Next Generation Vehicle Positioning – Automotive Panel Update

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Overview

- Technical Update
  - Integration Update
  - Camera Road Edge Detection
  - Lidar Road Edge Detection
  - Subsystem Update

- Demonstration Planning
  - Proposed scenarios
  - Panel suggestions

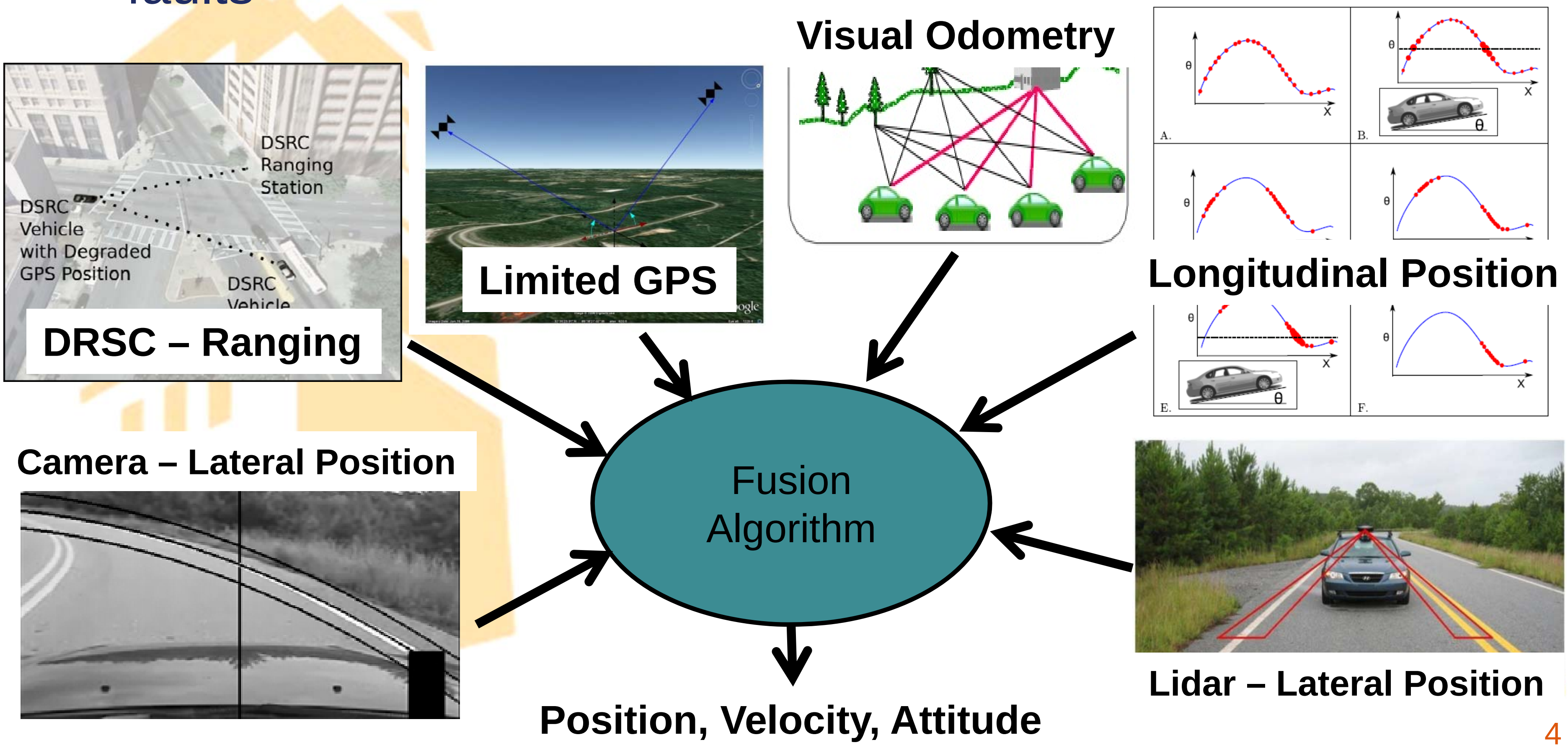
Project Overview

- Funding – Provided by FHWA as part of the E.A.R. program
- Objective – Provide ubiquitous precise positioning supporting vehicle safety and automation in presence of GPS degradation
- Partners – Auburn University, Kapsch TrafficCom, Penn State University, Stanford Research Institute

