Sensor Fusion for Navigation in Degraded Environements

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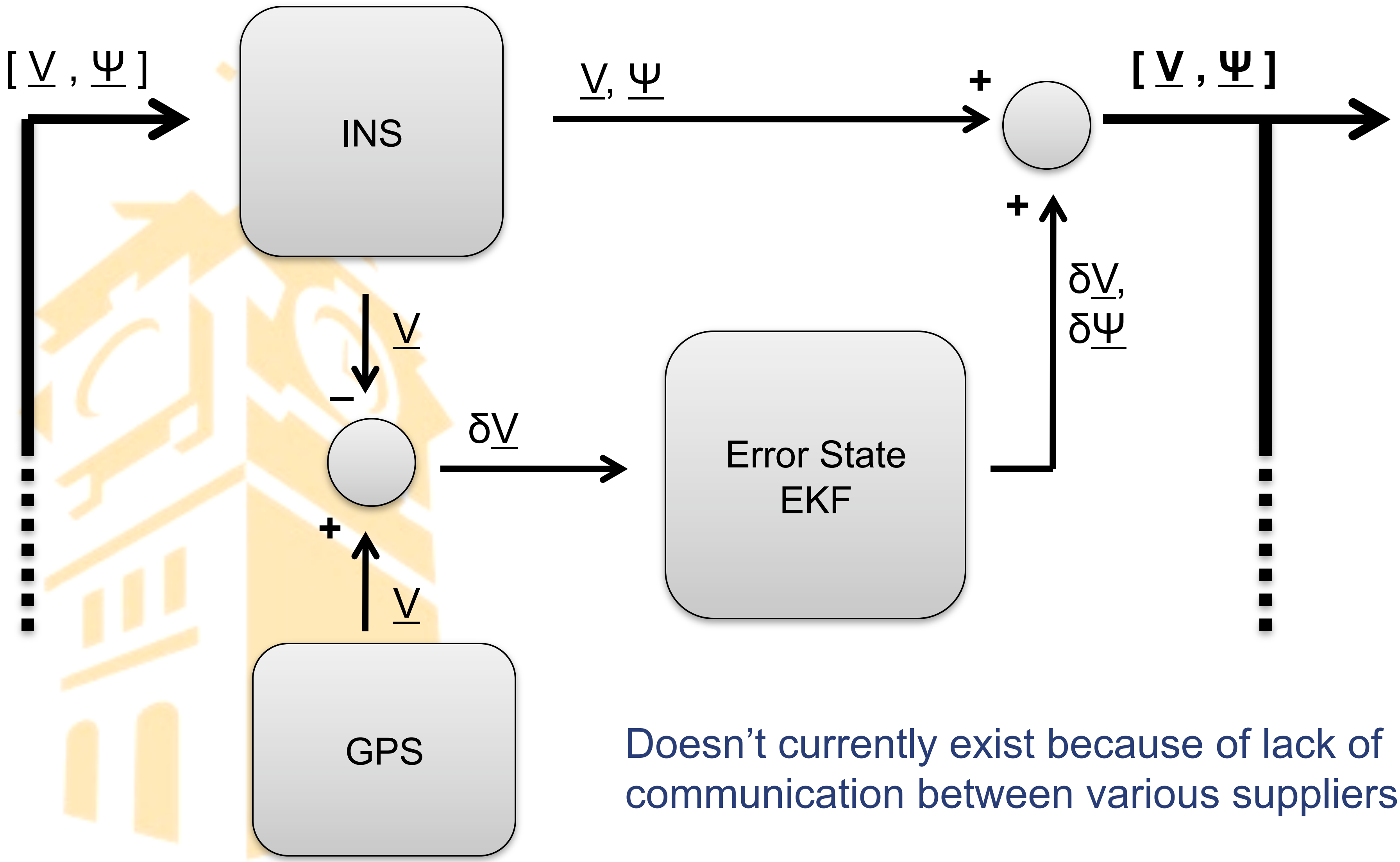
Control of Vehicles

- Need to know vehicle:
  - Position (lane level), Velocity, Direction of travel, Orientation
- Above measurements can be made using GPS to:
  - Improve vehicle state estimation for Electronic Stability Control (ESC)
  - Provide lane keeping control technologies
  - Create other driver assistance systems
- 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
  - Used to overcome some of the limitations
  - Increase flexibility through software defined radios
    - Bring in news sensor measurements easily
      - including wireless signals (signals of opportunity)
    - Fully reprogrammable
    - Allows any integration scheme
      - Loosely, tightly, ultra-tight/deep integration
    - FPGA -> ASIC

Vehicle Control Using of GPS

UNIFIED GPS/INS KALMAN FILTER BASED STATE ESTIMATION

Loosely Coupled Algorithm

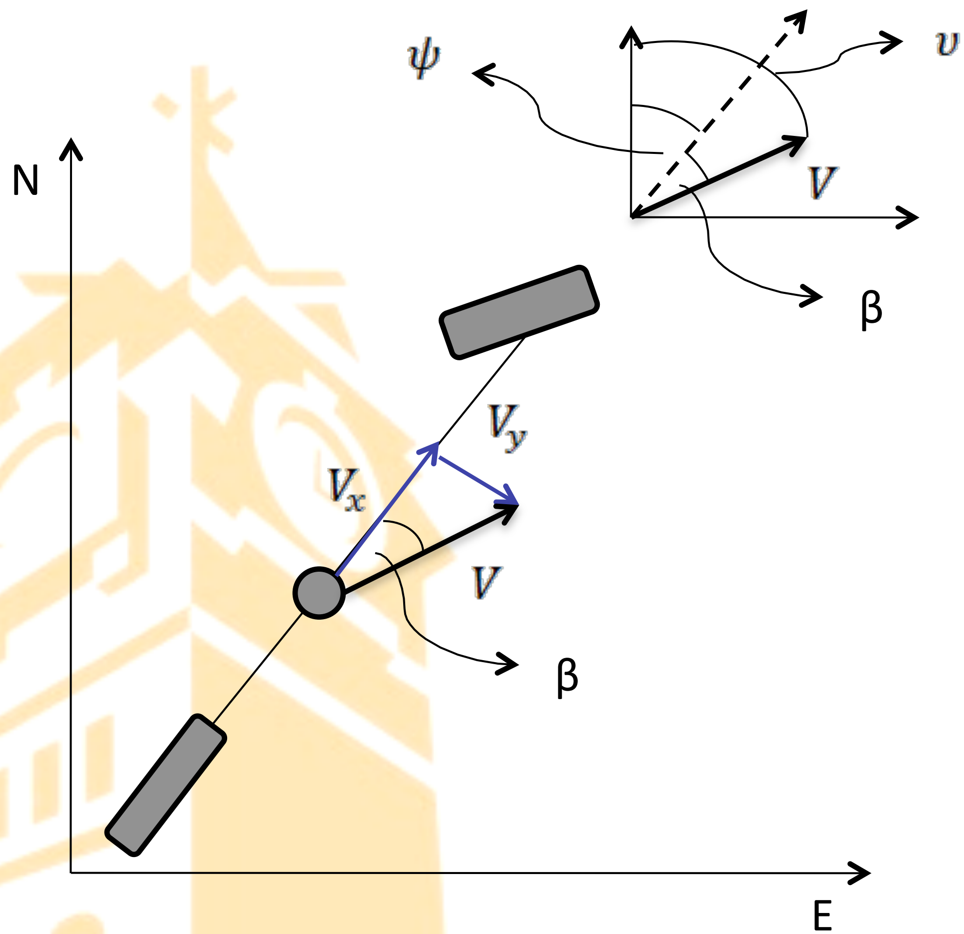


Doesn't currently exist because of lack of communication between various suppliers

What to Expect (from Literature)

- Loosely Coupled filter is not fully observable during steady driving.
  - P,V observable *(V in the NED frame, not XYZ)*
  - *Combination* of biases and attitudes observable
  - *Biases and attitudes are not independently observable* (can't separate)
    - Exception: the vertical accelerometer bias is always observable.
- Acceleration changes make the filter observable.
- Constant axial acceleration or steady turning improves the observability, but not fully.
- *These conclusions also apply to the AUNAV estimator!*

