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

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EXPLORATORY ADVANCED RESEARCH PROGRAM

Auburn University

Sarnoff Corporation

The Pennsylvania State University

Kapsch TrafficCom Inc.

NAVTEQ North America LLC

Quarterly Report 3

April – June 2010

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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 Sarnoff Corporation Contribution

The scope of 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.

As mentioned in the previous quarterly report, Penn State has already developed the capability to simulate commercial-grade sensors. Further, as part of task (2), Penn State is currently developing Simulink diagrams for real-time simulation, and QuaRC/Simulink architecture for real-time implementation of terrain-based localization algorithms. The simulated commercial-grade sensors, developed as part of Task (1), are currently being used to analyze the performance of the localization algorithms. Work on Task (3) has been initiated, and means to optimize the real-time system are being evaluated. The details of the progress since the previous quarterly report and current and upcoming work are included in the following sections.

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

Auburn’s team has been working with each partner in anticipation of the full system integration for Year 2.

2.1 Sarnoff Progress

Sarnoff has been developing a Visual Odometry + Landmark Matching system to be deployed onto Auburn University’s vehicle test platform. Sarnoff’s Landmark Matching system usually loads all the pre-computed landmarks into memory for fastest performance. While this has been an acceptable solution for most of their previous projects it is not very scalable to very large areas, such as those that could be encountered by a vehicle. During testing over larger distances Sarnoff realized that in order to maintain the scalability of their system they would have to develop a caching mechanism for the landmark database.

Sarnoff’s approach relies on the fact that at any given time they only need the landmarks that could be visible from the current location. Sarnoff developed a caching system based off of spatial proximity to the current location of the vehicle. The landmark database is broken up spatially into tiles and then indexed for fast searching by a tile manager. This whole process is done offline during initial landmark database computation and does not diminish the performance of our live system. When running live, the tile manager loads the tiles adjacent to our current and possible future locations based on the current movement properties of the vehicle. In between landmark matches, Sarnoff’s visual odometry system keeps track of the movement of the vehicle. Since the drift characteristics of the visual odometry are known Sarnoff can increase the radius of tiles to load based on possible drift over time and distance travelled since last landmark match. In the figure below you can see a representation of the system with Landmark Match caching.

Figure 1 shows a black diagram of Sarnoff's Landmark Caching system. The Visual Odometry block sends the Current Pose to the Landmark Cache. The Current Pose is sent from the Landmark Cache to the Cache Cleanup. The Shot Returned is sent from the Landmark Cache block to the Landmark Matching block and the Shot Request is sent from the Landmark Matching block to the Landmark Cache block. The Title containing the shot is sent to the Tile Manager block from the Landmark Cache block. The Current Pose is sent from the Landmark Cache block to the Tile Manager block. The Landmark Database sends information to the Tile Manager block and the Tile Manager block sends information to the External Storage. The Tile Manger and Landmark Database blocks are both offline processes.

