GPS and Its Use for Vehicle Control

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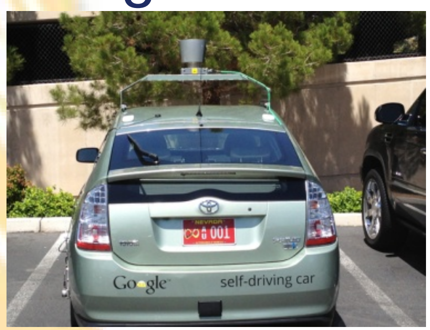
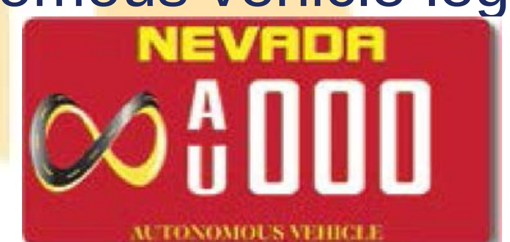
GPS and Vehicle Dynamics Lab

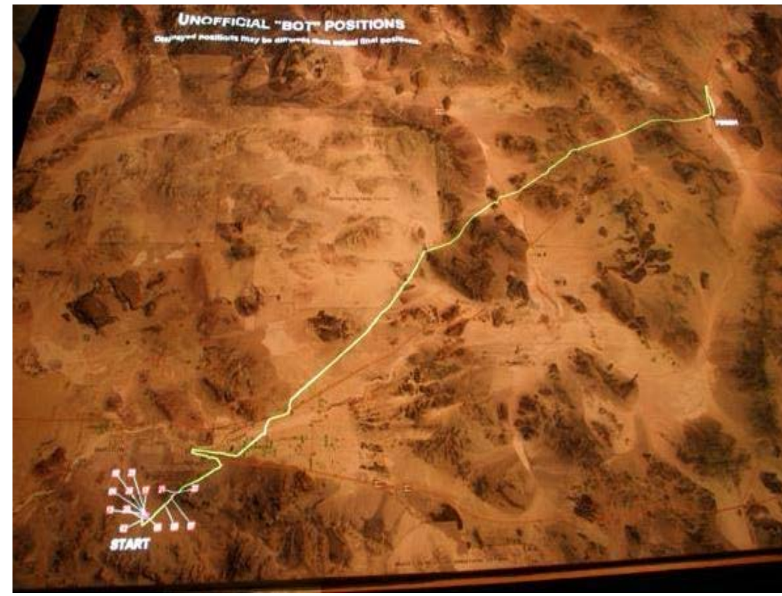
Autonomous Driving

- 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



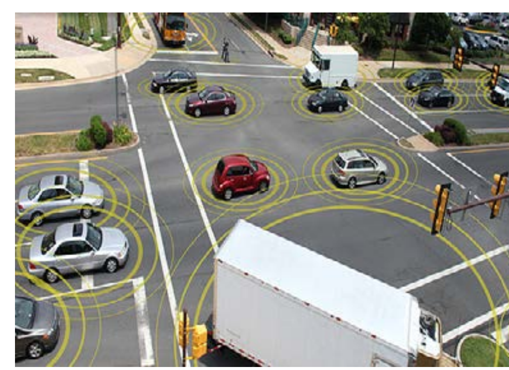
- States have started passing autonomous vehicle legislation





Need for Vehicle Automation

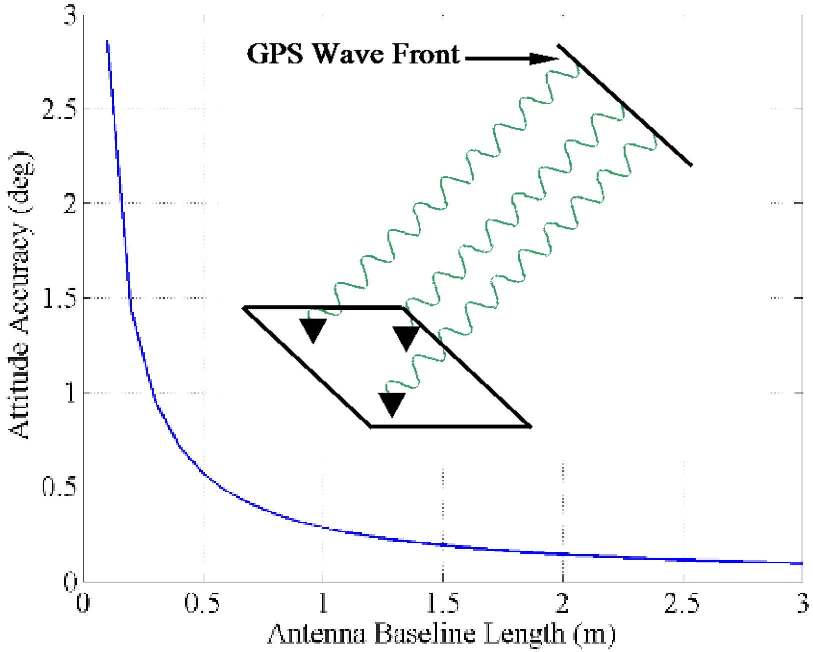
- Vehicle accidents are a top cause of fatalities
  - Approximately 42,000 roadway fatalities/year
  - 50% resulting from vehicle lane departure
- Increase in technology, processing power along with decrease cost of new sensors is leading to more intelligence in vehicles
  - Lane Departure Warning (LDW)
  - Adaptive Cruise Control (ACC)
  - Advanced Driver Assistance Systems (ADAS)
    - Volvo's City Safe (anti-collision)
    - Inifiniti'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

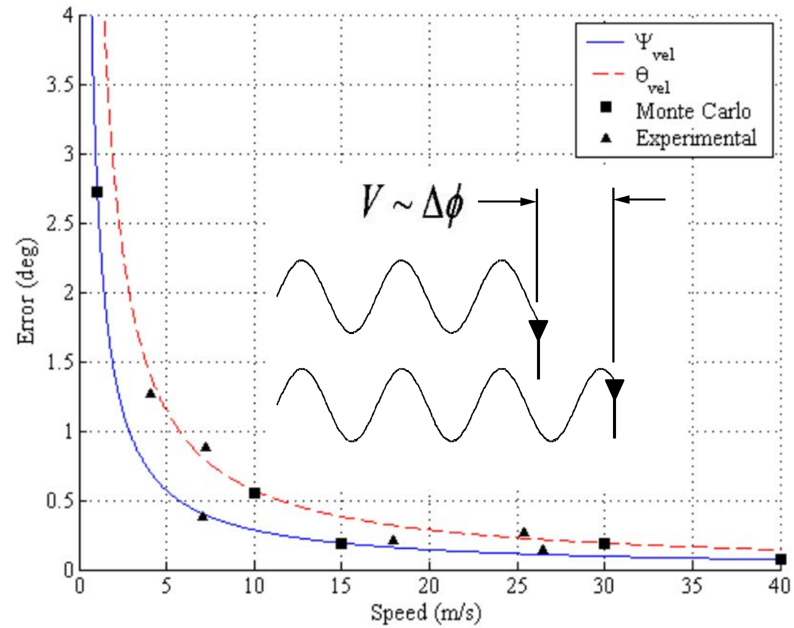


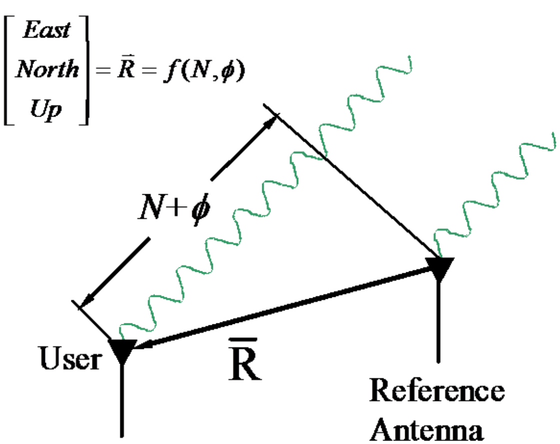
Control of Vehicles

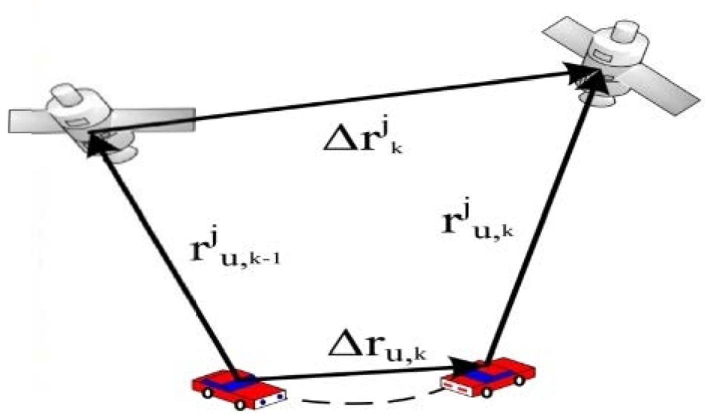
- Need to know vehicle:
  - Position (lane level), Velocity, Direction of travel, Orientation
    - LDW- Lane Departure Warning
      - Send warning to driver if lane is being approach
      - Helps to prevent un-intended lane departure
    - ADAS – Advanced Driver Assistance Systems
      - Lane Keeping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







