GPS and Its Use for Vehicle Control

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Autonomous Driving

• DARPA Grand Challenge (11 years ago)
  – No finishers in Year 1
  – 5 teams finish 1.5 years later

• Companies move towards autonomous driving
  – Google Car
  – BMW (2025)
  – Mercedes
  – Ford/GM

• States have started passing autonomous vehicle legislation
Need for Vehicle Automation

- Vehicle accidents are a top cause of fatalities
  - Approximately 42,000 roadway fatalities/year
  - 50% resulting from vehicle lane departure

- Increase in technology, processing power along with decrease cost of new sensors is leading to more intelligence in vehicles
  - Lane Departure Warning (LDW)
  - Adaptive Cruise Control (ACC)
  - Advanced Driver Assistance Systems (ADAS)
    - Volvo’s City Safe (anti-collision)
    - Infiniti’s Lane Departure Prevention
    - Mercedes’ Traffic Jam Assist
    - Lexus’ Automated Parallel Parking

- V2V and V2X will enable more capabilities with smart connected cars
  - Cooperative ACC (C-ACC)
  - Automated Platooning
Control of Vehicles

• Need to know vehicle:
  – Position (lane level), Velocity, Direction of travel, Orientation
  • LDW- Lane Departure Warning
    – Send warning to driver if lane is being approach
    – Helps to prevent un-intended lane departure
  • ADAS – Advanced Driver Assistance Systems
    – Lane Keeping and Lane Centering
    – Hidden View Safety Systems

• Above measurements can be made using GPS to:
  – Improve vehicle state estimation for Electronic Stability Control (ESC)
  – Provide lane keeping control technologies
  – Automated vehicle following

• Issues associated with positioning for vehicle safety systems:
  – Integrity and Security (when communicating and sharing data)
  – Reliability and Robustness (due in part to ubiquitous nature)

• Integration with other sensors (ex: IMU, Cameras, etc.)
  – Used to overcome some of the limitations
GPS Measurements

\[ \begin{bmatrix} \text{East} \\ \text{North} \\ Up \end{bmatrix} = \bar{R} = f(N, \phi) \]

\[ V \sim \Delta \phi \]
Vehicle Communications

- **V2X**
  - Vehicle to Vehicle
  - Vehicle to Infrastructure
- **Dedicated Short Range Communications (DSRC)**
  - IEEE 802.11p
    - Wifi like signal
- **Basic Safety Message (BSM)**
  - Contains position and time
- **Crash Avoidance Metrics Program (CAMP)**
  - Currently using GPS for BSM
  - Recently Complete a Safety Pilot Program

### BasicSafetyMessage (SAE j2735-2009)

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<th>name</th>
<th>bytes</th>
<th>note</th>
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<tr>
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<td># of milliseconds</td>
</tr>
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<tr>
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<tr>
<td>accelSet</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Latitude: meters/second^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vertical: G</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YawRate: degree/second</td>
</tr>
<tr>
<td>brakes</td>
<td>2</td>
<td>On/off statuses for different brakes</td>
</tr>
<tr>
<td>size</td>
<td>3</td>
<td>Vehicle’s size information</td>
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<tr>
<td>extensions</td>
<td>-</td>
<td>Optional; variable length</td>
</tr>
</tbody>
</table>
Perception Positioning (Lidar/Camera)
Perception Positioning vs. GPS

- **GPS Positioning**
  - May not provide the required accuracy without differential corrections
  - Interference, obstruction, etc.

- **Perception based positioning**
  - Requires data base (map) storage
  - What will be the reference frame
  - Data base may require frequent updating
  - Features may be blocked
  - Limited FOV
  - Cost
UNIFIED GPS/INS
KALMAN FILTER BASED
VEHICLE
STATE ESTIMATION
Loosely Coupled Algorithm

