EXPLORATORY ADVANCED RESEARCH

The Exploratory Advanced Research Program

Vehicle Positioning, Navigation, and Timing: Leveraging Results from EAR Program-Sponsored Research

WORKSHOP SUMMARY REPORT • November 2012

U.S. Department of Transportation
Federal Highway Administration

Foreword

To examine dependable, precise, and commercially affordable positioning and navigation for roadways, the Federal Highway Administration's (FHWA) Exploratory Advanced Research (EAR) Program and Office of Operations Research and Development convened a panel of Government program managers and researchers involved in positioning and navigation. The workshop was held on November 20, 2012, at the Turner-Fairbank Highway Research Center and titled "Vehicle Positioning, Navigation, and Timing: Leveraging Results From EAR Program-Sponsored Research." It brought together experts who deal with research, development, deployment, or regulation of vehicle positioning and navigation for increased safety, mobility, and efficiency in transportation systems.

The panel of experts shared information about the results of EAR Program-sponsored research on vehicle positioning and navigation, addressed potential follow-up applied research, and discussed continued fundamental research gaps. They looked into summary requirements for determining appropriate positioning requirements. The group also identified key government, industry, and academic audiences that would be interested in the results as well as ways the EAR Program can help connect the audiences with the results. Their findings are presented in this report.

The EAR Program-sponsored research is looking at the next generation applications for vehicle positioning and navigation as well as opportunities to apply the results to other transportation modes. This research was undertaken to increase mobility on our Nation's highways and should be of interest to State highway agencies, academia, other Government agencies, industry, and the vehicle positioning and navigation community.

Joseph I. Peters
Director, Office of Operations Research and Development

Debra S. Elston
Director, Office of Corporate Research, Technology, and Innovation Management

Notice

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16. Abstract
On November 20, 2012, FHWA's Exploratory Advanced Research (EAR) Program and Office of Operations R&D convened a panel of Government program managers and researchers involved in positioning and navigation. The workshop was titled "Vehicle Positioning, Navigation, and Timing: Leveraging Results From EAR Program-Sponsored Research." It brought together experts who deal with research, development, deployment, or regulation of vehicle positioning and navigation for increased safety, mobility, and efficiency in transportation systems.

The panel of experts shared information about the results of EAR Program-sponsored research on vehicle positioning and navigation, addressed potential follow-up applied research, and discussed continued fundamental research gaps to be resolved to provide dependable, precise, and commercially affordable positioning and navigation for roadways. They looked into summary requirements for determining appropriate position requirements. The group also identified key government, industry, and academic audiences that would be interested in the results as well as ways the EAR Program can help connect the audiences with the results.

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Introduction

On November 20, 2012, at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA, the Federal Highway Administration's (FHWA) Exploratory Advanced Research (EAR) Program and Office of Operations Research and Development (R&D) convened a workshop to share information about the results of EAR Program-sponsored research on vehicle positioning and navigation.

The workshop, titled "Vehicle Positioning, Navigation, and Timing: Leveraging Results From EAR Program-Sponsored Research," was held to identify key government, industry, and academic audiences who would be interested in the results and how the EAR Program can assist in connecting the audiences with the results. It provided an opportunity to discuss potential follow on applied areas of research in addition to addressing continued fundamental research gaps that still need to be resolved to provide dependable, precise, and commercially affordable positioning and navigation for roadways.

The audience included Government program managers and researchers involved in the research, development, deployment, or regulation of positioning and navigation for increased safety, mobility, and efficiency in transportation systems.

The workshop began with a welcome from Joe Peters, Director, Office of Operations R&D at TFHRC. Peters described the work of the Saxton Transportation Operations Laboratory at TFHRC. He stated that the Saxton Laboratory includes exploratory work in automated systems and described the three teams that comprise the Office of Operations R&D as follows:

- Transportation Enabling Technologies.
- Transportation Operations Concepts and Analysis.
- Transportation Operations Applications.

This Vehicle Positioning, Navigation, and Timing Workshop was sponsored by the Transportation Enabling Technologies Team. Peters highlighted the vital importance of position, navigation, and timing (PNT) technologies. As an example, without a global positioning system (GPS) signal providing a reliable timing reference, traffic signals would lose the ability to function in a coordinated way, resulting in widespread traffic jams.

David Kuehn, EAR Program Manager, stated that FHWA's research is mission-driven to deliver mobility to the Nation's highways. The EAR Program looks for solutions beyond transportation, exploring the fields of science and engineering for next-generation applications, but remains ever mission-focused.