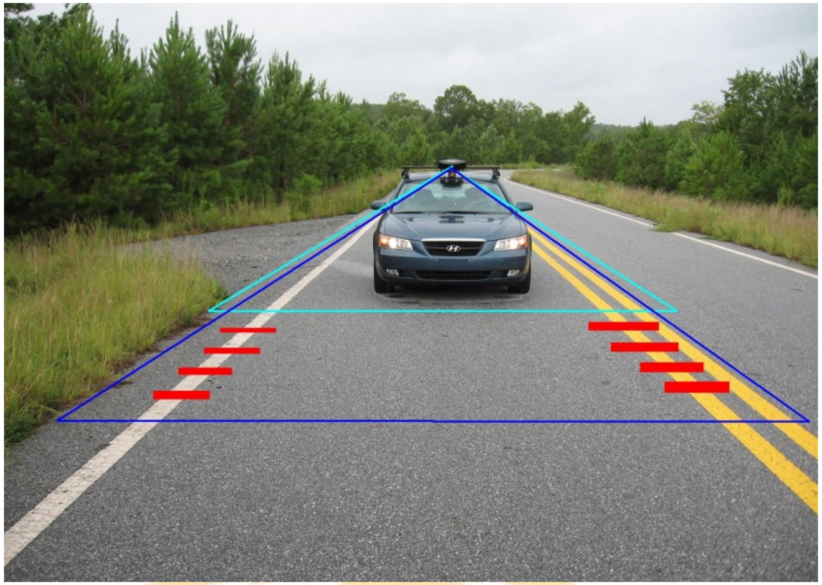


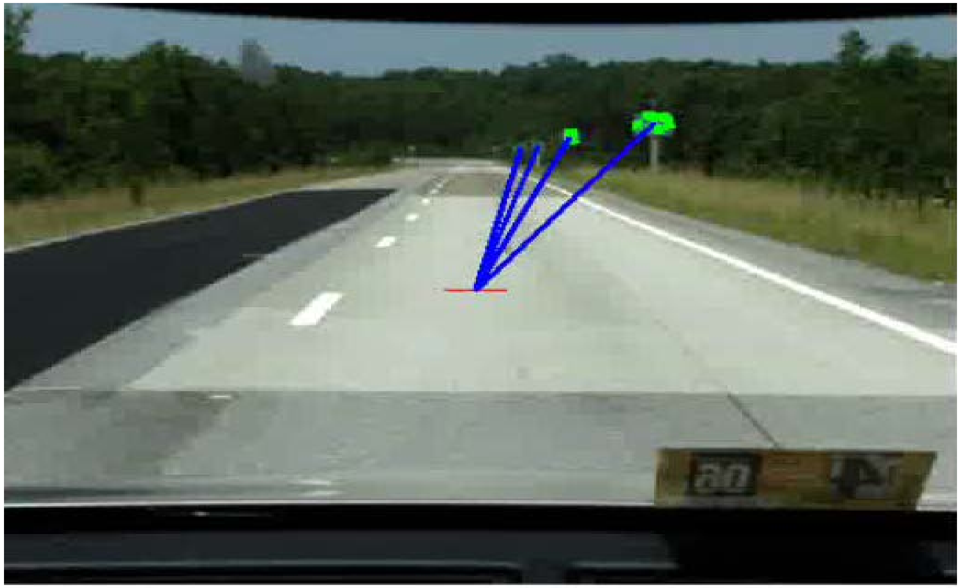
Vehicle Communications

AUBURN UNIVERSITY

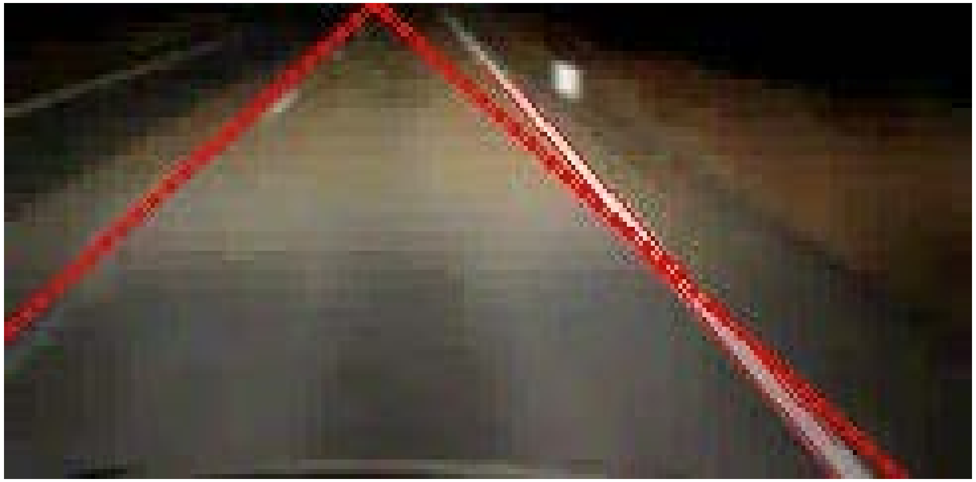
- V2X
  - Vehicle to Vehicle
  - Vehicle to Infrastructure
- Dedicated Short Range Communications (DSRC)
  - IEEE 802.11p
    - Wifi like signal
- Basic Safety Message (BSM)
  - Contains position and time
- Crash Avoidance Metrics Program (CAMP)
  - Currently using GPS for BSM
  - Recently Complete a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

BasicSafetyMessage (SAE j2735-2009)		
name	bytes	note
msgCnt	1	
id	4	
secMark	2	# of milliseconds
lat	4	latitude
long	4	longitude
elev	2	elevation
accuracy	4	
speed	2	Speed *and* transmission
heading	2	degrees
angle	1	Steering wheel angle
accelSet	7	Longitude: meters/second^2
		Latitude: meters/second^2
		Vertical: G
		YawRate: degree/second
brakes	2	On/off statuses for different brakes
size	3	Vehicle’s size information
extensions	-	Optional; variable length



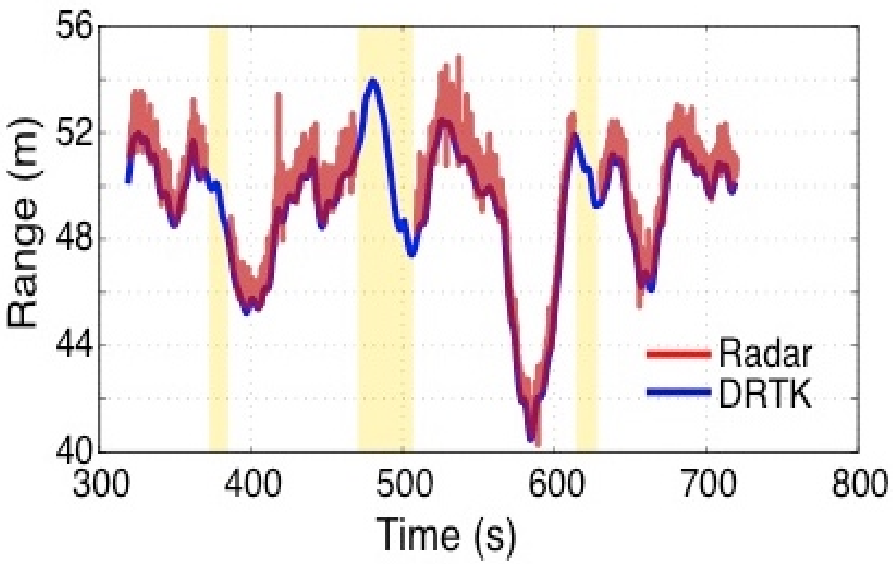



Setup
DAQ
Test CAN
LDW
RIGHT
LEFT
Vehicle
RPM:
YAW:
LAT:
ANG:
CRV:
RMC Data
Messages
UTC:
Date:
Status: A
Lat:
Long:
Vel:
Track:
CPU Time



