# Next Generation Vehicle Positioning Techniques for GPS-Degraded Environments to Support Vehicle Safety and Automation Systems

FHWA BAA DTFH61-09-R-00004

EXPLORATORY ADVANCED RESEARCH PROGRAM

Auburn University

SRI

The Pennsylvania State University

Kapsch TrafficCom Inc.

NAVTEQ North America LLC

## Quarterly Report 8

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# 1. Scope

In an open environment, GPS provides a good estimation of vehicle position. Numerous improvements over the basic GPS framework have provided accuracies in the centimeter range. However, blockages of the GPS signal create significant problems for the positioning solution. In so-called "urban canyons", GPS signals are blocked by the presence of tall buildings. Similarly, heavy foliage in forests can block line-of-sight to the satellites. Because of these problems, a broader approach is needed that does not rely exclusively on GPS. This project takes into account three key technology areas which have each been individually shown to improve positioning solutions where GPS is not available or is hampered in a shadowed environment. First, terrain-based localization can be readily used to find the vehicle's absolute longitudinal position within a pre-mapped highway segment – compensating for drift which occurs in dead-reckoning system in long longitudinal stretches of road. Secondly, visual odometry keys upon visual landmarks at a detailed level to correlate position to a (visually) premapped road segment to find vehicle position along the roadway. Both of these preceding techniques rely on foreknowledge of road features – in essence, a feature-enhanced version of a digital map. This becomes feasible in the "connected vehicle" future, in which tomorrow's vehicles have access to quantities of data orders of magnitude greater than today's cars, as well as the ability to share data at high data rates. The third technology approach relies on radio frequency (RF) ranging based on DSRC radio technology. In addition to pure RF ranging with no GPS signals, information from RF ranging can be combined with GPS range measurements (which may be inadequate on their own) to generate a useful position. Based on testing and characterization of these technologies individually in a test track environment, Auburn will define a combined Integrated Positioning System (IPS) for degraded GPS environments, which will also incorporate ongoing FHWA EAR work at Auburn in fusion of GPS and on-board sensors. This integrated approach will blend the strengths of each technique for greater robustness and precision overall. This research is expected to be a major step forward towards exceptionally precise and reliable positioning by taking advantage of long-term trends in on-board computing, connected vehicles, and data sharing.

## *1.1 SRI Sarnoff Contribution*

The scope of SRI Sarnoff's work under Year One of this project is the evaluation of their Visual Aided Navigation System for providing highly accurate positioning for vehicles. As such there are 3 major tasks:

(1) Evaluate and provide a survey of Sarnoff's existing Visual Navigation results

(2) Integrate Visual Navigation system on Auburn Engineering's G35 vehicle test platform and collect test data using the integrated system.

(3) Process and analyze the data from the tests and evaluate the performance and recommend any improvements and optimizations.

## *1.2 The Pennsylvania State University Contribution*

For sake of clarity and coherence, the scope of Penn State's contribution to the project, as discussed in previous quarterly reports, is reproduced here. The primary objectives under Penn State's purview are:

(1) Developing the proven particle filter approach so that it can be used for localization with commercial-grade sensors, rather than defense-grade sensors,

(2) Modifying and optimizing the particle filter algorithm, and exploring alternative approaches, so that localization can take place online (in real-time) rather than offline, and

(3) Modifying and optimizing the algorithms as well as terrain map representation, so that the localization algorithms work over a large network of roads, rather than a small section of a single road alone.

## *1.3 Kapsch TrafficCom Inc. Contribution*

Kapsch will investigate the accuracy of close proximity calculations available from the 5.9 GHz DSRC communications channel. A great deal of information related to positioning can be inferred from the DSRC communications channel. Basic calculations may provide a location region achieved through the channel ranging calculations to more precise lane based proximity determinations through advanced analysis of the communications channel. Kapsch will research a combination of both approaches through available data defined in the IEEE 802.11p standard for 5.9 GHz communication and through scientific Radio Frequency (RF) analysis.