Several EAR Program-funded projects are related to positioning and navigation. The results of two of these projects were presented at the workshop and are detailed in this report. Although these projects are highway-focused, this workshop serves as an opportunity to apply these results to other transportation modes.

An overview of the two projects was then presented. Jim Arnold introduced the University of California at Riverside's research on new approaches in vehicle positioning. He stressed that one of the most importation aspects in research is a better definition of requirements.

David Gibson introduced Auburn University's research on vehicle positioning in GPS-degraded environments. He emphasized the importance for having calibrated test tracks in test environments.

Gary Pruitt of ARINC and Scott Andrews of Cogenia Partners then presented a talk on "Position Technology and Requirements for Connected Vehicles." An assessment on accuracy and positioning errors was presented. The focus of the talk was mainly on positioning errors and methods to improve accuracy.

Pruitt and Andrews attempted to define a process for systematically deriving requirements for positioning requirements for a given application. To accomplish this, there needs to be a better understanding of positioning errors and methods for improving position estimates. There are two main types of errors—random and offset.

- Random position errors cause position estimates to change from measurement to measurement. These errors are specified in terms of a statistical representation.
- Offset errors will affect all receivers of the same type in the same general manner. These errors are either systematic or ionospheric. They can be minimized by using differential GPS.

Other errors were also discussed, including motion errors. From moving platforms, a person only gets one sample at a given point instead of at a distribution of points. Latency errors are small time errors between platforms. These can be fixed with synchronized clocks. There may also be a processing lag caused by the use of algorithms to help smooth variations in position measurements. Map errors—where landmark positions are incorrect—were also discussed.

The talk then focused on decision errors, in which measurement and reality are compared. Correct decisions are made when measurement and reality are the same, whereas decision errors occur when measurement and reality are not the same. These error conditions cause false positives and false alarms. A false positive (i.e., when the measurement indicates *true* when in fact the reality is *false*) can lead to a missed detection or a dangerous situation. A false negative (i.e., when the measurement indicates *false* when in fact the reality is *true*) can lead to a nuisance or false alarm.

Next presented was a discussion of error tolerance and tolerable errors. In practical systems, some level of a tolerable error needs to be defined. These tolerances are different for false positives and false negatives, with a much larger tolerance for false positives.

The presentation then focused on hazard analysis, in which severity, exposure, and controllability determination were discussed. *Severity* was defined as a range that spanned from no injuries to life-threatening injuries, the term exposure varied from an incredibly low to a high chance of occurrence, and *controllability* indicated a range that spanned from generally controllable to difficult to control. Severity, exposure, and controllability determinations could be measured by a probability of occurrence.

The talk concluded with a summary of requirements and a summary of positioning technology. The presenters recommend the development of a decision–error method for determining appropriate positioning requirements. They also identified additional requirements based on dynamic factors and suggested time syncing to determine relative positioning. The summary of the presenters' review of positioning technologies identified GPS as the most promising (other technologies are less accurate and require significant infrastructure). They stressed that there is an emerging interest by GPS makers to explore low-cost, high-accuracy vehicle solutions.

Several questions were asked in response to the presentation. One question pertained to the scale of production or potential market for purchasing positioning technology. The response involved a discussion on receivers used for survey instruments. There is marginal additional cost for the hardware, but companies may charge more for additional performance as a way of recouping development costs. For example, some receivers are sold with full capabilities and users purchase licenses to activate the desired features. Further discussion pertained to errors and latency and how to develop budgets for cumulative errors.

PART ONE: PRESENTATIONS

Next Generation Vehicle Positioning

David Bevly
Auburn University

David Bevly along with three graduate students (Jordan Britt, Chris Rose, and Scott Martin) from Auburn University presented a talk on the status of Auburn's next generation vehicle positioning. The objective of the project was to provide ubiquitous precise positioning in regard to vehicle safety and automation in the presence of GPS degradation. Auburn partnered with Kapsch TrafficCom, Penn State University, and Stanford Research Institute (SRI) on this project. The project scope was to assess diverse positioning and data-fusion techniques, characterize achievable accuracy and robustness, and test and demonstrate capabilities on test track and roadway scenarios. The technical approach of this study was to fuse outputs from various technologies in an extended Kalman filter, which is used to smooth multiple measurements, exploit accuracy, and mitigate faults, as shown in figure 1.

Each technology was analyzed based on cost, availability, a six degrees-of-freedom (DOF) position, a three DOF position, drifting, environmental influences, and a requirement for an infrastructure, map, and central processing unit (CPU). A chart showing the results of this analysis for each examined technology is included in figure 2.

