

Next Generation Vehicle Safety System Research via Wireless Communication

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ABSTRACT

In 2007, more than 41,000 people were killed in traffic collisions in the United States (NHTSA 2007). As the number of vehicles on U.S. roads continues to increase, and we at Honda continue to research autonomous safety systems, a new area of safety research has emerged – specifically, wireless communication-based active safety technology. Using wireless communication, vehicles exchange highly reliable, low latency safety messages with each other and the infrastructure to help prevent collisions. This effort represents a major step toward the goal of “vehicles that do not crash.”

This paper presents an overview of the projects in DSRC communication based Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) safety technology research. Prototype system development and testing results are presented, as well as USDOT proposed further research plan.

1. Introduction

A wireless communication enabled safety system has the potential to complement or in some instances, provide alternative approaches to autonomous safety system.

In 1999, the US Federal Communications Commission (FCC) allocated a wireless spectrum in the 5.9 GHz frequency range for use by Dedicated Short Range Communications (DSRC) systems for supporting Intelligent Transportation Systems. National Highway Traffic Safety Administration (NHTSA) and automakers collaborated through the Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications Consortium. The potential of Vehicle to Vehicle (V2V) and Vehicle-to-infrastructure (V2I) communication to enhance vehicle safety was investigated. In 2006, reflecting the results of the research experience, the FCC refined the rules for DSRC to explicitly consider “vehicle-to-vehicle collision avoidance and mitigation.”

Honda is dedicated to providing our customers with top level safety features. We are continuously searching for new solutions to enhance safety for our customer.

Since 2006, Honda R&D Americas has engaged in cooperative agreements with CAMP to conduct pre-competitive system development research on V2I and V2V communication-based safety applications in the Cooperative Intersection Collision Avoidance System – Violation (CICAS-V) and the Vehicle Safety Communications-Applications (VSC-A) projects.

2. Cooperative Intersection Collision Avoidance System (CICAS-V) project

Intersection-related collisions account for 12% of fatal accidents in the U.S., based on NHTSA Fatality Analysis Report System 2006 data. The CICAS-V project focuses on intersection signal violation warning application through DSRC communication between a vehicle and an intersection.

The objective of the CICAS-V project was to design, develop, and test a prototype system to help prevent intersection collisions by warning the driver when the in-vehicle system determines a potential intersection traffic signal or sign violation.

2.1. Concept of operation

The concept is shown in Fig. 1. A CICAS-V equipped intersection has a Roadside Equipment (RSE) that continuously broadcasts DSRC messages over the air. The messages contain the signal phase and timing (SPAT) of the traffic signal controller output for each direction of travel, a digital representation of the intersection geometry (GID) with high accuracy, and the GPS differential corrections.

A CICAS-V equipped vehicle has an Onboard Equipment (OBE) that receives DSRC messages from the RSE as the vehicle approaches a CICAS-V equipped intersection. The OBE continuously monitors the distance from the vehicle to the intersection stop bar, the vehicle speed, the lane of travel, as well as the signal

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phase and timing of the traffic light corresponding to the lane in which the vehicle is traveling. The OBE then determines whether the vehicle has enough time to pass the intersection before the traffic light turns to red. If it is determined that a violation is likely to occur, the OBE issues a warning to the driver.

For stop sign intersections, the OBE determines the potential stop sign violation by calculating whether the vehicle has enough time to come to a stop before reaching the stop bar.

2.2. Geometric intersection description (GID)

In order for the vehicle OBE system to determine the correct traffic signal that the vehicle is heading toward, an accurate intersection digital map is necessary. In CICAS-V project, the intersection digital map was based on a 30 cm level accurate road and lane geometry for all the lanes and roads near the intersection.

The road and lane geometry in the original survey data are too large to fit into one DSRC packet size of 1.4KB. Therefore, the geometry information is compressed into a simplified form, which contains an array of points that are packaged into a single DSRC message. The vehicle's OBE parses the package and recreate the accurate intersection geometry map.

Figure 2 illustrates the contents of a typical GID. In a GID, all geometry points are offsets from a single reference point with absolute latitude, longitude and altitude location information, and this point serves as the origin of the GID coordinate.

Lanes and roads are described as an array of points with lane width information at each point. The order of

the points starts from the stop bar towards the outskirt of the intersection in that lane/road. Each of the lane points represent the location of the center of the lane or road. The array of points for each approach covers a 300 meter distance from the stop bar.