Kapsch will support Auburn for the characterization of the ability to utilize the 5.9 GHz DSRC communication channel for next generation non-GPS localization services. The Received Signal Strength Indication (RSSI) in-conjunction with other aspects of the DSRC communications channel will be analyzed and a method developed for signal ranging. Kapsch does not believe RSSI ranging techniques will fully meet the desired localization needs. Year 2 will yield more advanced algorithms and DSRC equipment capable of providing lane level localization from the DSRC communications channel. This task includes the following sub-tasks:

(1) System Engineering and Deployment of DSRC Infrastructure at the Auburn Test Track

(2) Lab testing of DSRC signal ranging solution

(3) On-site testing of DSRC signal ranging solution

(4) Analysis of DSRC signal ranging test results

# 2. Current Progress

## 2.1 Penn State Current Progress

Auburn has interfaced to Penn State's latest deliverable and Auburn is in the process of collecting and analyzing data utilizing this latest deliverable. Penn-State's latest deliverable has been an implementation of the road-fingerprinting algorithm which attempts to find the vehicle position along the road network.

## 2.2 SRI Current Progress

The laptop from SRI has been returned in order to update the SRI Visodo system with the modifications described in the last quarterly report. SRI has also submitted their final report, which is available on request. SRI will continue to provide aid in the demonstration of the system to FHWA.

Figure 1 shows four results of one of the test runs on Auburn’s NCAT test track with varying degradation in GPS. The top left plot shows 2m degradation and the estimate corresponds well with the track’s coordinates. The top right plot shows 4m degradation and the estimate corresponds well with the track’s coordinates, albeit with several drifts. The lower left plot shows 6m degradation in GPS and the drift is more pronounced. The lower right plot shows the visual odometry with no GPS, and the drift is clearly evident as the estimate of the path is significantly changed from the track. The right side of the track corresponds well, but the left side of the track is angled at a 30 degree angle away from the track’s coordinates.