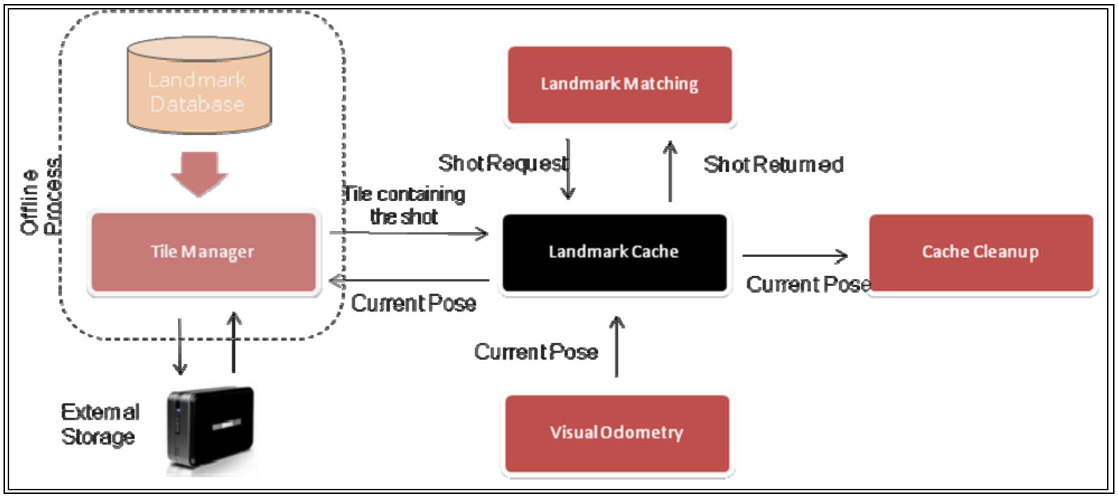

Figure 1: Block diagram of Landmark Match caching system

Additionally during testing Sarnoff found a few issues with the integration of IMU and Visual Odometry in the Kalman filter. During visual odometry failures (low visibility or low texture areas) the filter provides navigation solution solely based on the IMU. 6-DOF pose is derived using the IMU mechanization equations to integrate the gyro and accelerometer readings. However, this is accurate for a brief time and starts drifting very rapidly in the absence of visual odometry poses to correct the errors in the IMU solution. To account for this Sarnoff has changed the filter to only provide 3-DOF orientation after a few seconds of visual odometry outage. When visual odometry becomes available again, the regular operation resumes.

Another issue Sarnoff found was that in certain situations we were exceeding the specs of the gyro in the IMU and the measurements were wrapping around creating completely incorrect results. This is illustrated in the figure below.

Figure 2 shows a plot of corrected and uncorrected gyro measurements. The uncorrected gyro measurement wrap at 300 deg/s. The corrected gyro measurements does not contain the wrapping.

