Innovative Approaches for Next Generation Roadway Mapping and Vehicle Positioning

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Outline:

- Big picture: Positioning and Mapping
- FHWA Project: Precision Mapping: Objectives & Approach
- FHWA Exploratory Advanced Research Project in Precise Vehicle Positioning: Objectives & Approach
- Latest Results and Applications
- Interesting Directions

Mapping and Positioning Research to Support Lane-Level ITS Applications

Objectives:

- To analyze mapping and positioning technologies:
  - Automated and sensor-based for low-cost map production
  - High precision for next-generation (lane-level) applications (Lane Departure Warning, Curve Overspeed Warning, Signal Phase and Timing, by lane, Intersection management and collision avoidance, etc.)
  - Most precise mapping and positioning for ITS research is based on relative coordinates rather than absolute coordinates

Such applications are transformative improvements for safety, mobility, and environmental performance

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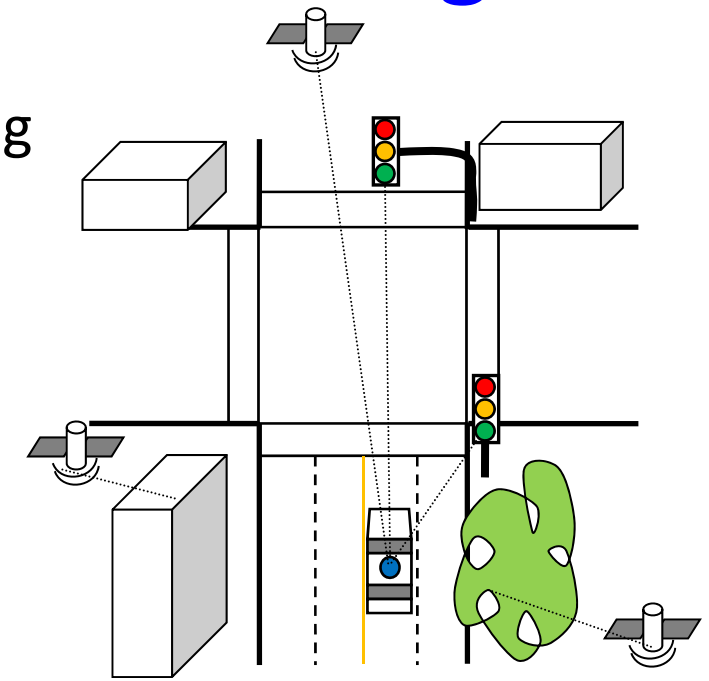
Precision Real-time Positioning

- Many ITS Applications need Positioning with high degrees of:
  - ***Accuracy*** – Less than one meter
  - ***Continuity*** – High sample rate
  - ***Availability*** – Works in diverse environments
  - Accomplished at a ***Low Cost***
- Solution: Sensor Fusion using
  - Inertial Measurement Unit
  - Differential GPS
  - Feature sensors: RADAR, LIDAR, Camera
  - Existing Infrastructure



ITS *Safety* Example Applications:
lane-departure warning, freeway merge assistance, intersection collision avoidance, curve over-speed warning

ITS *Mobility* Example Applications:
vehicle navigation assistance, congestion warning systems, adaptive cruise control, and parking assistance

Aiding Sensor Categories

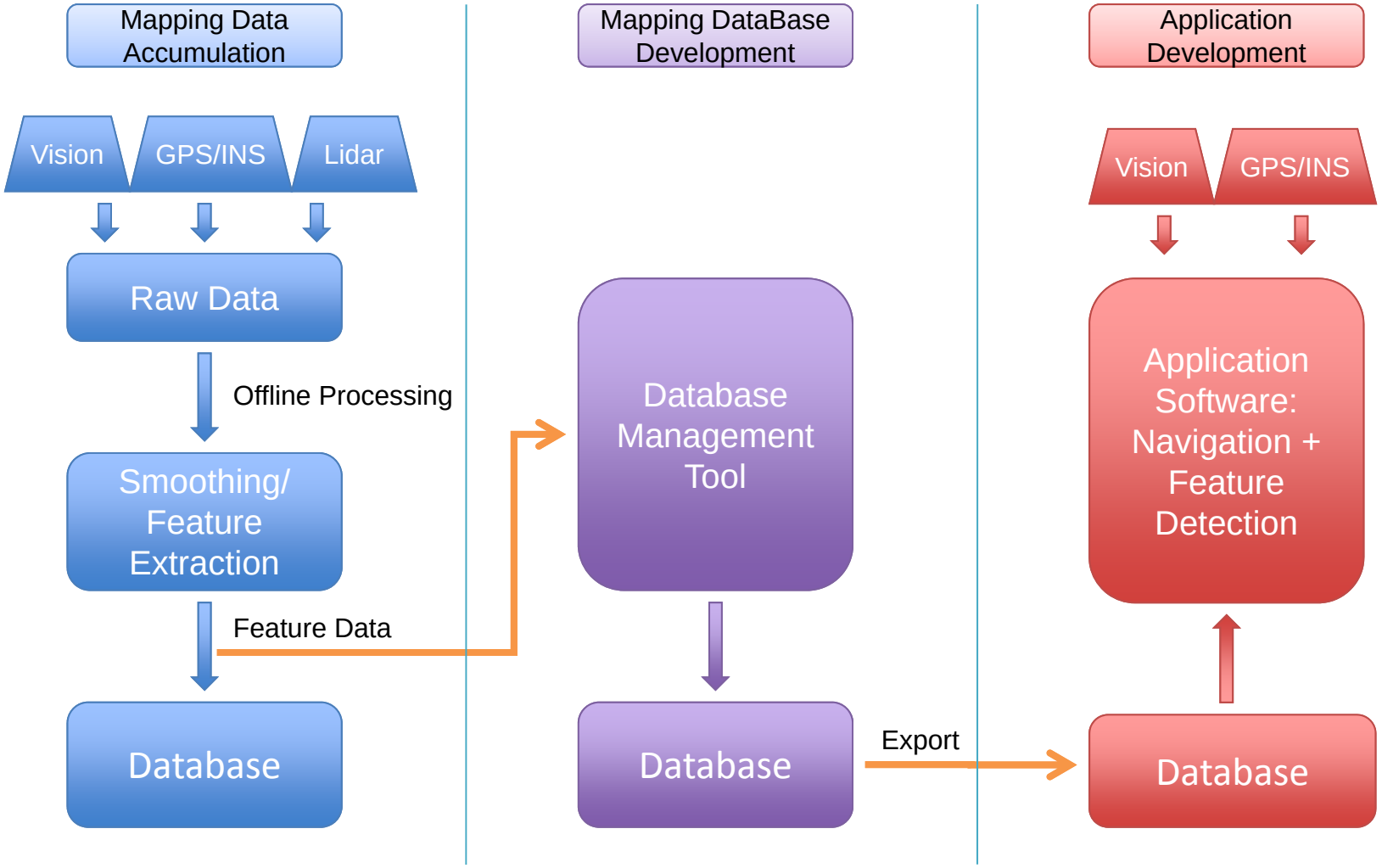
	Technology	Principle	Range Accuracy	Veh. Cost	Rdwy. Cost	Req'd Advances
	GPS	TOA	10 m	Low	Bases, comms	Modernization
	DGPS		1 m	Low	Bases, comms	Modernization
	CPDGPS		0.01 m	High	Bases, comms	Modernization
	Pseudolites	TOA, TDOA	0.01 m	Med	High	> First generation
Terrestrial Radio Navigation	-- Cell Phone	RSSI	km's	Low	Existing	
	-- Cell Phone	TOA, TDOA	100's m	Low	Existing	Physical layer timing
	-- TV - digital	TOA	10's m	??	Bases, comms	??
	-- Radio AM Analog	TOA	10's m	Low	Existing	??
	-- Radio FM Analog	TOA	??	Low	Existing	??
	-- Radio Digital	TOA	??	Low	Existing	??
	-- Packet Radios	TOA, TDOA	km's	Low	High	Physical layer timing
Feature Based	Vision	AOA		Low-Med	Feature Mapping	Feature Robustness
	Radar	AOA, RTOA	0.1 m	Low-Med	Feature Mapping	Feature Robustness
	Lidar	AOA, RTOA	0.01 m	High	Feature Mapping	Feature Robustness

GNSS: Proven with open skies. Challenging in urban environments.

TRN: Shows great promise as physical layer timing advances

FB: Assessed as viable *if precision roadway feature maps are available*. Research leading FB positioning demonstrations was the project focus after year one.

Precision Mapping & Real-time Positioning



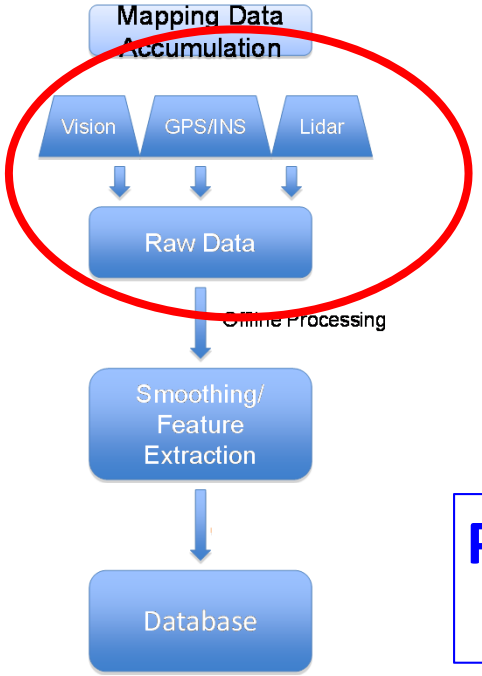
Feature based positioning and ITS application performance are enabled and enhanced by precise roadway feature maps.