Sideslip Definitions



$$\upsilon = \beta + \psi$$

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

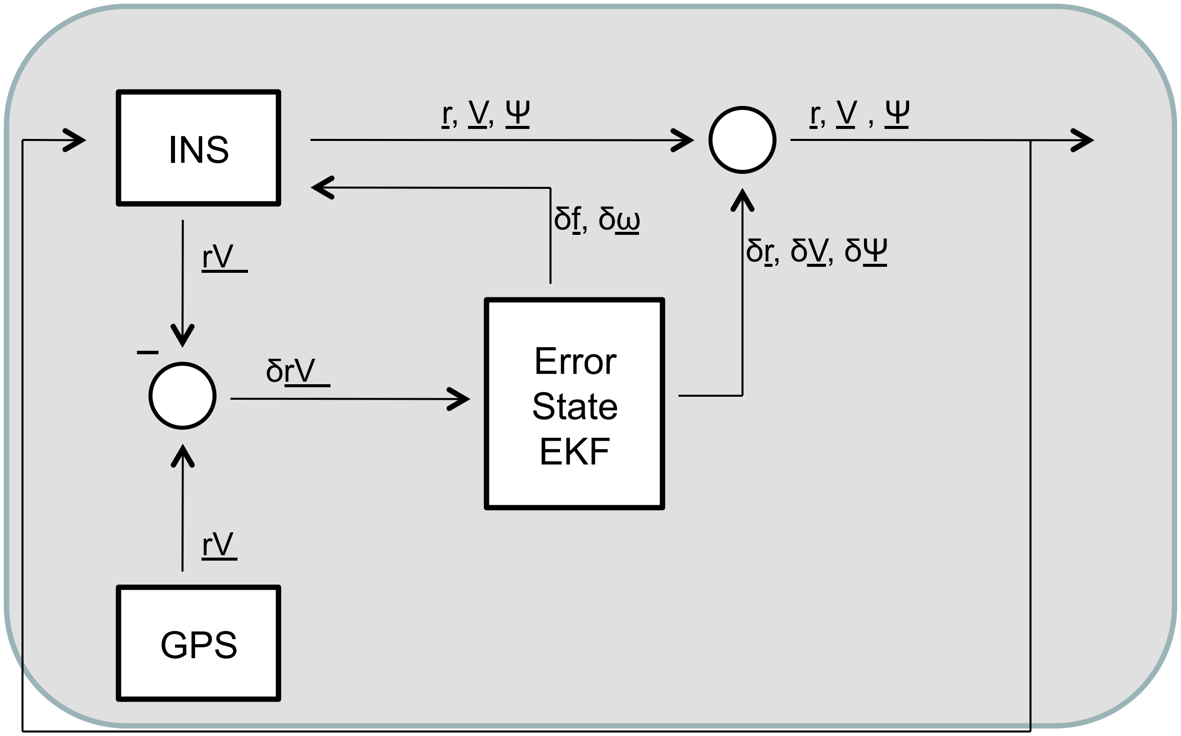
$$\beta = Sideslip$$

$$\upsilon = Course$$

$$\psi = Heading$$

Loosely Coupled Integration

- Components:
  - INS (6DOF)
  - GPS (single antenna)
  - EKF
- EKF states (15):
  - INS solution errors (9)
  - INS sensor biases (6)



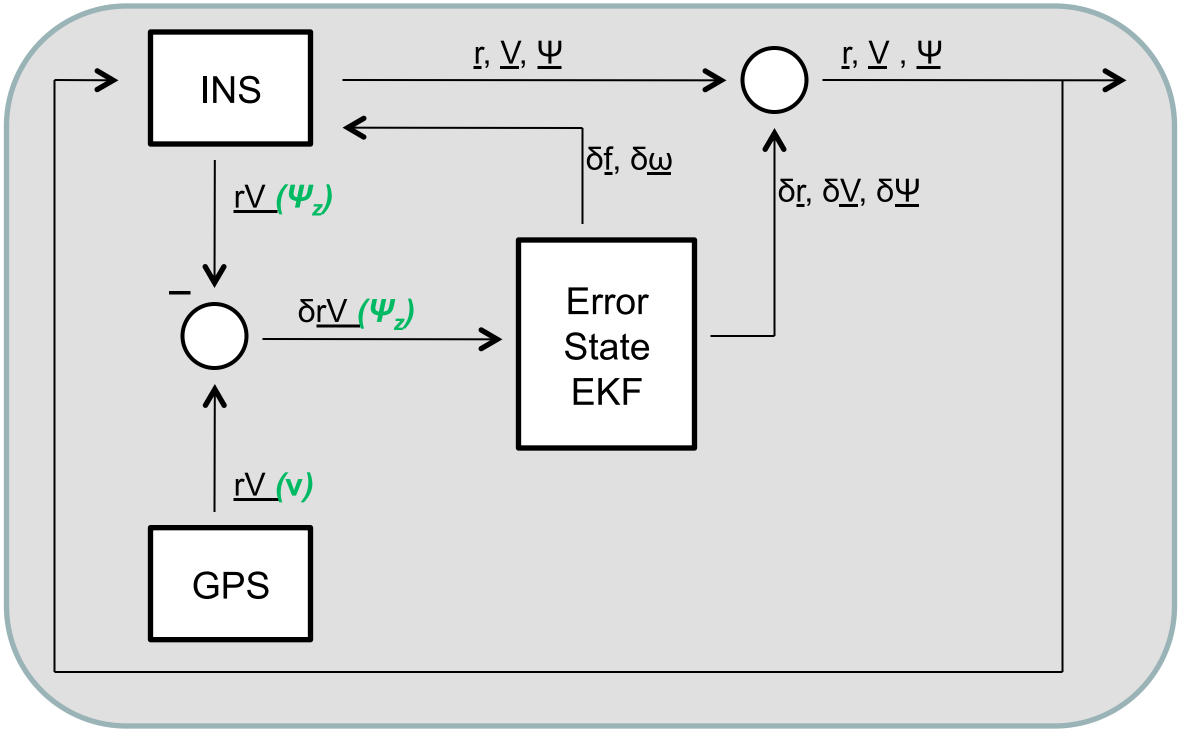
$$\delta\underline{\hat{X}} = \left[\begin{array}{ccccc} \delta\underline{\hat{r}}, & \delta\underline{\hat{V}}, & \delta\underline{\hat{\psi}}, & \delta\underline{\hat{f}}, & \delta\underline{\hat{\omega}} \end{array}\right]'$$

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

- $\underline{r}$ – position
- $\underline{V}$ – velocity
- $\underline{\Psi}$ – attitude
- $\delta\underline{f}$ – accelerometer biases
- $\delta\underline{\omega}$ – gyroscope biases

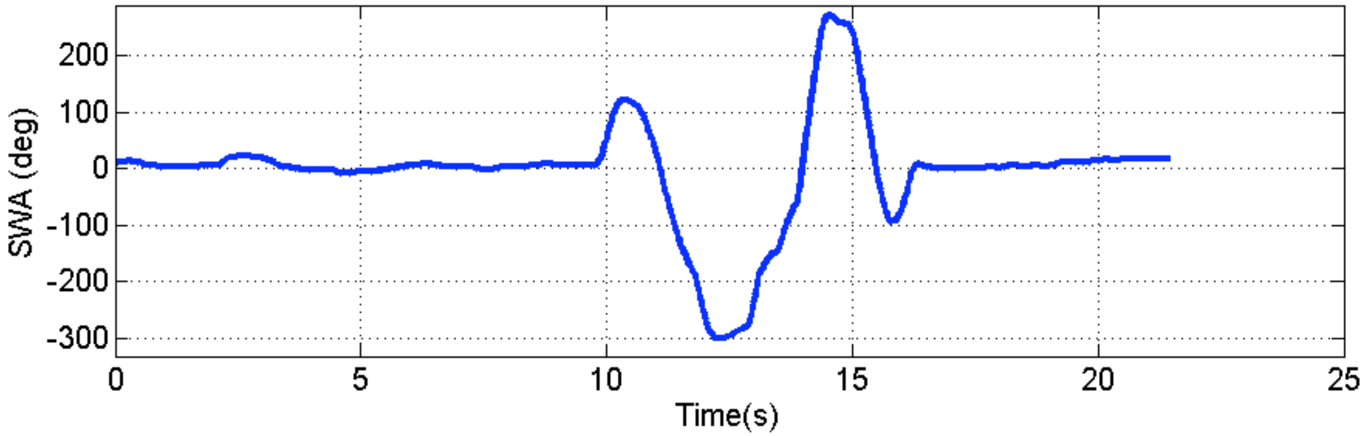
Automotive Navigation Estimator

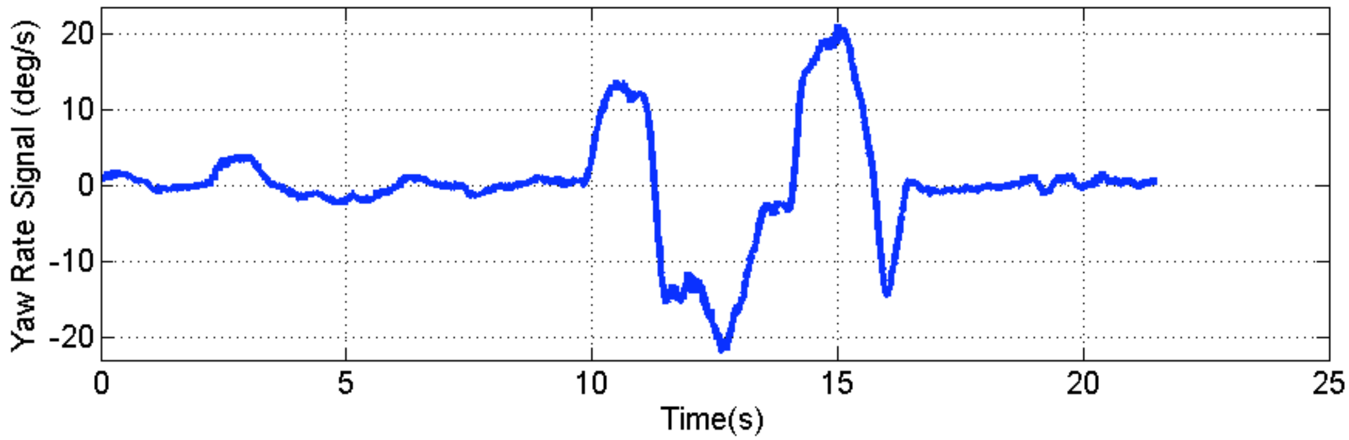
- Pitch rate gyroscope is removed.
- Yaw constraint added during periods of straight driving
  - GPS course measurement used as a yaw measurement.
- If yaw rate signal is less than some threshold for some time period, then the constraint is added.
  - Threshold, time window are tuning parameters of the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