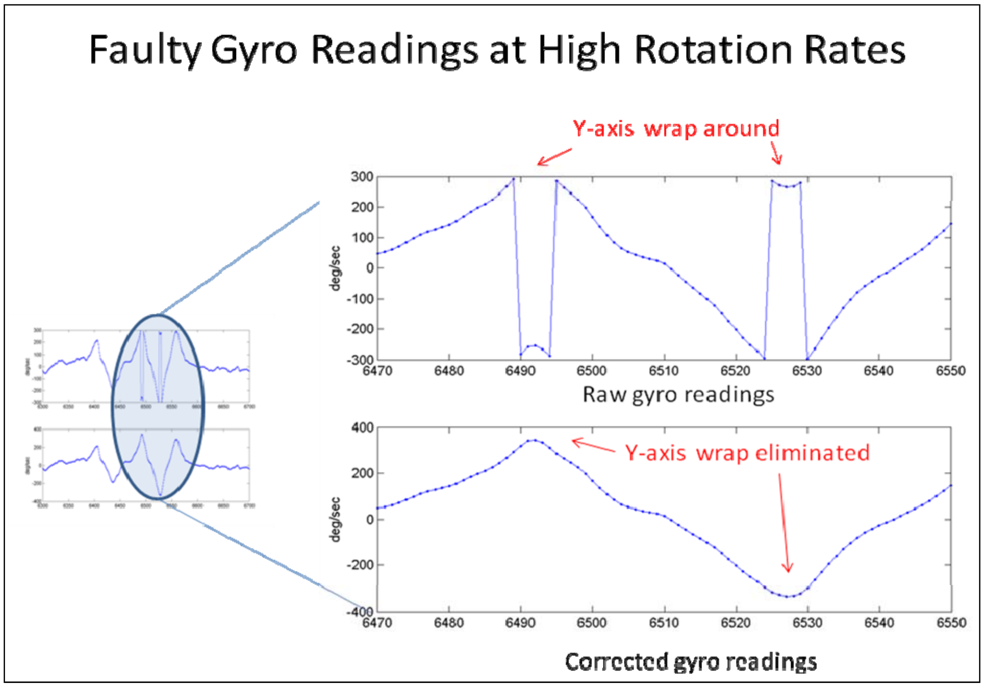

Figure 2: Faulty and corrected gyro reading

2.2 Penn State Progress

2.2.1 Real-Time Implementation

Task (2) entails the development of a real-time implementation of the localization algorithm. The localization algorithm is intended to provide accurate position estimates during periods and/or regions with weak or absent GPS signals. In the previous report, Penn State had outlined the system architecture for implementing such an algorithm. It was also mentioned that the algorithm would utilize the Unscented or Sigma-Point Kalman Filter (SPKF) as the estimator. Since then, Penn State has built a Simulink model to simulate the real-time implementation of the SPKF. The real-time simulation indicates that the algorithm can achieve meter-level accuracy using the commercial-grade sensor (Figure 2). However, the model is still being tested to analyze the algorithm's performance under different conditions such as when parameters such as map decimation, sampling frequency etc. are changed.

Figure 3 shows the tracking error during real-time simulation. The tracking error (in meters) starts around 0. At 20 seconds, the error increases to 1.4 meters.

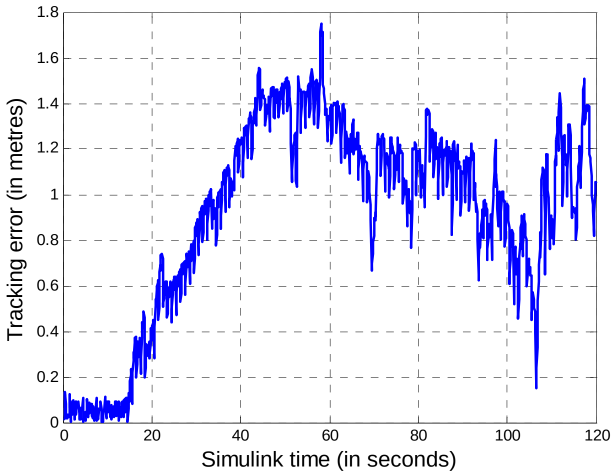

Figure 3: Tracking error during real-time simulation. (Data set: LTI test track)
Meter-level tracking accuracy is achieved using simulated commercial-grade sensor.

2.2.2 Database Management

An important part of the real-time implementation is database management. The SPKF relies on a pre-recorded map of the terrain (containing attitude and location information) to predict the attitude at the current position estimate for use in the algorithm. In order to retrieve the required information, the estimator subsystem in the Simulink model queries the terrain database. The terrain database will typically contain information for the entire road (or road network). A segment of this information is retrieved and stored in a buffer to be used later by the algorithm. Database management refers to the handling of the buffer in an optimal manner.

The buffer (or terrain buffer) may be operated in one of the following two ways:

- **Static buffer**: In the static buffer configuration, a large road segment in retrieved from the database and stored in the terrain buffer for continuous use by the algorithm. The terrain database is not accessed again till the algorithm approaches the end of the terrain buffer. This configuration results in reduced overheads due to accessing the terrain database (fewer function calls) at the cost of reserving a large memory space for the buffer.
- **Dynamic buffer**: In the dynamic buffer configuration, a small road segment is retrieved from the database based on the current location of the vehicle. As the current position estimate is updated, the terrain database is queried to retrieve information based on the updated position. This approach leads to reduced memory requirements, at the cost of increased overhead due to repeated database access.

Penn State has incorporated the latter configuration in the Simulink model. The static buffer configuration is currently being added, and as part of Task (3) the optimal configuration as well as optimum buffer size will be determined. The bounds of the information included in the terrain buffer under the dynamic buffer configuration are shown in Figure 4.

Figure 4 shows a graph of the dynamic buffer configuration. The sigma points lines start a 0 meters and increases to 50 meters over 9 seconds. The Lower bound starts at 0. At 3 seconds the Lower bound increased from 0 meters to 45 meters over 6 seconds. The Upper bound starts at 30 meters and mirrors the Lower bound line.