- Project Scope – Assess diverse positioning and data-fusion techniques, characterize achievable accuracy and robustness, test and demonstrate capabilities on test track and roadway scenarios

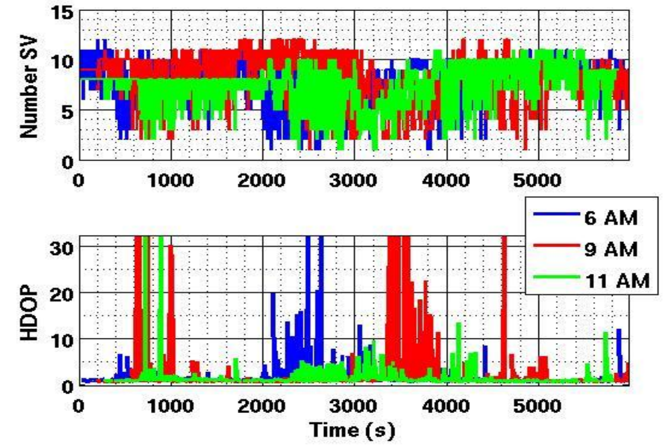
Project Overview

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



Integration Work – Testing

- Test route developed by Honda to meet road-use class proportioning found by FHWA
- Environments included trees, tree canopies, overpasses, buildings, urban canyons, and tunnels



	Environment	Features: Terrain	Vegetation	Buildings	Overpasses	Tunnels
	Open	flat or mildly undulating; mask ≲ 5°	almost none	almost none	none	none
Rural	Sparse		scattered trees	rare, low, far	none	none
Rural	Moderate	mountains masking 5-20°	some tree canopies	some low	maybe but rare	
Rural	Dense	mountains mask 20-60°	dominant tree canopies	negligible compared to natural obstructions although there could be a long tunnel		
Urban	Sparse	usually flat or mildly undulating with mask ≲ 5	scattered trees	some, low or far	none	none
Urban	Moderate		moderate number, some short canopies	multi-story, rare high-rises	some	rare
Urban	Dense			dominant high-rise canyons	frequent	long

Integration Work – Methodology

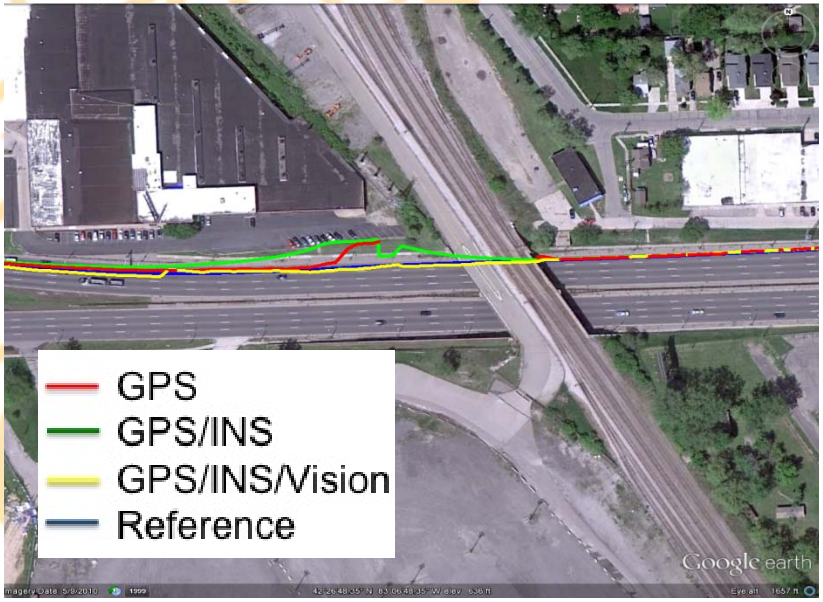
- Sensor combinations
  - Reduced inertial system, L1 GPS, wheel speeds
  - 6 DOF MEMS IMU, L1/L2 GPS, wheel speeds
  - 6 DOF MEMS IMU, L1/L2 GPS, wheel speeds, vision and map based lateral positions
- Extended Kalman filter implementation
- Estimated position, velocity, and attitude of vehicle
- Integrated vision information using low resolution map developed using Google Earth