2.3. Signal phase and timing

The RSE in a CICAS-V equipped intersection broadcasts the DSRC message, which contains the SPAT information in a fixed frequency. Normally the frequency is set to 10 Hz. The SPAT message contains the current signal phase, time to next signal phase change and the approaches that are associated with that signal, for each of the signals in that traffic signal control unit.

The signal phase information is obtained through the traffic control unit in real time, and the information is packaged into a single DSRC message.

2.4. GPS corrections

In order for the vehicle to map itself to the correct lane in the GID received by the vehicle's OBE system, it is necessary to apply external position corrections to the vehicle's GPS positioning system. In the CICAS-V project, the RSE is designed to be able to collect differential GPS (DGPS) information through an external high-accuracy GPS receiver, package the DGPS correction data into a single DSRC packet in the standard Radio Technical Commission for Maritime Service (RTCM) format, and broadcast the correction packet over the air.

Figure 3 illustrates the structure of the GPS correction module of the RSE system.

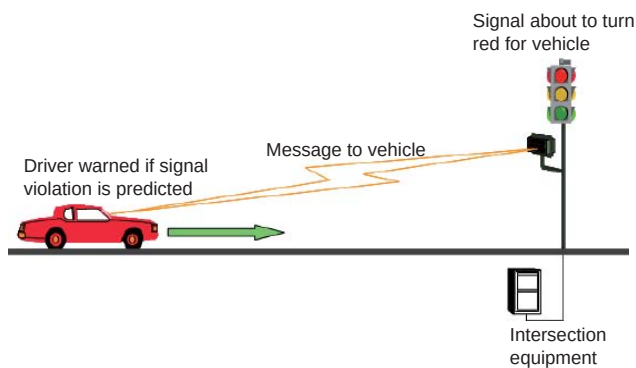


Fig. 1 CICAS-V concept of operation

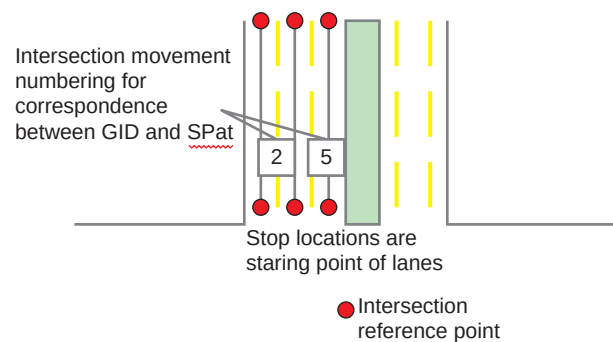


Fig. 2 GID description

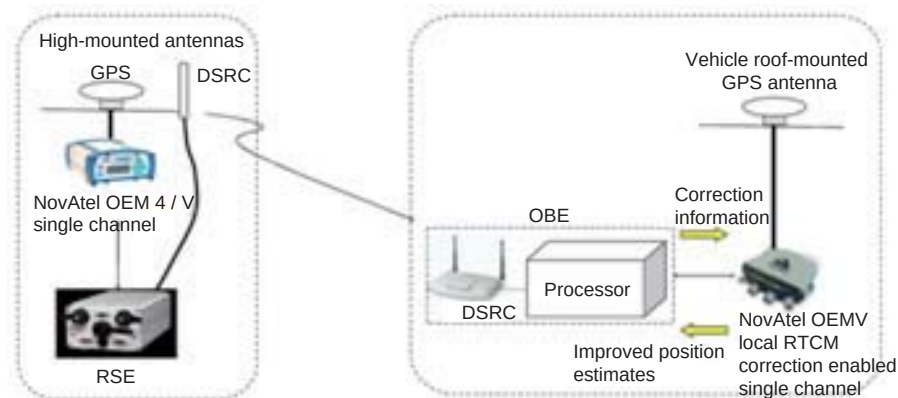


Fig. 3 CICAS-V GPS correction equipment

The RTCM 1001 form is selected to be an adequate form with good accuracy improvement and a modest over-the-air data volume requirement. In most cases, the RTCM 1001 correction message is less than 100 bytes.

2.5. OBE system architecture

Figure 4 illustrates the system architecture of the OBE in a CICAS-V vehicle. Figure 5 shows the OBE and other hardware installed in a vehicle.