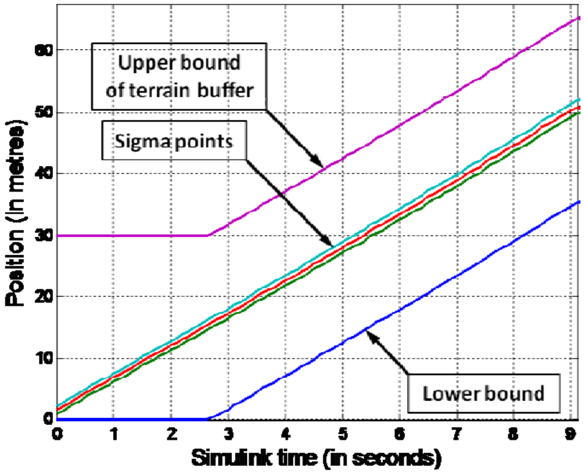

Figure 4: Dynamic buffer configuration maintains a constant window of terrain information centered on the current position estimate

2.3 Kapsch TrafficCom Inc. Progress

This section summarizes the work activities accomplished by Kapsch TrafficCom Inc. and the Auburn University Research group in support of Year 1 Task 5 activities during the reporting period.

1) KTC supplied two (2) DSRC radios (MCNU R1500) to AUR. AUR setup radios on the bench.
2) KTC and Auburn agreed on the initial installation and testing strategy. One radio will be installed on the test vehicle. The other radio will be installed at the NCAT test track. Once both radio are installed and interfaced, preliminary range testing will begin.
3) KTC prepared initial version of the ranging test software.

2.3.1 Hardware Description

Each DSRC radio is enclosed in a Multiband Configurable Networking Unit (MCNU). The MCNU is a computer in a rugged enclosure. Inputs into the MCNU include 3 Ethernet connections, 1 serial port, 2 USB connectors, 4 N-type radio antenna connectors for DSCR communications, and 1 SMA connector for a GPS antenna. The MCNU has a built in ublox GPS receiver. The DSRC radio antenna for the car is magnetic for easy installation on the test vehicle. The test vehicle's DSRC antenna also contains a GPS antenna. The MCNU on the test vehicle will be interfaced using an Ethernet connection. The MCNU is connected to a router along with the existing PC in the trunk of the test vehicle. This will allow information to pass between the MCNU and the PC. Also the router will allow remote connection to both the PC and the MCNU.

Another identical MCNU will be used to simulate roadside DSRC infrastructure. The location of this MCNU has not been decided. The decision on where to set up the roadside MCNU will depend on the ranging capabilities and limitations of the unit. More than likely, a few mounting points will be chosen at the track with the ability to quickly move the MCNU between sites for different types of testing.

2.3.2 Initial Range Testing

The initial plan for testing the ranging capabilities of DSRC radios will be to simply collect range strength and "truth" range measurements. The range measurements will come from RTK GPS measurements. The ranges provided by the RTK GPS will be accurate on the centimeter level. The range measurements will be compared to the signal strength measurements to see what correlation exists between the measurements. This will give us an idea of the accuracy that can be expected when only using DSRC signal strength to estimate range between receivers.

2.3.3 Testing Software

The initial testing will utilize the test software running on both radio devices. The transmitting portion of the test software will send test messages using 5.9GHz DSRC wireless link. All messages will be transmitted with the fixed power in broadcast mode using omni-directional antenna. The receiver radio will execute the receiving portion of the test messages which will log received messages and their characteristics. For each message, the receiver log will capture signal Receive Signal Strength Indicators (RSSI), time stamp, and a message index. Also, the receive radio will log GPS information from the built-in Ublox GPS receiver.

KTC has prepared the initial version of the test software for the transmitter and receiver radios. KTC will provide the software source to AUR for further customization. Customization may include optimization of the log files and message parameters to allow for easier evaluation and comparison of the collected data to the RTK GPS data.

3. Future Work

Auburn University will continue to work with each partner to equip the test vehicle for testing.

3.1 Sarnoff Future Work

Future work for Sarnoff’s portion of the project involves the integration and testing of the system at Auburn University.

