Automated Precision Roadway Inventory Mapping & Characterization

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Outline:
• Big picture: Positioning and Mapping
• Precision Mapping
• Real-time Vehicle Position Estimation
• Project: Results and Applications
• Interesting Future Directions
Precision Automated Mapping & Assessment

**ITS Safety & Mobility Applications:**
Lane-departure warning, Freeway merge assistance, Curve over-speed warning, Adaptive cruise control, Congestion warning systems, Signal Phase and Timing, Lane-level Intersection management and collision avoidance, Headlight steering into curves

- Positioning with high degrees of:
  - **Accuracy** – Less than one meter
  - **Continuity** – High sample rate
  - **Availability** – Works in diverse environments
  - Accomplished at **Low Cost**

Enables ITS applications with transformative improvements for safety, mobility, and environmental performance

- Automated roadway inventory mapping and characterization:
  - Efficient characterization and management of highway assets
  - Rapid and objective assessment of roadway condition

Locations: signs, lights, signals, road or lane edges, ...
Heights: tunnels, curbs, ...
Roadway: rutting, roughness, cracking, ...
Construction documentation

Automated, sensor-based mapping for accurate and low-cost roadway map production at centimeter to decimeter accuracy
Precision Roadway Map: Data Acquisition

- **Sensor Platform**
- **Mapping Data Accumulation**
  - Vision
  - GPS/INS
  - Lidar
- **Online Processing**
- **Smoothing/Feature Extraction**
- **Database**

**Table:**

<table>
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<tr>
<th>Sensor</th>
<th>Bytes/Msg.</th>
<th>Msgs./sec</th>
<th>Bytes/Sec</th>
<th>GB/Hr</th>
<th>GB/Hr (with timestamp overhead)</th>
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<td></td>
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<td>982 GB/Hr</td>
<td>983 GB/Hr</td>
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<td>Hrs. of collection per TB:</td>
<td></td>
<td></td>
<td></td>
<td>≈1 Hr.</td>
<td>≈1 Hr.</td>
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<tr>
<td>Miles of coverage per TB (assuming a speed of 30 mph):</td>
<td></td>
<td></td>
<td></td>
<td>≈30 miles</td>
<td>≈30 miles</td>
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</table>
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.
- Provides sensor platform pose at high accuracy and high rates
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 carrier phase when integers are available, otherwise, use pseudo-range and Doppler

• Can be Utilized Extensively in Mapping

• See:
  • A. Vu, J. A. Farrell, M. Barth, “Improved Vehicle Trajectory and State Estimation using Raw GPS and IMU Data Smoothing”, IEEE Intelligent Vehicle Symposium, Madrid Spain, June 2012.
UCR Implementation Trajectory
• 3.6 km campus ring
• Significant tree cover
• Buildings and terrain shading
Trajectory Estimation Results

[Graphs showing trajectory estimation results for Pseudorange and Carrier Phase]
Trajectory Estimation Results: Residuals

Process 1:
- Code, Doppler, IMU
- Bayesian Smoothing

Process 2:
- Integer Estimation
- Bayesian Smoothing
  - Integer-resolved phase and IMU when available
  - Code, Doppler, IMU otherwise
Features (e.g., road signs, lane markings, road curves, etc.) are extracted and identified from the raw data.
Road Signs Locations
**Sign Descriptions**

1. Speed Limit – 25 MPH
   24”x30”
2. Speed Limit – 25 MPH
   24”x30”
3. Traffic Signal Ahead
   30”x30”
4. Stop - 24” (diameter)
5. Stop - 24” (diameter)
6. Speed Limit – 30 MPH
   24”x30”
7. Speed Limit – 30 MPH
   24”x30”
8. Speed Limit – 25 MPH
   24”x30”
9. Speed Limit – 25 MPH
   24”x30”
10. Speed Limit – 30 MPH
    24”x30”
11. Speed Limit – 25 MPH
    18”x24”
12. Speed Limit – 35 MPH
    24”x30”
13. Speed Limit – 25 MPH
    18”x24”
14. Fork in Road - 24”x24”
15. Front: Fork in Road - 24”x24”
    Rear: Yield - 28” (each side)
16. Front: Fork in Road - 24”x24”
    Rear: Yield - 28” (each side)
17. Stop - 24” (diameter)