From the bottom of the Fig. 4, the CICAS-V WSU software service API module interfaces with the vehicle's Control Area Network (CAN) to obtain vehicle information, such as brake status, vehicle speed, and acceleration. The GPS positioning data obtained from the on-board GPS receiver feeds into other modules through the API module as well. The DSRC radio interfaces with the radio handler and data demux module, and sends and receives CICAS-V DSRC messages. The radio handler/data demux module packages outgoing DSRC messages, parses incoming DSRC messages, and feeds the parsed data into other modules for further processing. The GID module maintains the latest GID information. The SPaT module parses the signal phase and timing data and feeds the information to other modules. DAS logger is a data logging module that records the vehicle status and other module status constantly for post-processing.

The intersection identification module determines the intersection the vehicle is heading toward based on the vehicle heading direction, current location, and the GID mapping.

The map matching module determines the most likely lane and approach the vehicle is traveling and the distance to the stop bar of that approach or lane.

Once the correct intersection is determined and the

vehicle is mapped on a specific lane and the corresponding approach with its signal phase and timing known to the OBE, the warning algorithm module determines whether a signal violation is likely to occur, and warns the driver when necessary.

A generic version of a driver-vehicle interface (DVI) is implemented with a colored intersection icon and an audible warning output. It receives output from the warning algorithm module and then issue the visual and/or audible warning depending on the warning level determined by the warning algorithm.

2.6. Objective testing

A set of test procedures was developed by the team and an objective test of the CICAS-V prototype system was performed in 2008 at the Virginia Tech Smart Road on a closed test track. Signalized intersections and stop sign intersections were used for the tests. Both true-positive and false-positive tests were conducted. The system passed all tests.

2.7. Conclusion

The prototype system was implemented successfully. It demonstrated the feasibility of implementing such

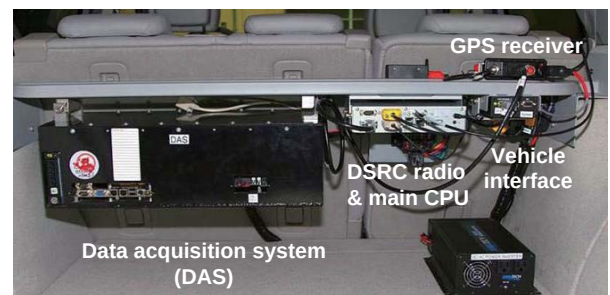


Fig. 5 CICAS-V components in a vehicle

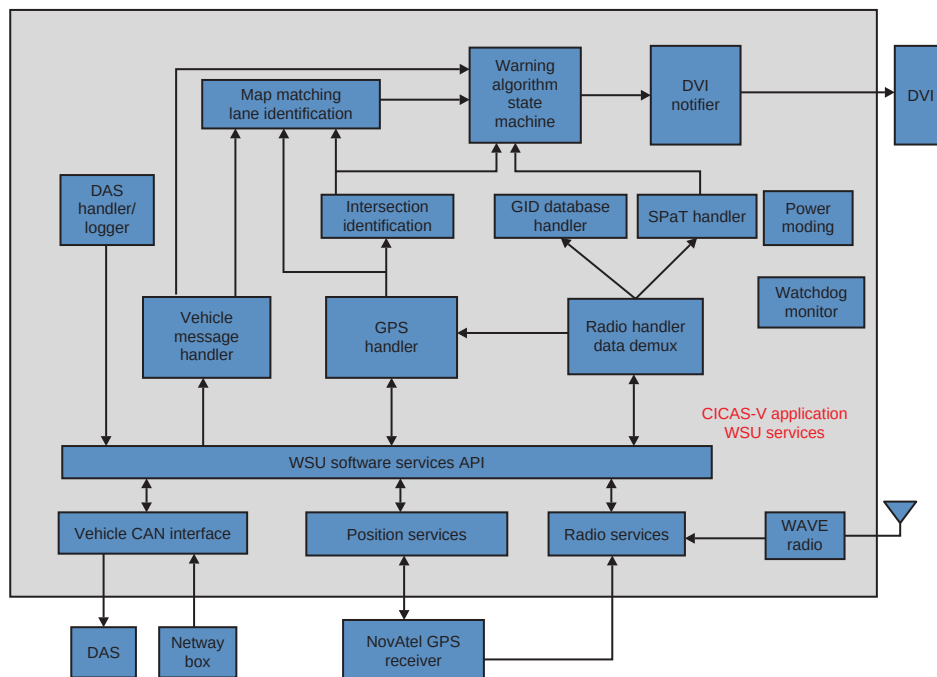


Fig. 4 CICAS-V OBE architecture

systems in multiple locations across multiple vehicle manufacturers. The DSRC messages created in CICAS-V project are incorporated into the SAE J2735 standard and are being further refined in the next standard publication.