1. Build and calibrate individual sensor bars
2. Create software testing system and procedures
3. Integrate, calibrate, and test whole system onto Auburn’s Vehicle Test Platform

Each sensor bar will consist of 2x AlliedVision Marlin F-033B cameras and a CloudCap Crista IMU. The stereo baseline will be about 40cm. Firewire, trigger, power and serial cables will be bundled from each bar and routed inside the vehicle where the computer and trigger device will be located. Data will be able to be recorded or processed live on a Windows PC (small form factor or laptop).

3.2 Penn State Future Work

Penn State's plans for the near future involve field testing of the real-time implementation task of the project. By the next report, the estimator is expected to be functioning reliably in real-time and providing position and covariance estimates to the Integrated Positioning System (IPS). A terrain map of the testing location at Auburn will be required to implement the estimator in the IPS framework.

As the overall objective of the project is to develop terrain-based localization algorithms which function over a large road network, the next steps will include modification of the existing Simulink model to include multiple SPKF estimator subsystems to handle road intersections. Additionally, as part of optimizing the algorithm for induction into real-time systems, Penn State will work on the database management subsystem to minimize memory and data transfer requirements.

3.2.1 Field Testing of Real-Time Implementation

Upcoming work in the project includes field testing the real-time implementation of the algorithm. Pending the conclusion of the testing process of the algorithm in the simulated environment (Simulink), Penn State plans to perform field tests to analyze the performance of the algorithm. Data has already been collected for a typical road intersection and is presently being post-processed to generate a terrain map.

3.2.2 Link Between Sensor Specifications and Localization Accuracy

Additionally, pending the completion of the testing process of the algorithm in a simulated environment, Penn State will analyze the relation between sensor specifications and localization accuracy. Data from various sensors will be simulated to analyze the impact of sensor specifications on localization accuracy.

3.3 Kapsch Future Work

This section summarizes the anticipated project tasks for the Kapsch team during the following quarter.

(1) Deploy 5.9 DSRC hardware and conduct on-site testing at the Auburn Test Track.

(2) Design and develop the software interface required for DSRC ranging experiments at the Auburn system.

Gantt Chart

	October	November	December	January	February	March	April	May	June	July	August	Septembe
Schedule (Proposal)												
1.0 Project Management	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	▨	▨
1.1 Team Meetings	🟩						▨					
1.2 Conduct Expert Panel Mtgs		🟩									▨	
2.0 Literature Survey	🟩	🟩										
3.0 Investigate Terrain-Based Localization		🟩	🟩	🟩	🟩	🟩	🟩	▨	▨			
3.1 Install on Test Vehicle		🟩	🟩									
3.2 Define Test Protocol			🟩	🟩								
3.3 Collect Characterization Data and Analyze Results				🟩	🟩	🟩	🟩	▨	▨			
4.0 Investigate Visual Odometry Based Positioning		🟩	🟩	🟩	🟩	🟩	🟩	▨	▨			
4.1 Install on Test Vehicle		🟩	▨									
4.2 Define Test Protocol			▨	▨								
4.3 Collect Characterization Data and Analyze Results				▨	▨	▨	▨	▨	▨			
5.0 Investigate DSRC-based RF Ranging		🟩	🟩	🟩	▨	▨	▨	▨	▨			
5.1 Install DSRC Equipment on Test Vehicle and Test Track		🟩	▨									
5.2 Define Test Protocol				🟩								
5.3 Collect Characterization Data and Analyze Results				▨	▨	▨	▨	▨	▨			
Milestone 1: Testing and Analysis Completed for Each Positioning Technique									▨			
6.0 Define Integrated Positioning System										▨	▨	
6.1 Define Initial IPS										▨		
Milestone 2: Define Initial Integrated Positioning System										▨		
6.2 Revise IPS Definition Based on Expert Panel Feedback											▨	
7.0 Demonstration and Final Report												▨
7.1 Demonstrate Vehicle Capability												▨
7.2 Develop Transition Plan												▨
7.3 Deliver Final Report												▨