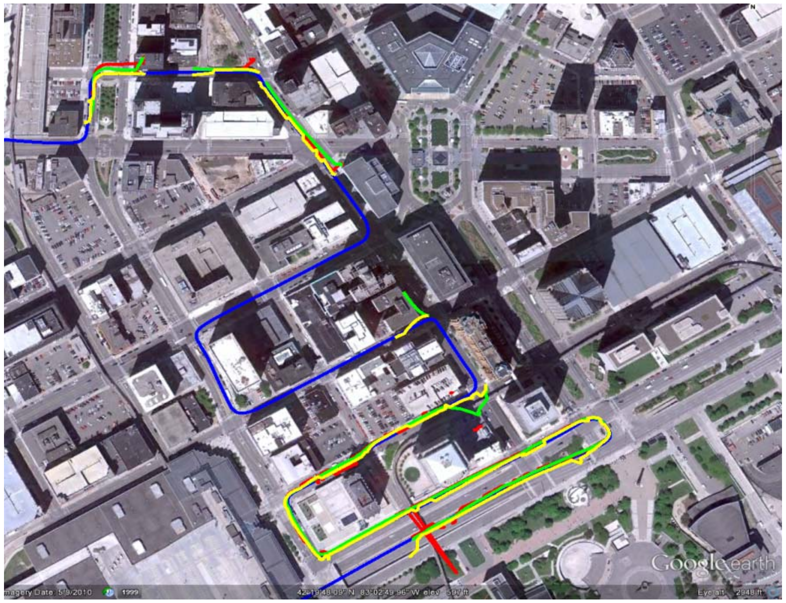
Production or Near-Production Grade			Beyond Production Grade			Reference System		
Type	Model	Rate (Hz)	Type	Model	Rate (Hz)	Type	Model	Rate (Hz)
GPS	Novatel Propak V3 (L1 only)	5	GPS	Novatel Propak V3 (L1 and L2)	5	GPS	NovAtel SPAN-SE	5
Wheel Speed	From in vehicle CAN network	50	IMU	Crossbow IMU 440, full	100	IMU	Honeywell HG1700 AG58	100
RISS	Crossbow IMU 440, reduced	100	Lidar	Ibeo Alasca XT	10	External encoder	Peiseler MT1000	Speed dependent
Camera	Logitech Quickcam 9000	10				DGPS	Differential GPS solution was calculated post-process	

Integration Work – Results

- GPS/INS provided improved results over standalone GPS particularly in heavy foliage and urban canyon environments
- Vision updates provided improvements where the lane of travel was assumed to be known (4 and 2 percentage point improvement in availability of lane level accuracy)

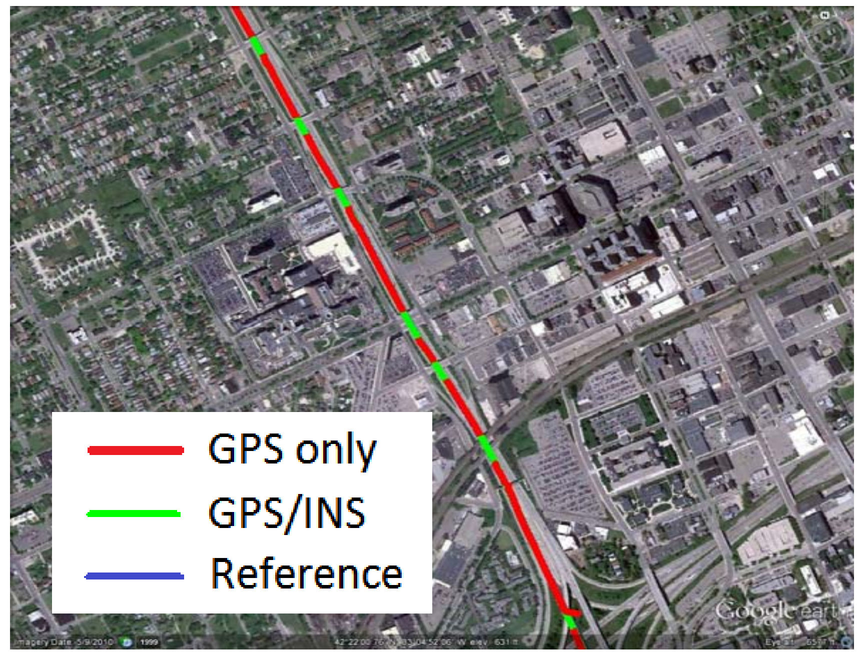
Device	Horizontal Error (m)		% < 1.5 m		% < 5 m
Propak_R3	2.9		46.7		88.8
GPS_INS_R3	2		59.8		95.5
Propak Overall	2.6		41.8		88.4
GPS_INS Overall	2.2		49.2		94.3
Device	Environment				
	Open	Ok	Trees	Canyon	All
Propak All Runs (%<1.5m)	67	49	33	14	42
GPS_INS All Runs (%<1.5m)	74	56	40	18	49
Precentage of Test Route	4	54	15	8	100