3. Vehicle Safety Communications – Applications (VSC-A) project

VSC-A project is a three year project that started in December, 2006. This project focused on V2V safety applications. The technology development objectives of the VSC-A program are to develop scalable and common vehicle safety communication architecture, protocols and messaging framework or interfaces necessary to achieve interoperability among different vehicle manufacturers. It also seeks to develop accurate and affordable vehicle positioning technology in conjunction with the 5.9 GHz DSRC to support most of the safety applications with high potential benefits, and to define a set of DSRC + positioning-based vehicle safety applications and establish a set of minimum system performance requirements.

3.1. Application Selection

Based on the 2004 NHTSA's General Estimate System (GES) data, the V2V applications such as rear-end, head-on, angle and sideswipe types are applicable to approximately 66% of the 6.2 million crashes. Seven crash scenarios were chosen based on their crash rankings by frequency, cost, functional years lost and a composite crash ranking based on the above three ranks.

The following applications were selected to correspond to each of the selected top crash types:

- Emergency Electronic Brake Light (EEBL) – the EEBL application enables a vehicle to broadcast a self-generated emergency brake event to surrounding remote vehicles. Upon receiving such event information, the surrounding vehicles determine the relevance of the event and, if necessary, warn the driver. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions, such as fog or heavy rain.
- Forward-Collision Warning (FCW) – The FCW application warns the driver of an impending rear-end collision with a vehicle ahead in traffic in the same lane and the same direction of travel. FCW is intended to help drivers avoid or mitigate rear-end vehicle collisions in the forward path of travel.
- Intersection-Movement Assist (IMA) – The IMA application is intended to warn the driver when it is not safe to enter an intersection due to high collision probability with other vehicles.
- Blind-Spot Warning (BSW) + Lane-Change Warning (LCW) – During a lane-change attempt, the BSW + LCW application informs the driver when a vehicle is detected in the driver's blind spot zone, and warns the driver if the zone the vehicle intends to change to is, or will soon be, occupied by another vehicle traveling in the same direction.

- Do-Not-Pass-Warning (DNPW) – When a driver attempts to pass a slower vehicle and the passing zone is or will be occupied by a vehicle traveling in the opposite direction, the DNPW application informs the driver and, if a potential collision is determined, the system warns the driver.
- Control-Loss Warning (CLW) - The CLW application enables a host vehicle to broadcast a self-generated control loss event to surrounding remote vehicles. Upon receiving such event information, the remote vehicle determines the relevance of the event and, if necessary, warns the driver.

3.2. System Architecture

In this project, vehicles equipped with the DSRC radio and vehicle positioning system periodically broadcast their location, travel path, and vehicle status (e.g., brake, acceleration, etc.) over the air through the DSRC radio. In addition to broadcasting messages, the DSRC safety system in each vehicle also receives over the air messages from other vehicles, and then determines the relevance of the contents in the message to the safety applications. If a potential collision is detected, advisory or warnings are presented to the driver through a common Driver-Vehicle Interface (DVI) in both audio and visual means.

The DSRC safety system consists of the following sub-system/modules:

- Interface subsystem: Vehicle Controller Area Network (CAN) to OBE interface module, data logger and engineering graphic user interface
- Communication subsystem: Wireless Message Handler (WMH), Security Module and DSRC radio
- Positioning Subsystem: GPS module and Forward-looking camera module
- Supporting Subsystem: Sensor Data Handler (SDH), Path History module (PH), Path Prediction module (HVPP), Target Classification module (TC)
- Application Module: all six applications
- Threat Arbitration module (TA)
- Engineering Driver Vehicle Interface Notifier (DVIN) module

Figure 6 shows the architecture design of the DSRC V2V system. Figure 7 describes the hardware components of the system.