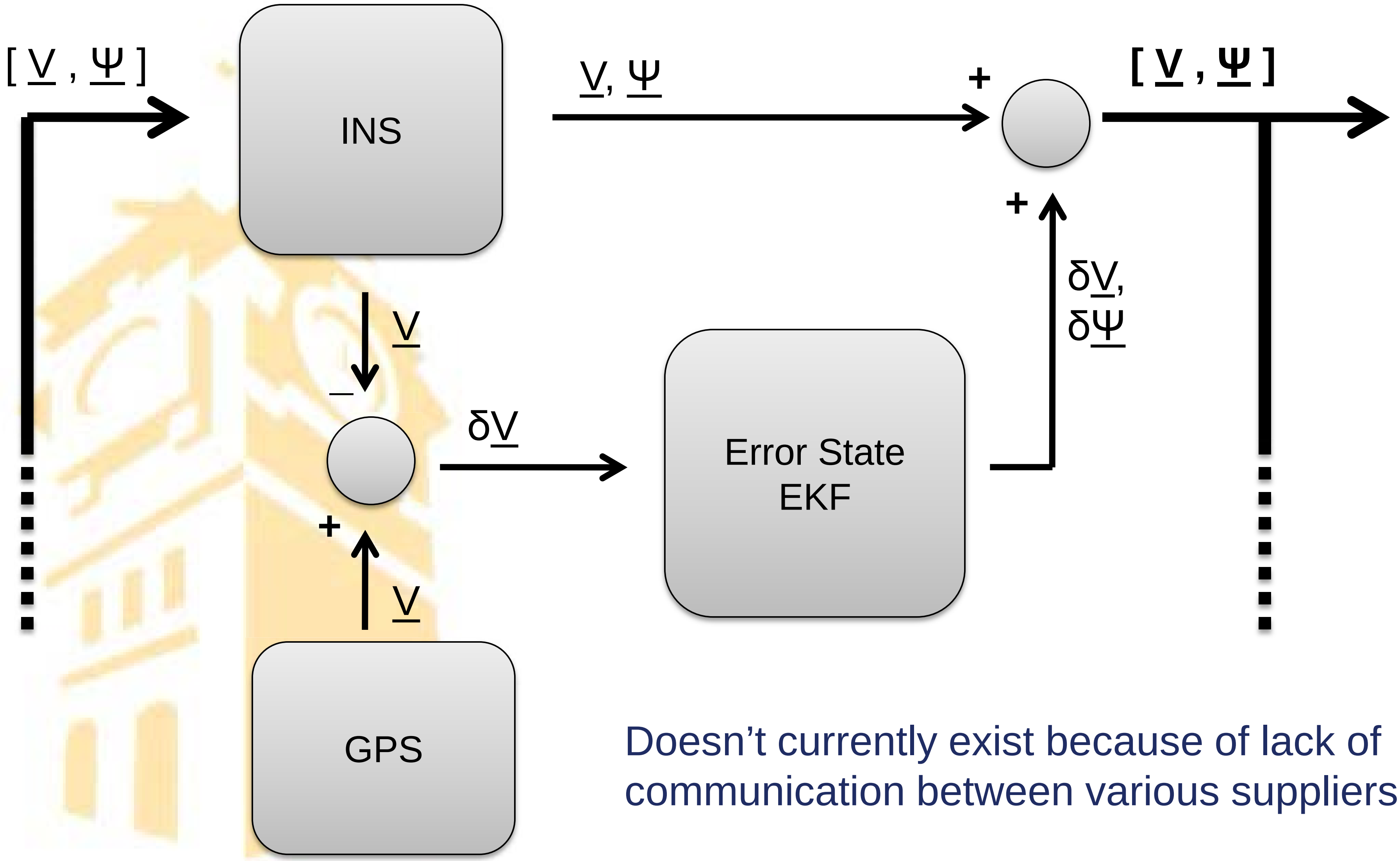
Perception Positioning vs. GPS

- GPS Positioning
  - May not provide the required accuracy with out 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