The first two navigation technologies presented were GPS and an inertial navigation system (INS). GPS fared well in availability, three DOF positioning, and drifting solution. It did not satisfy a six DOF position. INS satisfied the cost, six and three DOF positioning, and did well in denied environments, although it had a drifting problem. GPS and INS integration can satisfy all of the listed capabilities.

Jordan Britt presented Penn State University's road fingerprinting concept, as

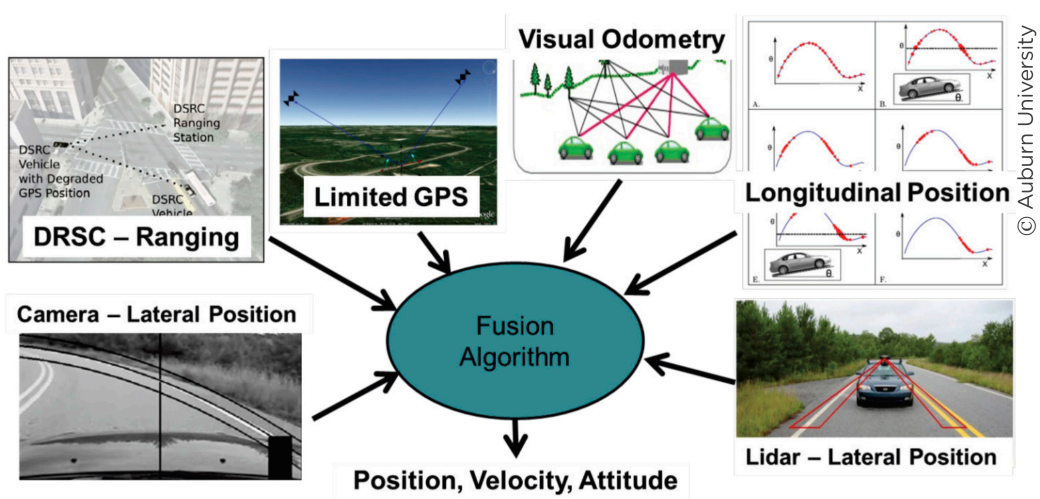

Figure 1. Diagram. The study fuses outputs from various technologies.

	Cost	Current Availability	Six DOF Position	Three DOF Position	Drifting Solution	Infrastructure Requirement	Map Requirement	CPU Requirement	Environmental Influences
GPS	✓ (yellow)	✓ (green)	✗ (red)	✓ (green)	✓ (green)	✓ (yellow)	✓ (green)	✓ (green)	✓ (yellow)
INS	✓ (green)	✓ (yellow)	✓ (green)	✓ (green)	✗ (red)	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Wheel Speed	✓ (green)	✓ (green)	✗ (red)	✓ (yellow)	✗ (red)	✓ (green)	✓ (green)	✓ (green)	✓ (green)
PSU-Road Fingerprinting	✓ (green)	✓ (green)	✗ (red)	✓ (green)	✓ (yellow)	✓ (green)	✓ (yellow)	✓ (yellow)	✓ (green)
AU-LDW LIDAR	✓ (yellow)	✓ (yellow)	✗ (red)	✓ (yellow)	✓ (green)	✓ (green)	✓ (yellow)	✓ (yellow)	✓ (yellow)
AU-LDW Camera	✓ (green)	✓ (green)	✗ (red)	✓ (yellow)	✓ (green)	✓ (green)	✓ (yellow)	✓ (yellow)	✓ (yellow)
SRI-Visual Odometry	✓ (yellow)	✓ (yellow)	✓ (yellow)	✓ (green)	✓ (yellow)	✓ (green)	✓ (green)	✓ (yellow)	✓ (yellow)
Kapsch-Gantry	✓ (yellow)	✓ (yellow)	✗ (red)	✓ (green)	✓ (green)	✓ (yellow)	✓ (green)	✓ (green)	✓ (green)

✓ (green)	No concern, current system capabilities not affected by criterion
✓ (yellow)	Some concern, criterion may limit implementation or capability
✗ (red)	Criterion cannot be overcome without additional subsystems

Figure 2. Diagram. The subsystem capability analysis matrix.

(NOTE: DOF = degrees of freedom, CPU = central processing unit, PSU = power supply unit, AU-LDW = Auburn lane-departure warning, LIDAR = light detection and ranging, SRI = SRI International.)

shown in figure 3. To use road fingerprinting, the road needs to have been surveyed. This is accomplished by driving with a high-grade inertial measurement unit (IMU) and a real time kinematic (RTK) GPS. The road survey must produce a map of the pitch signal, and the road fingerprinting is accomplished using a pitch gyro, wheel odometry, and the previously generated map. Required hardware is not a problem, because pitch gyro and wheel encoders currently exist on most automobiles. The capability analysis profile of this method is positive for cost, current availability, has no environmental influences, and requires no specific infrastructure to be in place. It does not provide a six DOF solution.