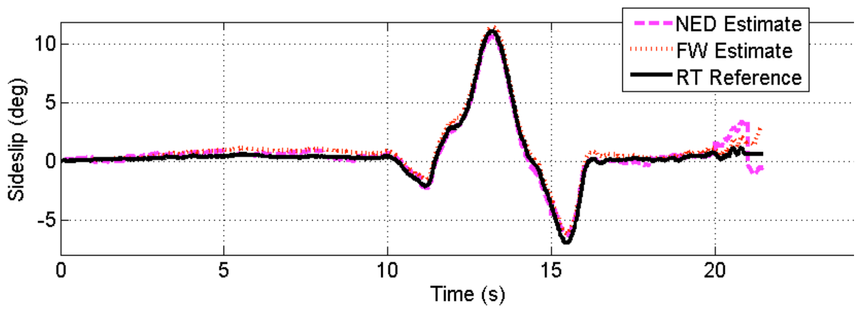
$$Y = \begin{bmatrix} \underline{r} \\ \underline{V} \\ \psi_{yaw} \end{bmatrix}_{GPS} - \begin{bmatrix} \hat{\underline{r}} \\ \hat{\underline{V}} \\ \hat{\psi}_{yaw} \end{bmatrix}$$

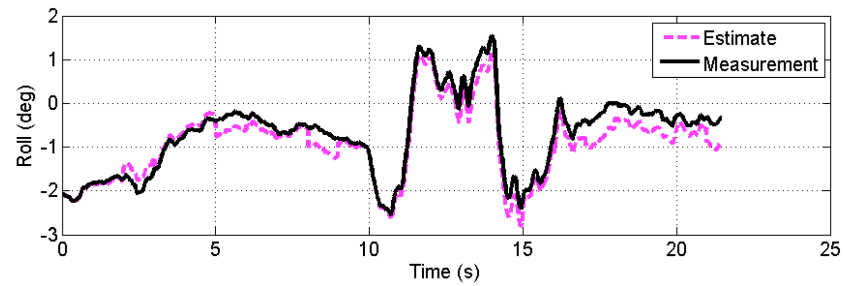
Lane Change Experiment

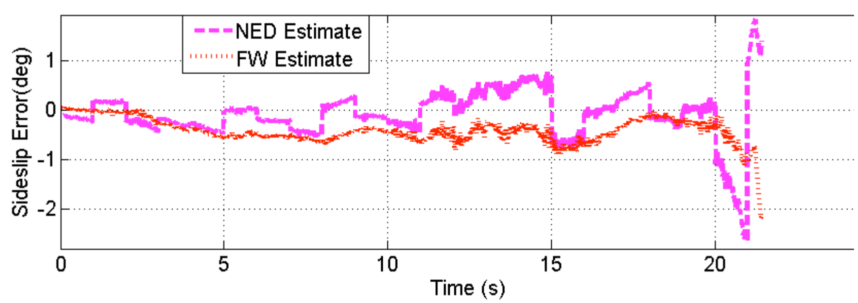


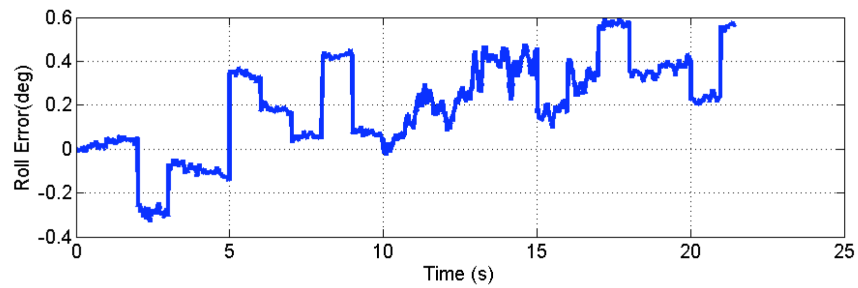


Lane Change Results









- Sideslip
- Roll

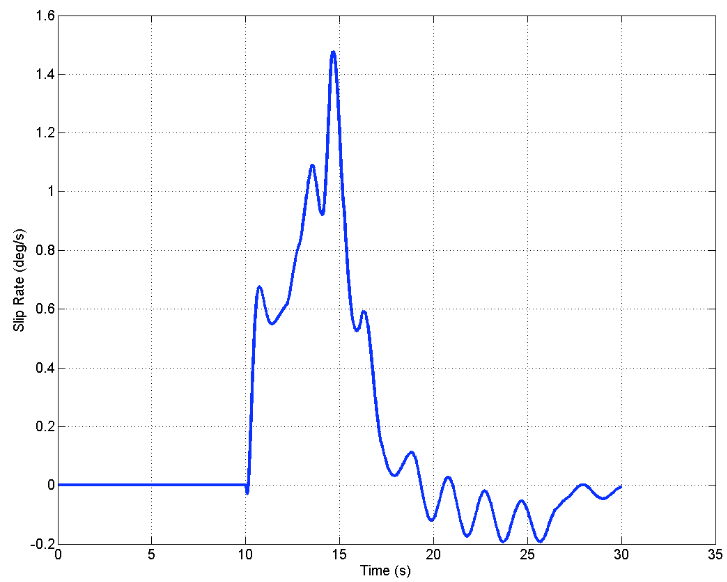
Low Rates of Sideslip Buildup

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

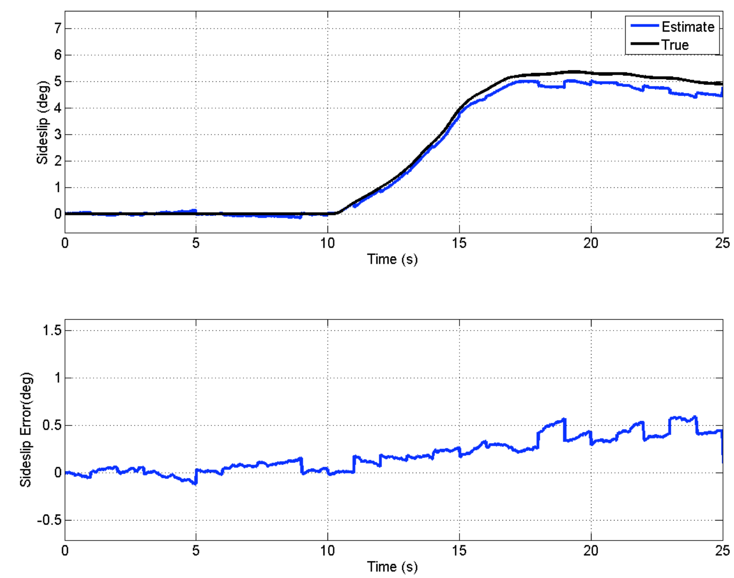
Video courtesy of
http://video.foxnews.com/v/4148911/raw-footage-lexus-gx460-rollover-risk

Low Rates of Sideslip Buildup

- The AUNAV estimator is able to accurately estimate the sideslip for the duration of the simulation.
- The estimate does begin to drift slowly once the dynamics settle out.

