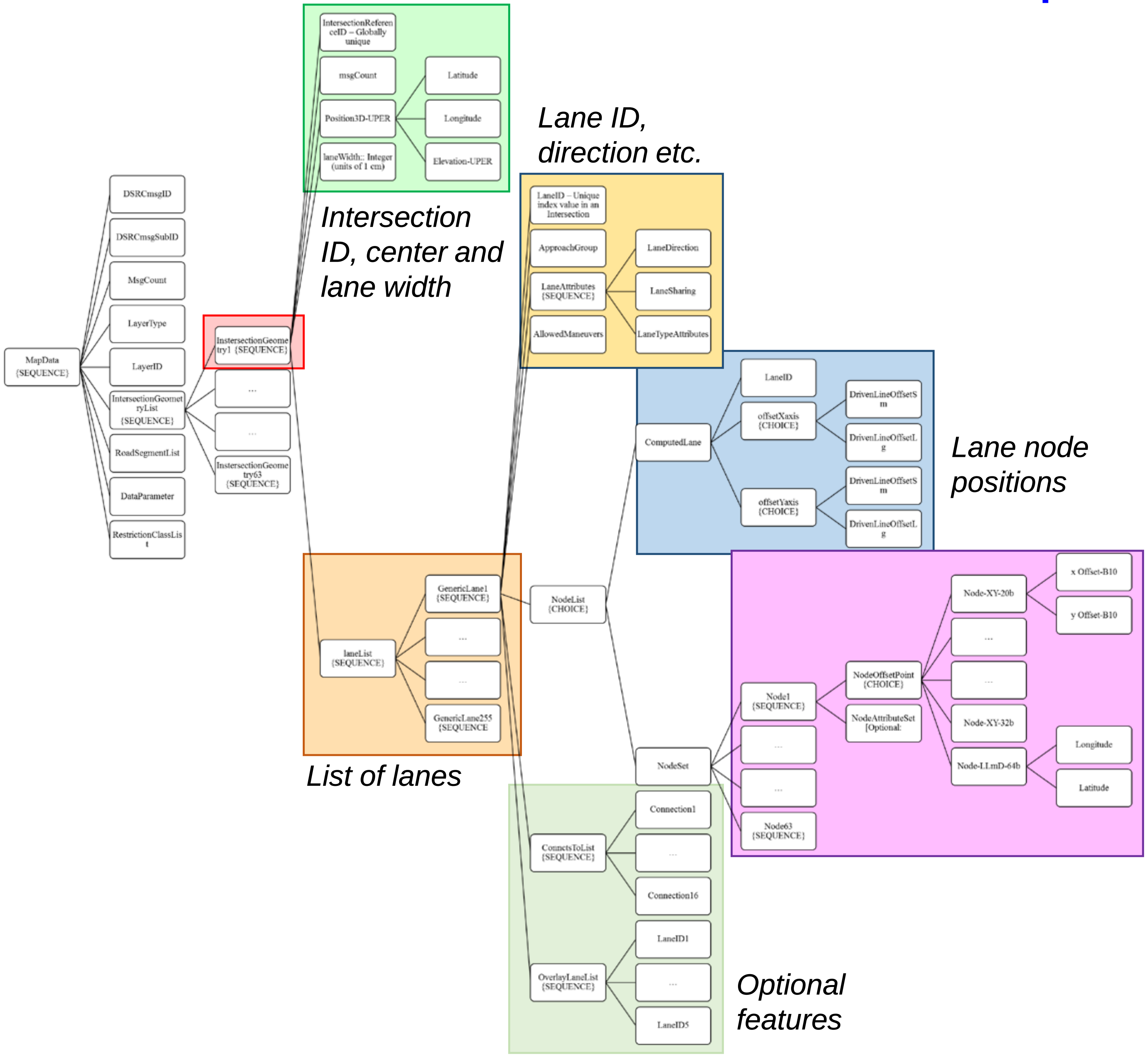
Task 3: Map Representations

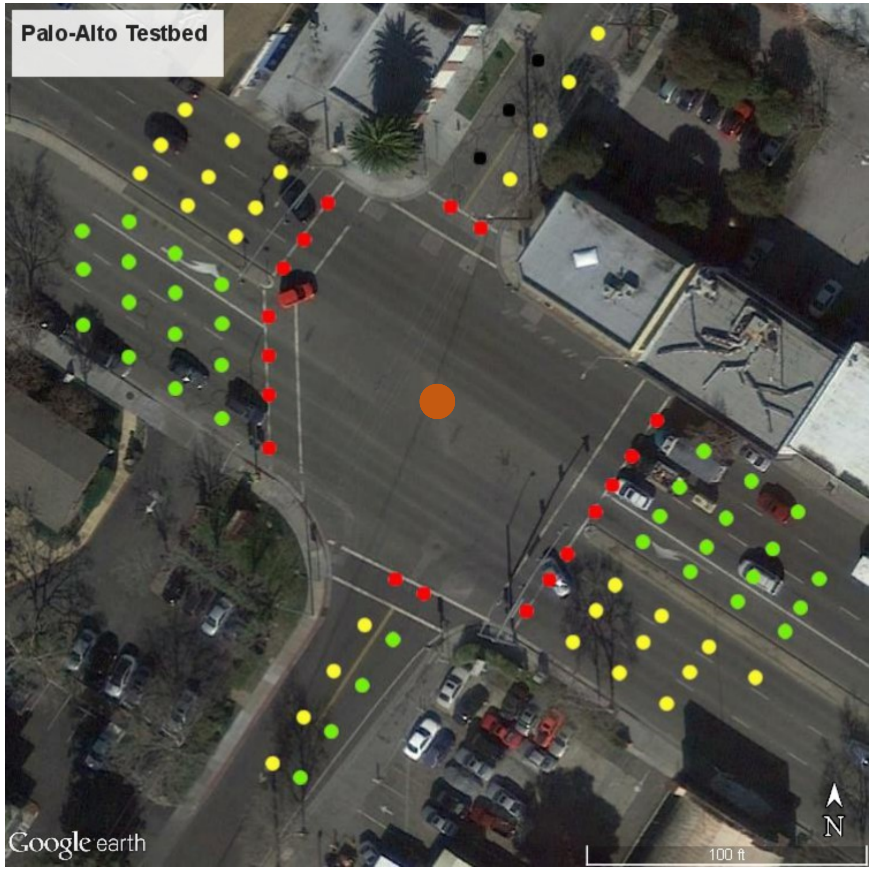
Summary:

- **Objectives:**
  - To assess map representations that have spatial continuity, automaker uniformity, concise, transmittable and updatable.

- **Conclusions:**
  - For commercial success, a single global database is required with uniform contents, accuracy and behavior across geographic boundaries, infrastructure and auto manufacturers.
  - SAE J2735 currently is the only format suitable for mapping roadways as it can convey both intersection geometry maps and dynamic information (SPAT).
    - All CV demos to date have found J2735 incomplete, lacking features and modified it to fit their purpose.
    - The SAE committee is monitoring the issues and taking action to make it a complete mapping standard.

Overview of J2735 Map Data





Orange Node: Intersection center
Red Nodes: Stop bar position
Green Nodes: Ingress node positions
Yellow Nodes: Egress node positions
Black Nodes: Nodes with undecidable direction