Jordan also presented Auburn's research into the use of light detection and ranging (LIDAR) in lane detection warning systems. Researchers conducted LIDAR tests by measuring the reflectivity on road markers and road edge detection, as shown in figure 4 and figure 5. They tested lane detection under various weather conditions and with various road conditions. Results were filtered and averaged. Except under rain conditions, the results were very good. For road edge detection, they used both distance and estimation of reflectivity. Data were bound and filtered. They conducted the tests during both day and night on country roads that had no outside lane markings. After post processing, the researchers found that the final results were quite accurate. The overall results of LIDAR processing were that it did not have a drifting problem and did not require an in-place infrastructure. The LIDAR solution does not provide a six DOF solution.

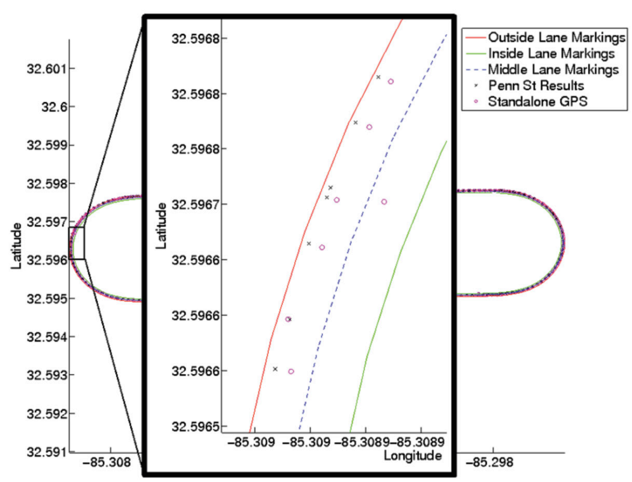

Figure 3. Chart.
Penn State University's road fingerprinting concept.

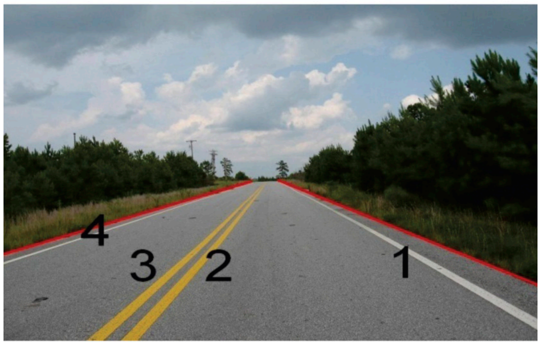

Figure 4. Photo. LIDAR Base Lane Detection.

Next was Chris Rose's presentation on the use of cameras in lane detection. Cameras already exist in newer vehicles. With no side markings on roads, color is used to determine the edge. This is difficult at night or in the shade. Edge detection is determined by using methods such as a Hough transform, least squares interpolation, Kalman filtering, and determining polynomial bounds. Researchers performed the test with a Webcam at low resolution, with a road width measurement taken far down the road, in day and night scenarios, and with induced error sources, including shadows, headlights, and road intersections. They compared the results of these tests with the physical conditions. The overall results for camera road edge detection were a low-cost solution with currently available technology, having no drift or infrastructure requirements. The camera road edge detection system did not provide a six DOF solution.

Chris went on to present results from testing of the SRI visual odometry system, shown in figure 6. This process tracks features from

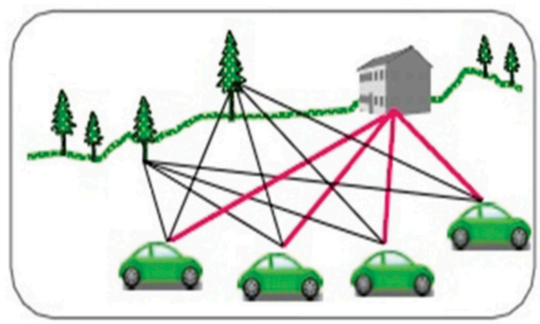

Figure 6. Diagram.
Stanford Research Institute's Visual odometry concept.

image to image and extracts egomotion, providing local odometry without GPS initialization. The sensor package includes the following components: two cameras with Ethernet interfaces, two lenses, an IMU operating at 100 Hz, a Netgear Ethernet hub, a computer, cabling, and connectors. The cameras are rear-mounted to minimize