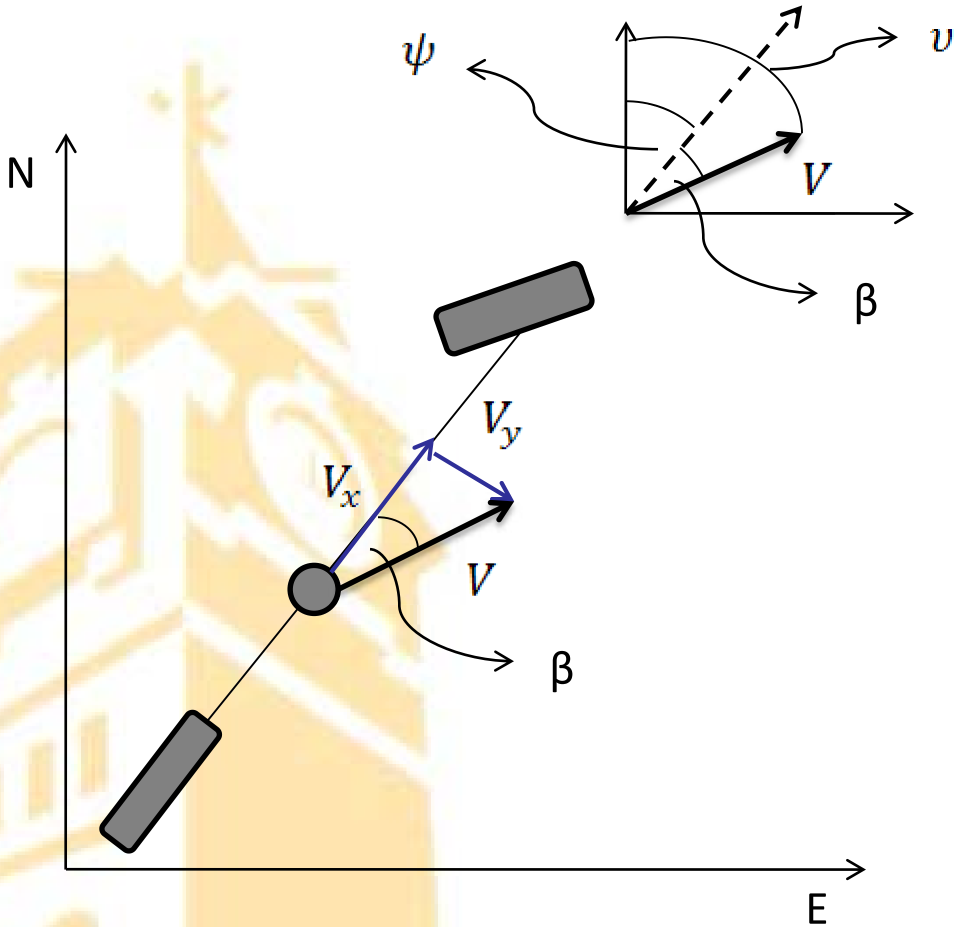
UNIFIED GPS/INS KALMAN FILTER BASED VEHICLE STATE ESTIMATION

Loosely Coupled Algorithm



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

Sideslip Definitions



$$\nu = \beta + \psi$$

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

$\beta = Sideslip$

$\upsilon = Course$

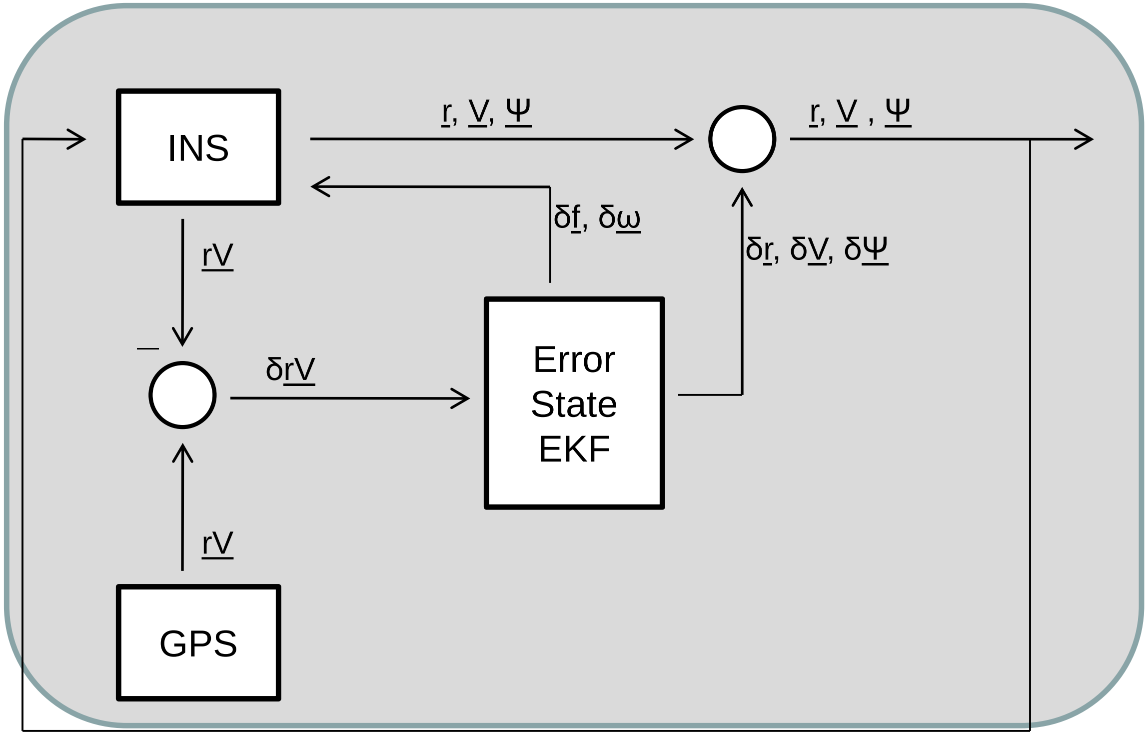
$\psi = Heading$

Loosely Coupled Integration

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

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

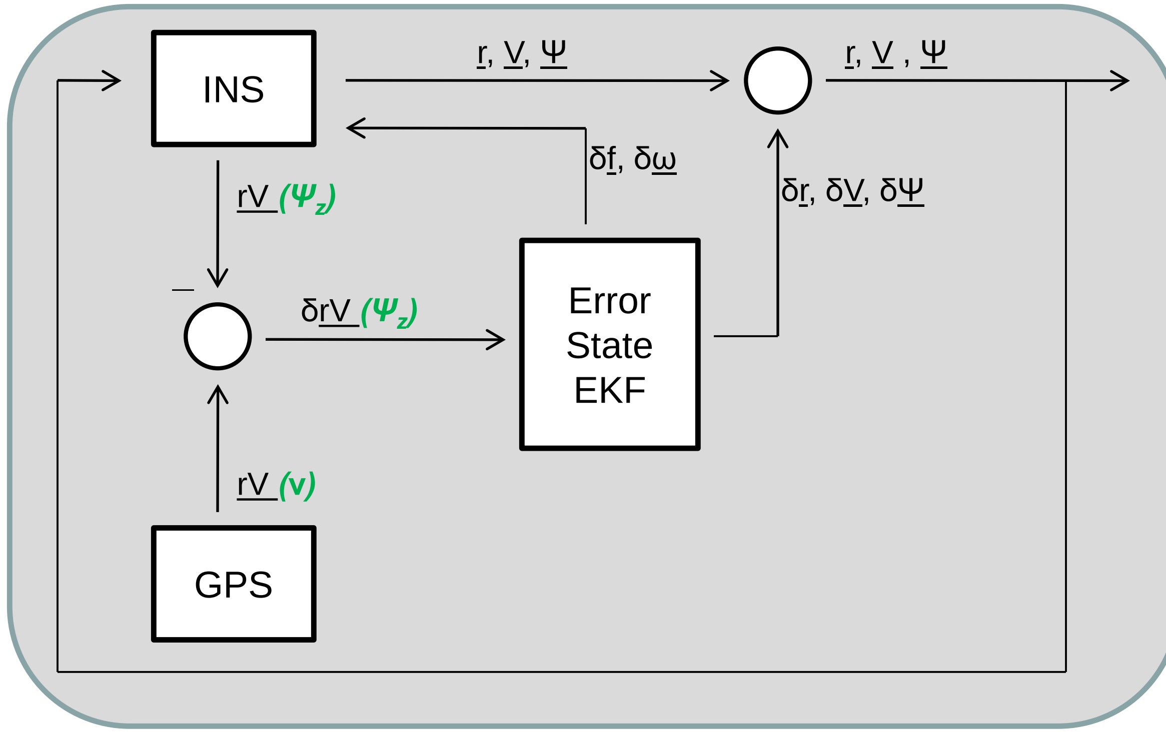
$$\hat{\beta} = \arctan\left(\frac{\hat{V}_{east}}{\hat{V}_{north}}\right) - \hat{\psi}_{yaw}$$



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

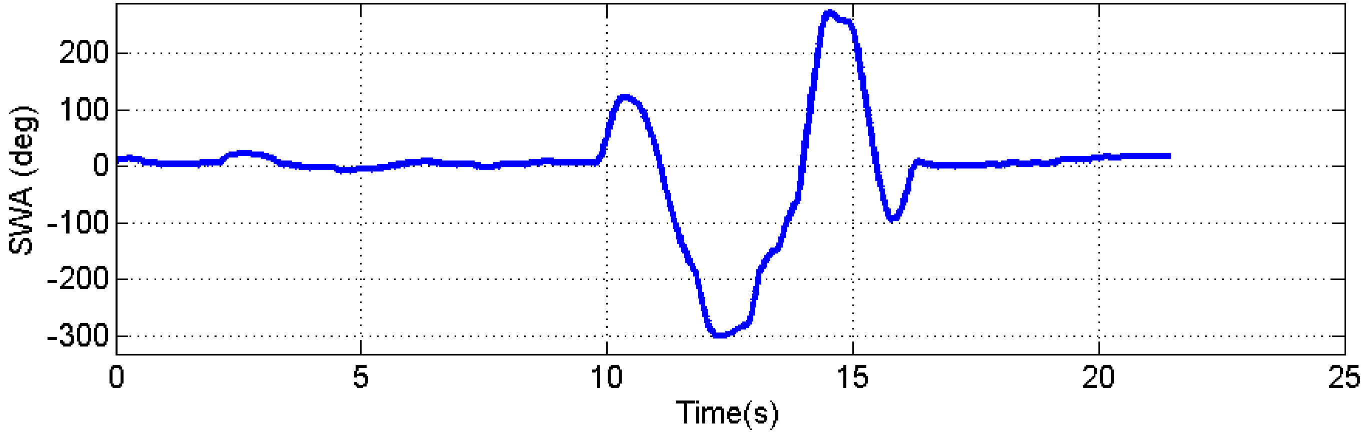
Automotive Navigation Estimator

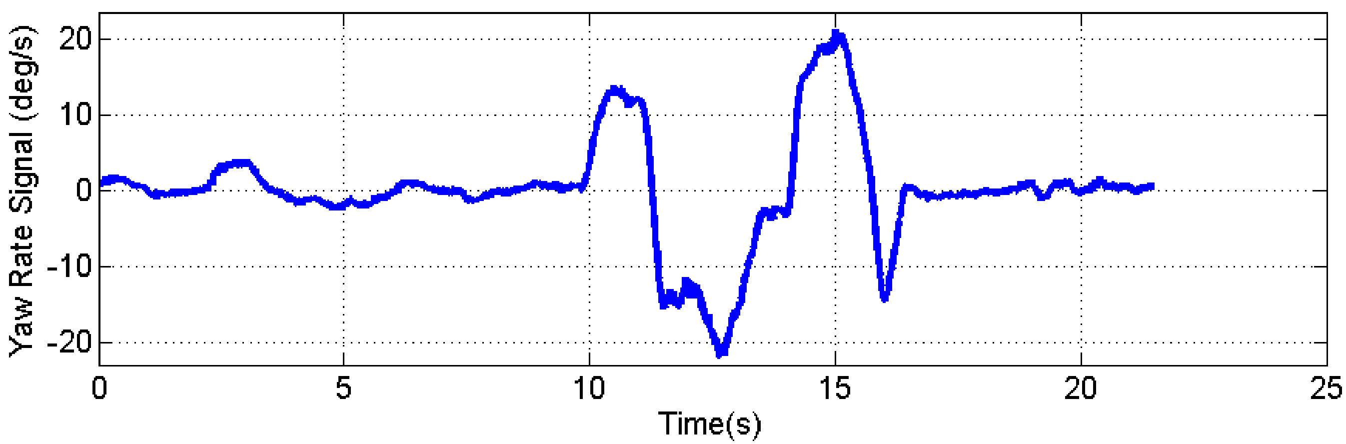
- Pitch rate gyroscope is removed.
- Yaw constraint added during periods of straight driving
  - GPS course measurement used as a yaw measurement.
- If yaw rate signal is less than some threshold for some time period, then the constraint is added.
  - Threshold, time window are tuning parameters of the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



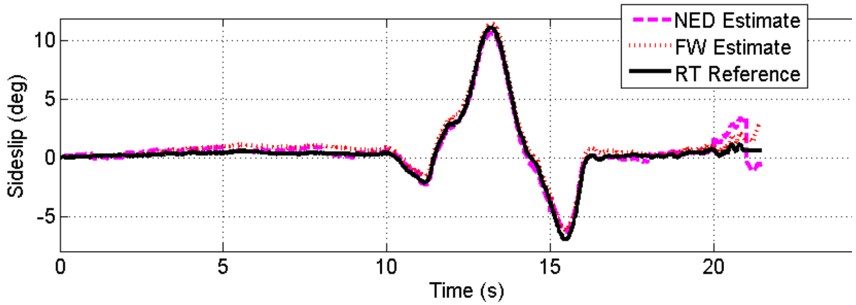
$$Y = \begin{bmatrix} \underline{r} \\ \underline{V} \\ \psi_{yaw} \end{bmatrix}_{GPS} - \begin{bmatrix} \hat{\underline{r}} \\ \hat{\underline{V}} \\ \hat{\psi}_{yaw} \end{bmatrix}$$