Integration Work – Future Work

- Lane detection algorithm leveraging new road edge detection methods and/or inertial information
- Real time integration of visual odometry, gantry-based position updates, and road fingerprinting



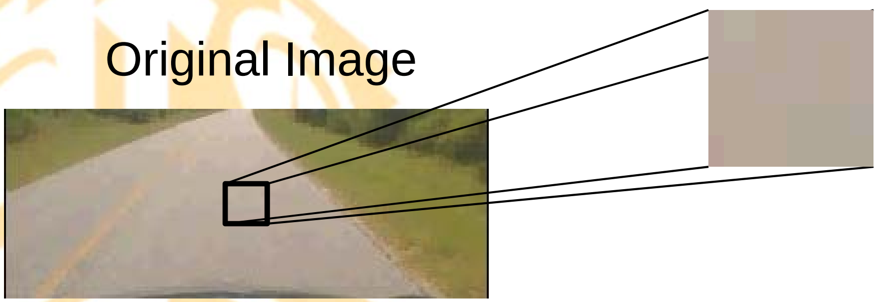
Road Edge Detection

- Motivation
  - FHWA request for extension of detection capability
  - Detect road boundaries
  - Particularly in areas where lane markings are unavailable

Camera Road Edge Detection

- With a sample of current road surface, the road in the image can be found
- Correlation matching with a sliding window is used to determine a metric for how similar a point in the image is compared with the template

Original Image



Sample (or template) of road

Correlation matching (Unnormalized)

Correlation matching (Normalized) – handles varying lighting

Camera Road Edge Detection

- Pick out road edges with conditions to reduce erroneous detections
  - Local area
    - Reduces impact of branching roads, driveways, etc.
  - Distance (in pixels) between road edges must be within a threshold of expected lane width
    - Reduces impact of consistent erroneous measurements
- Kalman Filter
  - Further reduces impact of erroneous lane measurements from shadows, vehicles, degraded road edge, etc.
  - Actual lane width calculated using precalibrated scale factor

Edge Map

Road edge local area

Lane width threshold

Marked Ideal Image

Marked Unideal Image
Dusk with Heavy Shadows

Red: road surface
Green dot: road edge measurement
Red dot: no measurement
Black circle: road edge estimate (from filter)
Blue rectangle: template (5x5)

Camera Road Edge Detection

- Testing
  - Webcam at low resolution (cropped image): 240x100 pixels
  - Road width measurement taken far down the road
  - Day and Night
  - Error Sources
    - Tree Shadows (especially at dusk)
    - Headlights (template match problems due to headlight illuminating the road ahead)
    - Driveways, road intersections
- Mean estimates over the course of the run were compared with a physical measurement at the start of the test run

Error	County Road 84	County Road 188	Miss James Road
Day- Average Error	.0706 m	.1043 m	.1704 m
Day- Std. Dev.	.2191 m	.1638 m	.2972 m
Night- Average Error	.0720 m	.1384 m	.0667 m
Night- Std. Dev.	.2780 m	.2253 m	.1574 m

Lidar Road Edge Detection

- Utilize both distance and reflectivity estimation
- Use a derivative filter to accentuate changes in height or reflectivity
- Select peaks based on a dynamic threshold based on the current road
- Bound, filter, and compare height and reflectivity results before reporting a result

Lidar Road Edge Detection

- Tested on County Roads with no outside lane markings
- Day and Night testing
- Data was Post Processed
- Errors are derived from estimating lane width

	Average Error	Std of Error	% Detection
Day	7.6cm / 3in	16.1cm / 6.3in	88.5%
Night	6.7cm / 2.6in	0.13.8cm / 5.5in	91.5%