In Fig. 6, from the bottom, the system interfaces with vehicle sensor output through the CAN bus, receives GPS location information from an external GPS receiver and antenna, transmits and receives DSRC over the air messages through an embedded DSRC radio, has a security module that signs outgoing messages and verifies incoming messages, and has a wireless message parsing/scheduling module –Wireless Message Handler (WMH). The received vehicle sensor data, GPS location data and remote vehicle's data are then processed through the sensor data handler, and feeds into the Target Classification module (TC) and Path Prediction Module (PH) to further determine the relative position of each of the remote vehicles. The applications receive TC output and determine the relevance of the remote

vehicle's position and status, and then output the threat level. The Threat Arbitration module (TA) arbitrates the threats when multiple threats are present from multiple applications, determines the ranking of the threats, and outputs the rankings and threat-relative data to the DVI module that controls how and when to inform and warn the driver.

3.3. Sub system design – path history

One of the challenges in identifying surrounding vehicles' locations relative to the host vehicle (e.g., ahead, ahead left/right, intersecting left/right, etc.) is that the instantaneous position and heading of the remote vehicle is not sufficient to generate the relative coordinate due to the road shape. For example, on a curved road, the leading vehicle may be several meters

distance away laterally at the middle of the curved road while the host vehicle is just entering the curve in the same lane. In this case, if only the instantaneous latitude, longitude and heading of the remote vehicle are utilized to calculate the relative positioning, the result will point the remote vehicle toward far right from the host vehicle. In order to improve the performance on target classification, the vehicles generate a set of points that represents the past 300 meter distance of travel, which is called the Path History. The path history of each vehicle is then transmitted over the air, to assist the surrounding vehicle in determining the vehicle's classification.

Due to the limitation on DSRC bandwidth, the data exchanged over the air needs to be minimized. Therefore, the path history object was further refined and