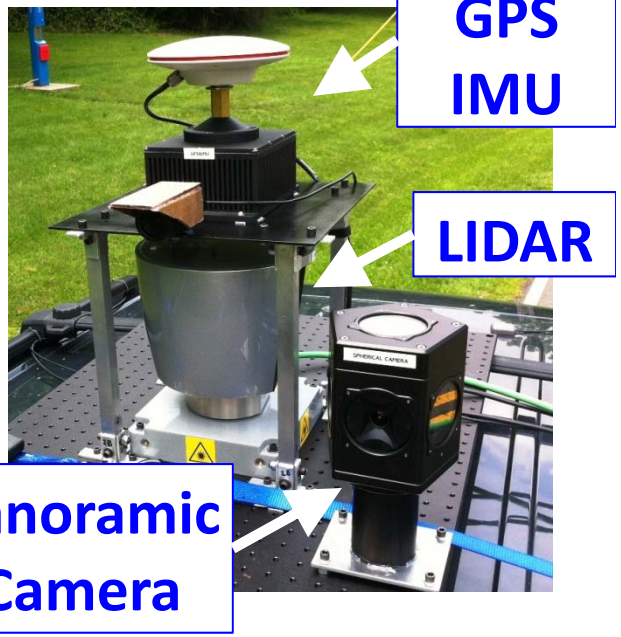
Precise Roadway Feature Maps

- **Analyze, develop, & demonstrate roadway feature mapping technologies:**
  - **Automated and sensor-based for low-cost map production**
  - **High precision (decimeter) for next-generation applications**
    - **Lane departure warning**
    - **Curve overspeed warning**
    - **Headlight steering into curves**
    - **Signal Phase and Timing by lane**
    - **Intersection management and collision avoidance**

  Such applications are transformative improvements for safety, mobility, and environmental performance
- **Roadway features: Road & lane edges, Sign type & location, Street and stop lights, stop bars, …**

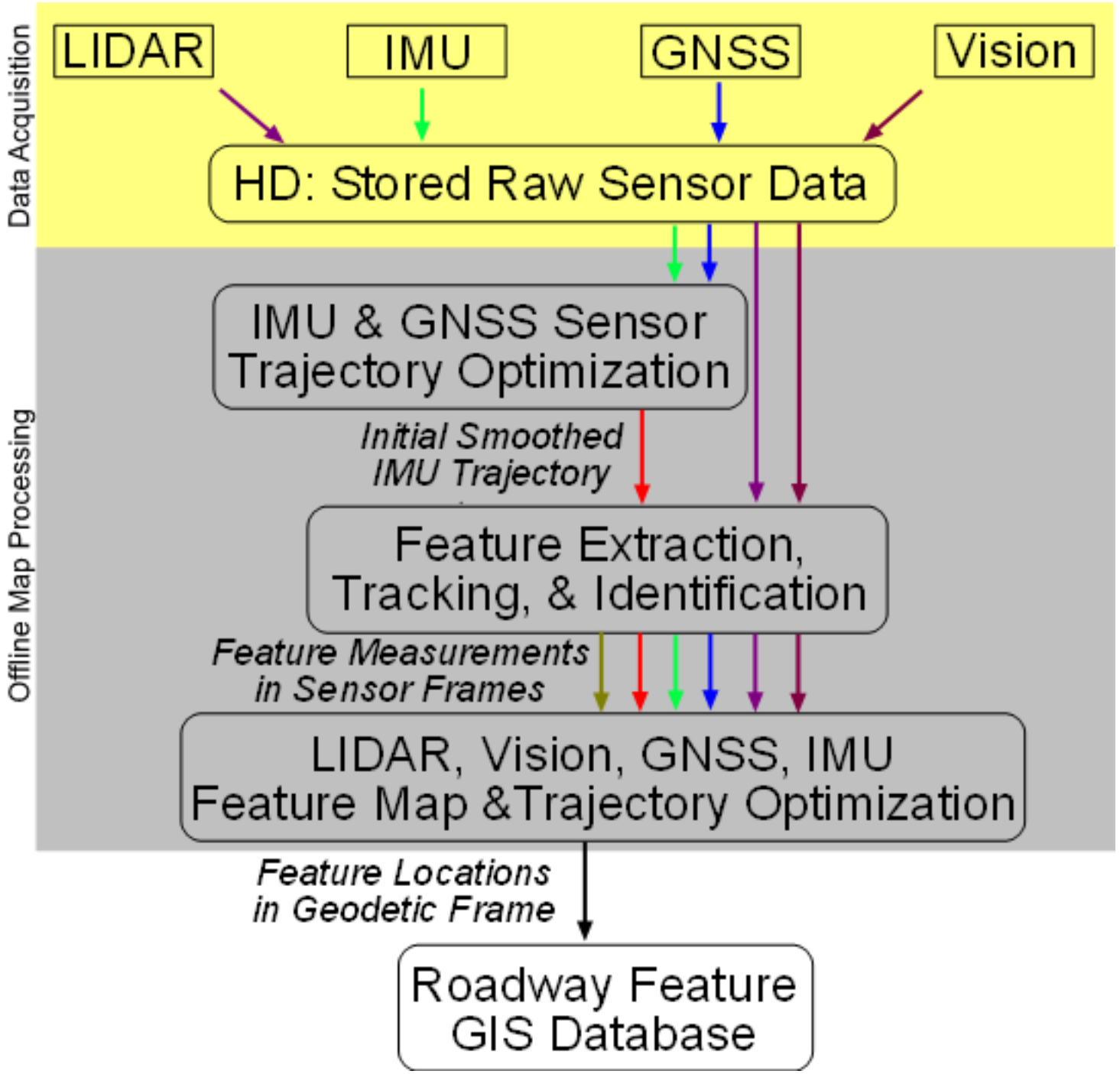
Precision Roadway Map: Data Acquisition





Sensor	Bytes/Msg.	Msgs./sec	Bytes/Sec	GB/Hr	GB/Hr (with timestamp overhead)
IMU	19	200	3800	0.013	0.232
LIDAR	1206	3473	4,188,438	15.08	15.278
Camera	35,836,416	7.5	268,773,120	967.583232	967.583
GPS measurement data	612	1	612	0.002	0.0374
GPS Ephemeris data	256	.002	.512	1.8432e-6	3.13344e-5
DGPS data	1071	1	1071	0.0038	0.0039
		Total:	273 MB /sec	982 GB/Hr	983 GB/Hr
		Hrs. of collection per TB:			≈1 Hr.
		Miles of coverage per TB (assuming a speed of 30 mph):			≈30 miles

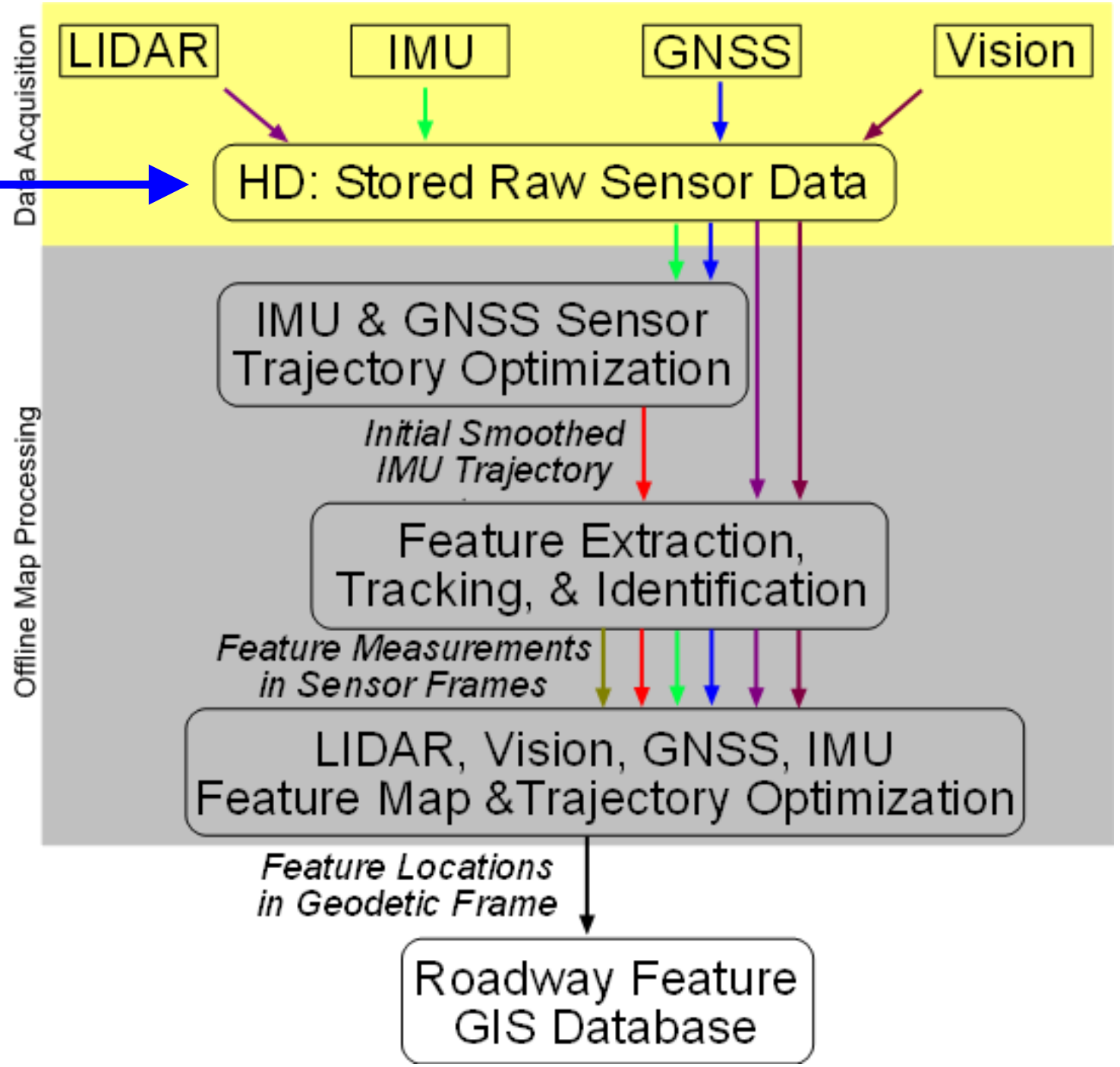
Mapping Process



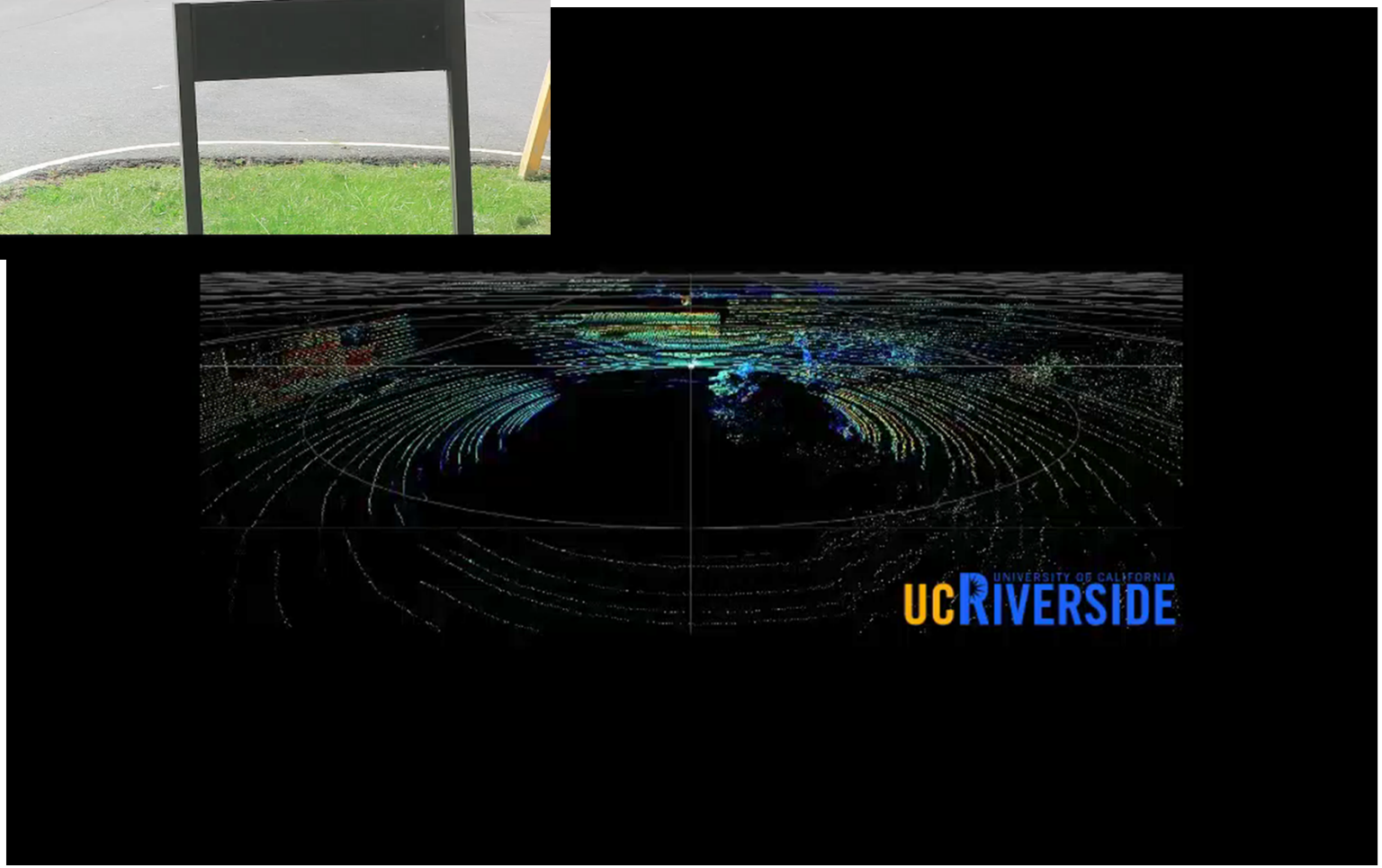
Equipment:

- LIDAR
- Camera set
- IMU
- GNSS Receiver
- High capacity HD
- Roof Platform
- Power supply
- Matlab
- DGPS station
- Data Communication
- GIS
- High Performance CPU

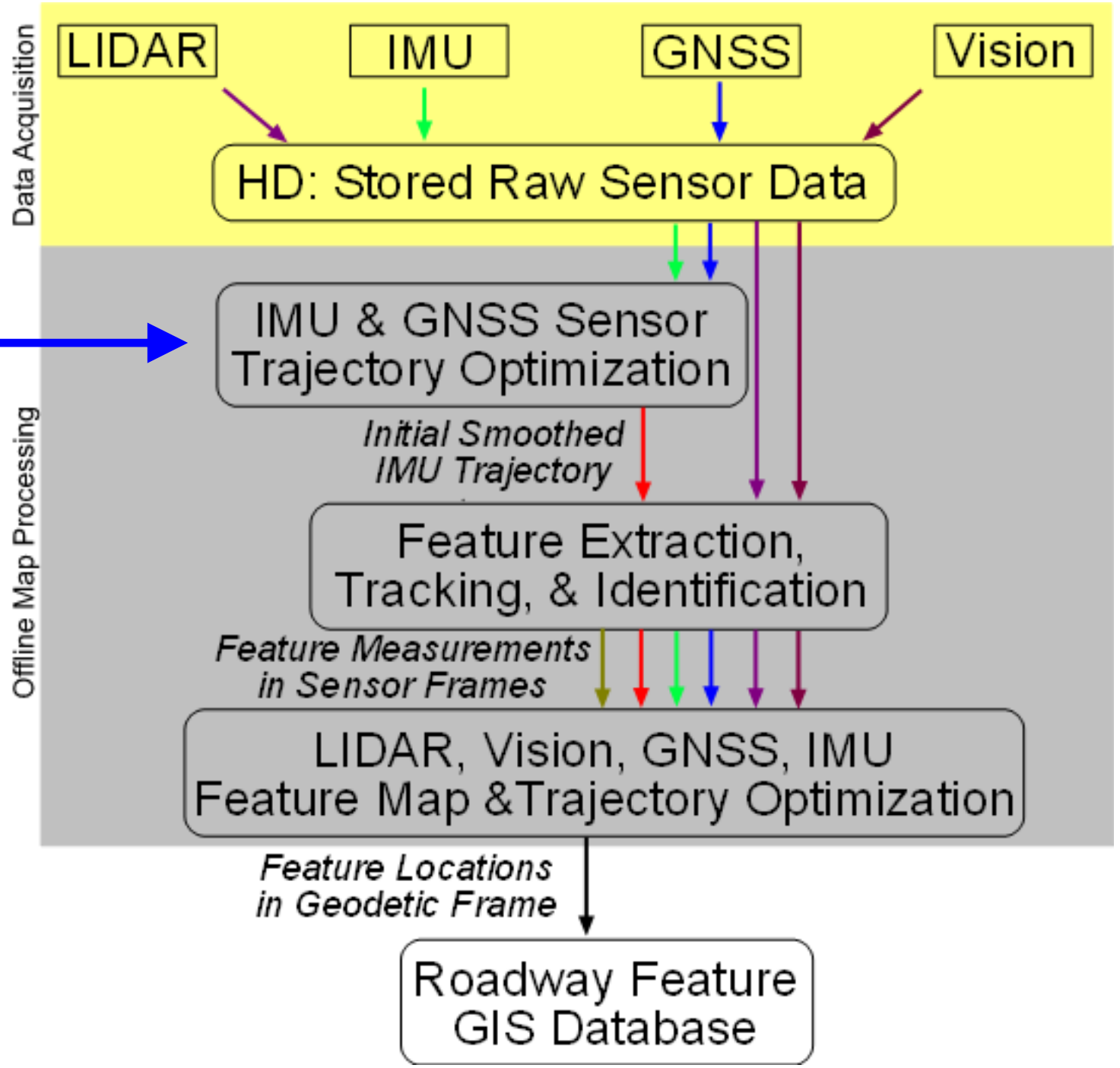
Vehicle is driven and data are collected



Driving and data collection …

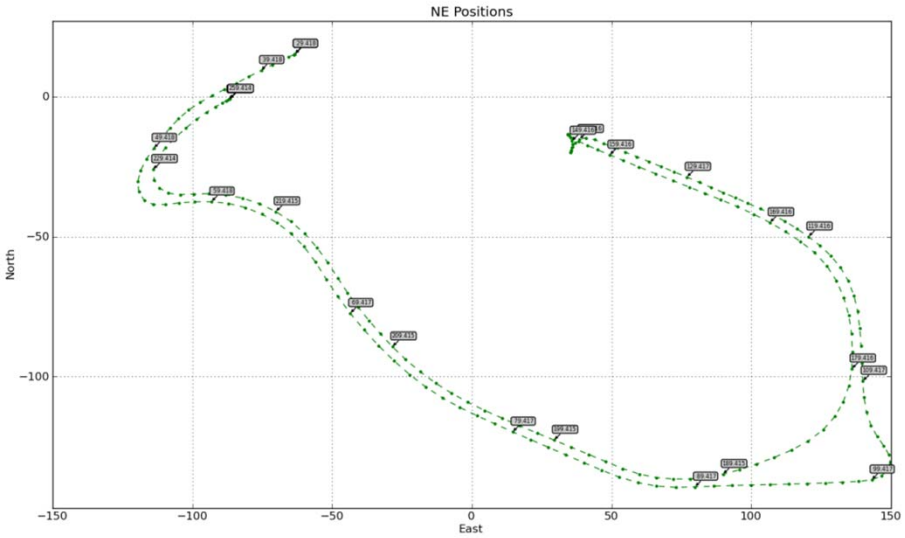


IMU and GPS data are smoothed providing a continuous smooth trajectory

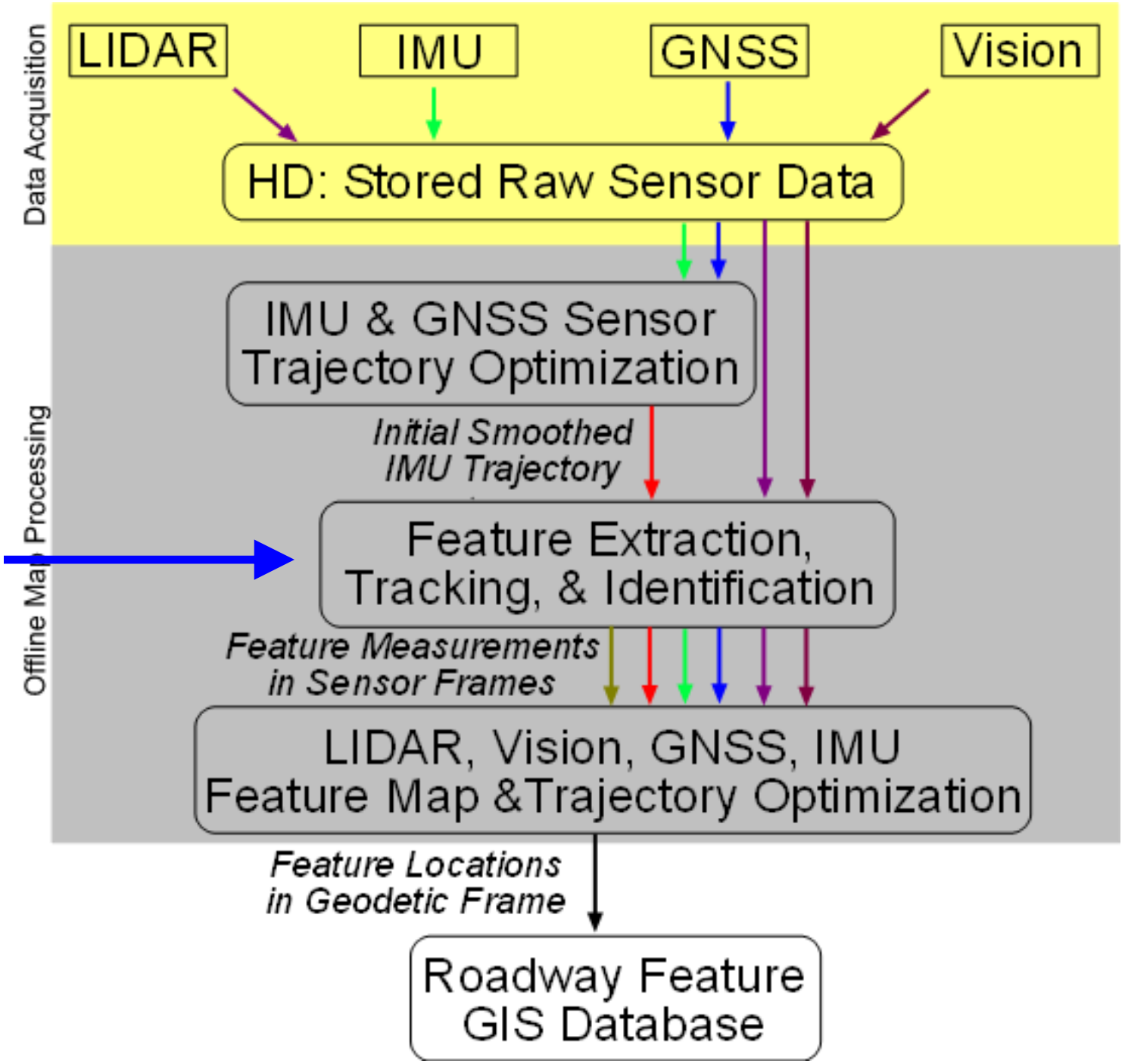


Trajectory Estimation

- **Solve for Integer Ambiguity**
  - **Smooth trajectory using inertial measurements, pseudo-range, and Doppler measurements**
  - **Use smooth trajectory to find integer intervals**
  - **Extend integers from known intervals to adjacent intervals**
- **Final Trajectory Smoothing**
  - **Use integers when available, otherwise, use pseudo-range and Doppler**
- **Can be Utilized Extensively in Mapping**
- **See:** **A. Vu et al., (2012) "Improved Vehicle Trajectory and State Estimation using Raw GPS and IMU Data Smoothing", in press, *IEEE Intelligent Vehicle Symposium*, Madrid Spain, June 2012.**