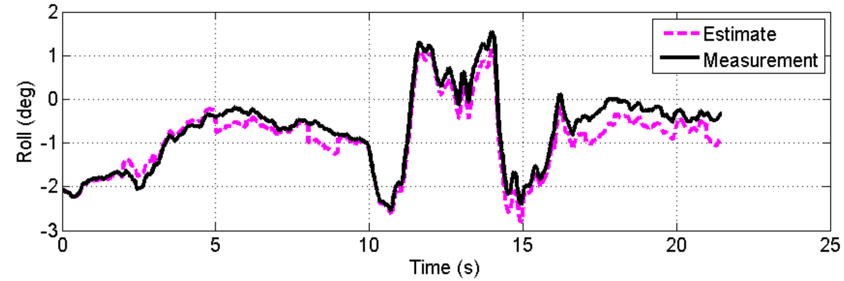
Lane Change Experiment

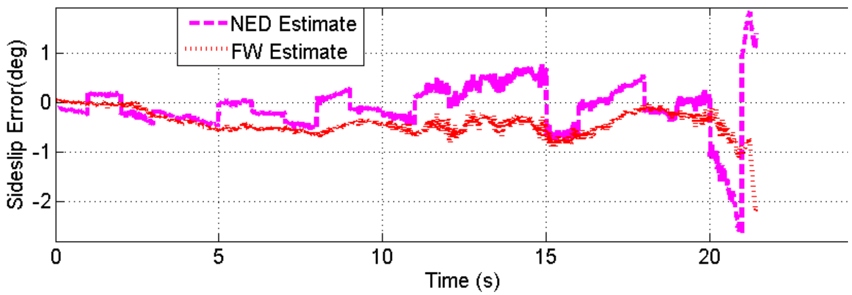


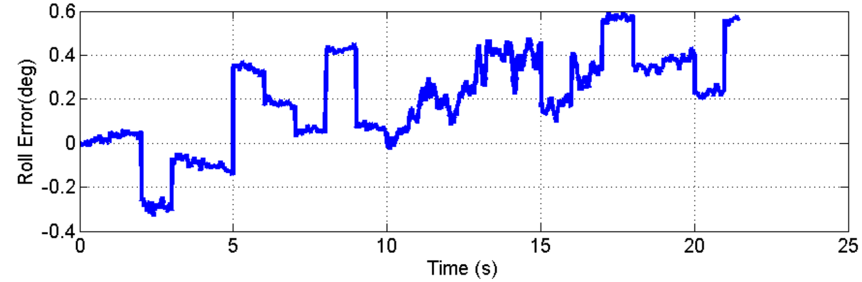


Lane Change Results









- Sideslip
- Roll

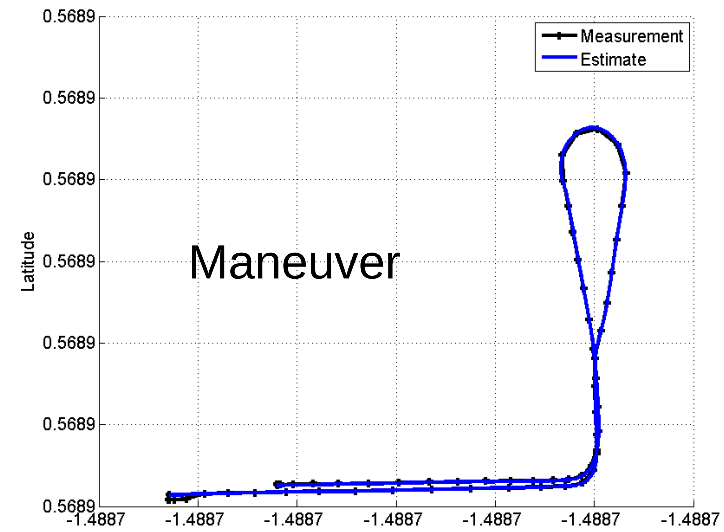
Low Rates of Sideslip Buildup

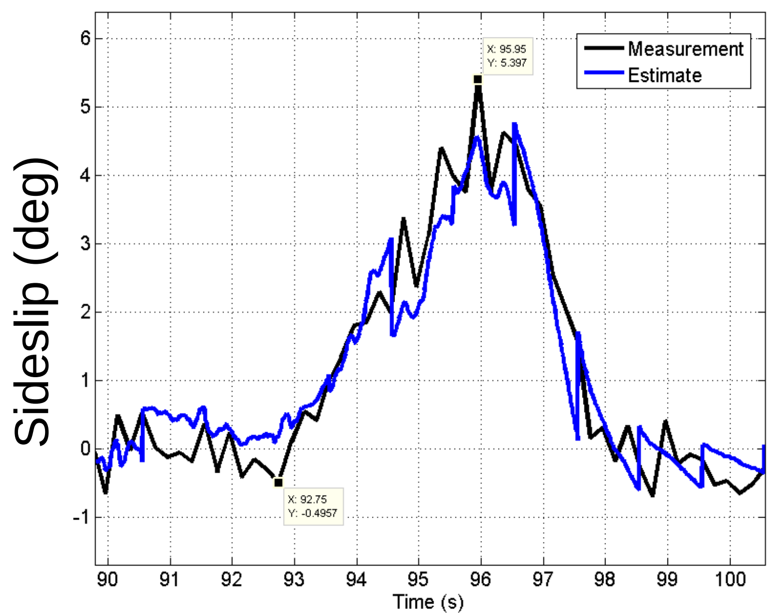
- Slow sideslip buildup is generally difficult to estimate
  - Low signal to noise ratio.
  - Lateral accelerometer bias
  - Lateral acceleration vs. roll