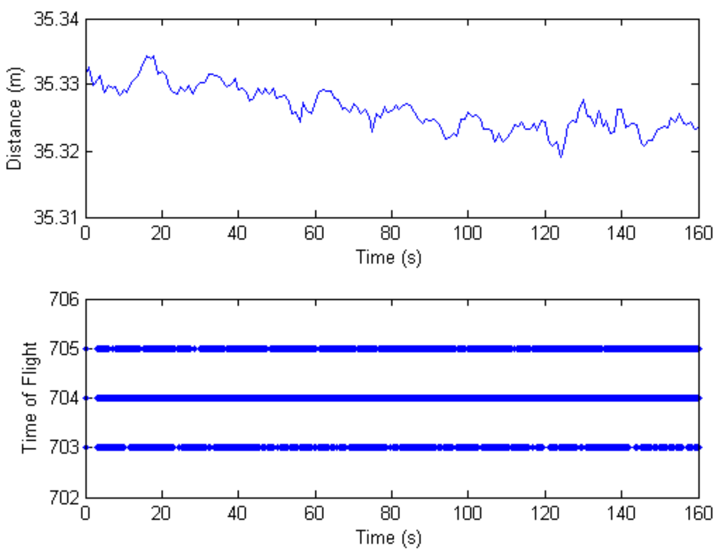
SRI – Visual Odometry

- Testing was conducted in Detroit sporadically
  - 247 GB of stereo data was recorded over the 3-day period
  - Nights: Difficult
  - Testing served as a good test of the full system

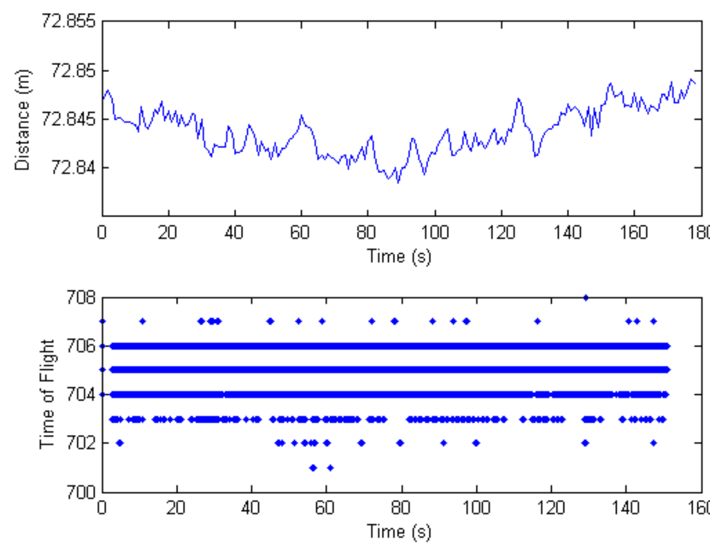
SRI Testing: Occupy Detroit in Downtown Detroit

Kapsch – TrafficCom

- Static range tests
  - Distance (from RTK GPS) and time of flight (from DSRC) were compared
  - 35m and 72m distances
  - time of flight variation increases with distance