Features (e.g., road signs, lane markings, road curves, etc.) are extracted and identified from the raw data

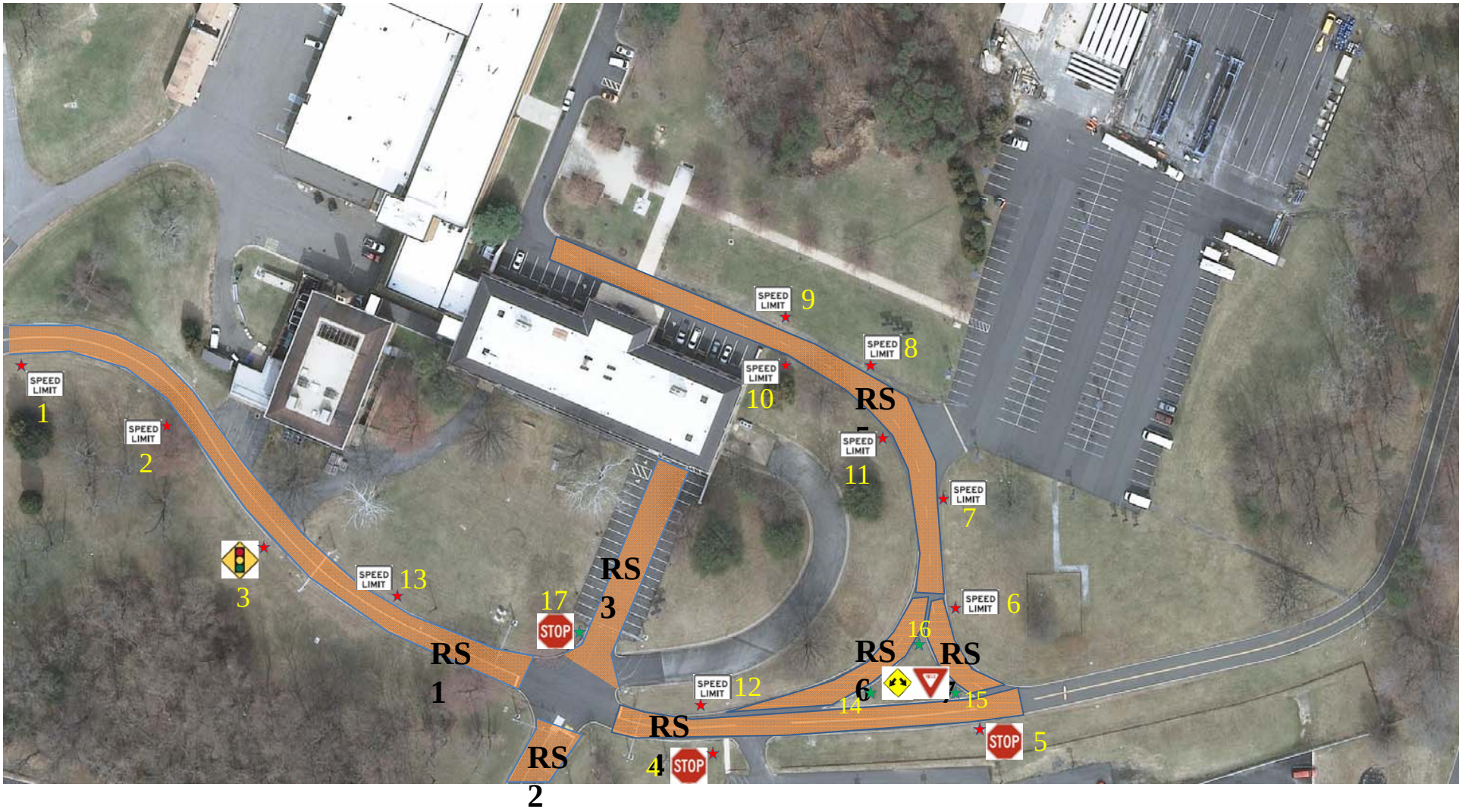


Feature Extraction and Identification (1)

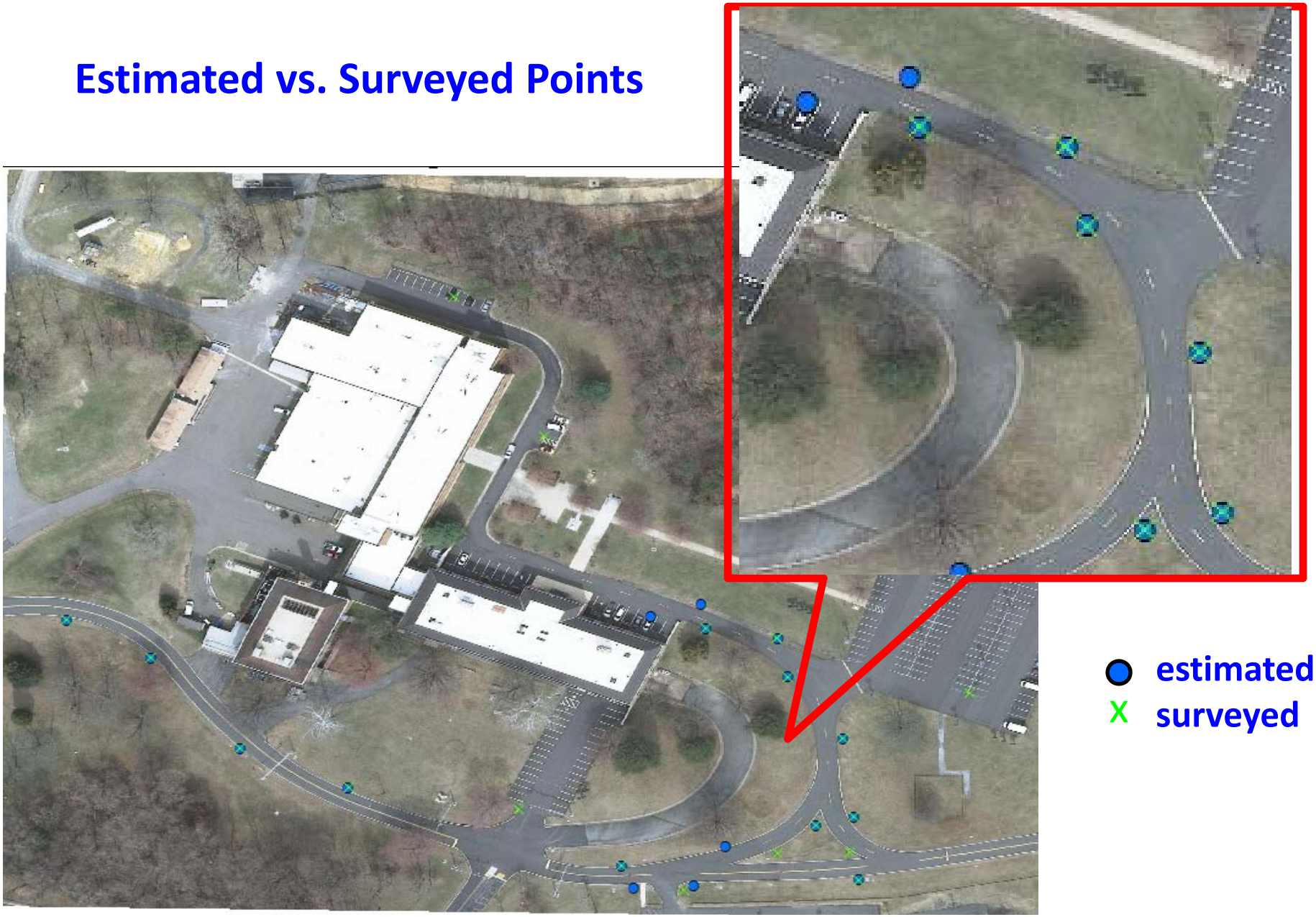
- ***Traffic Sign Extraction***
  - **Primary sensor: LIDAR 64-laser, 20 Hz laser range finder**
  - **Processing step 1: *Feature Detection***
    - **From projected measurement images of intensity and range**
    - **Output: Candidates in LIDAR frame (each has a position & normal)**
  - **Processing step 2: *Feature Association***
    - **Output: Candidate features grouped to objects**
  - **Processing step 3: *Optimization***
    - **Transformation of features from LIDAR to ECEF**
    - **Optimal combination of grouped features to estimate sign position and normal**

- ***Traffic Sign Verification***
  - **Primary sensor: LIDAR candidates and camera**
  - **Processing: Template matching based on extracted signs**
  - **Output: Tags are given to traffic signs extracted from the previous step**

Road Signs Locations



Estimated vs. Surveyed Points



Estimated Plane Position vs. Surveyed Plane Position

Sign Post #	Survey North (m)	Survey East (m)	Max Survey ECEF Std (m)	Computed North (m)	Computed East (m)	Abs. Horiz. Error (m)
1	-41.192	-87.313	0.042	-41.133	-87.345	0.067
2	-55.321	-62.332	0.126	-55.271	-62.328	0.050
3	-89.666	-36.001	0.159	-89.656	-36.112	0.111
4	-142.194	80.051	0.057	-142.244	80.054	0.050
5	-139.078	146.342	0.047	-139.101	146.358	0.028
6	-115.571	144.863	0.009	-115.658	144.923	0.106
7	-85.860	141.540	0.031	-85.882	141.543	0.022
8	-47.903	122.360	0.025	-47.952	122.415	0.073
9	-35.369	99.666	0.045	-35.381	99.686	0.023
10	-44.498	101.259	0.024	-44.433	101.281	0.068
11	-62.597	125.258	0.04	-62.555	125.306	0.063
12	-134.138	76.493	0.025	-134.073	76.519	0.069
13	-104.598	-4.185	0.061	-104.569	-4.152	0.044
16	-118.704	133.631	0.015	-118.618	133.724	0.126