**Note:** 14-17 are pre-existing signs.
Traffic Sign Extraction...

Detection criteria:
1. High reflectance
2. Size
3. Planar surface
Plane Feature Estimation
see corresponding sign numbers and normals
Estimated vs. Surveyed Points
### Estimated Plane Position vs. Surveyed Plane Position

<table>
<thead>
<tr>
<th>Sign Post #</th>
<th>Survey North (m)</th>
<th>Survey East (m)</th>
<th>Max Survey ECEF Std (m)</th>
<th>Computed North (m)</th>
<th>Computed East (m)</th>
<th>Abs. Horiz. Error (m)</th>
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<td>0.042</td>
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</table>
Sign Identification Process...
Lane Edge Extraction and Curve Estimation

• **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 Representation in ArcGIS

Bing Map with TFHRC aerial image overlay
Georectified LIDAR-based intensity image
Bing Map, TFHRC Aerial Image, LIDAR-based intensity image overlay
Map Representation in Positioning Graphical User Interface (GUI)
Sensor platform for positioning

- Inexpensive GPS/IMU
- No LIDAR sensor platform
- Inexpensive rectilinear camera
- No panoramic camera
Application Data Flow

- IMU
- GNSS
- Vision

State Estimation

Vehicle State

Roadway GIS

GUI Software

User Interface
Inertial Navigation

- Gyros
- Accelerations
- Velocity
- Position
- Gravity Calculation
- Coriolis Correction Calculation
- Initial position & Vel.
- Body mounted Accelerometer
- Resolution of the Force Measurement
- Attitude Calculation
- Initial Attitude
- Body mounted Gyroscopes
- Pos.
- Vel.
Real-time Navigation system

1. High rate sensors
   - Encoder or IMU
2. Aiding measurements
   - GPS, image features
3. CRLB

Application Graphical User Interface...
Lane Departure Warning...
Curve Overspeed Warning...
Real-Time Traffic Sign Recognition Process
Sign Aiding ...
Signal Phase and Timing Infrastructure

- Intersections:
  - 3M in US, 300k are signalized
  - # fatalities has not changed significantly
  - # of intersection fatalities is unchanged at 22-23%
  - ~50% of all accidents and injuries occurred at intersections
- Next Generation SPAT: Relies on communication and positioning

- Traffic Signal Controller
  - SPaT processor
  - *wireless*
  - On-board DSRC
  - On-board GPS/IMU computer interface
Signal Phase and Timing Setup (vehicle)

On-board computer

DSRC transceiver

Roadway GIS → GUI Software → User Interface

IMU → GNSS → Vision

State Estimation

Vehicle State

SPAT Controller
FHWA Project Summary

• Automated sensor-based mapping enables nationwide lane-level map production
  – This 1 yr. project developed software and demonstrated automated sensor-based mapping with \textit{centimeter-level} accuracy

• Three lane-level applications built on the foundation of lane-level maps were demonstrated using \textit{decimeter-level} positioning techniques
  – Lane departure warning
  – Curve over-speed warning
  – Signal Phase and Timing, at lane-level

Prior \textit{Caltrans} support for relate research and demonstration projects was instrumental to the software, hardware, and theoretical infrastructure that formed the foundation of this US DOT-FHWA project.

US DOT FHWA Project Managers: Rudy Persaud, James Arnold, Deborah Curtiss
Caltrans Project Managers: Asfand Siddiqui, Gurprit Hansra, Larry Baumeister
Future Interests

Projects: Research & demonstration collaborations with Caltrans districts

• Advanced Connected Vehicle Applications: enabled by precise navigation and mapping
  – Lane-based intersection management, traffic signal timing optimization, dedicated lane management

• Automated Mapping:
  – Roadway inventory – position and health of signs, rails, signals ...
  – Roadway surface characterization – roughness, cracking, rutting, ... versus location
  – Construction documentation

Sensors:

• Velodyne LIDAR, IMU, GPS, cameras
• Available for collaboration & sale-for-service