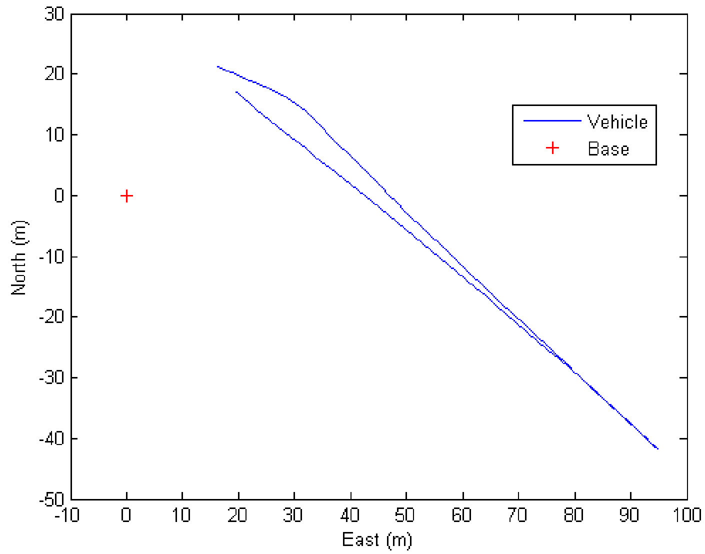
35m Static Range Test



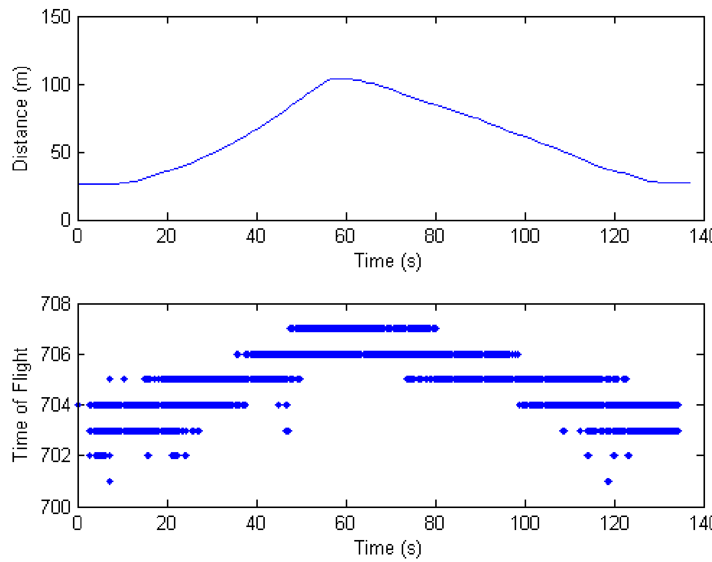
72m Static Range Test

Kapsch – TrafficCom

- Dynamic range test 1
  - Distance (from RTK GPS) and time of flight (from DSRC) were recorded
  - Vehicle was driven in a straight line, then reversed at slow speeds
- the time of flight changed by 1 for about every 13 meters of distance



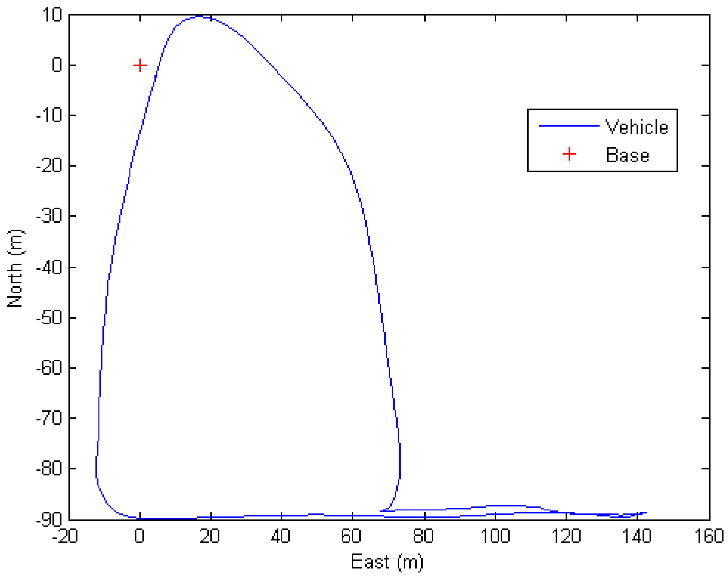
GPS positions of the vehicle and the base station



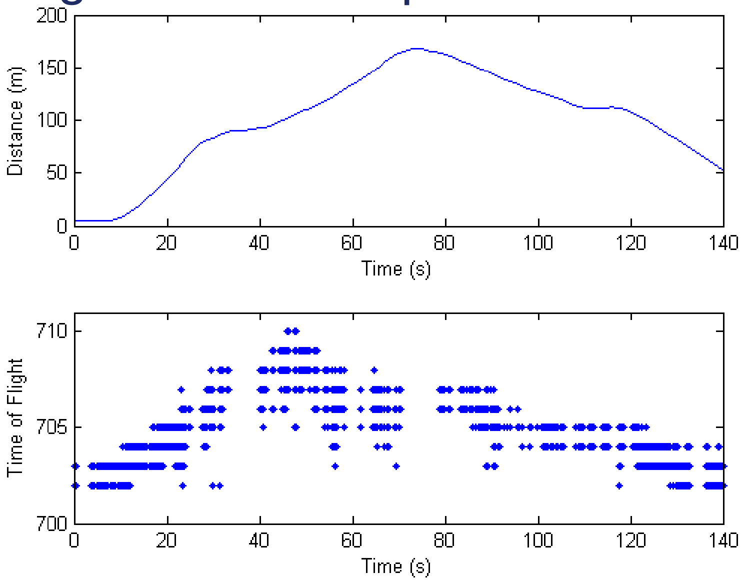
Distance and ranging output vs. time

Kapsch – TrafficCom

- Dynamic range test 2
  - Distance (from RTK GPS) and time of flight (from DSRC) were recorded
  - Vehicle was driven in a loop with a brief straight section
  - the time of flight changed by 1 for about every 13 meters of distance
  - Several obstacles were present between the vehicle and base station
- DSRC time of flight ranging was disregarded due to poor resolution