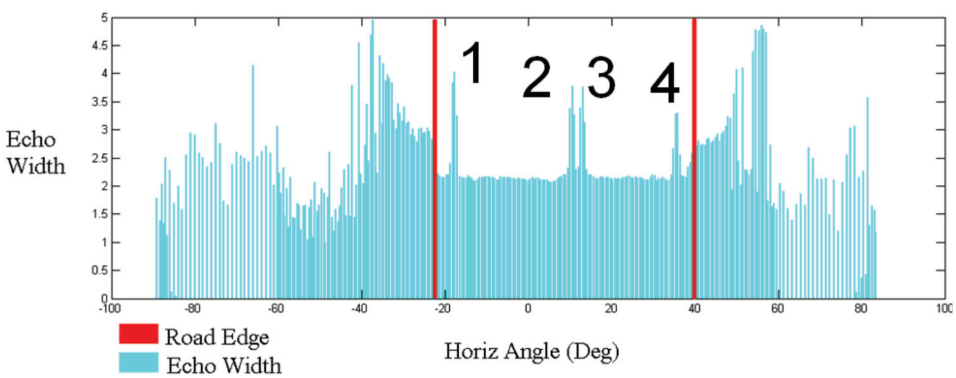

Figure 5. Chart. LIDAR Base Lane Detection.

glare problems. Researchers tested the system in inclement weather during which feature tracking and positioning remained functional and lenses covered with water droplets cleared once the vehicle reached higher speeds. The researchers determined that hoods overhanging the lenses might be sufficient to reduce the effects of sun glare and water droplets. The overall results from testing the SRI visual odometry system were a three DOF solution with no requirements for maps or specific infrastructure requirements. There were no critical problems with this solution.

The final system presented was the Kapsch-Gantry TrafficCom—a dedicated short-range communications (DSRC) system. The initial plan was to estimate the range based on the turnaround time for unsynchronized clocks. It was found that the project hardware was not capable of lane-level precision; however, the sensor may still provide some information if nothing else is available. Researchers at the National Center for Asphalt Technology (NCAT) test track collected time of flight data between the Kapsch radio base station and the Auburn test vehicle. The resulting variation in time of flight measurements proved to be insufficient for lane-level measurements. The overall results for the Kapsch TrafficCom system provided a three DOF, had no drifting problem, did not require a map or CPU, and was free of environmental issues. It did not provide a six DOF position.

Scott Martin then presented results of integration of the various systems. The INS was used as the base system with data from the other sensors fused in an extended Kalman filter implementation. Eighteen states were propagated from this scenario by using nonlinear relationship and IMU measurements. The outputs of the various systems are detailed in table 1.

Table 1. Outputs of various systems.

Subsystem	Outputs
INS navigation processor	Navigation frame accelerations and angular rates (bias corrected)
GPS processor	Range/range rates Positions/velocities
Camera LDW processor	Lateral lane position
LIDAR LDW processor	Lateral lane position
Fingerprint processor	Navigation frame position
Visual odometry processor	Navigation frame position

(NOTE: INS = inertial navigation system, GPS = global positioning system, LDW = lane-departure warning, LIDAR = light detection and ranging.)

Integration testing in Detroit, MI, was then discussed. Honda developed the test route to meet road-use class proportioning of vehicle travel in the United States.[1] Environments found at this test track included trees, tree canopies, overpasses, buildings, urban canyons, and tunnels. Testing scenarios included testing various combinations of sensors and an extended Kalman filter implementation. The

1. U.S. Department of Transportation, Federal Highway Administration, "Annual Vehicle-Miles of Travel 1980-2007, By Functional System, National Summary (Table VM-202, summary for 2007)," Jan. 2009, http://www.fhwa.dot.gov/policyinformation/statistics/vm02_summary.cfm.

results showed that GPS/INS integration improved results in heavy foliage and urban canyons, and vision updates were provided where the lane of travel was assumed. Further observations showed that, although subsystem integration improved positioning accuracy, it was limited by maps, survey accuracy, and availability. Limitations were identified on road fingerprinting and visual odometry. A new lane detection algorithm is needed that leverages new road edge detection methods and inertial information.

Testing at NCAT was discussed. The facility has a 1.7-mi (2.7 km) oval track, shown in figure 7, and is surveyed for lane markings and centers. The RTK base station supports wireless communications. Researchers collected four data sets of several laps. The results showed that a full system of sensors performed best, followed by a GPS sensor. The full system contained vision and fingerprint aiding, which improved lane-level accuracy. The GPS/INS integrated solution trailed as a result of memory limits.

Rose discussed the results of testing on driveways at TFHRC. A Novatel base station provided RTK corrections. Satellite visibility was degraded in some areas. The results showed limited precision in the fingerprint survey and lane-level accuracy was best with GPS/INS integration because of error correlation.