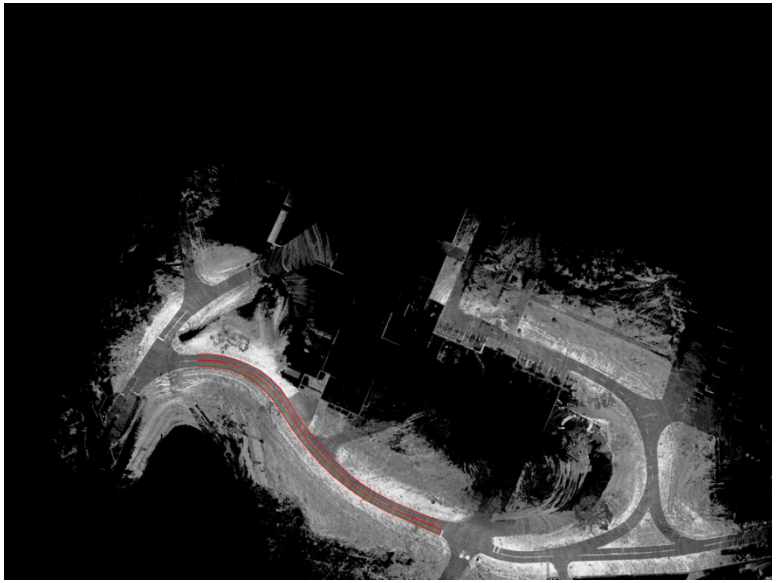
Sign Identification Process…

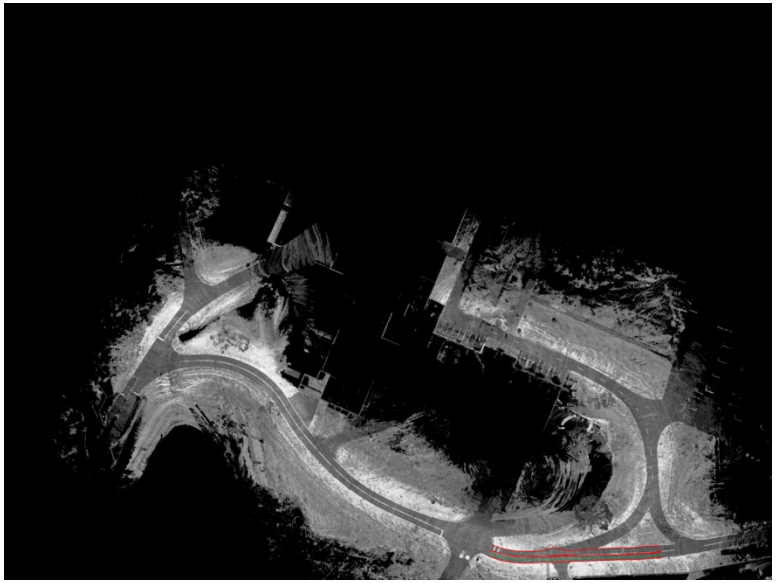
Feature Extraction and Identification (2)

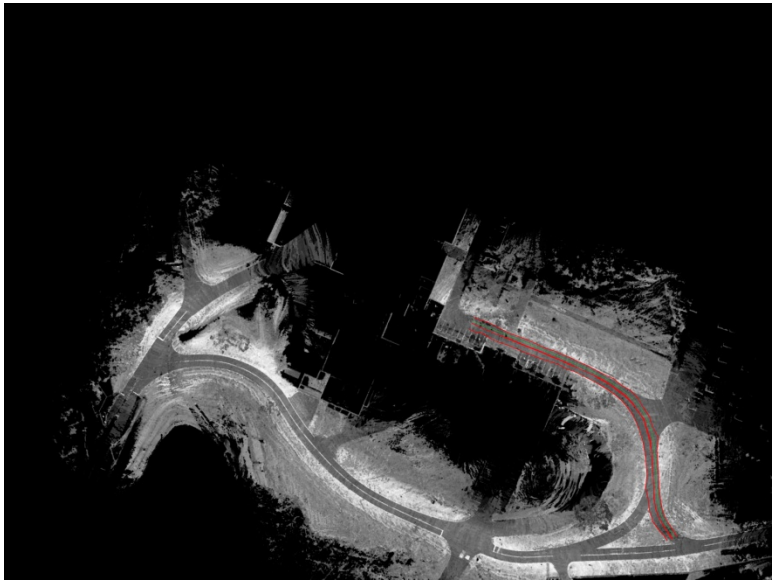
- ***Curve Extraction***
  - **Primary sensor: LIDAR 64-laser, 20 Hz laser range finder**
  - **Processing step 1:**
    - **Ground plane image projection from measurements**
    - **Output: intensity as a function of position**
  - **Processing step 2:**
    - **Curve detection using projected vehicle trajectory on ground plane images**
    - **Output: Curves composed of a set of sequential 3D positions in world frame**
- ***Curve Parameterization***
  - **Primary input: curves from previous step**
  - **Processing step: Curve Fitting**
  - **Output: roadway curve format suitable for GIS**