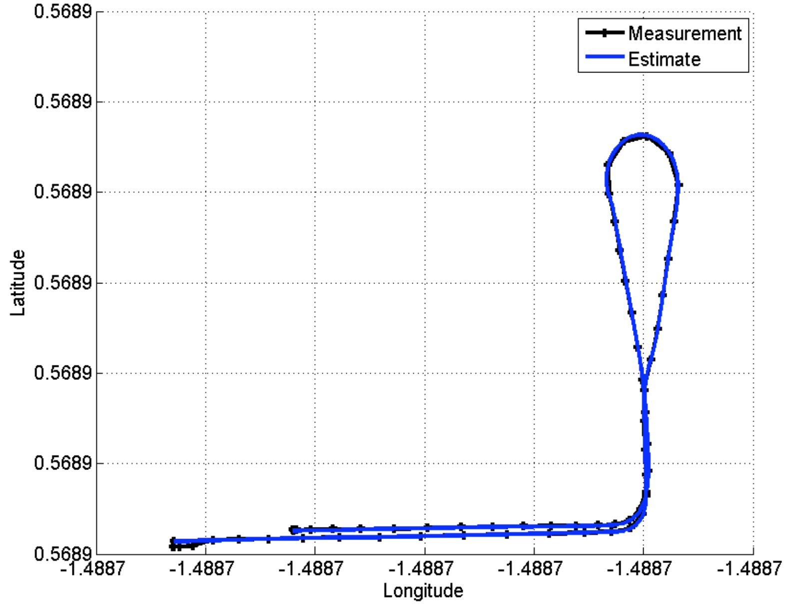


Simulation Slip Rate



Simulation Performance (Sideslip and Sideslip Error)

Results: Dynamic



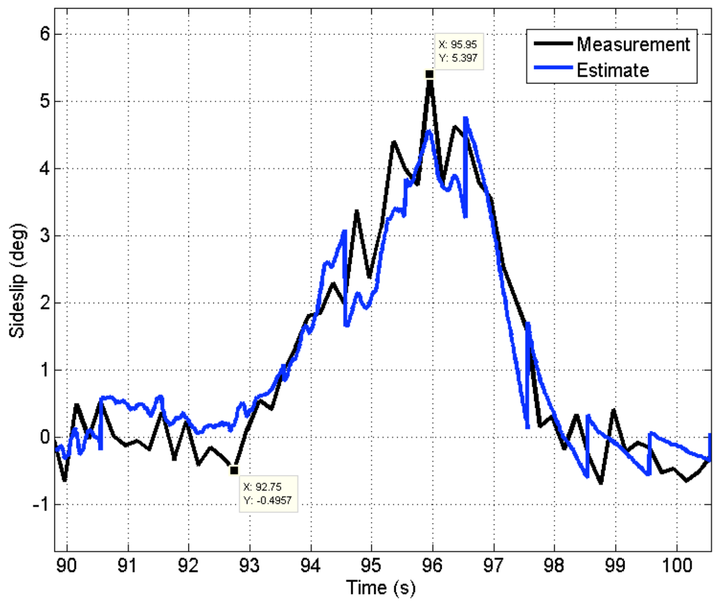
- NCAT skid pad
- Maneuver:
  - Straight
  - Turn uphill
  - Straight
  - Aggressive turn
  - Straight
  - Turn downhill

Low Rates of Sideslip Buildup

- Average rate of sideslip for third turn of the dynamic experiment is 1.8 deg/s.

- AUNAV estimator is able to accurately estimate the sideslip during this time.

- Conclusion: The AUNAV estimator can estimate sideslip at rates as a low as ≈ 1.8 deg/s.



Experimental Performance

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Integrating GPS with other on-board vehicle sensors

VEHICLE LANE POSITIONING

Need for Lane Level Positioning

- Vehicle lane departure – major cause of highway fatalities
  - 42,000 roadway fatalities in 2004
  - 50% resulting from vehicle lane departure
- ITS Research
  - 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
    - Keep vehicle in the intended lane
    - Help prevent intersection accidents


Photo courtesy of autoblog


http://safety.fhwa.dot.gov

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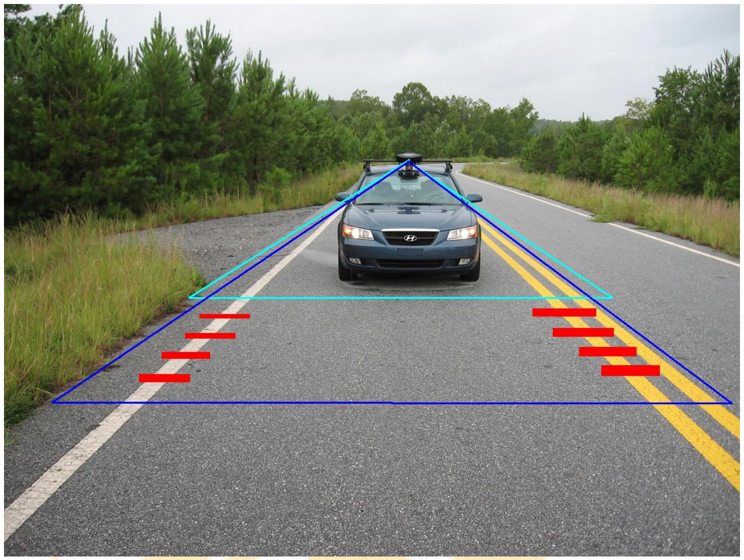
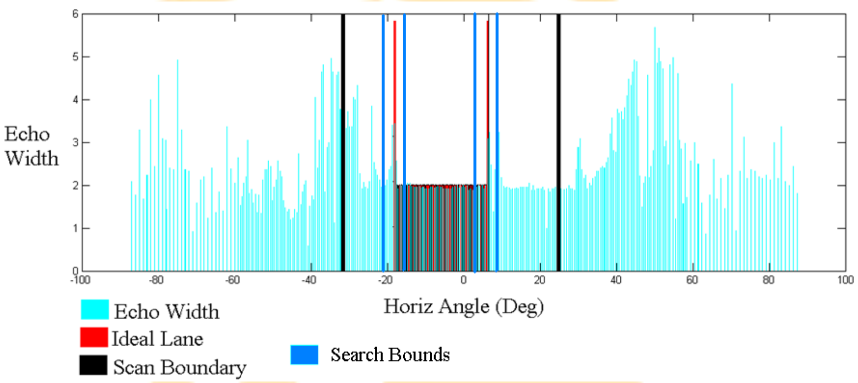
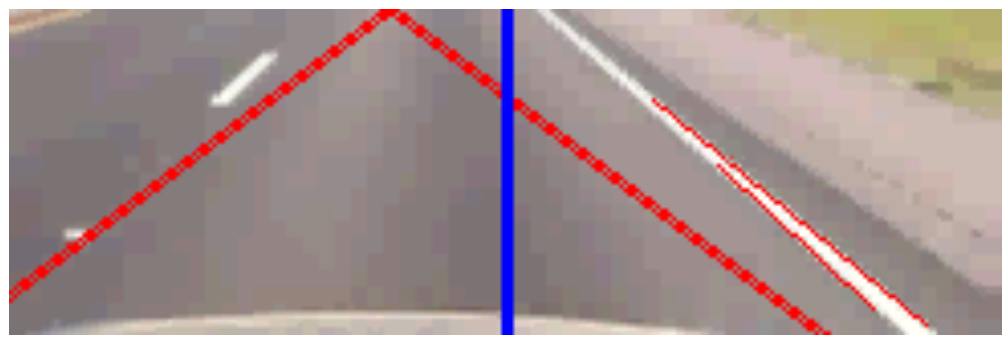
LiDAR and Vision based Lane Detection