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

Experimental Slow Sideslip Buildup

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



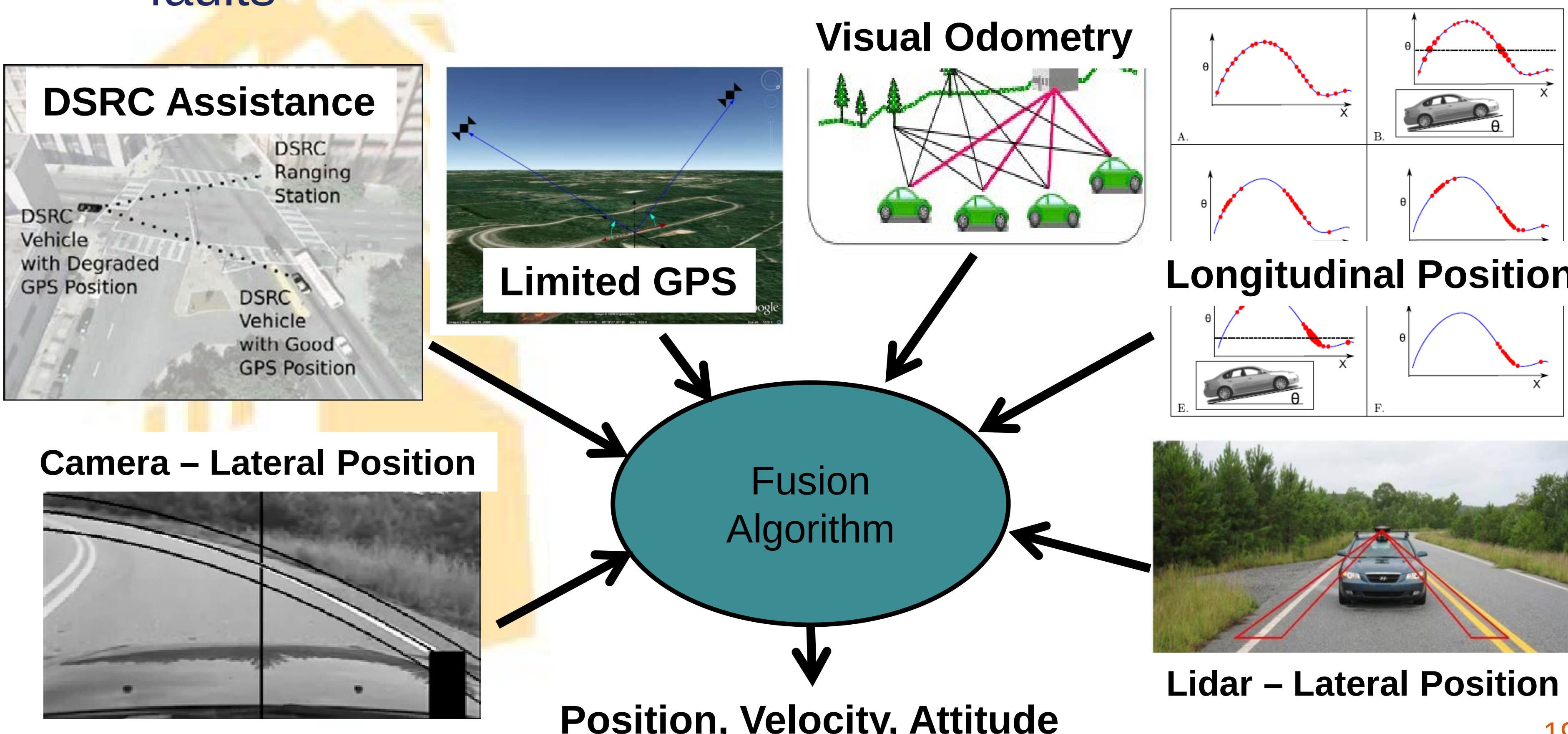


Integrating GPS with other on-board vehicle sensors

VEHICLE LANE POSITIONING

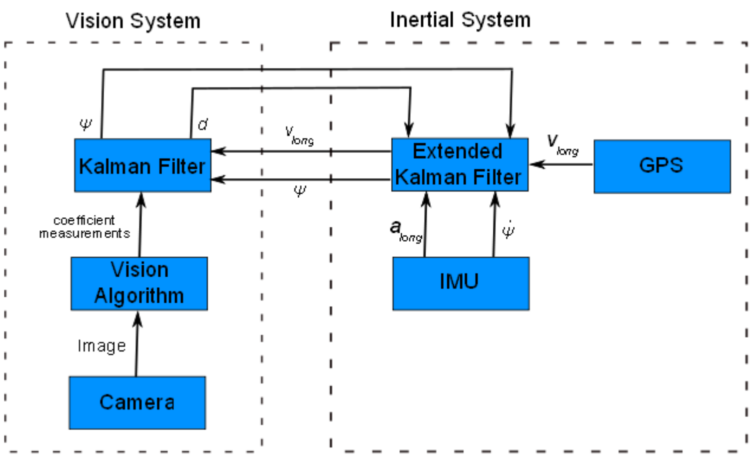
Project Overview

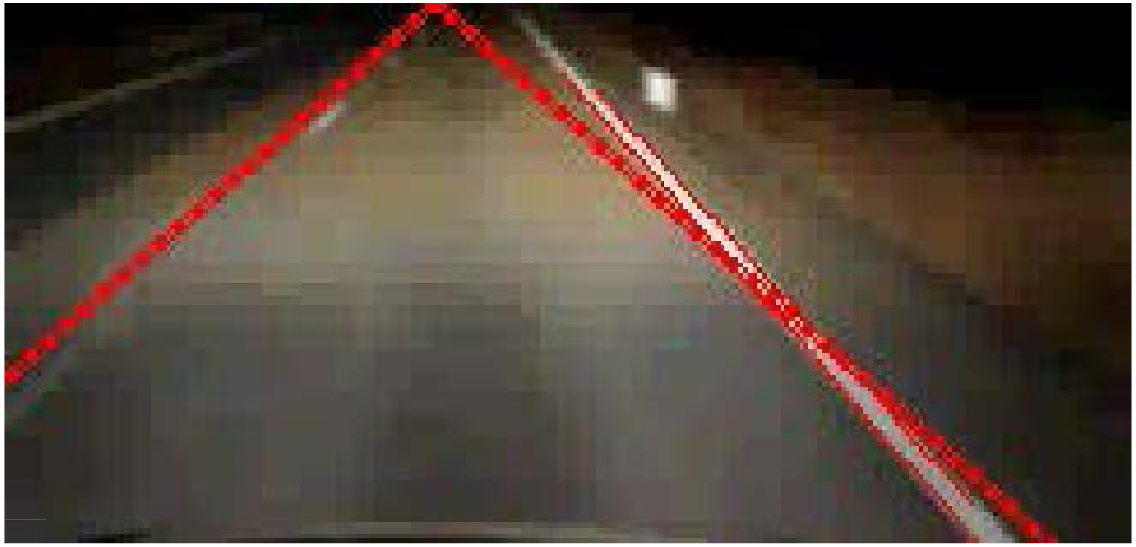
- Technical Approach – Fuse outputs of various positioning technologies in an extended Kalman filter exploiting accuracy/uncertainty and mitigating subsystem faults



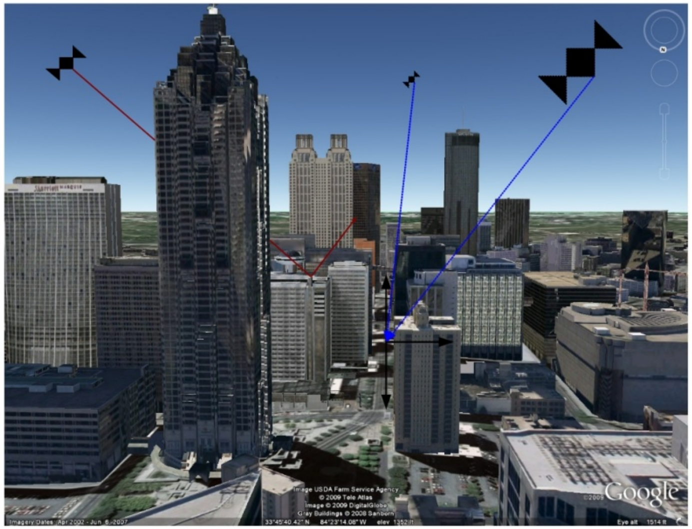
Vision / INS

- 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”





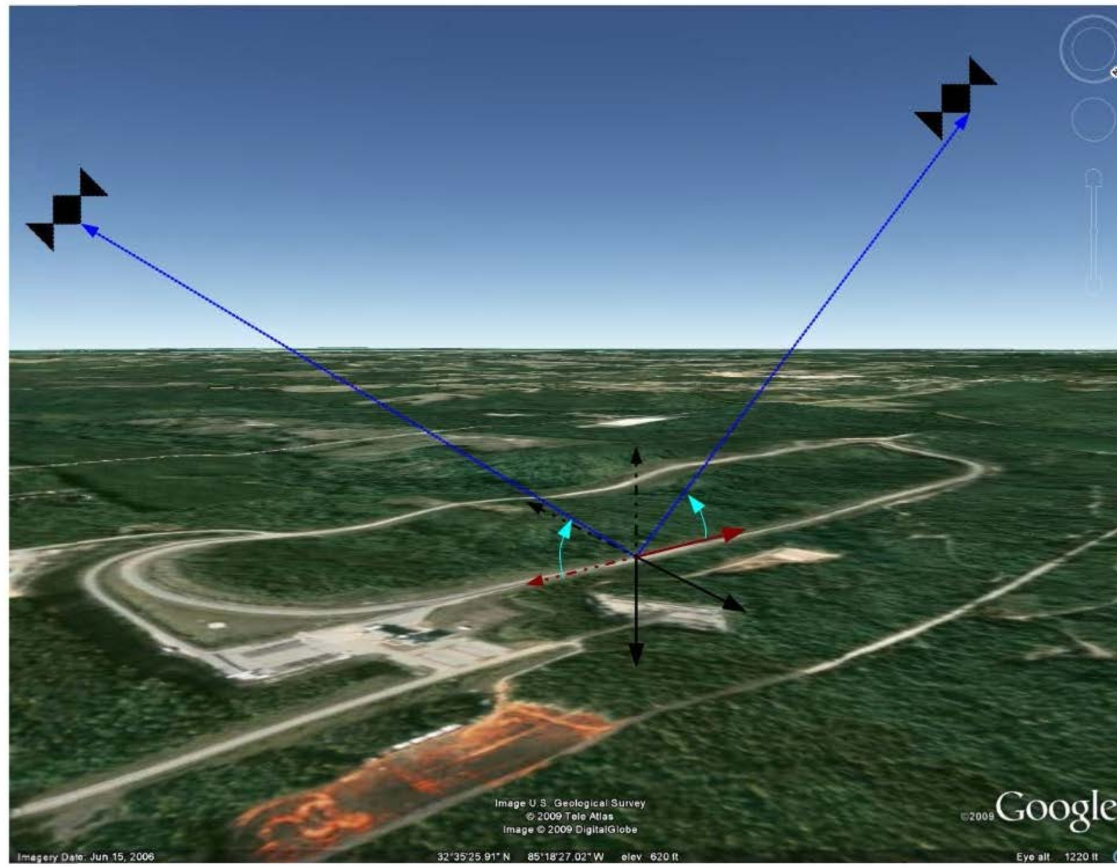
Positioning w/ Limited GPS Satellites



Utilize constraints to improve IMU solution

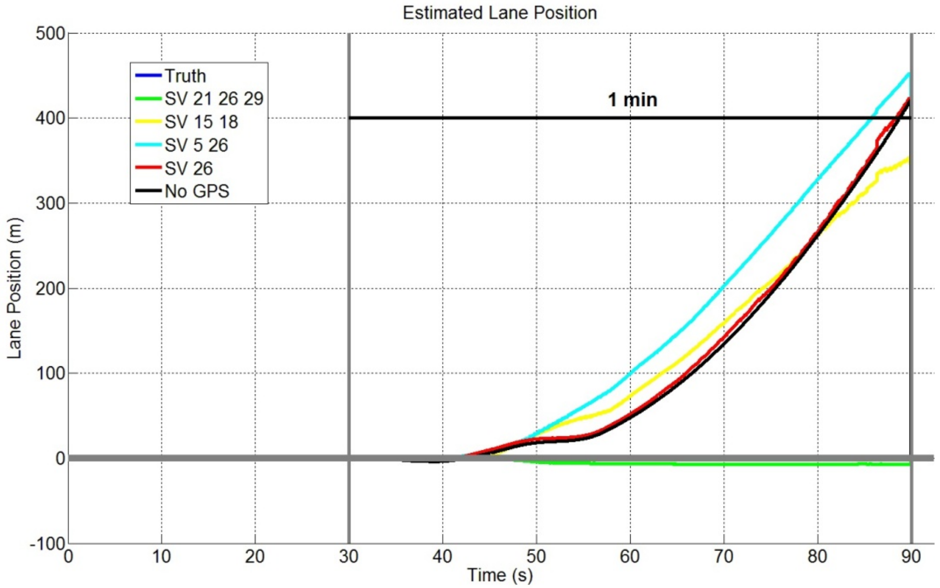
Validated at Auburn's NCAT Test Track using:

- Lateral Constraint
- Vertical Constraint
- 2 GPS Satellites

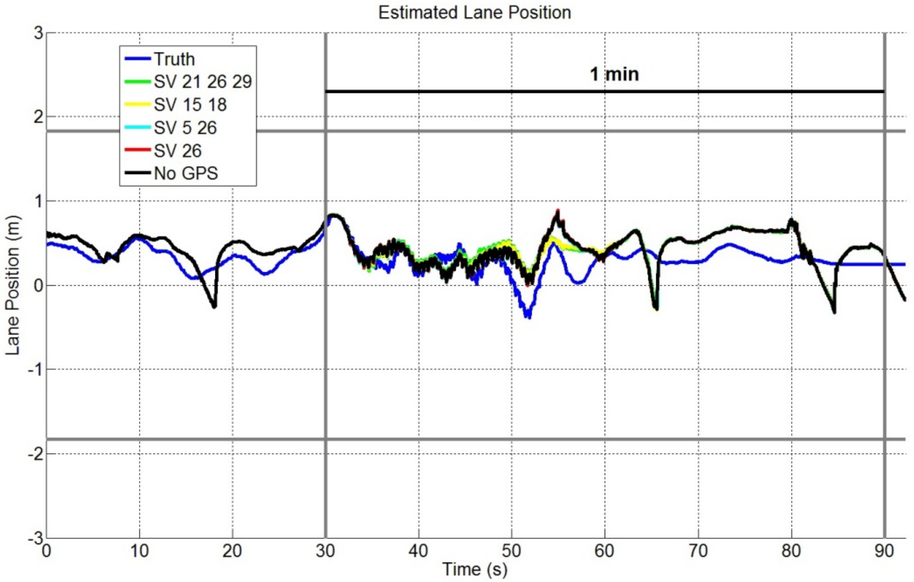


Lateral Error with Limited GPS Observations

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



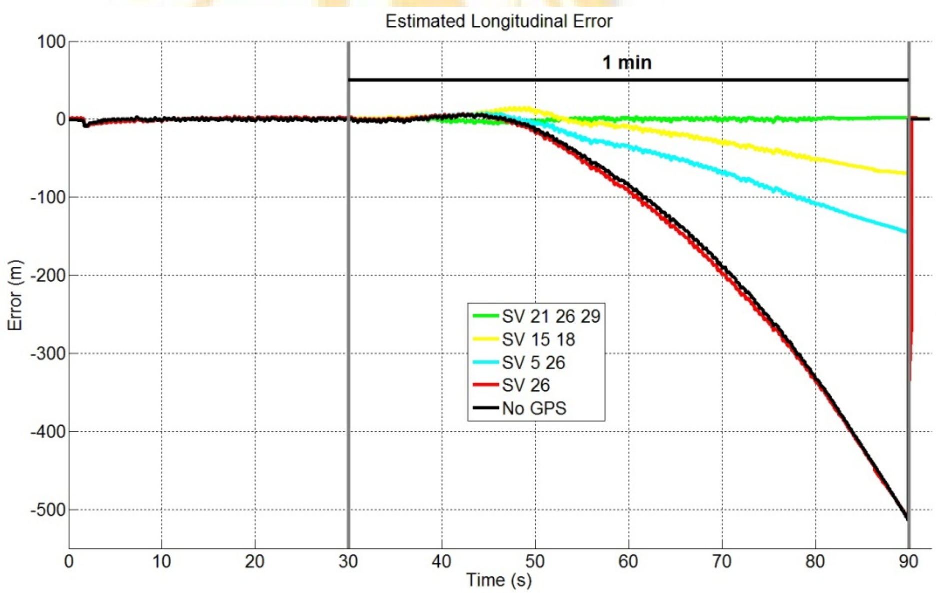
Without Lateral Perception Measurements



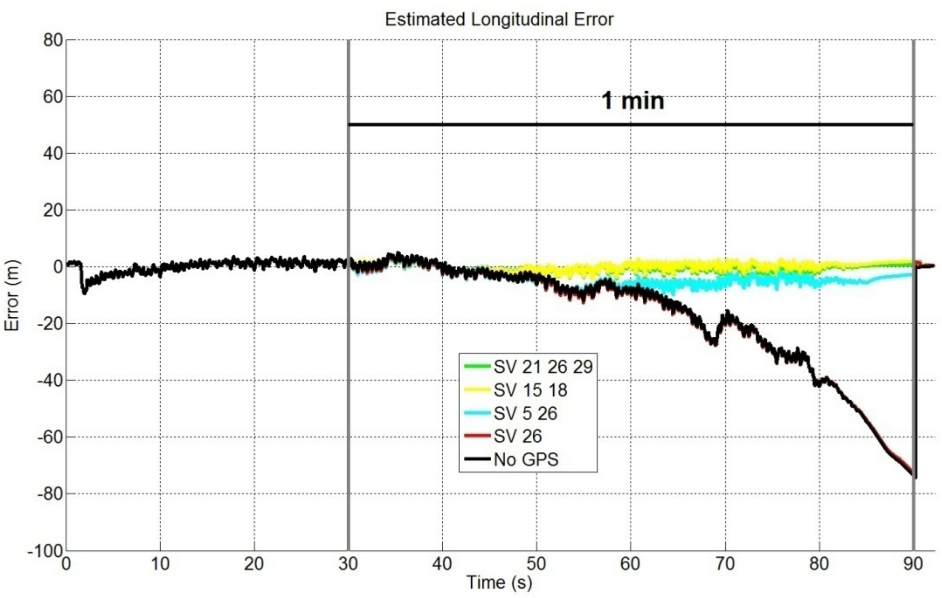
With Lateral Perception Measurements

Longitudinal Error with Limited GPS Observations

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

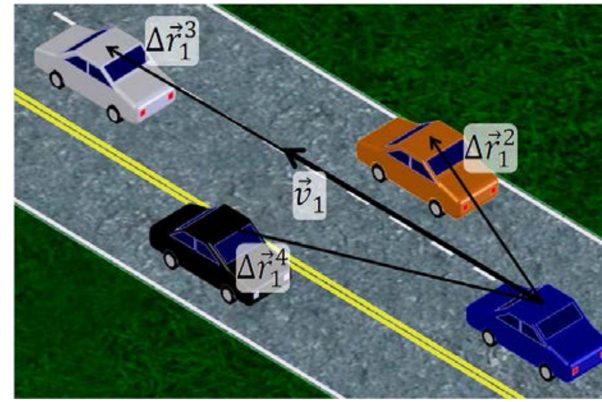


Without Lateral Perception Measurements

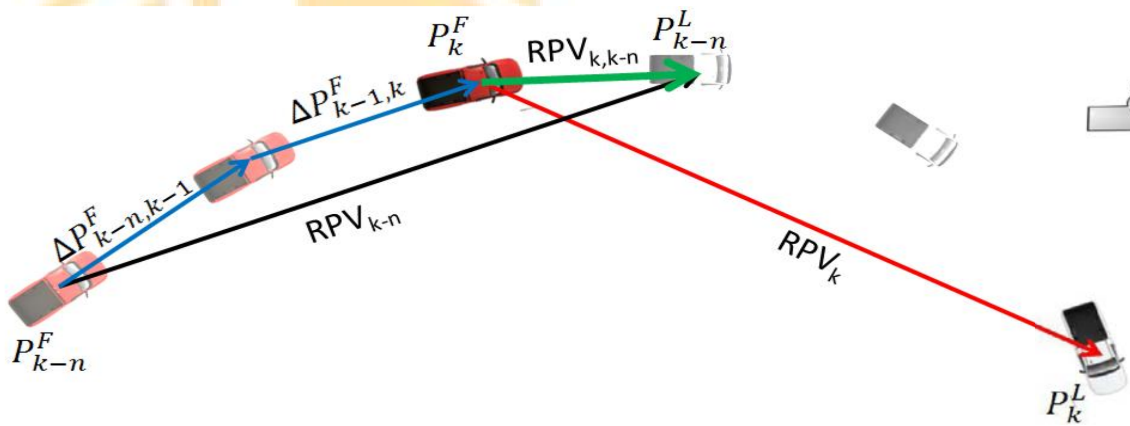


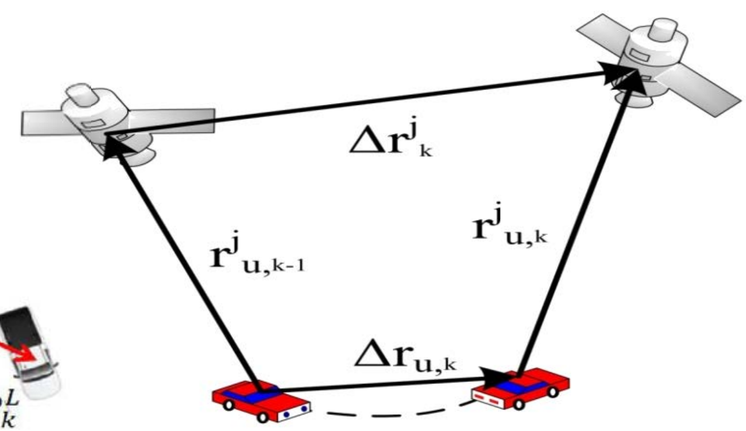