Task 4: Map Representation Updating

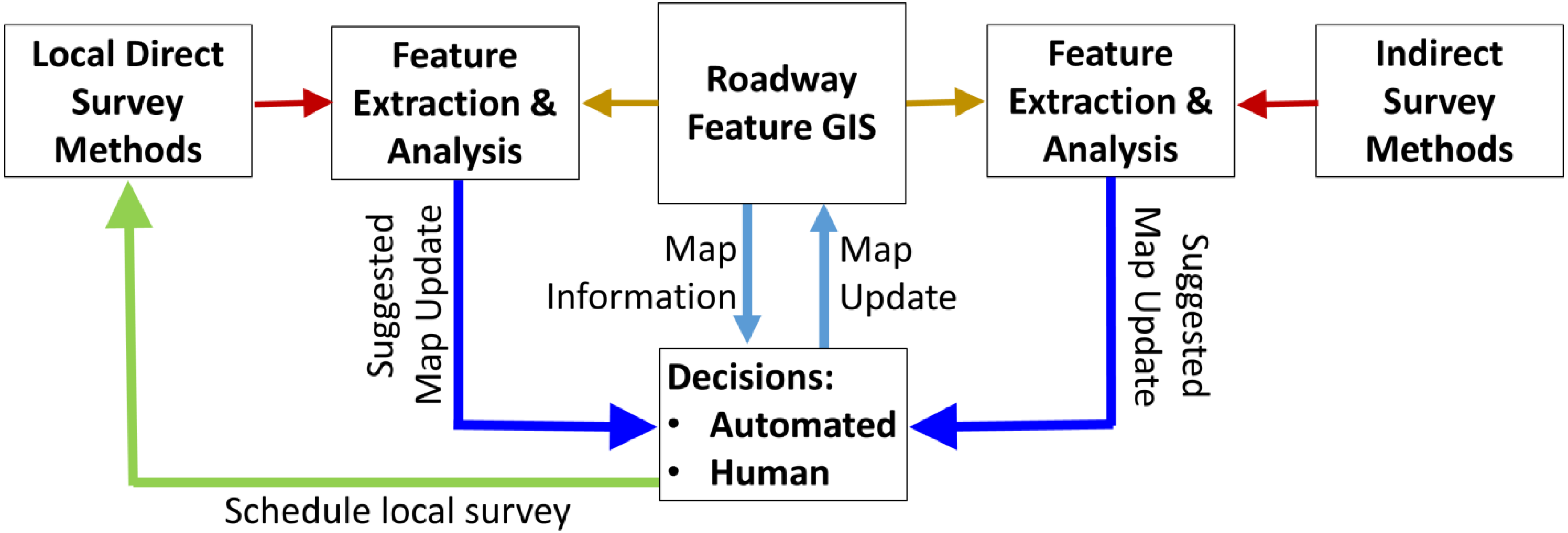
Summary:

- **Objectives:**
  - To assess methods to detect and trigger the map updates
  - To assess methods to integrate local map updates into the map database efficiently while maintaining spatial continuity
  - To assess methods to ensure data integrity if map updates are obtained from different sources
- **Primary Methods:**
  - *Direct:* Involves direct detection and calibration of roadway feature locations by MTLS
    - Pros: Data have a high-level of integrity and accuracy
    - Cons: Data collection can be expensive and time consuming
  - *Inferred (e.g. Crowd sourcing):*
    - Accumulation of sensor trajectory data from the millions of connected vehicles and/or users driving on the nations roadways
    - Mainly useful to prompt detection of changes to the roadway infrastructure

Task 4: Map Representation Updating

Recommendations:

1. Use crowd-sourcing to detect needed updates
2. Use MTLS to ensure the integrity of data



Task 5: Feature Extraction

Summary:

- **Objective:** Automated extraction of J2735 map message meta data from road way features:
  - Longitudinal features (e.g. Stop bar)
  - Lateral features (e.g. Lane edges)
- **Primary steps:**
  1. *Preprocessing*: extract the georectified point cloud and associated MPMS trajectory portions relevant to an intersection of interest
  2. *Road surface extraction*: Extract points belonging to the surface of the road where features of interest are located
  3. *Mapping of 3D point cloud to 2D image*: makes images processing tools applicable to data
  4. *Map message metadata extraction*: Automatically extract map message data (lane and stop bar node locations) and metadata (e.g., number of lanes, ingress or egress)
  5. *ECEF Map definition*: Translate metadata from pixel coordinate to world coordinates