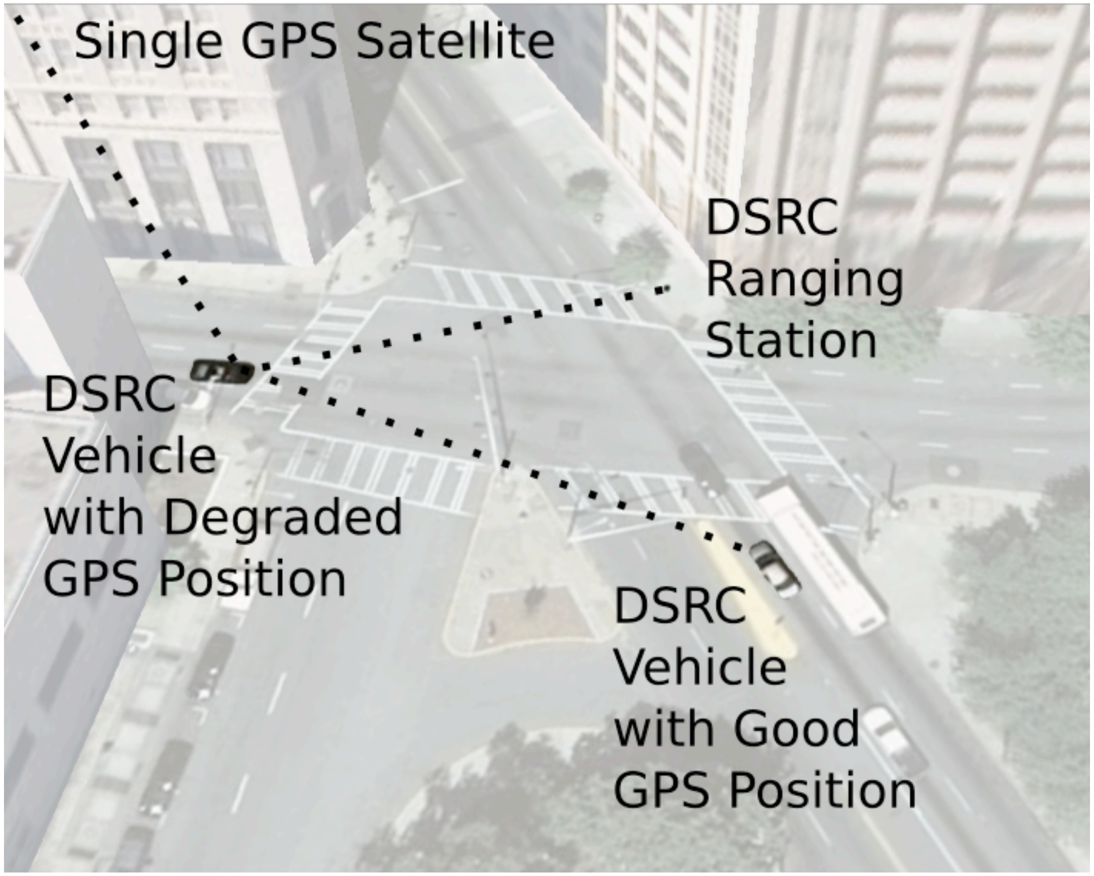






Collaborative/Assisted GPS

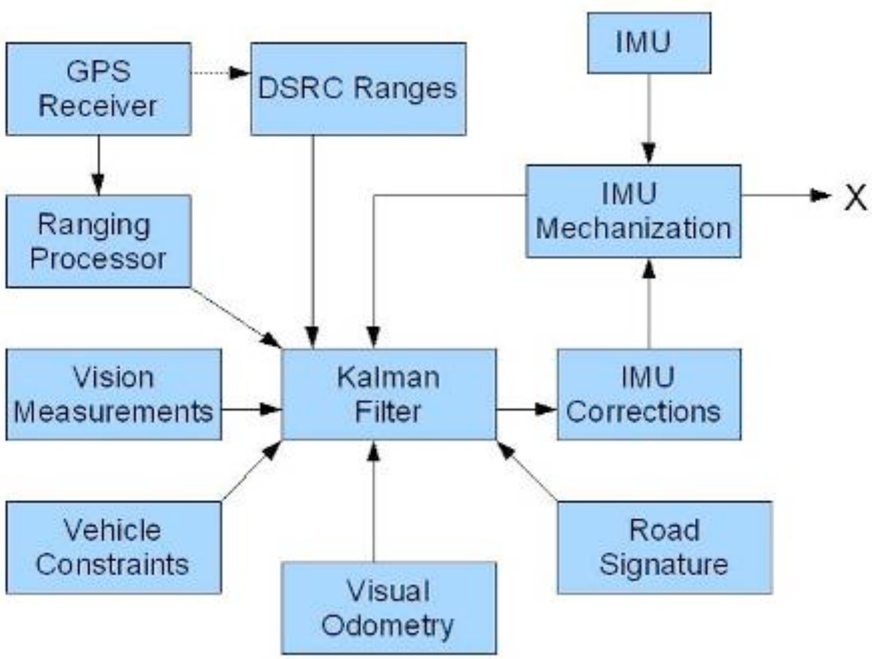
- Some scenarios provide poor GPS position
- Augment navigation with ranges to known positions
- Share GPS information for improved tracking and TTFF
- Provides more seamless operation
- Combine measurements
  - Visual odometry
  - Road signature
  - Map databases



DSRC -> Dedicated Short Range Communication
- WiFi like signal (802.11p, 5.9 GHz)
- Developed for V2V and V2I Communications

System Overview

- The goal of this project is to design a system that can track lateral lane position on a highway
- A Kalman Filter is used to blend measurements from an IMU and 3 other sensors.
  - Kalman Filter updates when a GPS, camera, or LiDAR measurement is received
  - GPS measurements must be rotated into road frame
- 3 types of measurement updates to KF
  - GPS/Map
  - Camera
  - (Light Detection and Ranging) LiDAR
- Include other available inputs
  - DSRC Ranges
  - Road Signature
  - Visual Odometry
  - Vehicle Constraints



Lane Detection and Lateral Distance Estimation

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Lateral Distance Estimation

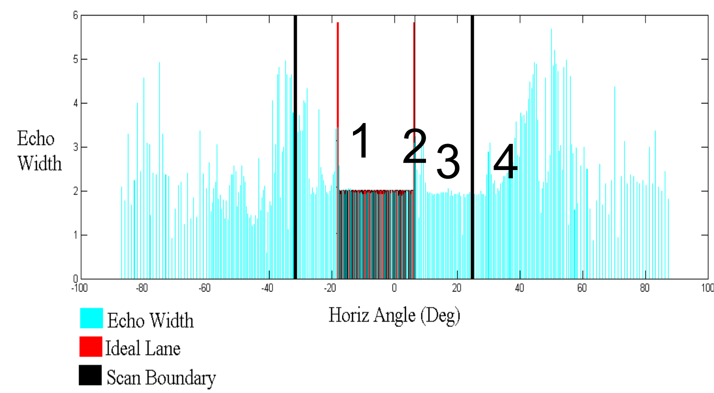
- Sensor fusion with camera and LiDAR for robustness of lateral distance measurement
- Used for lane level localization in multipath environments

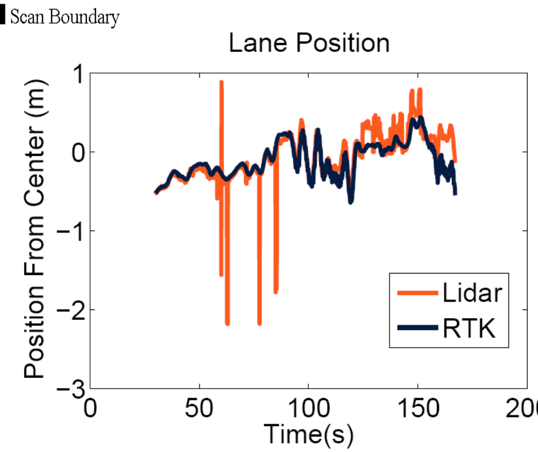
Lane Detection Sensors

- Logitech QuickCam Pro 9000
- IBEO ALASCA XT laser scanner
- both sensors have a update rate of 10Hz

Lidar Lane Detection

- Bound Scan Data
- Find minimum RMS error
- Check for false positive
- Filter data and weighted averaging
- Final Position

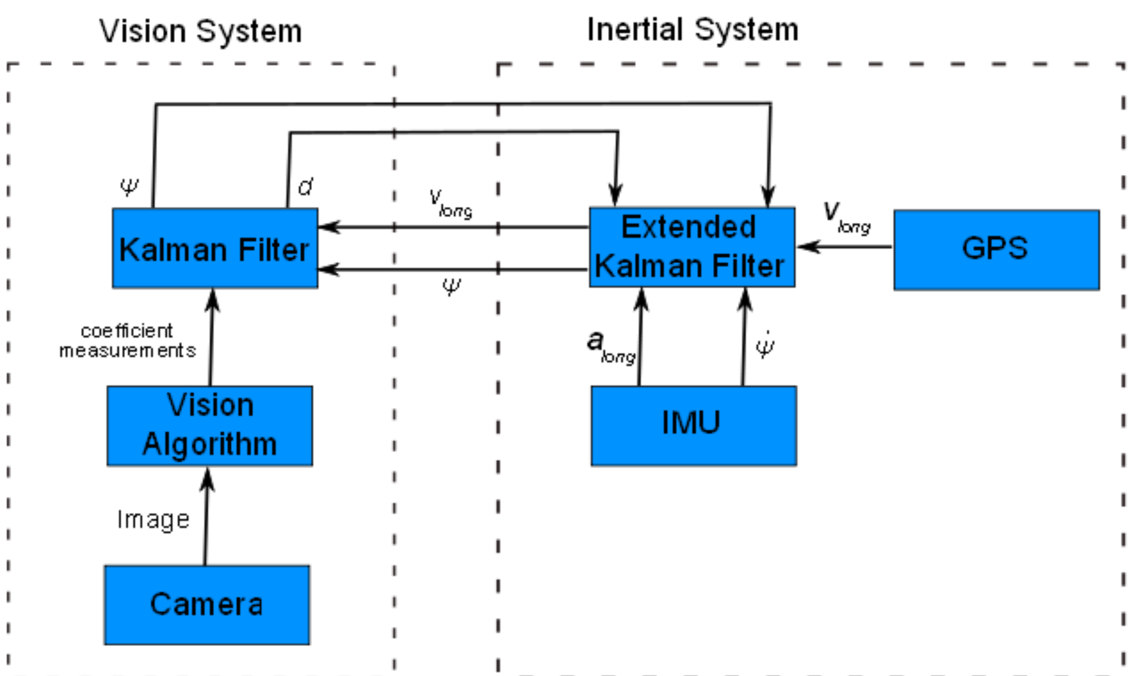




	Avg. Lane Width Error (m)	Std of Error (m)	Detection (%)
Highway	0.075	0.233	94.7
Yellow & White	0.042	0.272	81.7
Gravel on Surface	0.129	0.215	97.4
Grass Bordering	0.169	0.329	76.86