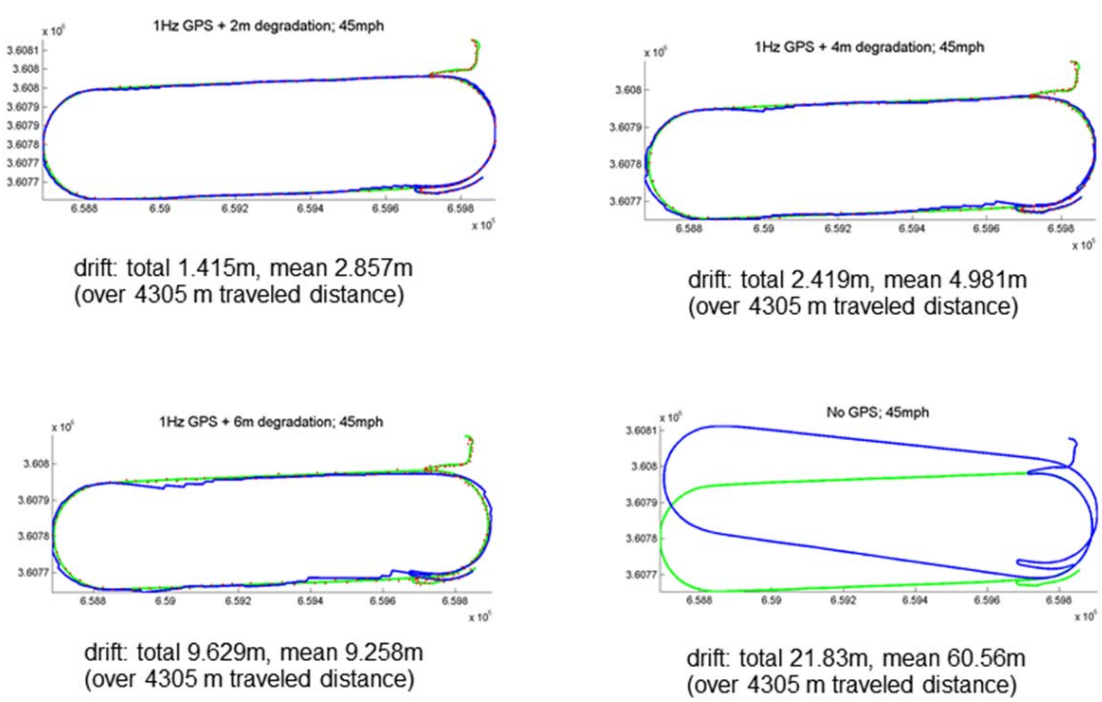


Figure 1: Results of visual odometry plus GPS at 50 mph

## 2.4 Auburn Current Progress

### 2.4.1 Detroit Testing

Auburn traveled to Detroit in October to test the system in various environments in and around the Detroit metro area. The test route was planned by Honda personnel to evaluate the performance of positioning algorithms experienced during the daily driving. The 46 mile route traversed suburban area, limited access highways, and severe urban convoys. The route trajectory is shown in Figure 2.

The figure below shows the test route for the test in Detroit. The route consists of about 15k meters north-south and 20k meters east-west. The route has a loop in a heavy foliage neighborhood in the westernmost part of the test route, and another loop to downtown Detroit in the westernmost part of the test route.

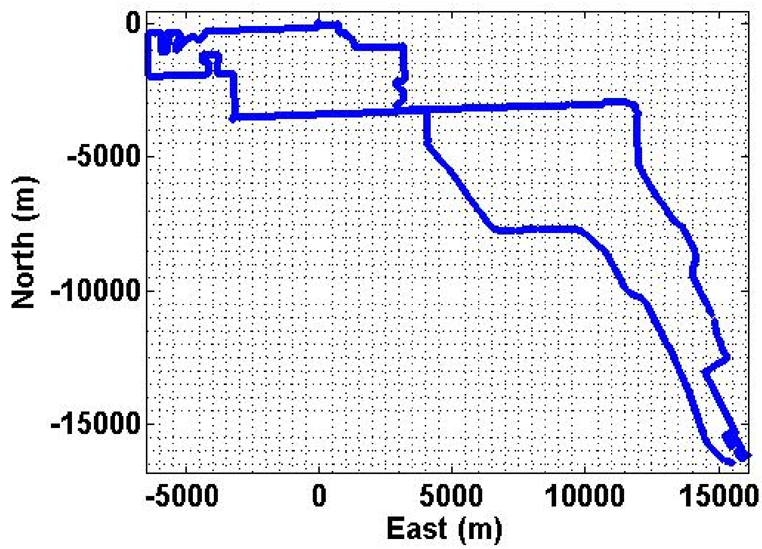


Figure 2: Test Route in Local North East Coordinates

Due to the lack of DSRC radio infrastructure along the route, the Kapsch system was not tested. Also, Penn State's system requires a map, and the map was not generated. As such, on SRI's Visual Odometry system was tested. In addition, data was taken of inertial measurements with the XBOW 440 IMU, GPS with a Novatel receiver and a u-blox receiver, CAN data from the Nissan G35, and longitudinal speed from a wheel speed sensor. Over 5 test runs, Auburn collected approximately 4 million lines of data per 1.5 hour test run. Analysis of the data is currently underway.

The performance of GPS in the challenging environments experienced during testing is of particular interest. In, Figure 3, the GPS horizontal dilution of precision (HDOP) calculated at each measurement epoch is shown as a function of location along the route. Since HDOP is time varying, the values are plotted for three test runs occurring over the morning of the first test day. Note that the higher HDOP values occur in the heavy foliage neighborhood areas in the northeast corner and the downtown area in the southwest corner of the test route.

The figure below shows a three dimensional plot. The test route is seen on the x-y axis in North-East coordinates, as seen from Figure 2. The z-axis shows three runs (6AM, 9AM, and 11AM) with the magnitude corresponding to the HDOP values. The higher HDOP values result in worse GPS, and can be seen mainly in the foliage and downtown areas in the plot.