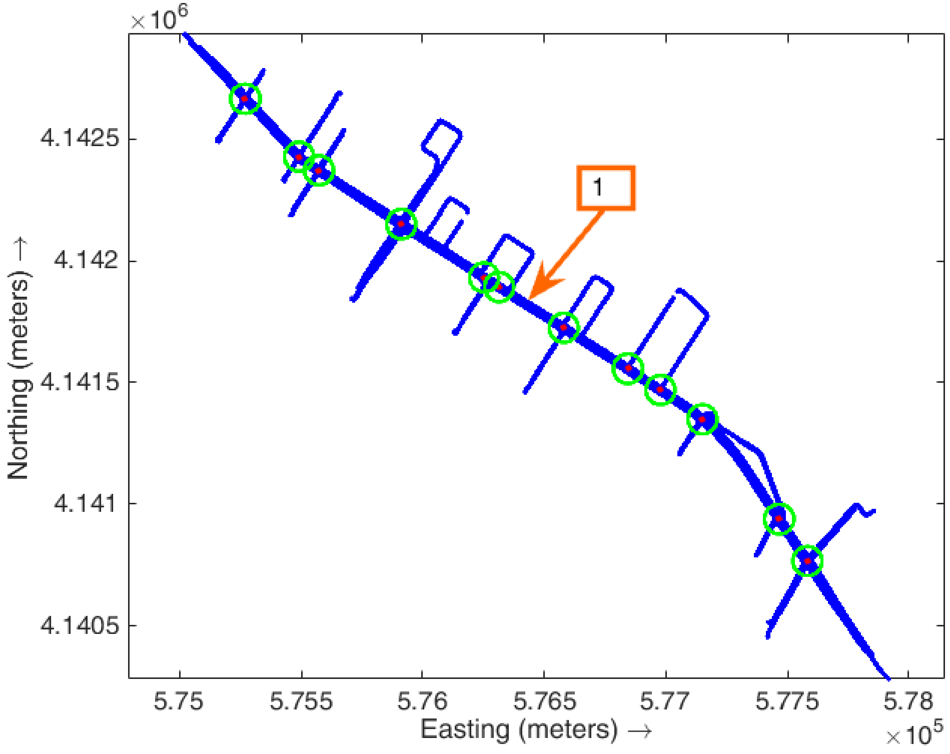
Task 5: Feature Extraction

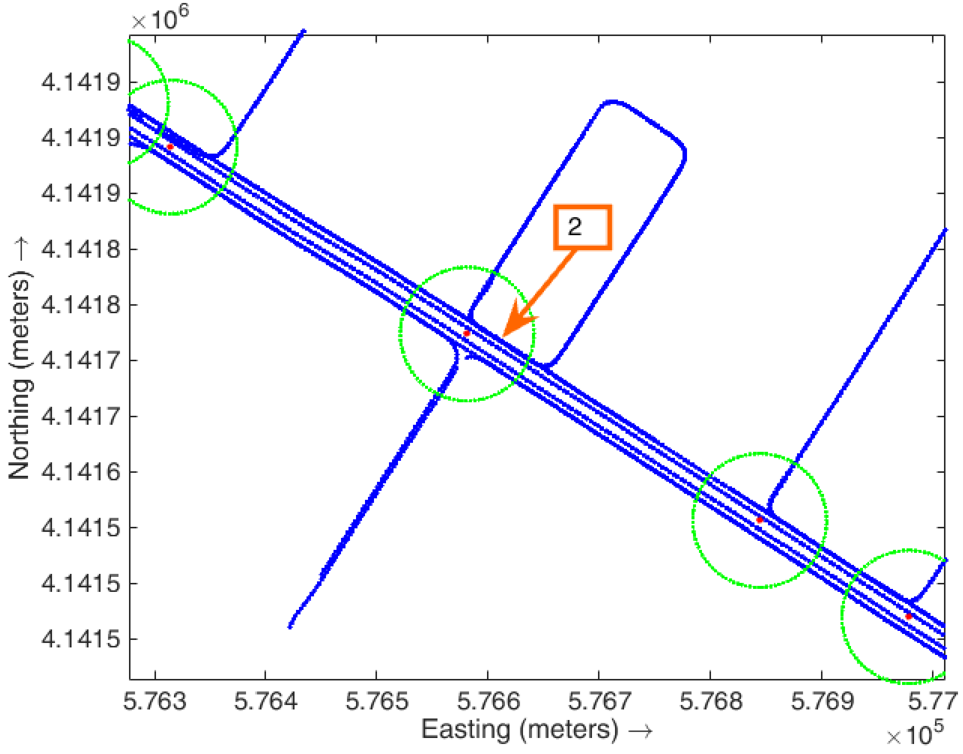
Automation Level

Step	Function	Automation level
1	Preprocessing	Semi-automated; Some intersections need human involvement due to non-standard/complex geometry
2	Road Edge Detection	Semi-automated; Algorithm fails for some road segments due to non-standard/complex road geometry
3	Road surface extraction	Intensity threshold parameter are tuned for different road segments
4	Mapping of 3D point cloud to 2D image	Automated
5	Map message metadata extraction	Semi-automated; Some parameters are tuned for different intersections when needed to improve performance
6	2D to 3D translation of map metadata	Automated