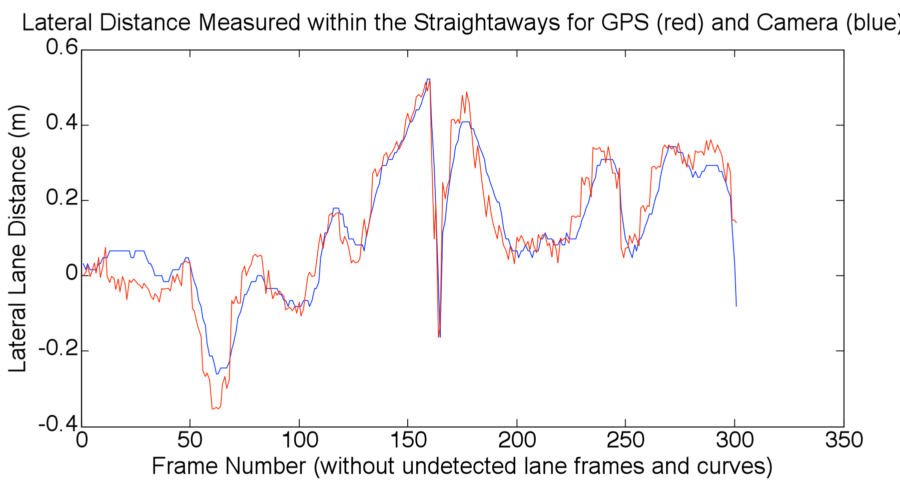
Vision / INS

- Commerical 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
- Integration of other sensors can provide lateral distance in the road when camera vision fails

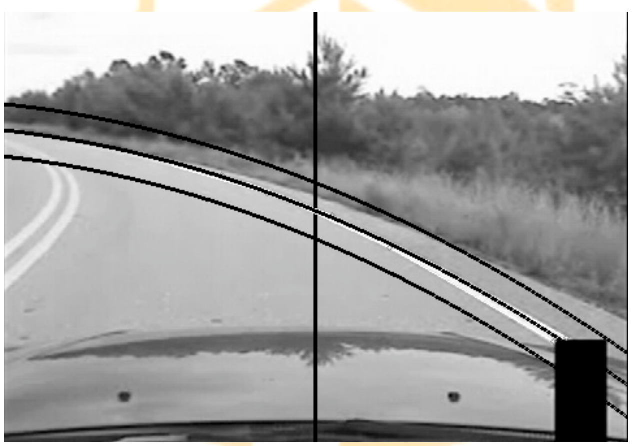


Lane Detection with Camera

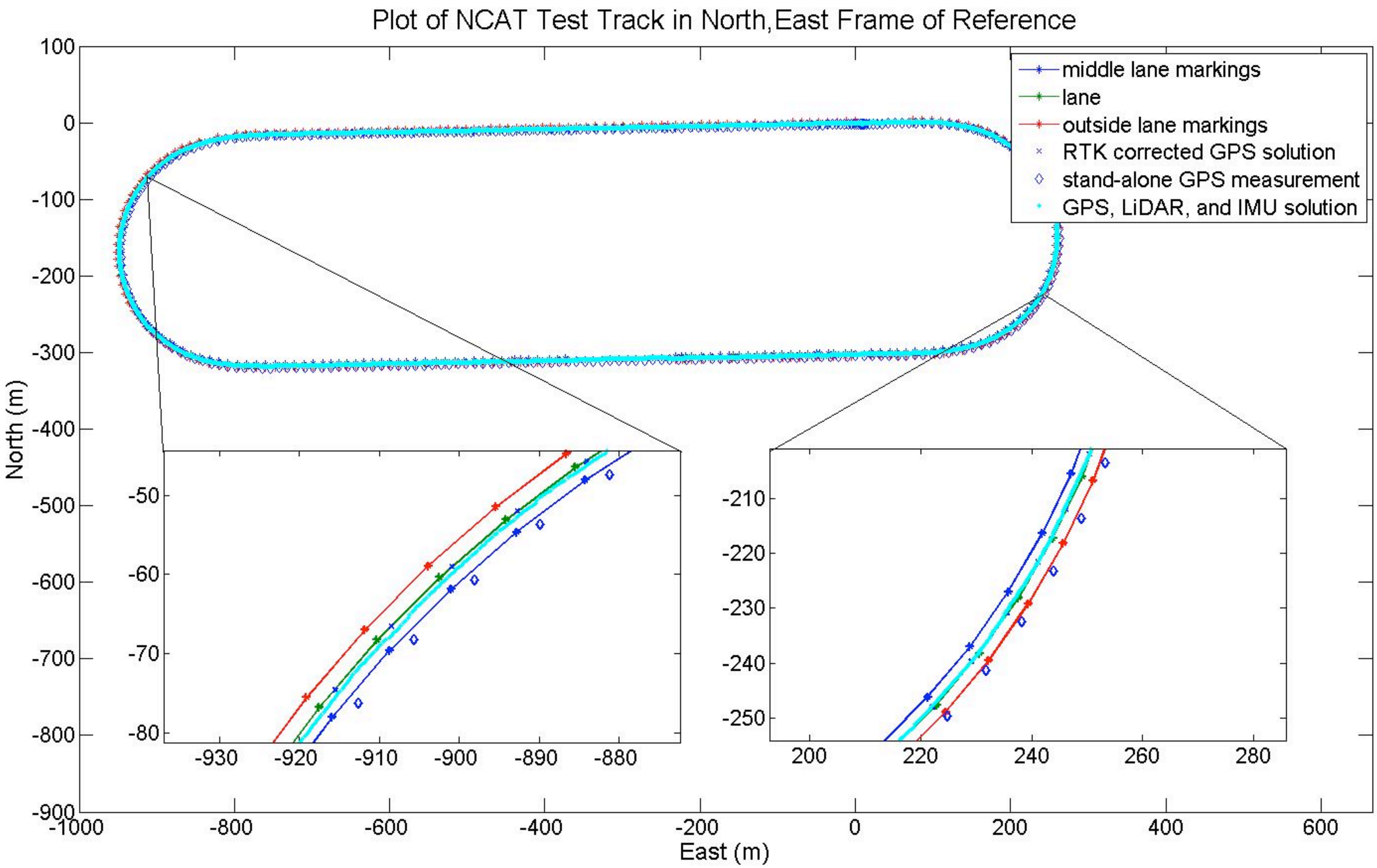
- Thresholding / Edge Detection
- Hough Transform
- Least Squares Interpolation
  - Interpolate 2nd order polynomial as model for lane
- Kalman filter
  - Estimate polynomial coefficients
- Polynomial Bounds
  - Lines for subsequent frames lie within polynomial boundary curves