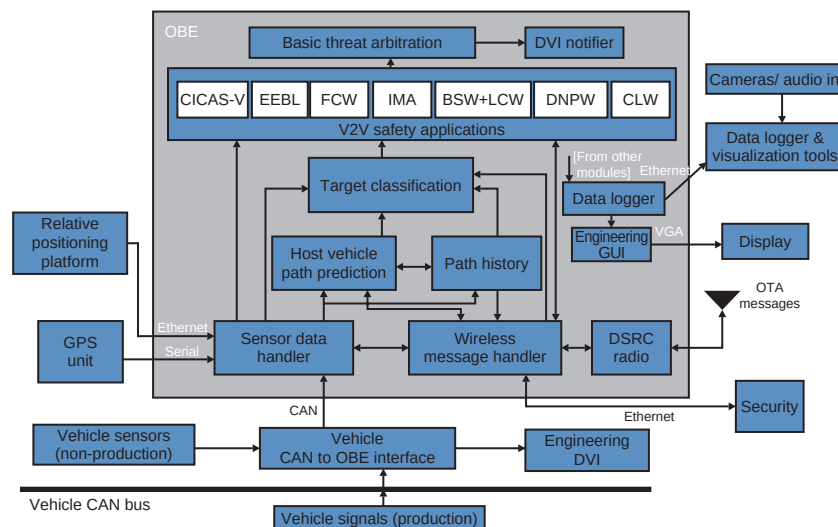


Fig. 6 VSC-A system architecture

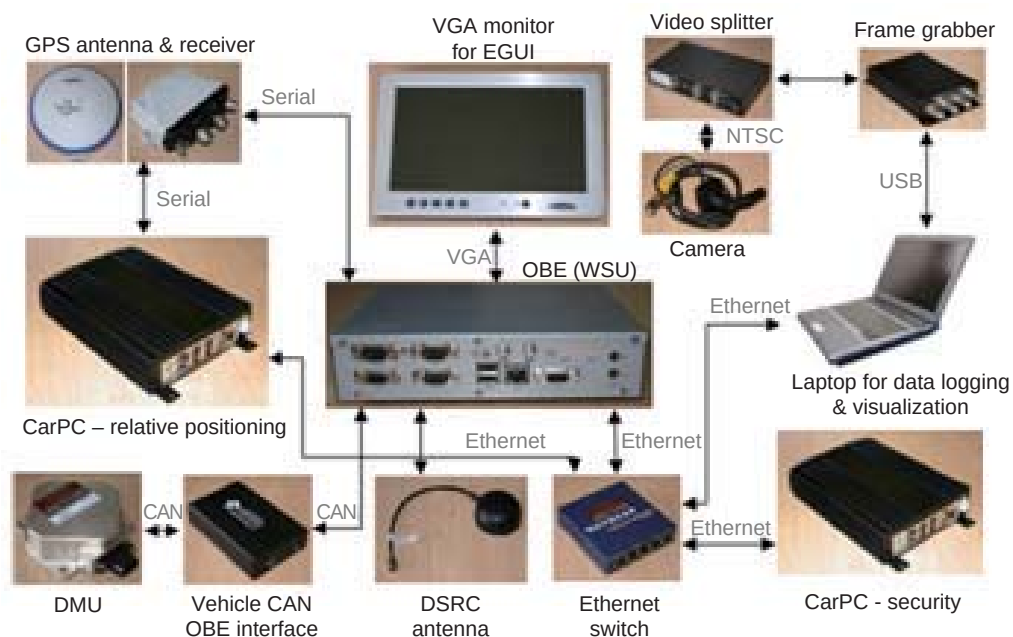


Fig. 7 System main hardware components

compressed using a concise point representation, depicted in Fig. 8.

The Path History module maintains an array of the vehicle's recent position and sensor data points over a certain distance, and computes a concise representation of the actual path history of the vehicle based on allowable position error tolerance between the actual vehicle path and its concise representation. The concise representation is updated periodically and then transmitted over the air by Wireless Message Handler (WMH) module.

After intensive testing, the error tolerance of one meter was found to be adequate for good performance of all the safety applications developed in this project.

Figure 9 shows a typical concise path history representation for a vehicle traveling on an oval track

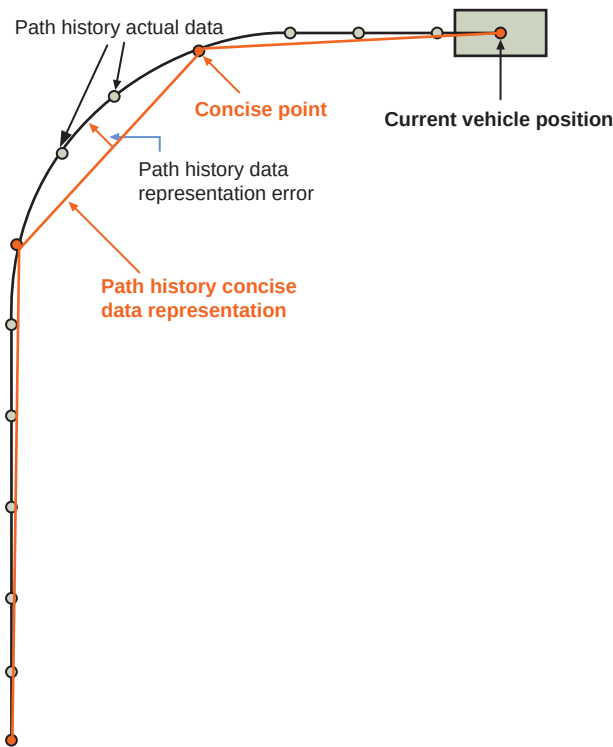


Fig. 8 Path history concise point representation

consisting of straight paths, tight curves with estimated radius of 279 meters, and wide curves. With one meter allowable error, for a 300 meter distance path history, the number of concise points that was required varied from two points to nine points.

3.4. Positioning

One of the objectives of the project is to develop an accurate and affordable vehicle positioning solution. DSRC communication enables the vehicle to keep track of surrounding vehicles and the potential threat. In order to determine the potential threat, lane level positioning precision is required so that the potential threat can be identified as to which lane it presents.

Two methods are implemented as shown in Fig. 10. One is to use GPS latitude and longitude data over the air exchange and difference the current vehicle location from the over the air surrounding vehicle data. The second method is to exchange pseudo range data from the vehicle's GPS receiver over the air and each vehicle processes the surrounding vehicle's pseudo range data and generates high-accuracy relative positioning data using an onboard RTK engine.

Extensive testing was conducted and the comparison between these two methods of relative positioning