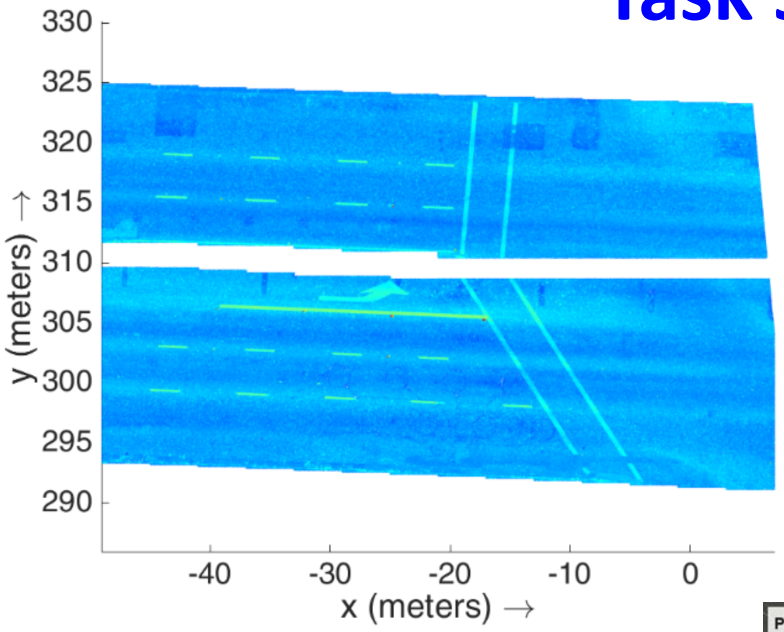
Task 5: Feature Extraction

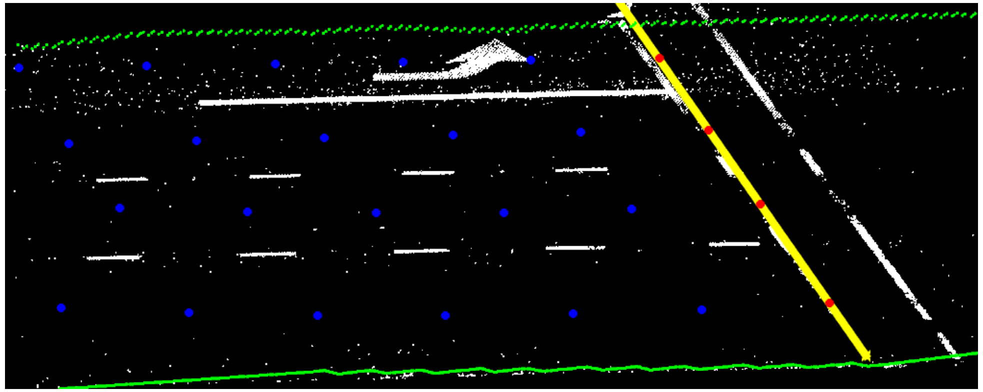
Preprocessing





Task 5: Feature Extraction





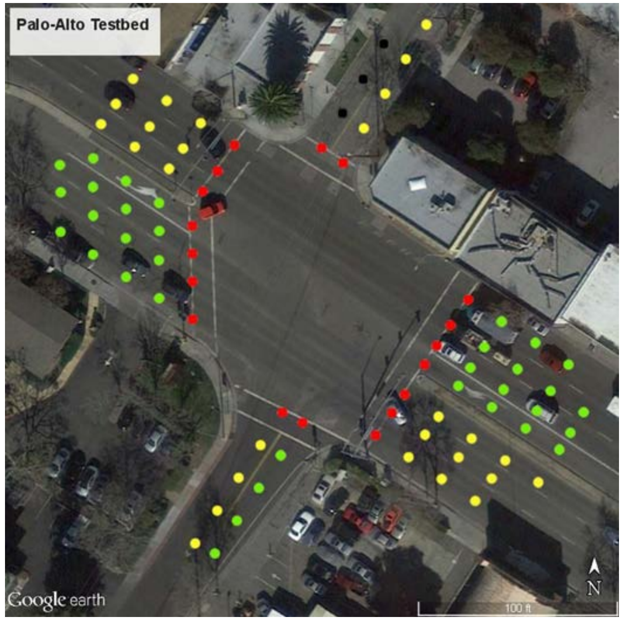


Table: Performance Analysis of Extracting J2735 Map Message

Intersection No	Intersection Type(Standard cross, Standard T, Non-standard)	Performance Analysis								Remarks (Depicting the reason of automation process failed)
		Road Edge Detection	Ingress Branch			Egress Branch			Ingress or Egress Branch Without Marking	
			Surface Detection	Lane Edge Detection	Stop Bar Detection	Surface Detection	Lane Edge Detection	Stop Bar Detection		
1	Standard cross	8 of 8	100 %	13 of 11	4 of 4	100 %	8 of 8	4 of 4	2 of 2	2 bike lanes were detected in addition to traffic lanes
2	Non- Standard cross	8 of 8	100 %	11 of 11	4 of 4	100 %	8 of 8	4 of 4		1 stop bar line has been detected and mapped at the wrong line of the pedestrian cross walk
3	Non- Standard cross	8 of 8	100 %	11 of 11	4 of 4	100 %	8 of 8	4 of 4		1 ingress lane was detected but could not be classified as ingress
4	Non- Standard cross	7 of 8	100 %	9 of 20	2 of 4	100 %	5 of 11	2 of 4		2 road segments (both ingress and egress) could not be processed due to the non-standard road geometry and faded lane striping.

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		Road Edge Detection	Ingress Branch			Egress Branch			Ingress or Egress Branch Without Marking	
			Surface Detection	Lane Edge Detection	Stop Bar Detection	Surface Detection	Lane Edge Detection	Stop Bar Detection		