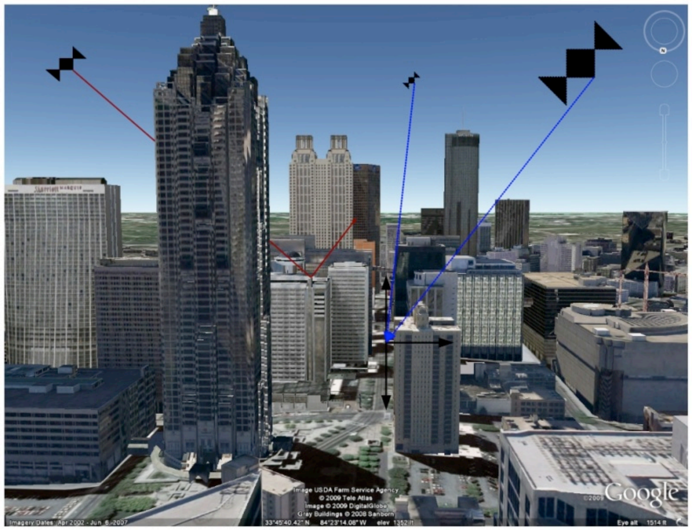
<10 cm accuracy on straight roads



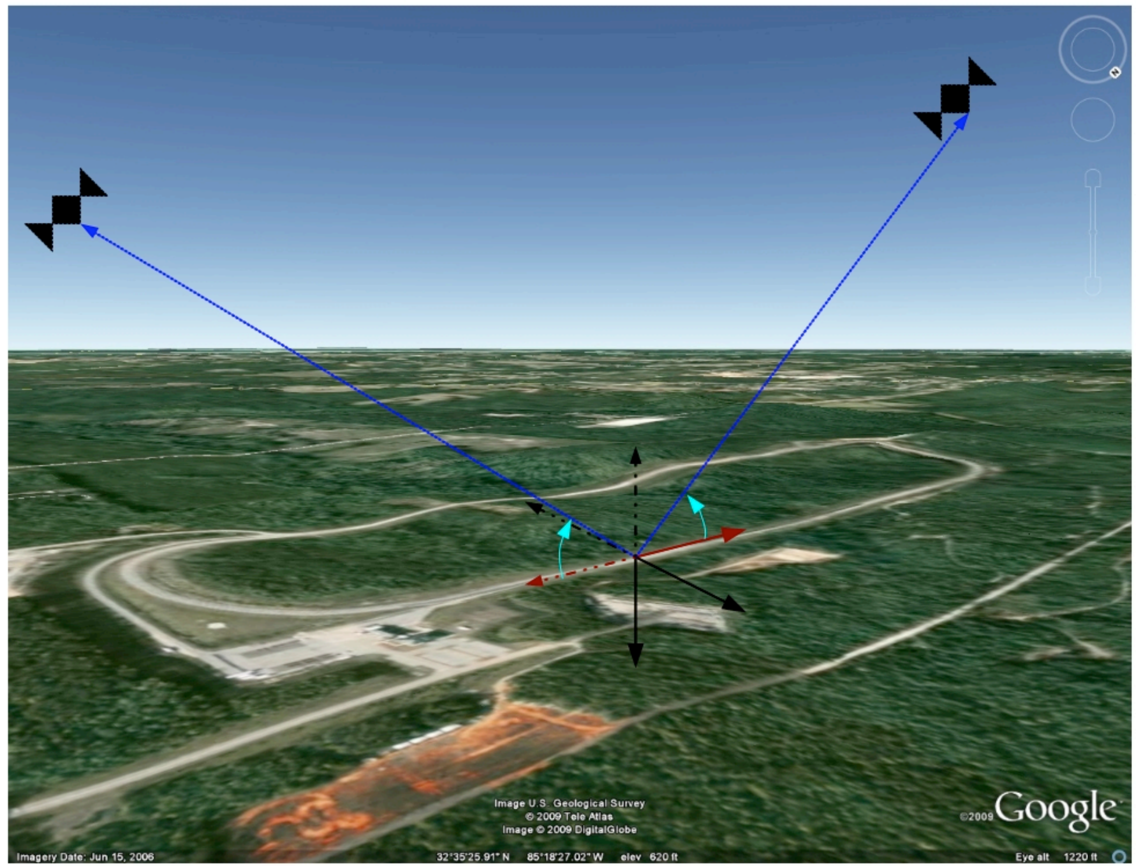
GPS / Camera / LiDAR / INS



Positioning w/ Limited GPS Satellites



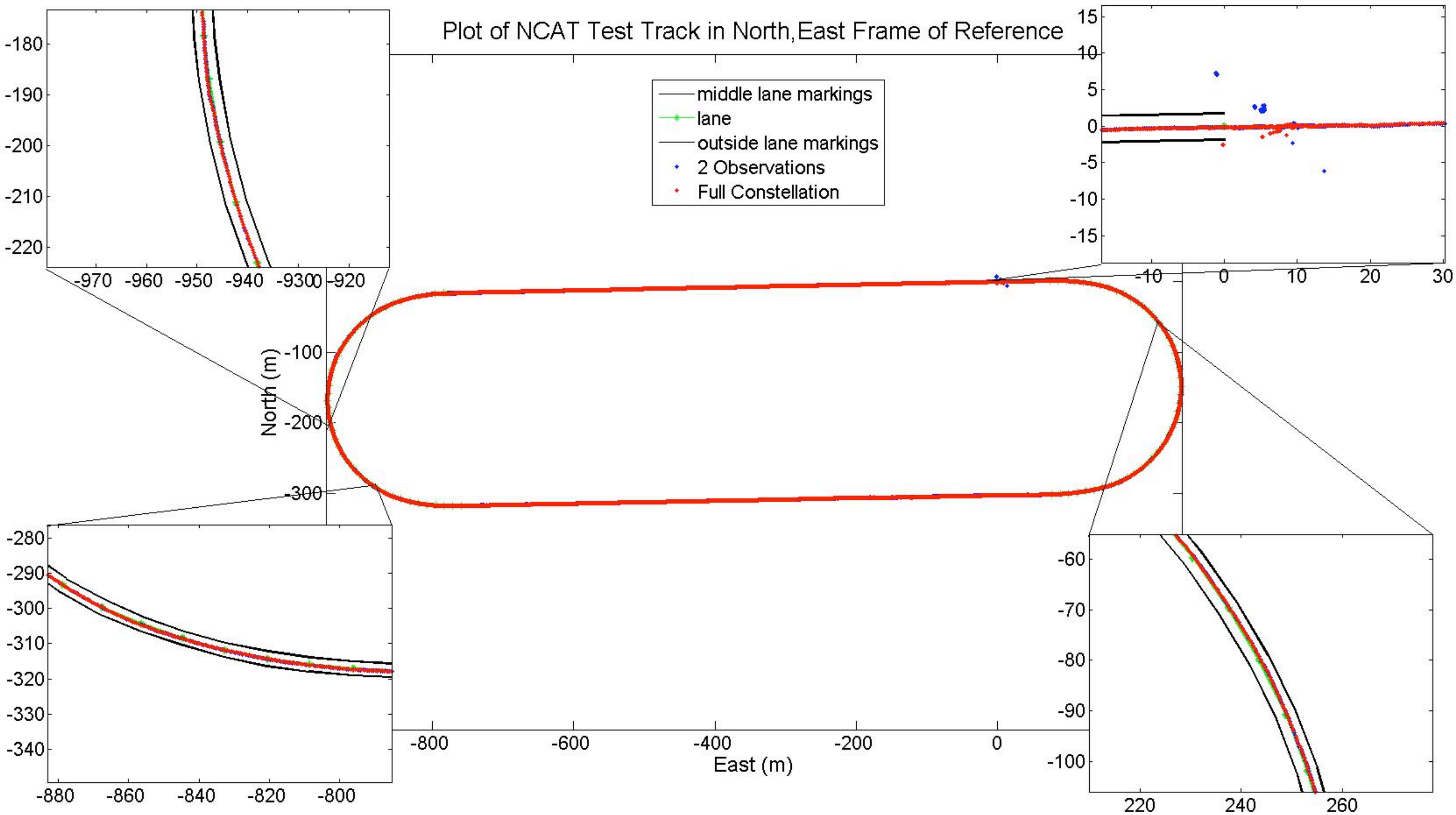
Urban Environment where only a few GPS Satellites may be available



Validated at Auburn's NCAT Test Track using:

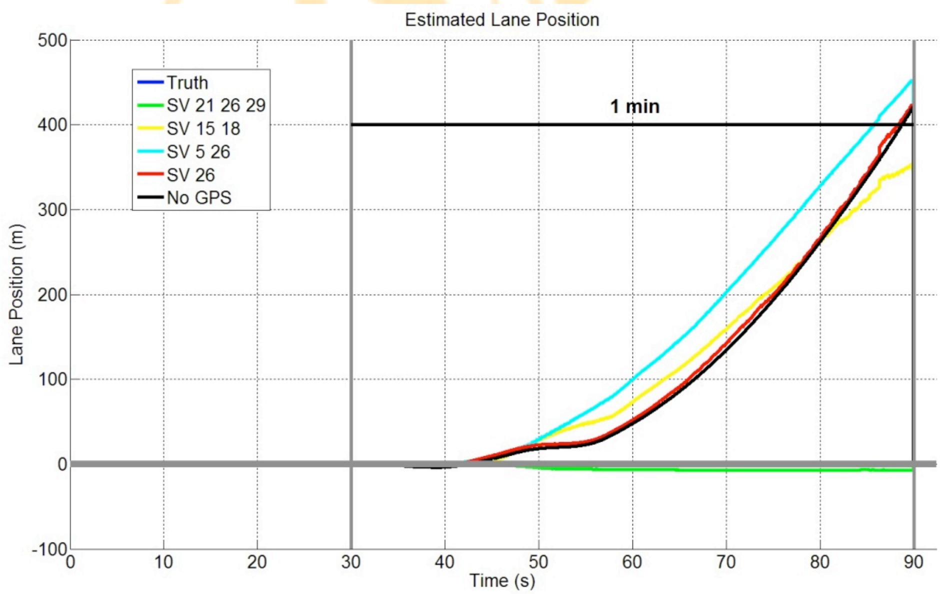
- Lateral Constraint
- Vertical Constraint
- 2 GPS Satellites

Positioning Results

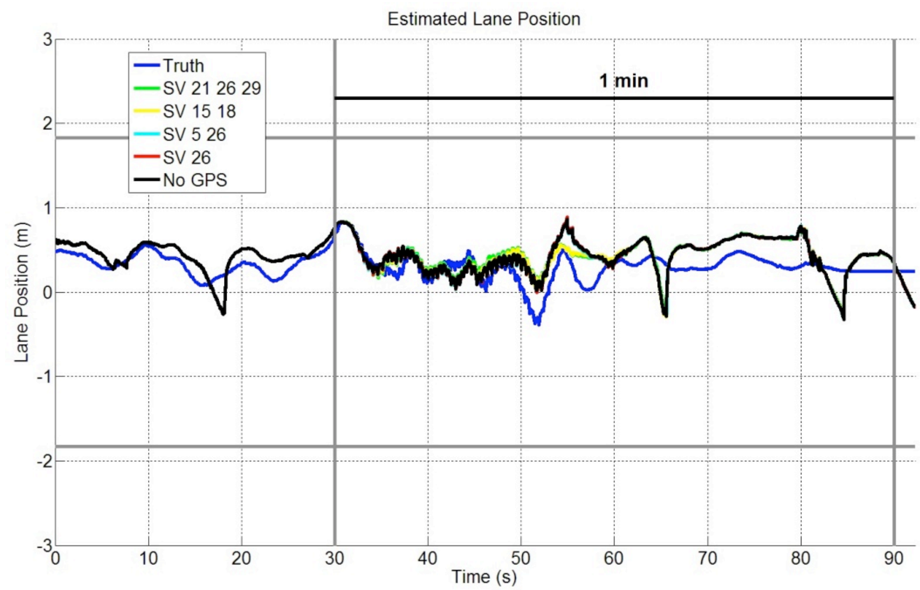


Estimated Lateral Error with Limited GPS Observations

- Plots show Estimated Lane Position without vision (left) and with vision (right) for several different satellite failure cases
- All Satellites excepts ones listed in legend are turned off 30 seconds into the run and turned back on after 1 min
- Without vision, the lane position estimate is not only biased but also drifts when less than 4 GPS observations are available
- With vision, the lane position estimate is unaffected by the number of GPS observations available