GPS positions of the vehicle and the base station



Distance and ranging output vs. time

Kapsch – TrafficCom

- Due to insufficient performance of DSRC ranging system, a system for localization in the road utilizing toll road technology will provide lane level positioning when passing under a gantry (soon installed on AU test track)

Kapsch TrafficCom Lane Level Localization*

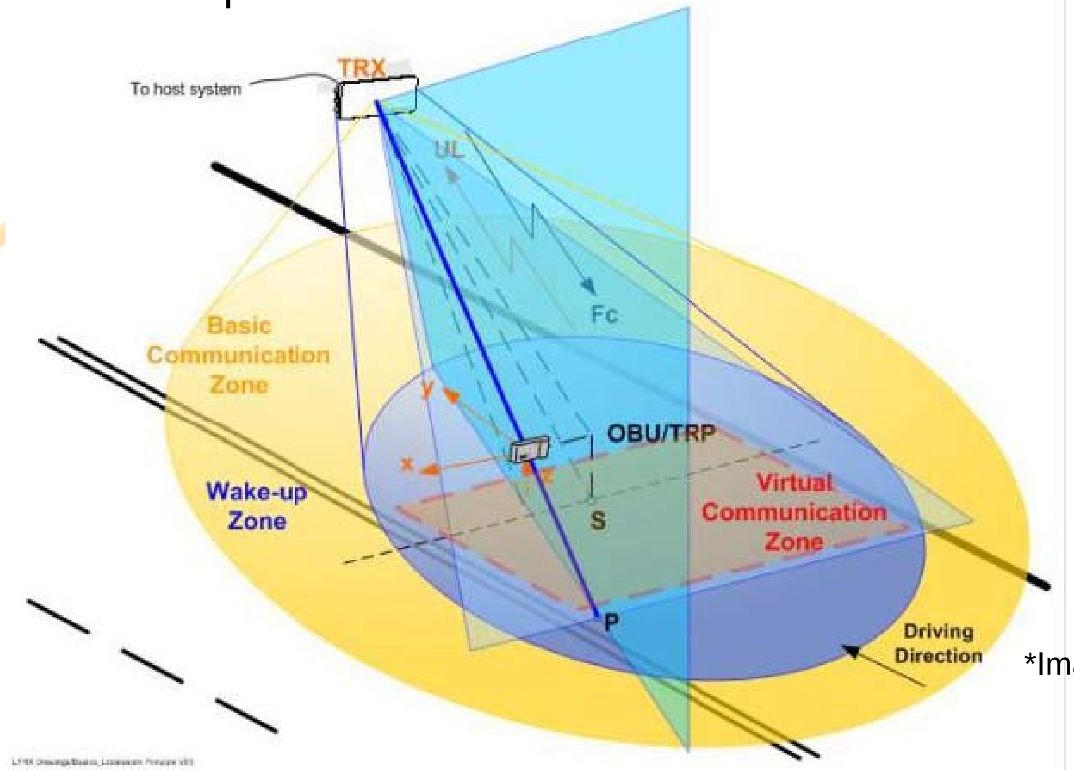


*Image From Kapsch TrafficCom

PSU – Road Fingerprinting

- Testing with previously logged data due to track maintenance.
- Still currently no way of adding new road networks
- Continue to receive updates as issues are discovered
- New track paving should allow for new and additional testing when completed