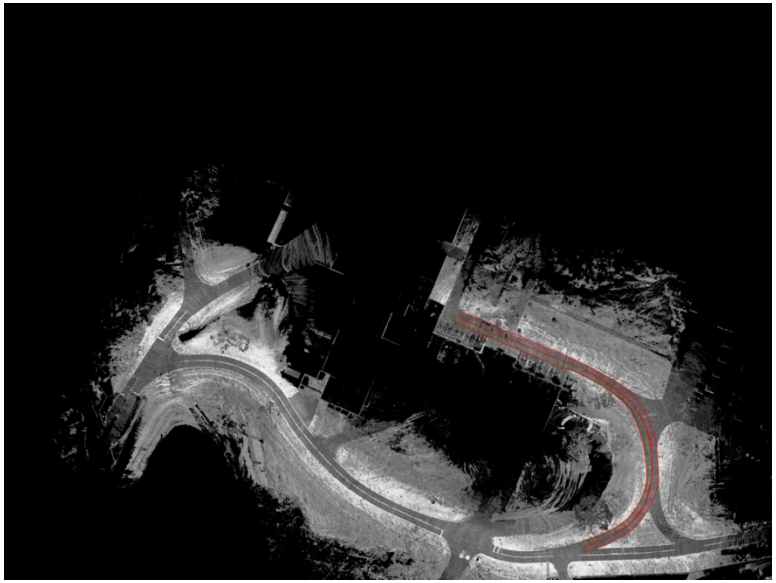
LIDAR Intensity Point Cloud…

Finding Lanes and Curves

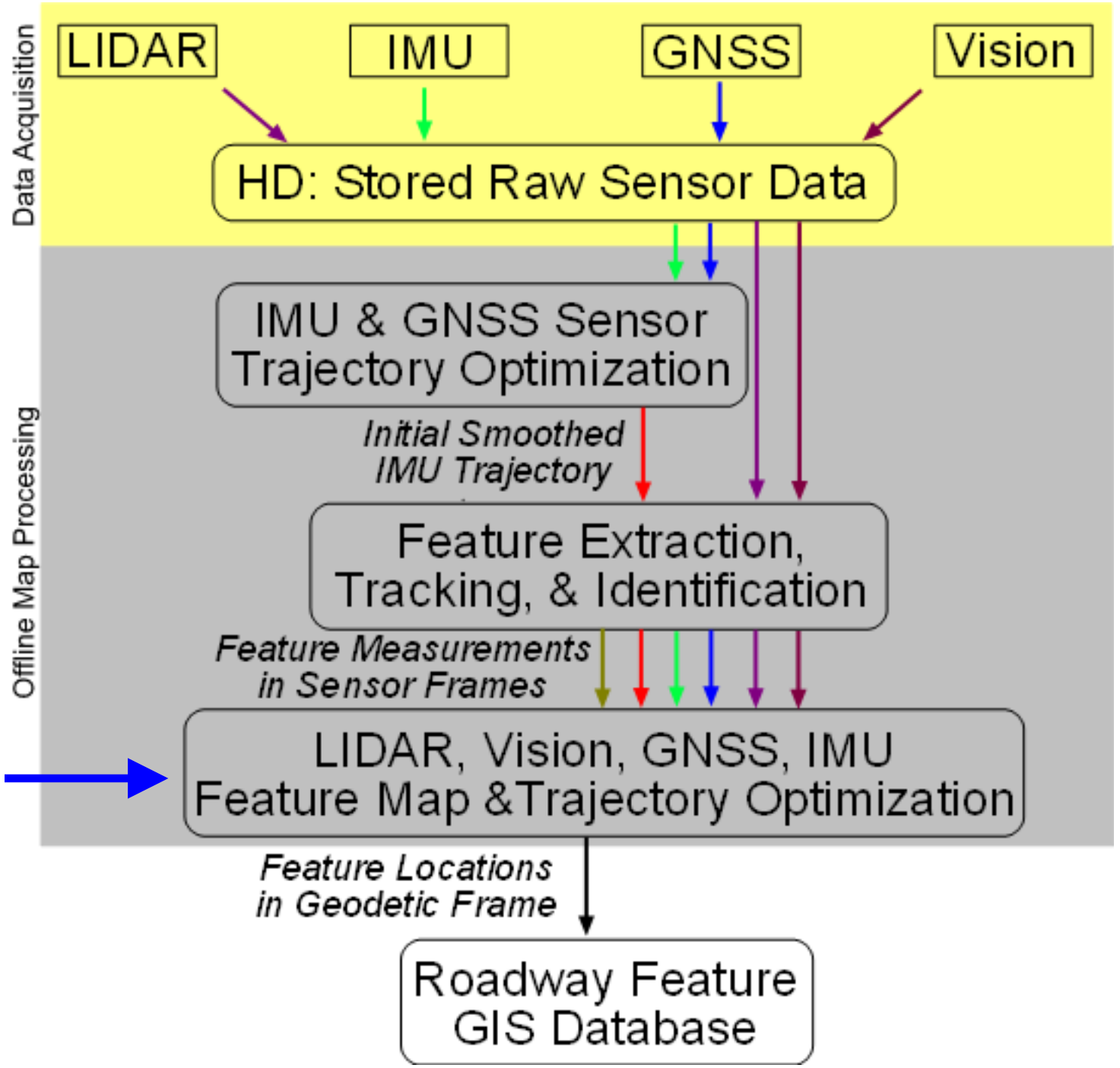




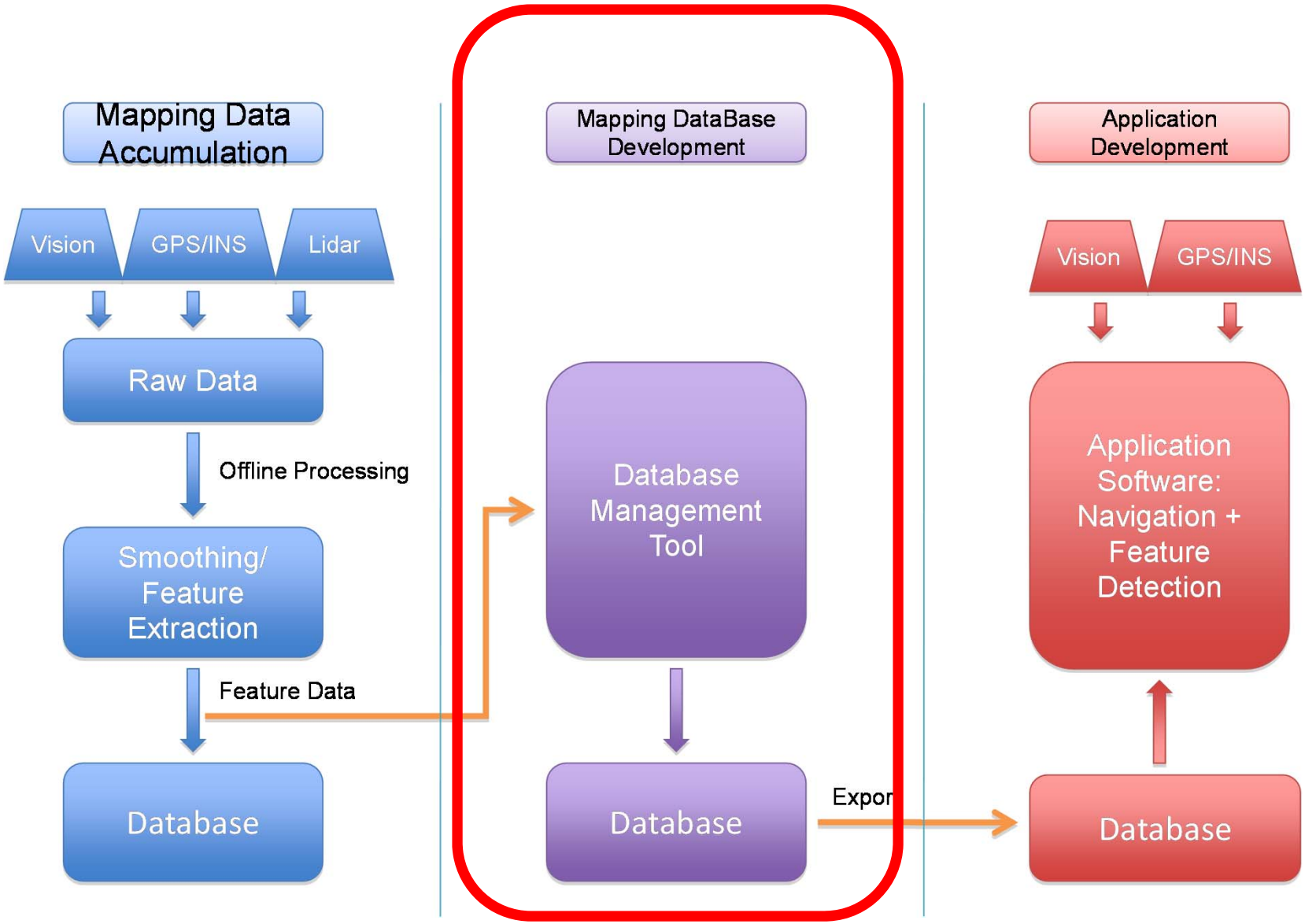




Relative map features are combined with absolute trajectory and placed in GIS database in world coordinates