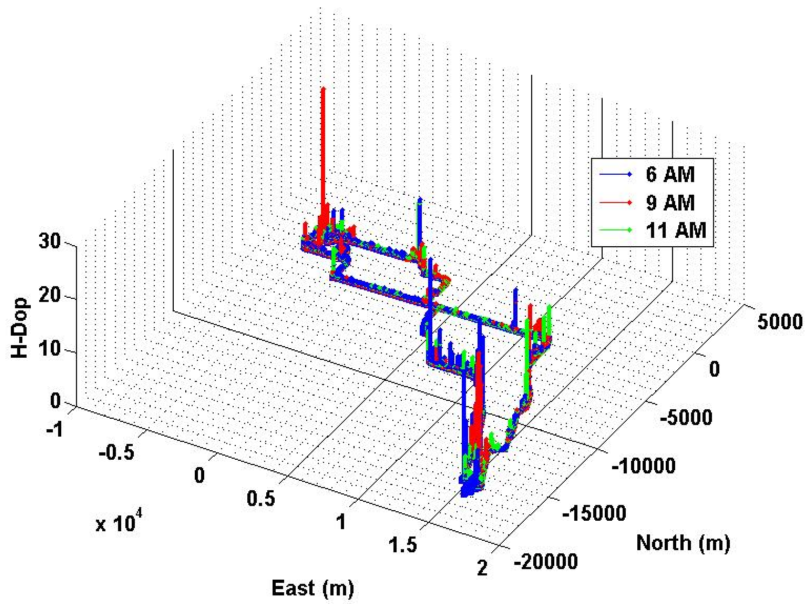


Figure 3: Horizontal dilution of precision as a function of position along test route. Heavy foliage (North West) and downtown (South East) exhibit high HDOP values.

# 3. Future Work

Auburn will continue to analyze the data taken in Detroit. Auburn will also take the lessons learned in the Detroit testing and apply them in the preparation for the testing in D.C. Also, another Automotive Panel Meeting is expected to occur sometime in late December / early February.

# Gantt Chart

| | A | AC | AD | AE | AF | AG | AH | AI |
|---|---|---|---|---|---|---|---|---|
| 1 | | 2012 | | | | | | |
| 2 | | January | February | March | April | May | June | July |
| 3 | Schedule (Proposal) | | | | | | | |
| 4 | | | | | | | | |
| 5 | 1.0 Project Management | | | | | | | |
| 6 | 1.1 Team Meetings | | | | | | | |
| 7 | 1.2 Conduct Expert Panel Mtgs | | | | | | | |
| 8 | 2.0 Literature Survey | | | | | | | |
| 9 | 3.0 Investigate Terrain-Based Localization | | | | | | | |
| 10 | 3.1 Install on Test Vehicle | | | | | | | |
| 11 | 3.2 Define Test Protocol | | | | | | | |
| 12 | 3.3 Collect Characterization Data and Analyze Results | | | | | | | |
| 13 | 4.0 Investigate Visual Odometry Based Positioning | | | | | | | |
| 14 | 4.1 Install on Test Vehicle | | | | | | | |
| 15 | 4.2 Define Test Protocol | | | | | | | |
| 16 | 4.3 Collect Characterization Data and Analyze Results | | | | | | | |
| 17 | 5.0 Investigate DSRC-based RF Ranging | | | | | | | |
| 18 | 5.1 Install DSRC Equipment on Test Vehicle and Test Track | | | | | | | |
| 19 | 5.2 Define Test Protocol | | | | | | | |
| 20 | 5.3 Collect Characterization Data and Analyze Results | | | | | | | |
| 21 | Milestone 1: Testing and Analysis Completed for Each Positioning Technique | | | | | | | |
| 22 | 6.0 Define Integrated Positioning System | | | | | | | |
| 23 | 6.1 Define Initial IPS | | | | | | | |
| 24 | Milestone 2: Define Initial Integrated Positioning System | | | | | | | |
| 25 | 6.2 Revise IPS Definition Based on Expert Panel Feedback | | | | | | | |
| 26 | 7.0 Demonstration and Final Report | | | | | | | |
| 27 | 7.1 Demonstrate Vehicle Capability | | | | | | | |
| 28 | 7.2 Develop Transition Plan | | | | | | | |
| 29 | 7.3 Deliver Final Report | | | | | | | |