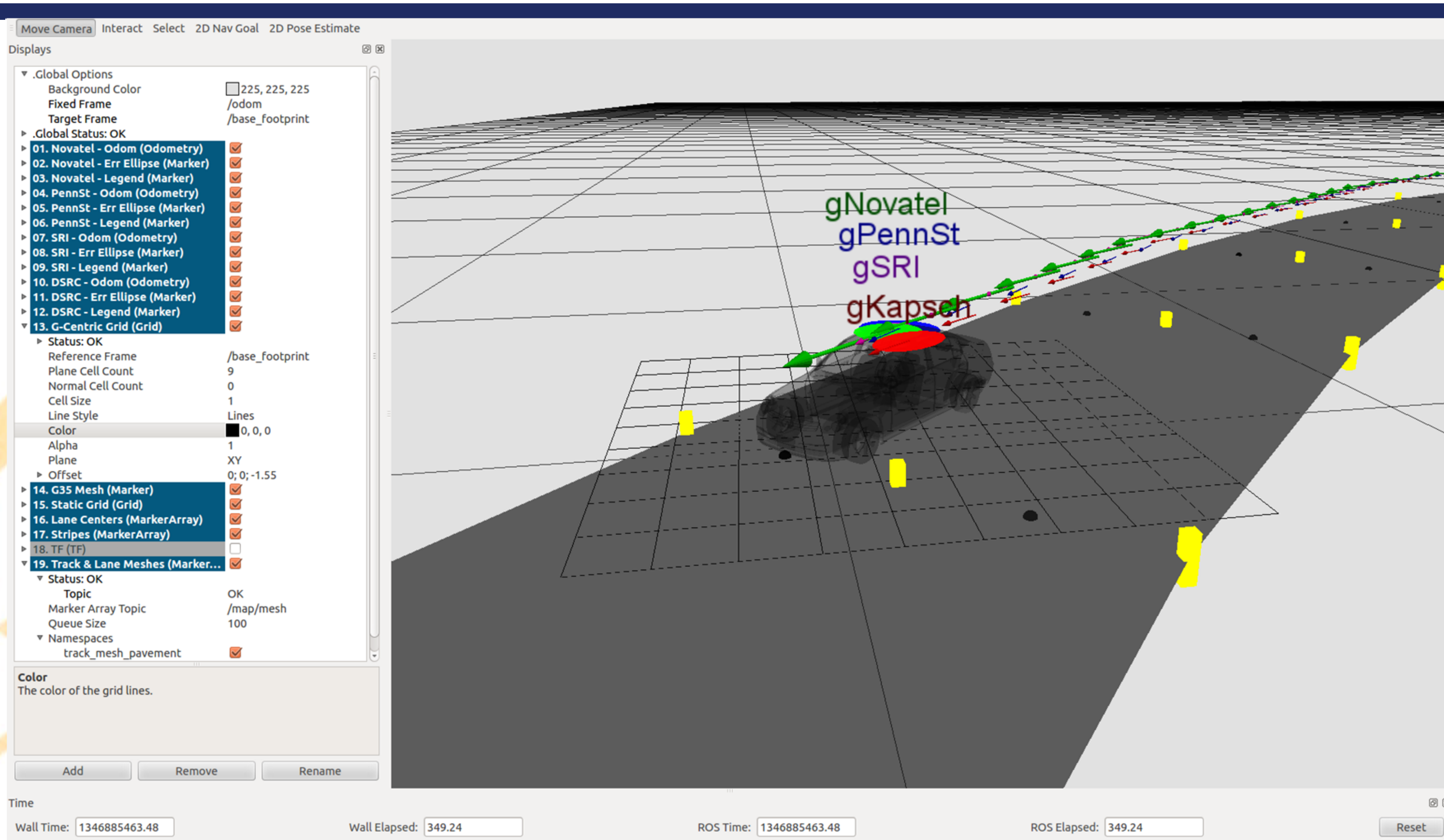
Timeline

- September
  - Real time integration algorithm development
  - Real time visualization software development
  - Survey of repaved track for road fingerprinting capability
  - Lab testing of real time algorithms using playback capability
- October
  - SRI hardware delivery
  - Tracking testing of real time algorithms
- November
  - Mid-November On Site Demonstration
- January
  - Mid-January Road Demonstration – Washington D.C.

Demonstration Site

- Nation Center for Asphalt Technology
  - 1.7 mile oval
  - Well Surveyed
    - Level
    - 2% Crowns
    - 15% Banked Turns
- RTK Base Station

Positioning Visualization



- Realtime display of positions from multiple sensors
- Error ellipse & pose history
- Easily import map data points

Demonstration

- Potential Test Scenarios
  - Varying speed runs
  - Varying sensor availability
  - Varying GPS satellite availability
  - …
- Presentation of results
  - Real time visualization
  - Trackside Error Statistics and Graphics
  - …