5(a)	Non-standard T	6 of 6	100 %	8 of 8	3 of 3	100 %	7 of 7	2 of 3	2 of 2	• 1 ingress lane could not be identified because there was no road painting. • One stop bar has been detected manually because stop bar marking was absent.
5(b)	Non- Standard T	6 of 6	100 %	9 of 9	3 of 3	100 %	7 of 7	2 of 3		• 1 ingress lane could not be classified because there was no trajectory information. • One stop bar has been detected manually because stop bar marking was absent.
6	Non- Standard T	6 of 6	100 %	10 of 10	3 of 3	100 %	8 of 8	3 of 3		• 1 misplaced stop bar is expected to be fixable in future efforts.

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Intersection No	Intersection Type(Standard cross, Standard T, Non-standard)	Performance Analysis								Remarks (Depicting the reason of automation process failure)
		Road Edge Detection	Ingress Branch			Egress Branch			Ingress or Egress Branch Without Marking	
			Surface Detection	Lane Edge Detection	Stop Bar Detection	Surface Detection	Lane Edge Detection	Stop Bar Detection		
7	Standard T shaped	7 of 8	100 %	9 of 9	3 of 3	100 %	7 of 7	2 of 3	2 of 2	• 1 ingress lane could not be identified because there was no road painting. • One stop bar has been detected manually because stop bar marking was absent. • 1 misplaced stop bar is expected to be fixable in future efforts.
8	standard T	6 of 6	100 %	9 of 9	3 of 3	100 %	7 of 7	2 of 3		• The absence of the painted stop bar on the road surface causes human interaction for that stop bar • 1 egress lane could not be classified because there was no trajectory information.