Conclusions of the Auburn studies were that subsystems help improve lane-level accuracy and continued testing is needed to assess system robustness. During a question-and-answer session, one participant of the workshop asked whether testing had been conducted with Jersey barriers. The response was that testing had not been conducted with Jersey barriers since Jersey barriers are not common near rural Auburn.

© Auburn University

Figure 7. Photo. The National Center for Asphalt Technology's oval track.

Innovative Approaches for Next Generation Vehicle Positioning

Jay Farrell
University of California at Riverside

Jay Farrell started his presentation with a discussion of real-time positioning and precision mapping. Many intelligent transportation applications require positioning with high degrees of accuracy, a high sample rate, and working in diverse environments at low cost. A solution to these requirements is to fuse high rate sensors, such as an encoder or IMU, with lower rate sensors, such as GPS, cameras, LIDAR, radio detection and ranging (RADAR), DSRC, and signals of opportunity. A chart showing the capabilities of the aiding sensors can be found in figure 8.

These aiding sensors have characteristics that help reduce the position uncertainty. For example, in an urban canyon with one GPS satellite available, the car sensor system can only see ahead. With the use of traffic signals, the system can make distance adjustments as the car travels perpendicular to the signal, as shown in figure 9. With LIDAR, there is access to raw data; with RADAR, raw data are inaccessible, only position data—range and angle—are available. Therefore, RADAR needs mapped features on which to plot these positions for the data to be useful.

	Technology	Principle	Range Accuracy	Veh. Cost	Rdwy. Cost	Req'd Advances
	GPS	TOA	10 m	Low	Bases, comms	Modernization
	DGPS		1 m	Low	Bases, comms	Modernization
	CPDGPS		0.01 m	High	Bases, comms	Modernization
Terrestrial Radio Navigation	Pseudolites	TOA, TDOA	0.01 m	Med	High	> First generation
	-- Cell Phone	RSSI	km's	Low	Existing	
	-- Cell Phone	TOA, TDOA	100's m	Low	Existing	Physical layer timing
	-- TV - digital	TOA	10's m	??	Bases, comms	??
	-- Radio AM Analog	TOA	10's m	Low	Existing	??
	-- Radio FM Analog	TOA	??	Low	Existing	??
	-- Radio Digital	TOA	??	Low	Existing	??
	-- Packet Radios	TOA, TDOA	km's	Low	High	Physical layer timing
Feature Based	Vision	AOA		Low-Med	Feature Mapping	Feature Robustness
	Radar	AOA, RTOA	0.1 m	Low-Med	Feature Mapping	Feature Robustness
	Lidar	AOA, RTOA	0.01 m	High	Feature Mapping	Feature Robustness

GNSS: Proven with open skies. Challenging in urban environments.
TRN: Shows great promise as physical layer timing advances
FB: Assessed as viable *if precision roadway feature maps are available*. Research leading to reliable and accurate FB positioning demonstrations was a project focus.

Figure 8. Diagram. The capabilities of aiding sensor categories.

(NOTE: GPS = global positioning system, DGPS = differential global positioning system, CPDGPS = carrier-phase differential global positioning system, TOA = time of arrival, TDOA = time difference of arrival, AOA = angle of arrival, GNSS = global navigation satellite system, TRN = terrain reference navigation, FB = feature based.)

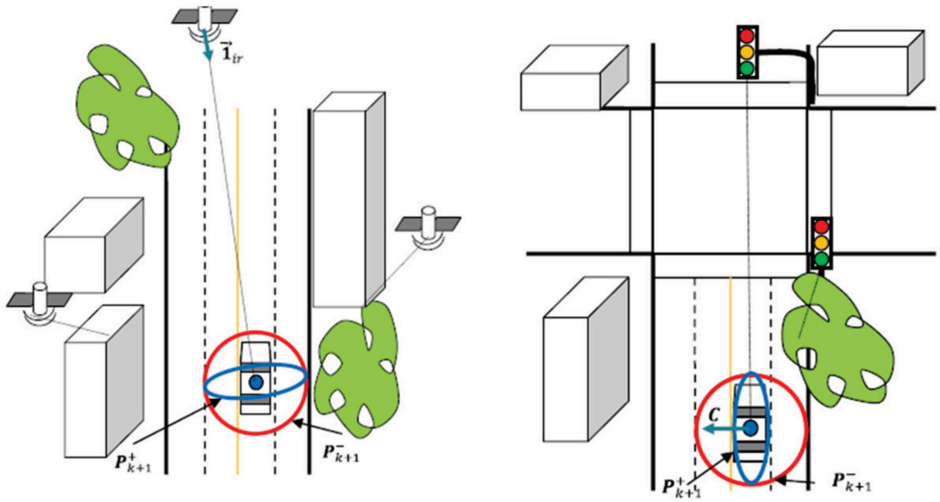

Figure 9. Diagram. Positioning uncertainty reduction.