Without Vision



With Vision

Estimated Longitudinal Error with Limited GPS Observations

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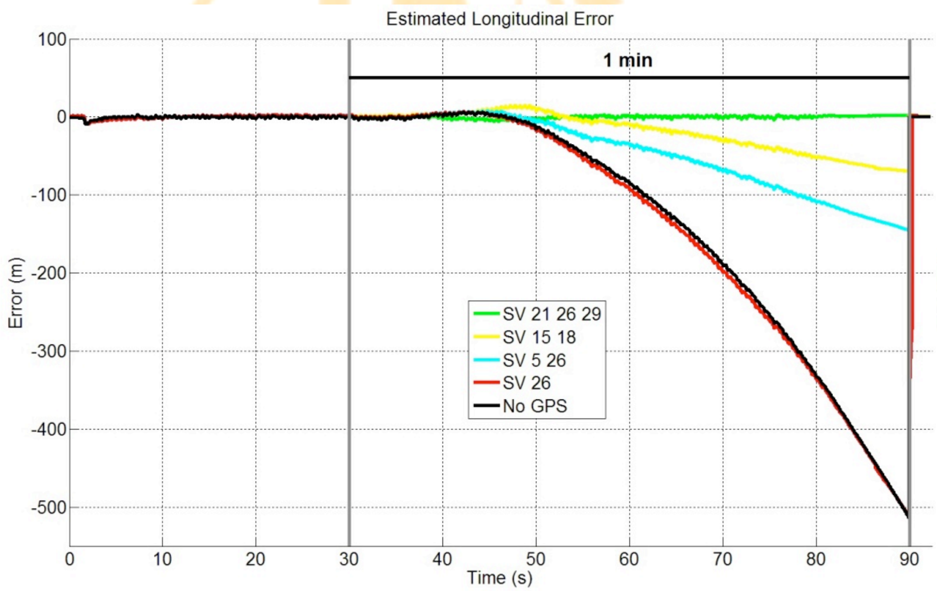
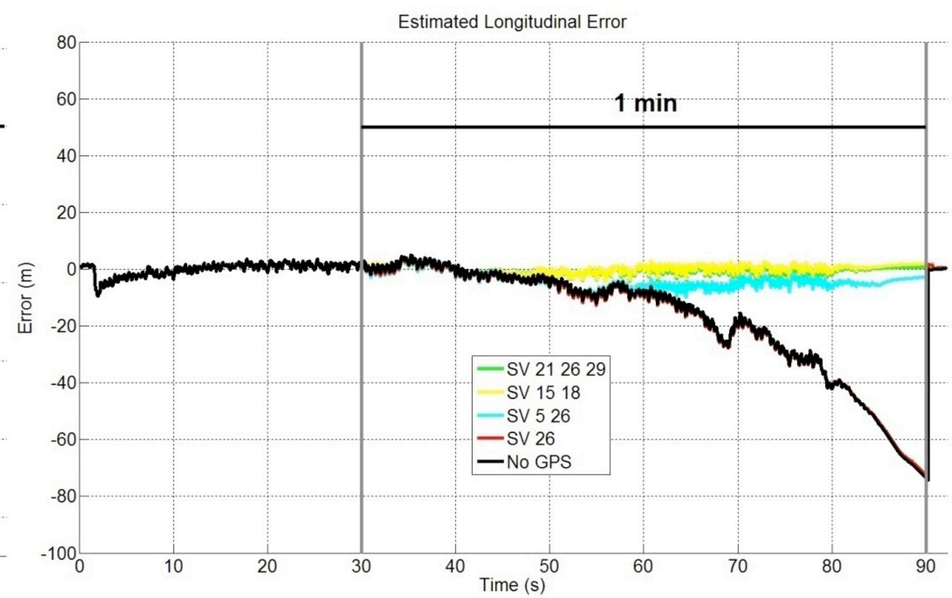
- Plots show estimated longitudinal lane error without vision (left) and with vision (right) for several different satellite failure cases
  - Longitudinal lane error is error in the axis parallel with the direction of travel (perpendicular to the lane position axis)
  - Error is based of RTK GPS Solution
- All Satellites excepts ones listed in legend are turned off 30 seconds into the run and turned back on after 1 min
- Without vision, the longitudinal lane error continuously grows when less than 4 GPS observation are available
- With vision, the longitudinal lane error growth is contained as long as 2 GPS observations are available
- Also with vision, there is no noticeable improvement using 1 GPS observation over having no GPS

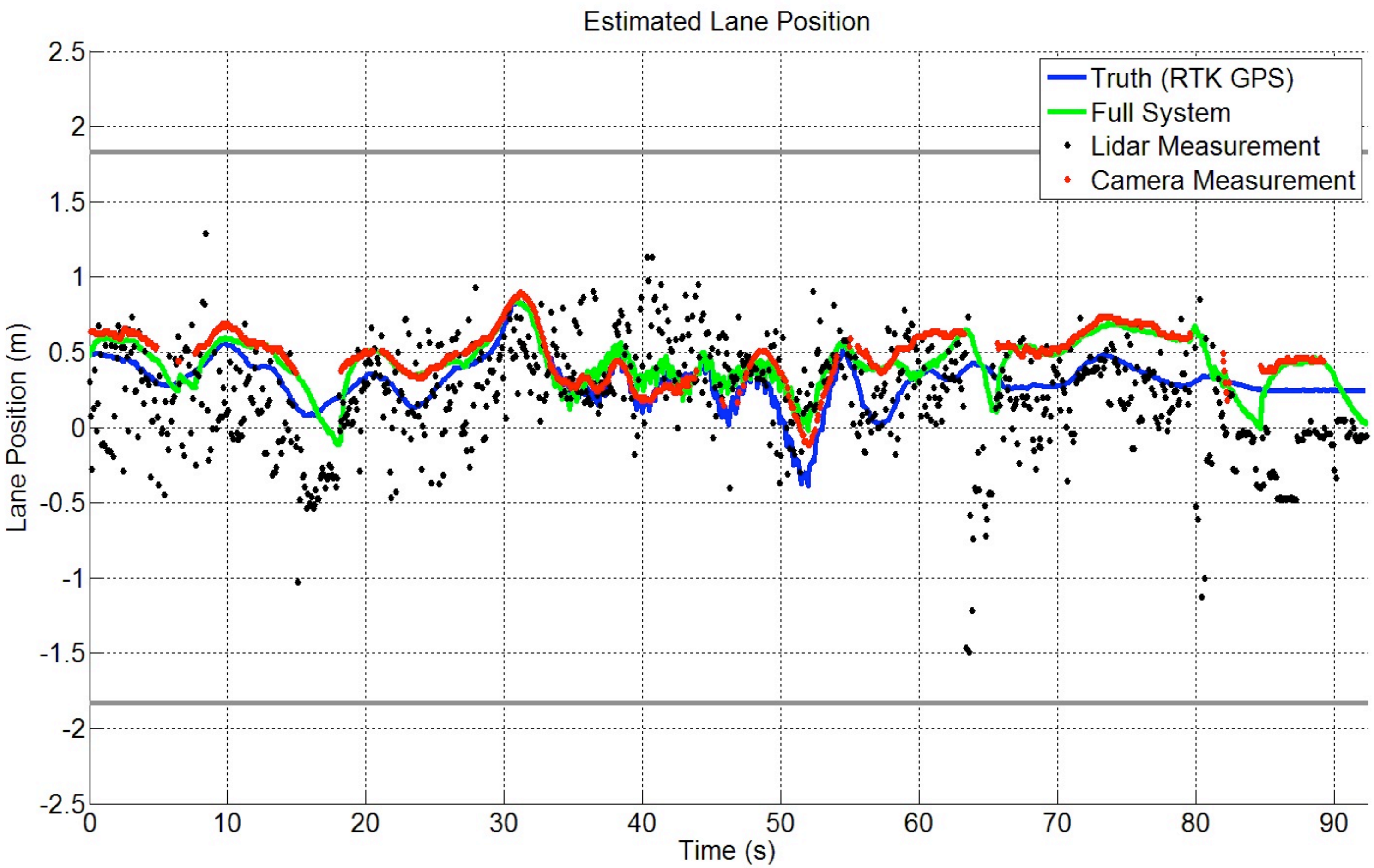


Without Vision



With Vision

Lane Positioning Results- Full System



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