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		Road Edge Detection	Ingress Branch			Egress Branch			Ingress or Egress Branch Without Marking	
			Surface Detection	Lane Edge Detection	Stop Bar Detection	Surface Detection	Lane Edge Detection	Stop Bar Detection		
9	Non- Standard cross	4 of 8	100 %	6 of 13	2 of 4	100 %	4 of 8	2 of 4		• 2 road segments (both ingress and egress) could not be processed due to the non-standard road geometry. • 1 ingress lane could not be identified because there was no trajectory information
10	Non- Standard cross	6 of 8	100 %	9 of 11	3 of 4	100 %	7 of 9	3 of 4		• 2 road segments (both ingress and egress) could not be processed due to the non-standard road geometry.
11	Standard cross	8 of 8	100 %	4 of 14	1 of 4	100 %	0 of 9	0 of 4		• 2 road segments (both ingress and egress) could not be processed due to the non-standard road geometry.

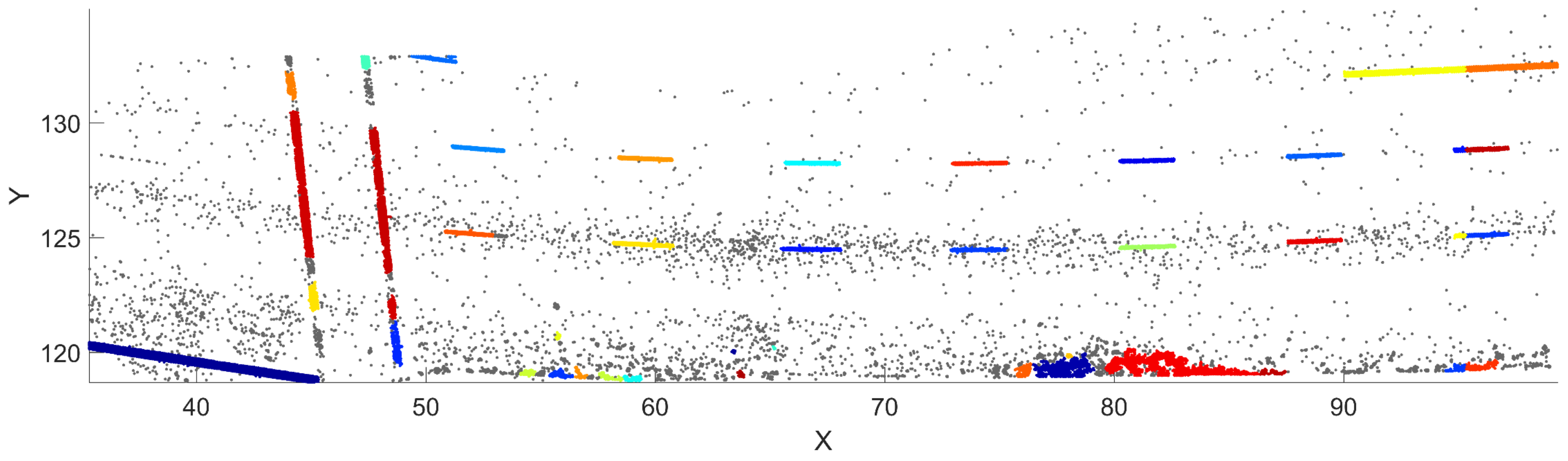
Extended Research: Enhanced Automation

Summary:

- **Objective:** Extract map message metadata directly from point cloud to preserve the accuracy of point cloud.
- **Primary steps:**
  - *Outlier Removal:* Outliers on the surface of the road point cloud are identified and removed based on intensity threshold techniques
  - *Cluster Analysis*: The point cloud is clustered using graph-based clustering techniques
  - *Feature Classification*: Clusters are classified based on topology, orientation and other characteristics and merged into features of interest
  - *Map message metadata extraction*: Map message metadata is automatically extracted from features

Extended Research: Enhanced Automation

- Automated local threshold selection
- Automated cluster (lane marker) detection based on intensity and distance based clustering



Future Research Recommendations

- Algorithmic Improvements:
  - Improve robustness
  - Enhance automation
  - Additional roadway map features
- Hierarchical map representations incorporating: intersections, roadways, ramps, highways
- Integrate crowd-sourced information and MTLS
  - Detecting need for map updating
  - Merging Data from diverse sources
  - Maintaining consistency of data across map layers and geographic boundaries
- Improve understanding of positioning requirements for CV and AV applications
- Collaborations with CV demos and testbeds involving mapping
- Enhancement of mapping data standards and methods