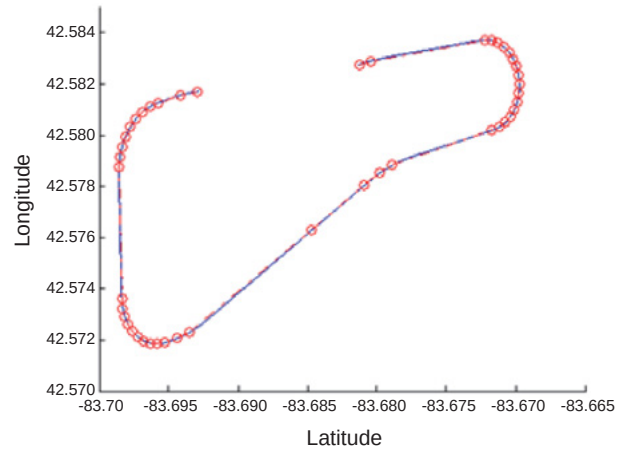


Fig. 9 Oval track vehicle trajectory and path history concise representation

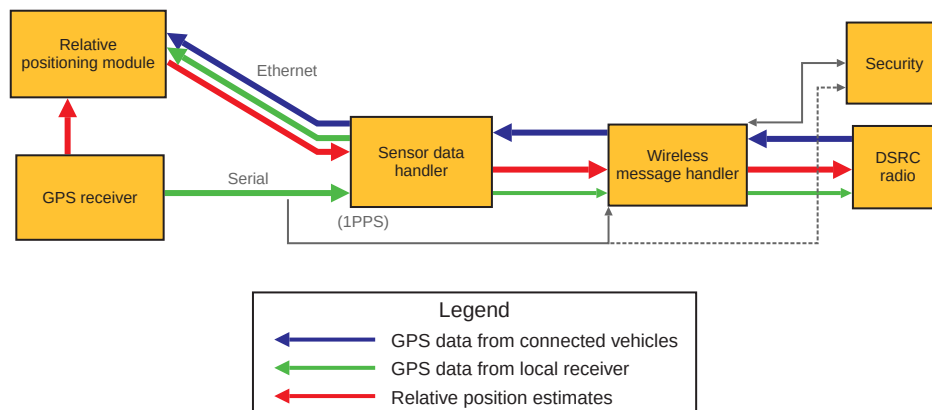


Fig. 10 Relative positioning module

solution is illustrated in Fig. 11. In the test scenario, two test vehicles were driven in the same lane on the straight road, so the lateral distance between the vehicles was maintained close to zero. The positioning system was configured to estimate the lateral distance using Real Time Kinematic (RTK) engine and using the latitude/longitude differentiation method (Single point method). The top plot in Fig. 11 shows the comparison of the output using both relative positioning approaches. Although both methods were able to provide less than one meter error in most parts of the driving, the output from the single point method was found to be more sensitive to the differences in the satellite visibility to each vehicle.

3.5. Performance specification and objective testing

A set of performance specifications for V2V safety systems were developed. The performance requirements include a common domain that applies to all of the VSC-A applications, such as the vehicle types, roadway characteristics, traffic density, GPS coverage constraints and weather conditions, the minimum requirements for the overall correctness of true-positive and false-positive warnings, and the detailed performance requirements for each application including the operating speeds, the detection/warning zone each application shall cover, and both the true positive and false positive aspects of the application performance.

A set of objective testing procedures was developed and the system was tested in June 2009 on a closed test track at the Transportation Research Center in East Liberty, Ohio using the objective testing procedures also developed by the project. The scenarios represent some of the typical crash types that each application is designed to help prevent. The performance specification and the test procedures can be used in the future to test application performance across different vehicles and application developers.

3.6. Interoperability and standard development

Another objective of this project was to develop a scalable and interoperable vehicle safety communication systems architecture, including channel considerations, protocols, and security.

The application level over the air data exchange

content based on the previous SAE DSRC J2735 standard was implemented. During the project development, the data contents continue to be refined and compressed in order to optimize the application performance while minimizing the over the air data volume.

The application level message consists of two main parts:

- Part I - Contains basic vehicle state, such as vehicle ID, GPS time, location information, motion, vehicle size, etc.
- Part II - Contains additional information, such as vehicle event, path history, path prediction, and RTC messages that are used to transmit GPS pseudo range data for high-accuracy relative positioning engine in the DSRC safety system.

A DSRC message with Part I is transmitted at 10Hz frequency as the default rate, while Part II data can be transmitted at equal or lower frequency.

The finalized message content is now included in the SAE J2735 version 2 which was published in November, 2009.

3.7. Conclusion

The VSC-A project was completed in December, 2009. The current implementation of the V2V safety system performs well in good conditions. The test results indicate that these types of test applications and systems potential can be deployed. We anticipate safety benefits by deploying such a system.

Through the development experience, it is identified that from the technical challenge perspective, further work is necessary, especially in V2V positioning and security implementation.