Farrell then focused on precise roadway feature maps. These features include road and lane edges, sign types and locations, street lights, traffic signals, and stop bars. High precision (sub-decimeter) positioning is needed for next generation applications. Some of these applications could include lane-departure warnings, curve-over speed warnings, signal phase and timing by lane, intersection management, and collision avoidance.

The mapping process was discussed. The first step is data acquisition from vision systems—GPS/INS and LIDAR. The data are gathered

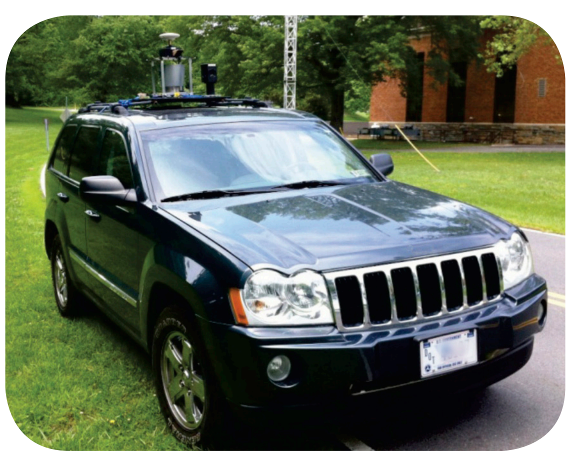

Figure 10. Photo.
Vehicle equipped with sensor platform on roof.

from these systems as the vehicle, shown in figure 10, is driven. Data are then smoothed to provide a continuously smooth trajectory. Features are then identified and extracted from the raw data. In the final step, relative map features are combined with absolute trajectory and placed in a geographic information systems (GIS) database in world coordinates.

No single independent sensor technology is capable of simultaneously attaining the accuracy, integrity, and availability specifications for lane-level positioning in expected diverse environments. Integrated positioning, which fuses asynchronous data from diverse sensors, is the best approach to reliably and accurately estimate vehicle position. Inertial Navigation Systems and Encoder Navigation Systems provide positioning solutions in all environments continuously at high rates; however, their accuracy drifts over time without aiding.

Global navigation satellite systems provide high accuracy in open areas where satellite signals can be received; however, performance degrades in dense urban areas. Feature-based navigation-aiding by using a camera, LIDAR, or RADAR can be successful when mapped features can be reliably detected and tracked. Several forms of ground-based radio communication systems, which can offer potentially useful position information, have been designed to penetrate the urban infrastructure and have the added advantage that their performance characteristics can still be influenced by the engineering community interested in roadway applications.

Farrell concluded the presentation by presenting ideas for future work:

Positioning

- DSRC modem-based time-of-flight positioning (direct contacts with manufacturers are in place).
- Terrestrial Radio Frequency Signals of Opportunity: Digital television, digital radio, and cellular.
- Enhance performance and robustness of feature-based methods, especially RADAR and LIDAR.
- Investigate safety- and integrity-monitoring for data-fused vehicle applications.

Mapping

- Improved and more fully automated mapping processes.
- Mapping additional feature types.
- Thorough evaluation in less-structured, more-dynamic environments.
- Maintenance of the precision map.
  - Crowd sourcing.
  - Targeted updates.
- Large-scale computer or cloud implementation to map larger environments.

Positioning and Mapping

- Thorough evaluation in less-structured, more-dynamic environments.

PART TWO: NEXT STEPS

Disseminating Project Results and Future Research Needs

David Kuehn
EAR Program, FHWA

David Kuehn initiated a discussion on sharing project results. Kuehn asked, from maps to ITS, what data can be shared?

It was stated that data from the Connected Vehicle Safety Pilot Program should be available soon. This will allow users to examine the formats of data so that they can best use the data.

The question of what is "state of the art" was also put forward. It was noted that the commercial world is now deploying, at a reasonable price, some of the concepts presented today.

Discussion proceeded to cover the IMU in long vehicles (e.g., buses and trucks) and the sensitivity issue and problem of losing the GPS signal. It was highlighted that in sharp turns, the distance from the center of gravity or rotation could be issues. Jay Farrell stated that center of gravity is not as important as using the center of axle position. It was suggested that robust control systems are needed and that multiple sensors are required to assist these issues.