With Lateral Perception Measurements

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



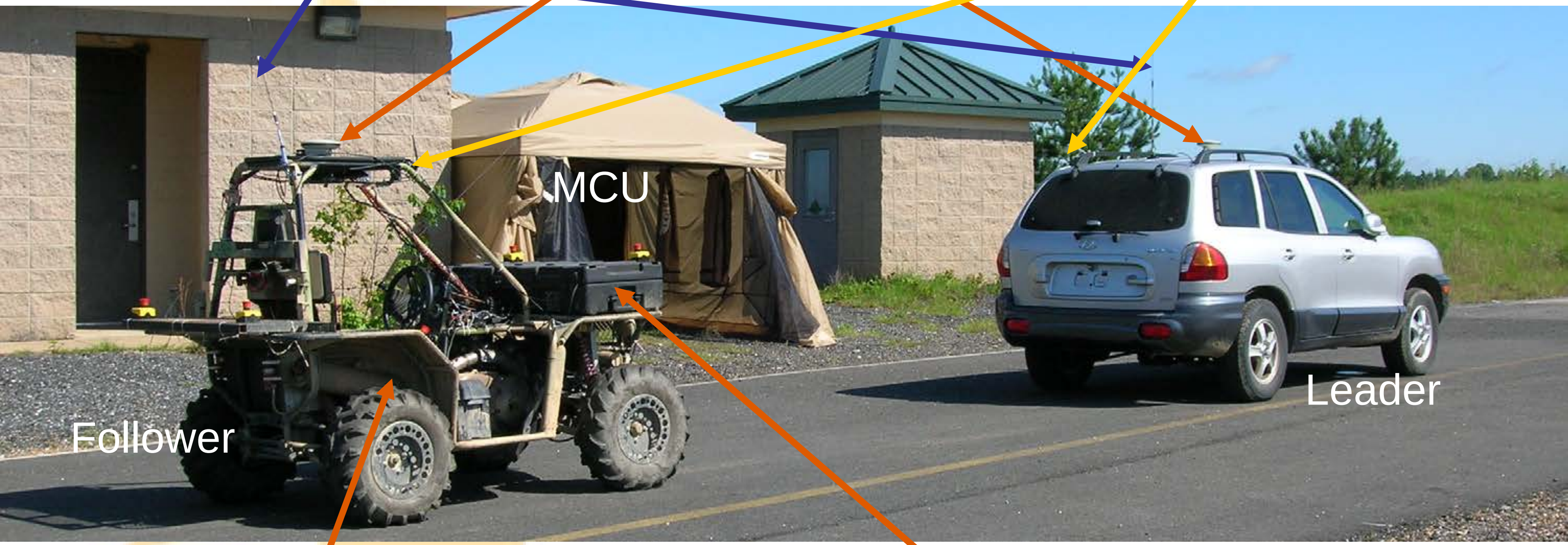


GPS Path Following

900 MHz Digi XTend RTK base station communication

NovAtel PropakV3

900 MHz Digi XTend inter-vehicle communication



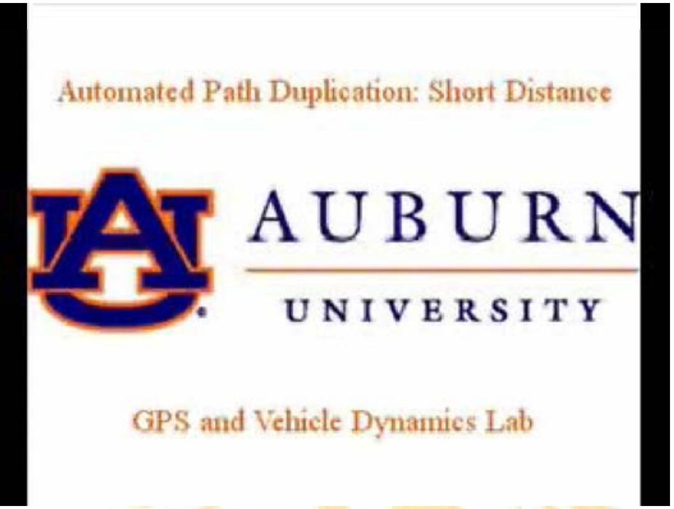
Crossbow IMU440 (under seat)

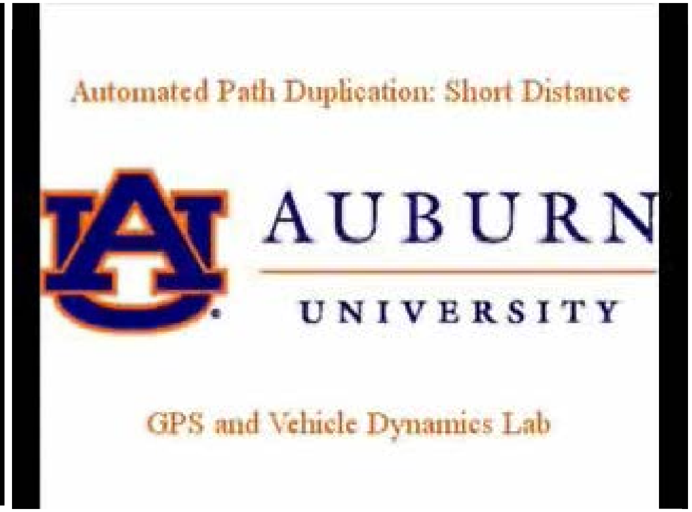
Advantech control and navigation computers

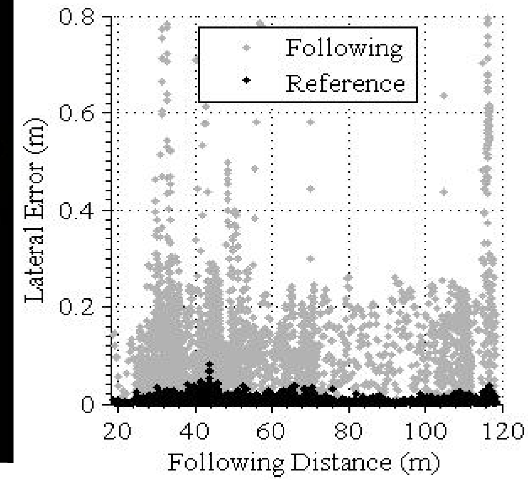
Servos

Power regulation and distribution

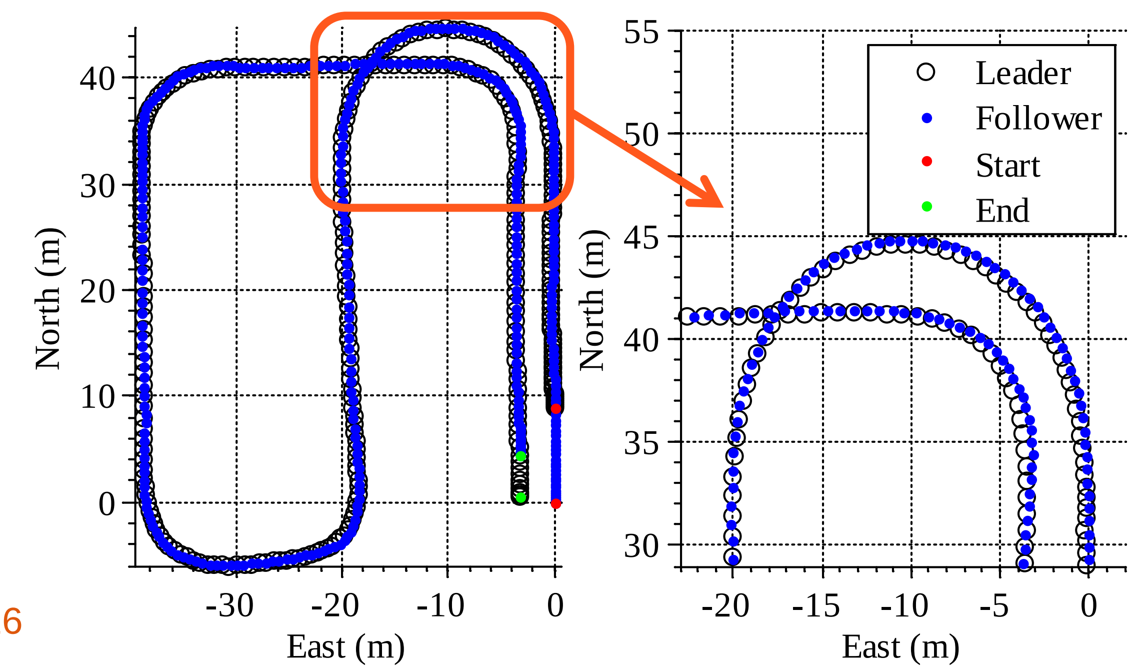
Experimentation – Autonomous Following







- 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