4. Next Step

The next phase of the V2V and V2I research is being planned. The 3-year research plan is shown in Fig. 12. It focuses on interoperability with larger scale implementation and is scheduled to start in December, 2009, immediately after the VSC-A project's completion. The USDOT's V2V research plan for the next phase is shown in Fig.12. It is anticipated that new V2I applications prototypes will be implemented as well.

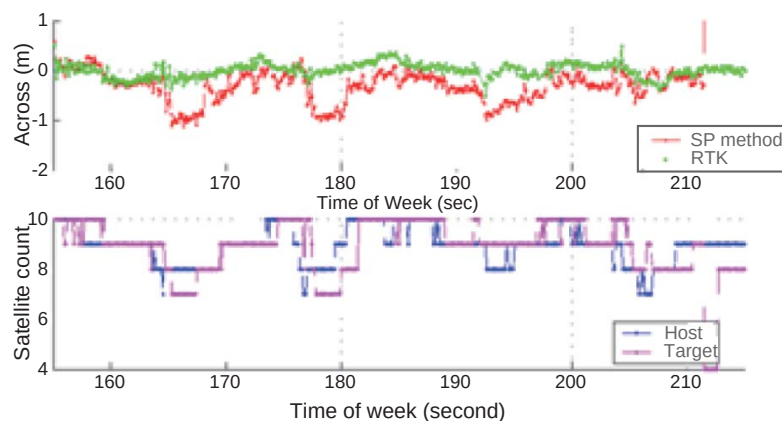


Fig. 11 Comparison of V2V lateral distance estimates

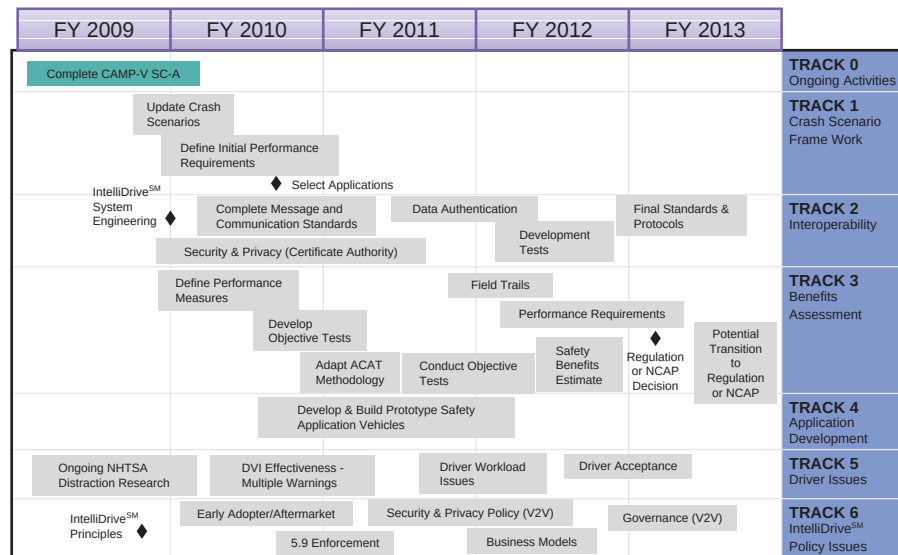
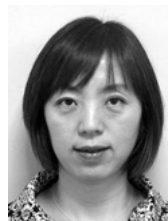


Fig. 12 Intellidrive V2V safety research plan

References

- (1) CICAS-V Final Report.
- (2) NHTSA Fatality Analysis Reporting System 2006 data at www.fars.nhtsa.dot.gov
- (3) "Intersection Collision Avoidance – Violation Project: Task 5 Final Project Report", Virginia Tech Transportation Institute, April 2007, DOT HS 810 749.
- (4) "Cooperative Intersection Collision Avoidance System for Violations (CICAS-V) for Avoidance of Violation-Based Intersection Crashes", Michael Maile, Luca Delgrossi, Mercedes-Benz Research & Development North America, Inc., Paper Number 09-0118
- (5) "Vehicle Safety Communications – Applications – VSC-A First Annual Report", DOT HS 811 073
- (6) Using Dedicated Short Range Communications for Vehicle Safety Applications – the Next Generation of Collision Avoidance, Arthur A. Carter, NHTSA, James Chang, Noblis, Paper Number 09-0330
- (7) "Vehicle-to-Vehicle Safety Application Research Plan", Ray Resendes, NHTSA.

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