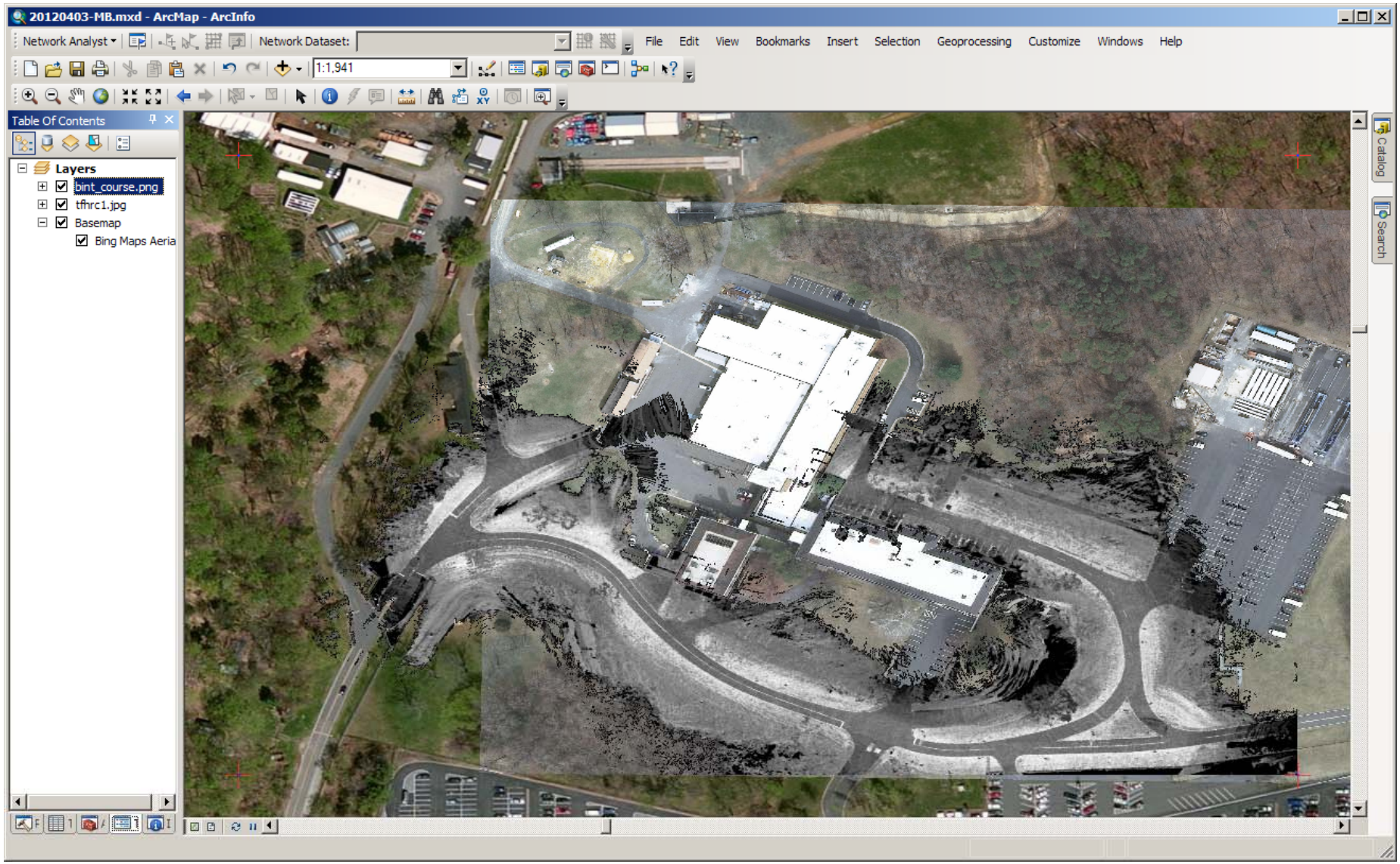


Map Database

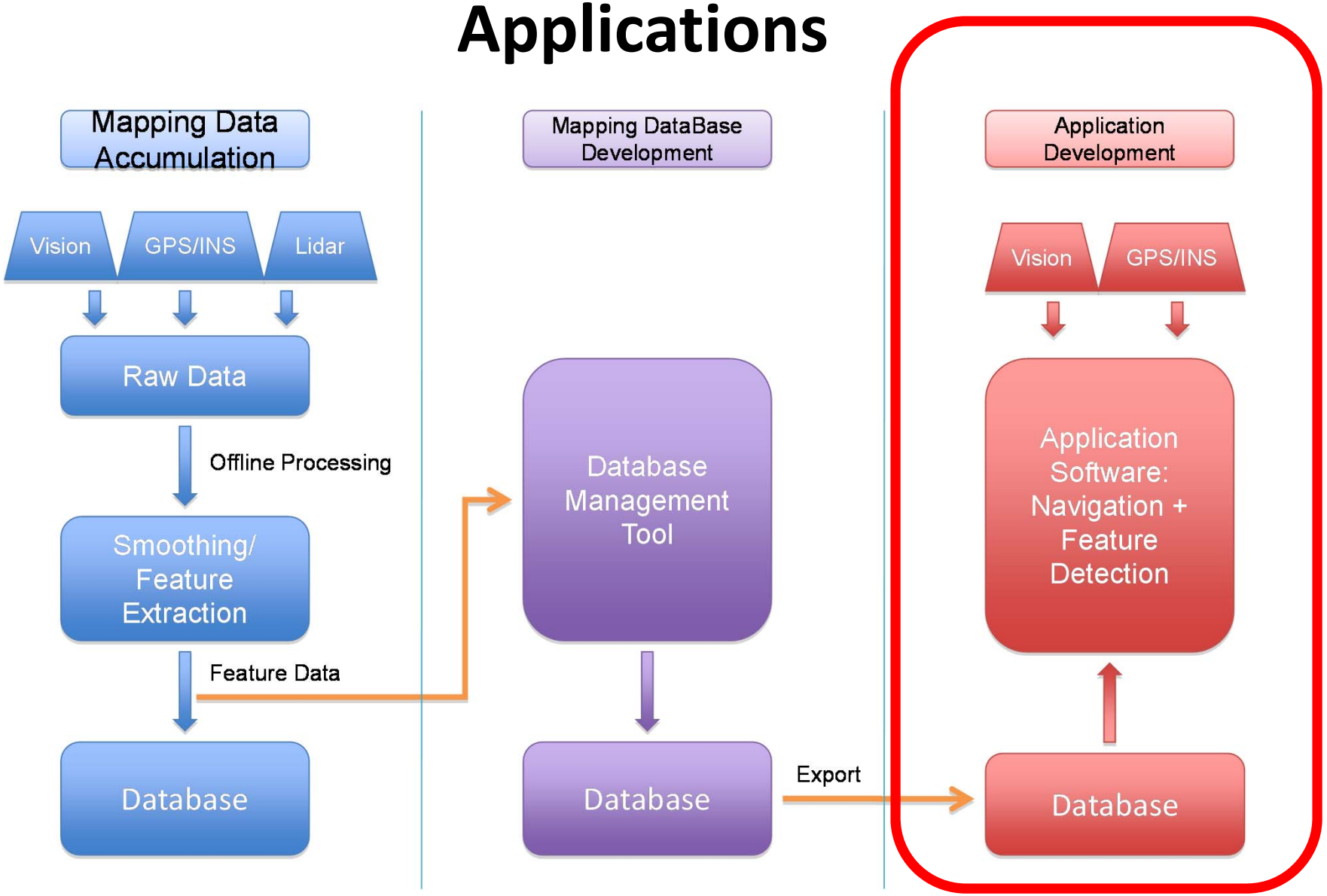


Map Representation in ArcGIS

Bing Map, TFHRC Aerial Image, LIDAR-based intensity image overlay



Applications

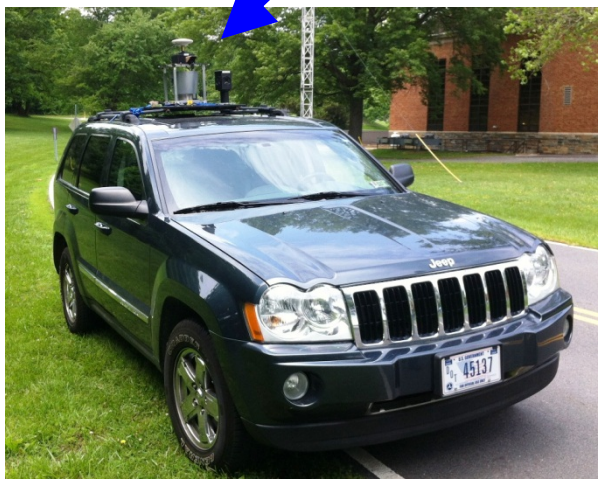


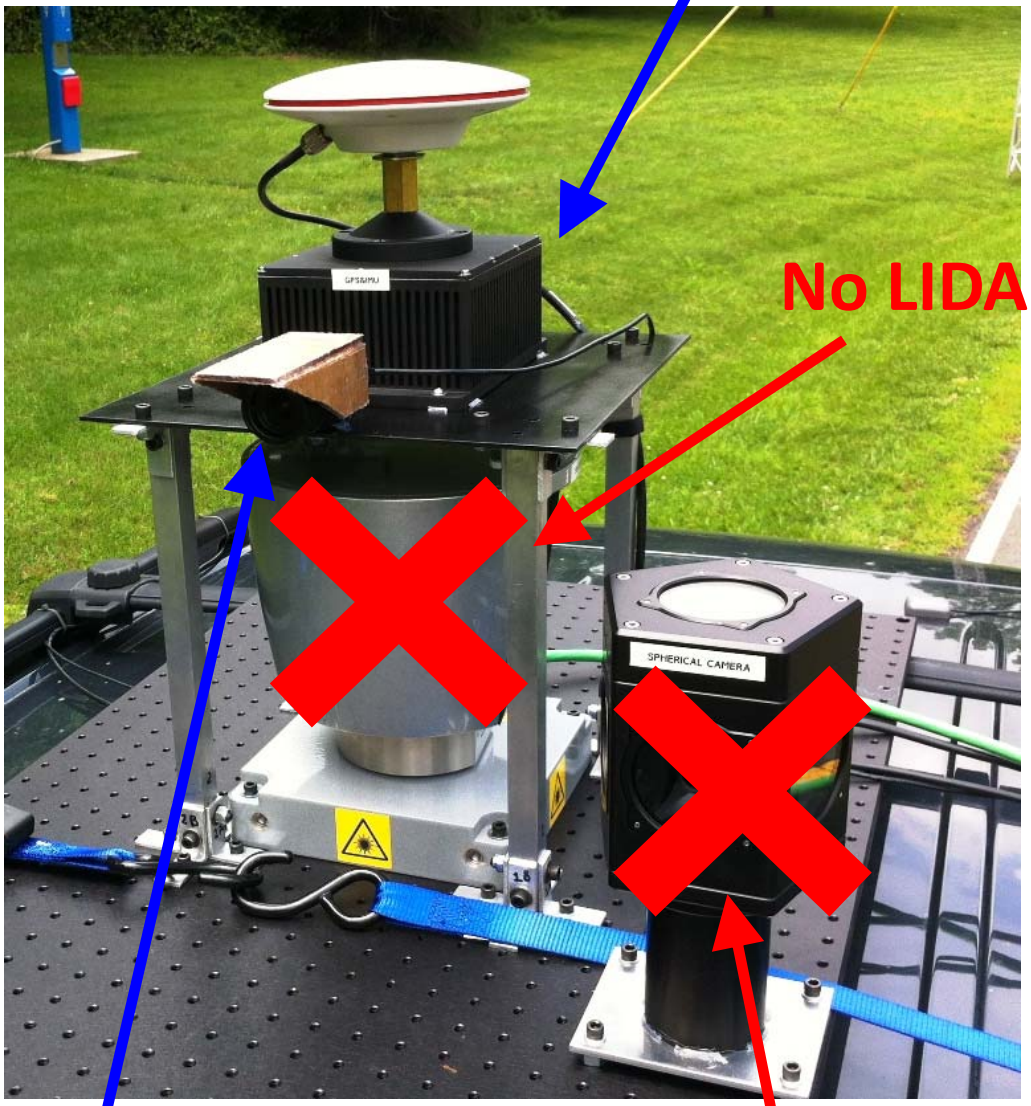
Sensor platform for *positioning*

inexpensive GPS/IMU

No LIDAR

sensor platform

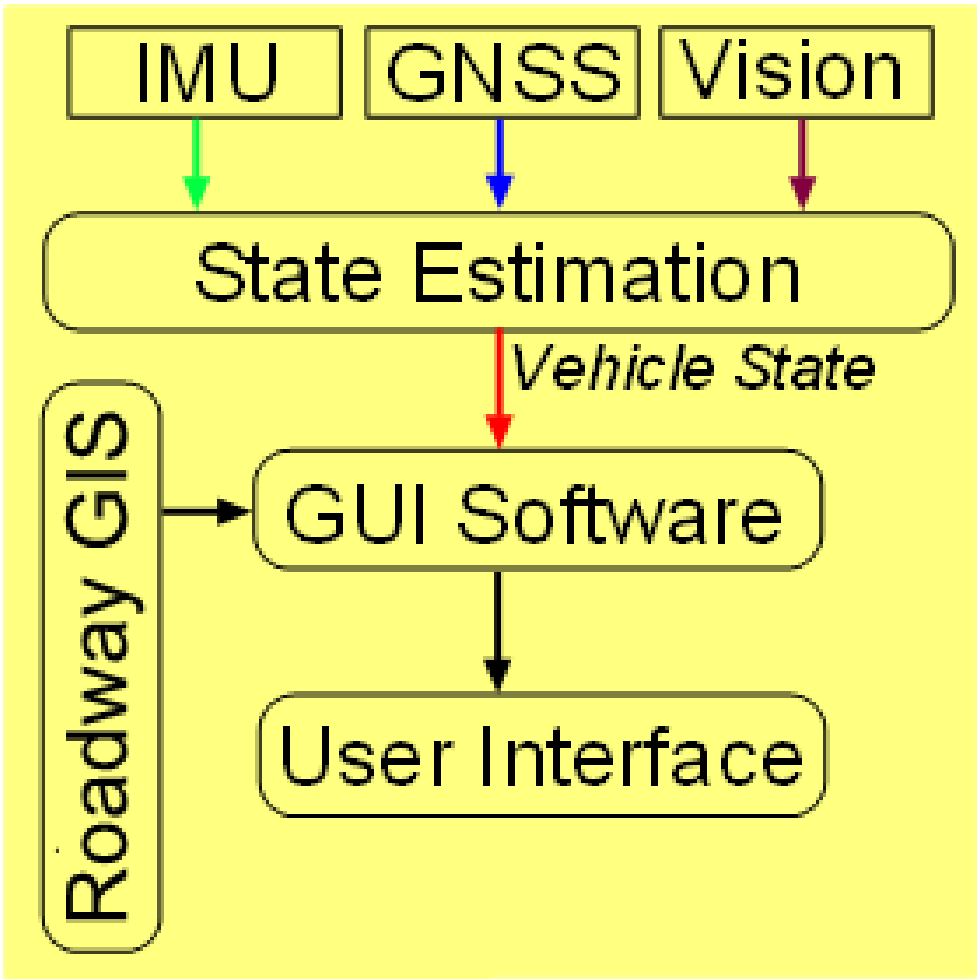




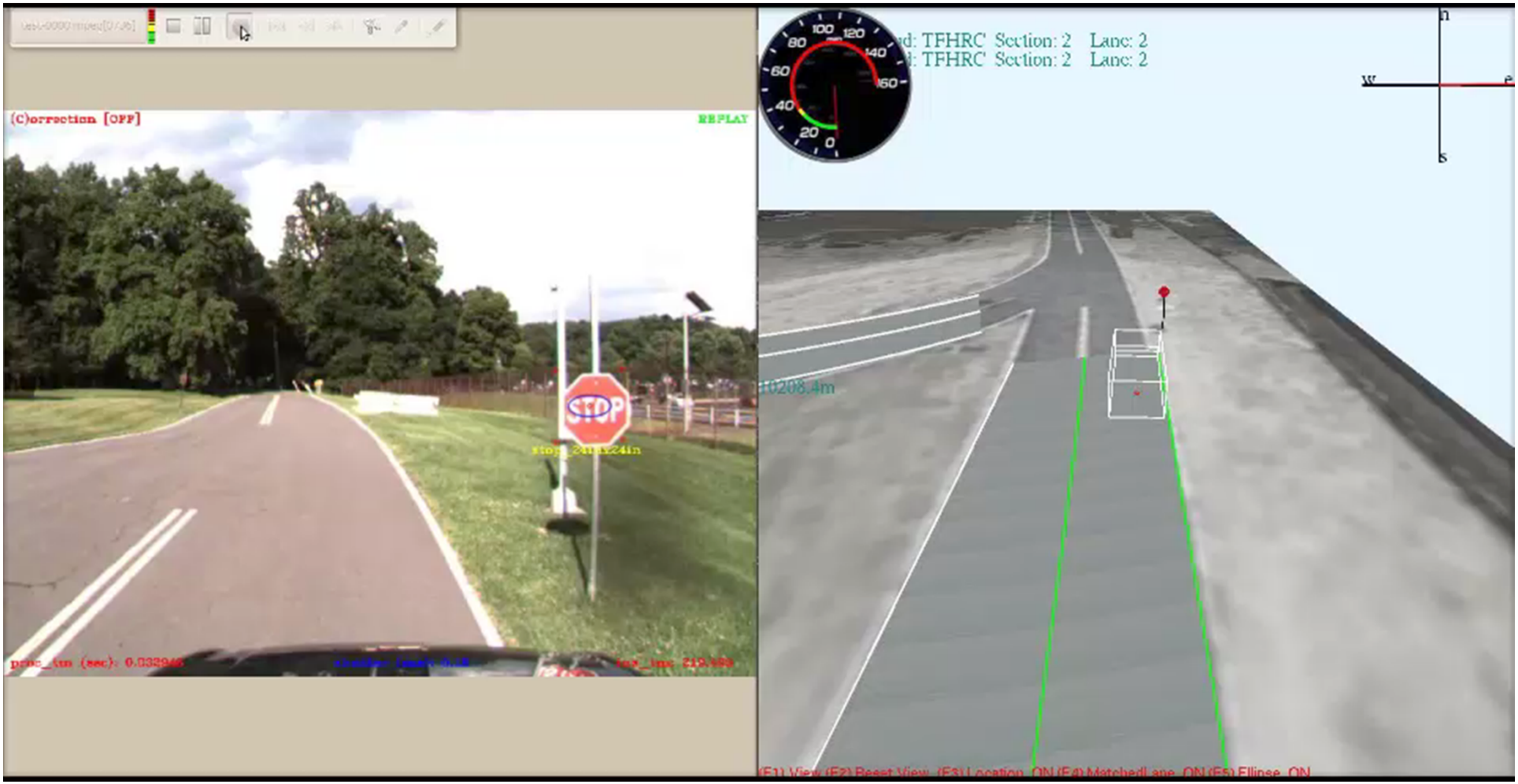
inexpensive rectilinear camera

No panoramic camera

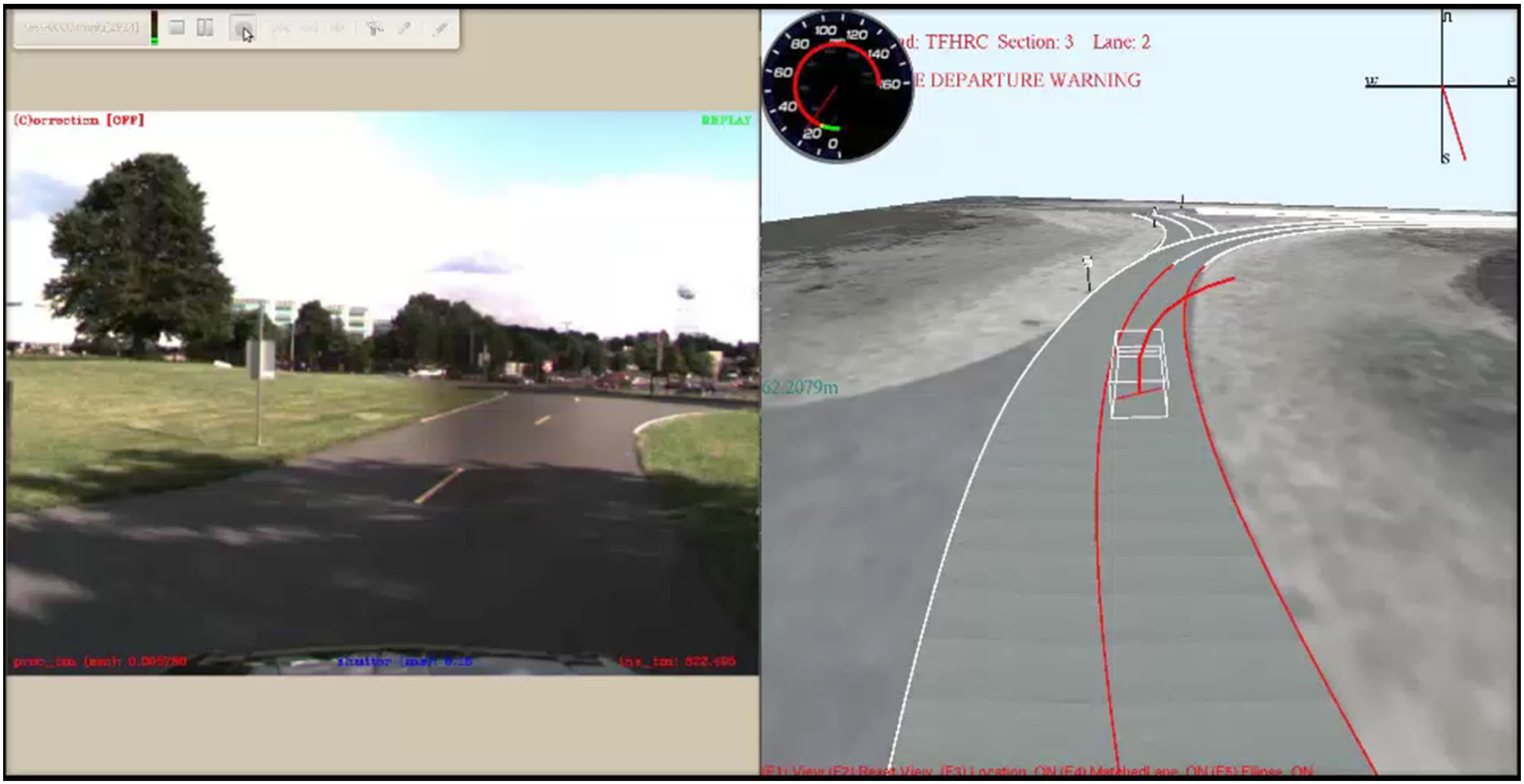
Application Data Flow



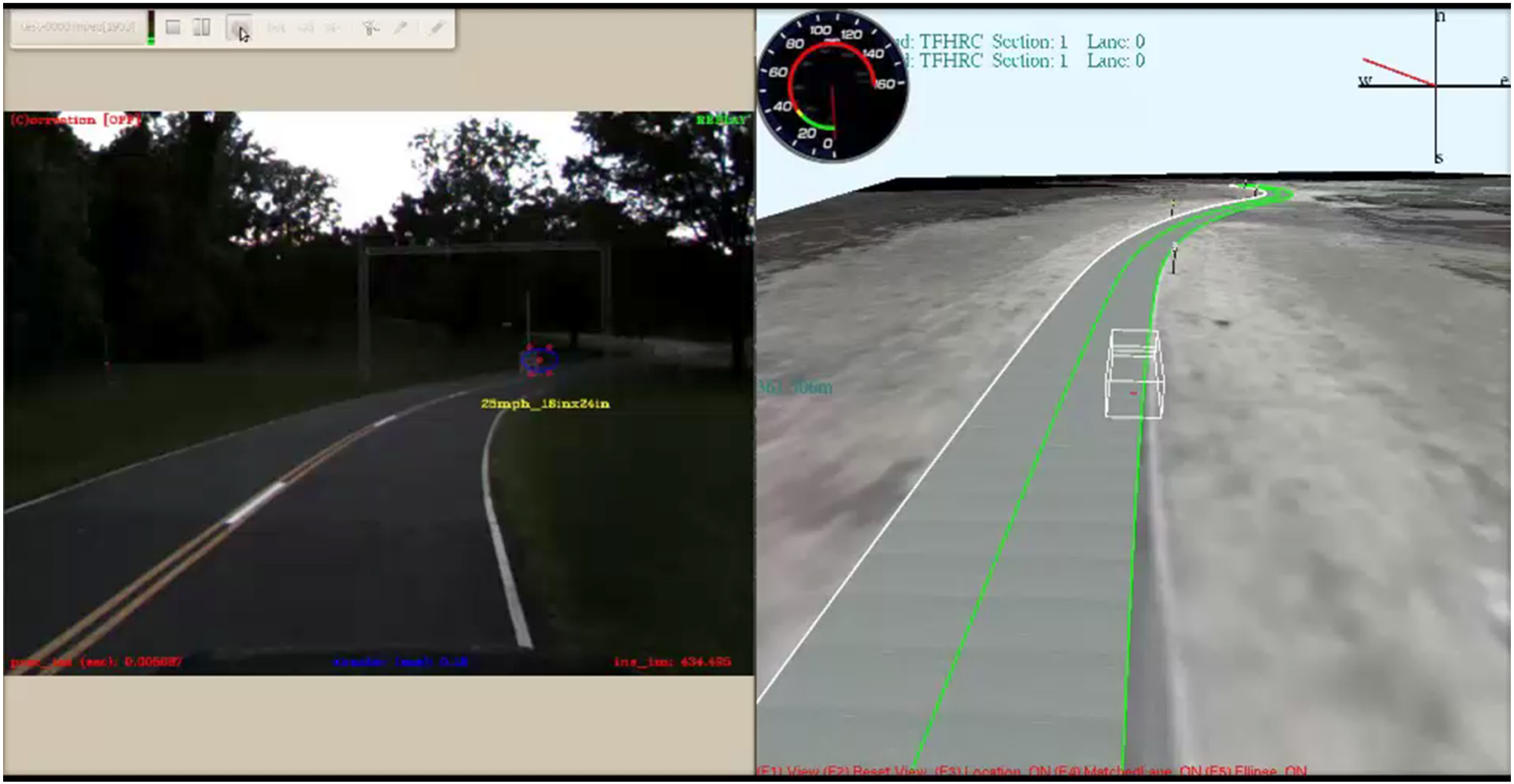
Application Graphical User Interface…



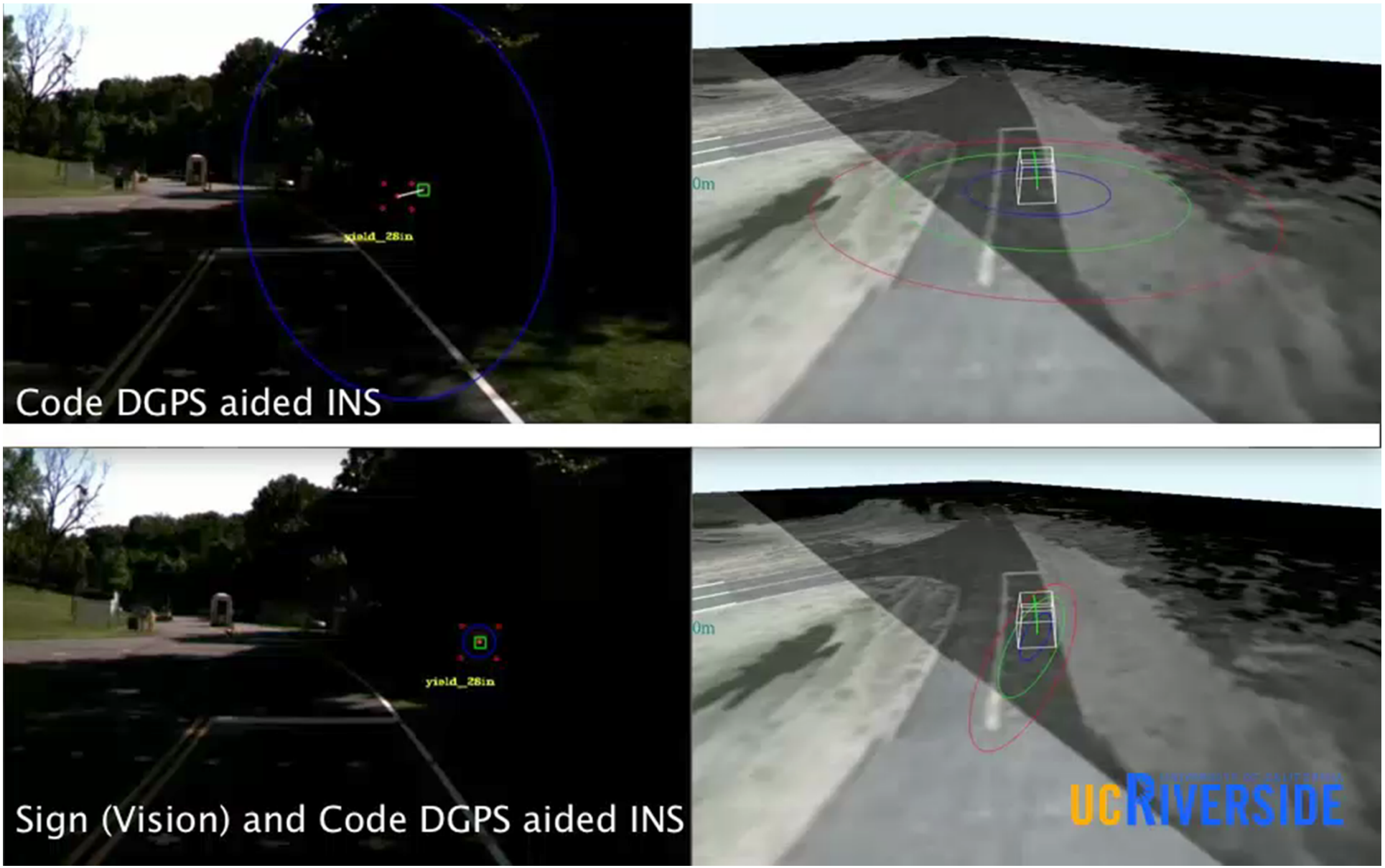
Lane Departure Warning…



Curve Overspeed Warning…



Sign Aiding …


yield_28in
Code DGPS aided INS
0m
yield_28in
Sign (Vision) and Code DGPS aided INS
0m
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Conclusions (1 of 2)

- **No single independent sensor technology is capable of simultaneously attaining the accuracy, integrity, and availability specifications for lane-level positioning in the expected diverse environments**

- **Integrated positioning that fuses asynchronous data from diverse sensors is the best approach to reliably and accurately estimate vehicle position**

- **Inertial Navigation Systems and Encoder Navigation Systems provide positioning solutions in all environments continuously at high rates; however their accuracy drifts over time *without aiding*;**

Conclusions (2 of 2)

- **GNSS provide high accuracy at low bandwidth in open areas where satellite signals can be received; however performance degrades in dense urban areas**

- **Feature-based navigation aiding using camera, LIDAR, or RADAR can be successful when mapped features can be reliably detected and tracked**

- **Several forms of ground based radio communication systems offer potentially useful position information, have been designed to penetrated the urban infrastructure, and have the added advantage that their performance characteristics can still be influenced by the engineering community interested in roadway applications.**