Doesn’t currently exist because of lack of communication between various suppliers
Sideslip Definitions

\[
v = \beta + \psi\]

\[
\beta = \tan^{-1} \frac{V_y}{V_x}\]

\[
\beta = \text{Sideslip}\]

\[
v = \text{Course}\]

\[
\psi = \text{Heading}\]
Loosely Coupled Integration

- Components:
  - INS (6DOF)
  - GPS (single antenna)
  - EKF

- EKF states (15):
  - INS solution errors (9)
  - INS sensor biases (6)

\[
\delta \hat{X} = \begin{bmatrix}
\delta \hat{r}, & \delta \hat{V}, & \delta \hat{\psi}, & \delta \hat{f}, & \delta \hat{\omega}
\end{bmatrix}^T
\]

\[
\hat{\beta} = \arctan\left(\frac{\hat{V}_{\text{east}}}{\hat{V}_{\text{north}}}\right) - \hat{\psi}_{\text{yaw}}
\]

- \( \hat{r} \) – position
- \( \hat{V} \) – velocity
- \( \hat{\psi} \) – attitude
- \( \delta \hat{f} \) – accelerometer biases
- \( \delta \hat{\omega} \) – gyroscope biases
Automotive Navigation Estimator

- Pitch rate gyroscope is removed.
- Yaw constraint added during periods of straight driving
  - GPS course measurement used as a yaw measurement.
- If yaw rate signal is less than some threshold for some time period, then the constraint is added.
  - Threshold, time window are tuning parameters of the overall estimator.

\[
Y = \begin{bmatrix}
  \hat{\ell} \\
  \hat{V} \\
  \hat{\psi}_{yaw}^{GPS}
\end{bmatrix} - \begin{bmatrix}
  \ell \\
  V \\
  \psi_{yaw}
\end{bmatrix}
\]
Lane Change Results

- Sideslip
- Roll
Low Rates of Sideslip Buildup

- Slow sideslip buildup is generally difficult to estimate
  - Low signal to noise ratio.
  - Lateral accelerometer bias
  - Lateral acceleration vs. roll

Video courtesy of
Experimental Slow Sideslip Buildup

- Average rate of sideslip for third turn of the dynamic maneuver is $1.8 \text{ deg/s}$.
- AUNAV estimator is able to accurately estimate the sideslip buildup at rates as low as $\approx 1.8 \text{ deg/s}$. 

![Graph showing maneuver and sideslip data]
Integrating GPS with other on-board vehicle sensors

VEHICLE LANE POSITIONING
Project Overview

- Technical Approach – Fuse outputs of various positioning technologies in an extended Kalman filter exploiting accuracy/uncertainty and mitigating subsystem faults
Vision / INS

- Commercial lane departure warning systems use camera vision to detect lane markings
- Various problems can hinder lane detection
  - Environment (lighting conditions, weather, population density)
  - Eroded lane marking lines or objects on the road
- Integrate IMU into the vision tracking algorithm
- Predicts features (road marking) during vision “outage”
Positioning w/ Limited GPS Satellites

Utilize constraints to improve IMU solution

Validated at Auburn’s NCAT Test Track using:
• Lateral Constraint
• Vertical Constraint
• 2 GPS Satellites
Lateral Error with Limited GPS Observations

- Camera (or Lidar) provides lateral measurements
  - Requires map database

Without Lateral Perception Measurements

With Lateral Perception Measurements
Longitudinal Error with Limited GPS Observations

- Camera only provides lateral measurements
  - Constraint decreases longitudinal errors
- From limited GPS and also IMU error growth

Without Lateral Perception Measurements

With Lateral Perception Measurements
Using GPS for Automated Following

- GPS can provide a very accurate (cm level) relative position vector (RPV)
  - Requires communication between vehicles (DSRC)
  - Provides a measurement to enable vehicle convoying
GPS Path Following

900 MHz Digi XTend RTK base station communication

NovAtel PropakV3

900 MHz Digi XTend inter-vehicle communication

900 MHz Digi XTend RTK base station

Leader

Follower

MCU

Advantech control and navigation computers

Servos

Power regulation and distribution

Crossbow IMU440 (under seat)
**Experimentation – Autonomous Following**

- **NLOS method implemented in real time on UGV**
  - Tested with dynamic paths through parking lot and on NCAT track
  - Following distances varied from 10 to 120 m
Automated Truck Platooning

- Drafting reduces fuel (& emissions)
- Improves safety
- Improves traffic flow/throughput

3-4% Savings

10-12% Savings