Several mapping issues that concern intersection geometry were discussed as follows:

- Location of stop line—How often does it change? Who updates the information?
- Striping—Put a GPS on a striping machine.
- Next time the intersection is reconfigured or re-striped, measure it digitally.
- Standards are needed.

Bridge height was put forward as another issue, because it is not correctly mapped or displayed. In addition, truckers may not know the correct height of their vehicles.

Test sites were also discussed, and it was noted that there was limited instrumented data from Michigan; the Honda site is the only one with a surveyed urban forest. It is important to have a greater variety of test sites or to have one test site that has great variety of test scenarios.

There was a discussion on having a larger follow-up workshop on positioning and navigation; however, it was also suggested that the commercial world may solve these problems before this group gets around to discussing them.

Other discussion topics included lane control and intersection control, the need for living laboratories, and the need of test beds to simulate age-of-road conditions.

It was also suggested that there should be more collaboration, including the potential for Auburn and Riverside to run each other's tests. Moreover, to cut down on testing costs, perhaps rental cars with mounted devices could be used.

During discussion, it was noted that no sensors talk to each other in modern-day automobiles. It was suggested that these sensors could communicate via the controller area network data bus or some other data-sharing mechanism. In addition, there needs to be time-stamped raw data.

The final discussion pertained to what research government should be involved in. The question of whether the lack of inoperability is because of lack of interest or a problem with future competitors was also highlighted.

The meeting ended with a tour of the laboratory and an opportunity to ride in the Auburn University test vehicle, pictured in figure 11.

Figure 11. Photo. Test vehicle outside the Turner-Fairbank Highway Research Center.

Appendix A

Agenda

Vehicle Positioning, Navigation, and Timing:
Leveraging Results from EAR Program-Sponsored Research
Turner-Fairbank Highway Research Center, McLean, VA, November 20, 2012

9:15 a.m.	**Welcome and Introductions** Joe Peters, *Director, Office of Operations R&D, FHWA*
9:30 a.m.	**Exploratory Advanced Research Program Context** David Kuehn, *EAR Program Manager, FHWA*
	Overview of EAR Projects Jim Arnold, *Office of Operations R&D, FHWA* David Gibson, *Office of Operations R&D, FHWA*
9:45 a.m.	**ITS Vehicle Positioning Requirements** Gary Pruitt, *ARINC*
10:30 a.m.	**Break**
10:45 a.m.	**Research Results**
	Next Generation Vehicle Positioning in GPS — Degraded Environments for Vehicle Safety and Automation Systems David Bevly, *Auburn University*
	Innovative Approaches for Next Generation Vehicle Positioning Jay Farrell, *University of California at Riverside*
12:30 p.m.	**Laboratory Visit and Lunch**
2:00 p.m.	**Next Steps: Disseminating Project Results** David Kuehn, *EAR Program Manager, FHWA*
3:15 p.m.	**Break**
3:30 p.m.	**Future Research Needs** David Kuehn, *EAR Program Manager, FHWA*
4:45 p.m.	**Close**

Appendix B

List of Attendees

Bruce Abernathy
Senior Principal Engineer
ARINC

Scott Andrews
Technical Partner
Cogenia Partners, Inc.

James Arnold
Electronic Engineer
Office of Operations R&D, FHWA

David M. Bevly
Professor
Auburn University

Jordan Britt
Student
Auburn University

Jay A. Farrell
Professor
University of California, Riverside

Walton Fehr
Program Manager
ITS Joint Program Office, RITA

Robert Ferlis
Technical Director
Office of Operations R&D, FHWA

David Gibson
Highway Research Engineer
Office of Operations R&D, FHWA

Helen Gill
Program Director
National Science Foundation

Terry Halkyard
Program Coordinator
EAR Program, FHWA

Cem Hatipoglu
Transportation Specialist
Federal Motor Carrier Safety Administration

David Kuehn
Team Director
EAR Program, FHWA

Mike Lukuc
Program Manager
National Highway Traffic Safety Administration

Scott Martin
Student
Auburn University

Jules G. McNeff
Vice President
Overlook Systems Technology

Rudy Persaud
Highway Research Specialist
Office of Operations R&D, FHWA

Joe Peters
Director
Office of Operations R&D, FHWA

James Pol
Team Lead
ITS Joint Program Office, RITA

Gary Pruitt
Senior Director
ARINC

Anura Rabel
HR Information Specialist
Office of Human Resources, FHWA

William Rabinovich
Optical Sciences Division
U.S. Naval Research Laboratory

Christopher Rose
Student
Auburn University

Jayne Rossetti
Senior Software Engineer
Volpe Center, RITA

Stephen Stasko
National Highway Traffic Safety Administration

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