Structured Systems Strategy for Integrating Sensor and Wireless Technology for Vehicle Safety

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Vision – 360° Driver Awareness and Assistance System

• There is a shared vision of industry and government for
  – A reliable, low-cost integrated sensor and wireless communication system which recognizes and warns drivers of an immediate hazard in real time, allowing drivers to avoid hazardous situations before a threat becomes imminent.
    - In the near term, the system will provide safety warnings
    - In the long term, the system will assist drivers with limited autonomous control

• The system monitors conditions in all directions and supports driver decisions *in advance of* a hazardous situation.

• The system fully integrates sensor and wireless systems for maximum benefit at least cost.

• The concepts for sensor and wireless based collision avoidance have been demonstrated, but substantial research and development is needed to architect an integrated system that supports near- and long-term goals effectively and efficiently.
Conceptual Architecture of an Integrated System

Smart combination of sensing and communications to:
• Reduce total cost
• Enable practical deployable system
• Enable more effective collision avoidance
• Allow graceful technology migration over time

Vehicle with sensors & communications capability

Use input from Sensors & comms to make decisions

Traffic Light Timing & Phasing

Alert: I Sensed Pedestrians Crossing

V2V

Use input local Comms & sensors from nearby vehicles to make decisions

V2P

Vehicle with only communications capability
Challenges of Accurate and Reliable Crash Hazard Detection and Warning

• Core technologies have been demonstrated
  – Integrated Vehicle Based Safety Systems (IVBSS) program demonstrated integration of autonomous sensor systems which can detect and warn of hazards.
  – Vehicle Infrastructure Integration (VII) program demonstrated wireless DSRC communication of location, speed and heading in “Heartbeat” messaging, which can be used to detect and warn of threats.

• However, there are major challenges
  – Sensor based systems can, theoretically, detect most collision threats including pedestrians and bicycles, but
    - Sensors are expensive
    - Algorithms to discriminate threats from nonthreats are complex
    - Has issues with nuisance warnings
  – Wireless systems such as DSRC, can be more accurate and substantially less expensive to deploy than sensor only systems, but
    - Requires full market penetration for complete effectiveness
    - Doesn’t directly detect pedestrians and bicycles
    - Substantial development and standardization is required for vehicle-to-vehicle communications without a supporting VII infrastructure
Overview of the Paper

• Perspectives
• Description of the Problem
• Structured System Strategy and Technical Approach
• Technology Development Needs
• Summary
Description of the Problem

• A reliable, low-cost integrated sensor and wireless communication system which recognizes and warns drivers of an immediate hazard in real time, allowing drivers to avoid hazardous situations before a threat becomes imminent.
  – In the near term, the system will provide safety warnings
  – In the long term, the system will assist drivers with limited autonomous control

• Multitude of variables and constraints include
  – Speed
  – Open highway versus congested urban
  – Multitude of potential collision scenarios
  – Density of vehicles in an area
  – Vehicle characteristics including size and mass
    - compact sedans, SUVs, delivery trucks, tractor-trailers
  – Drivers
    - Age, capabilities, experience, training
    - Distractions, fatigue, alcohol, drugs
  – Visibility and Weather
  – Road conditions
Traffic Environment: Different Challenges for Highway and Urban Traffic

• Highway conditions and speed
  – Cruising on highway, with small changes in acceleration and road curvature
  – Objects moving at 30% of vehicle speed or less can usually be disregarded
  – Cruise control systems typically disengage under 25-30 mph
  – Typically following distance is large >= 50m at 30 m/s
  – Control authority is low, driver is responsible for safety

• Urban stop and go
  – Greater likelihood of pedestrians and stationary objects that cannot be disregarded
  – Turns and curves increase blind spots, forward and side
    - Closely associated with lane change/merge collision in urban environment
  – Low speed, greater accelerations
  – Small following distances of the order of 5 to 20m
  – Control authority may need to be higher, driver may not be able to safely stop vehicle

*from PATH/CMU
Crash Imminent Test Scenarios
Rear End (after Ferrence, et al)

- Slower lead vehicle
- Decelerating lead vehicle
- Stopped lead vehicle
- Slower Lead Vehicle after lane change
- Lead vehicle stopped on curve
- Slower lead vehicle cut-in
- Lead vehicle cutting out revealing another lead vehicle decelerating
Crash Imminent Test Scenarios
Lane Change (after Ferrence, et al)

- Lane change on straight road
- Lane change on curve
- Lane change/merge
- Lane change after passing
- Lane change into approaching car
Crash Imminent Test Scenarios
Run-off-Road (after Ferrence, et al)

- Lane departure toward opposing traffic lane
- Right road edge departure
- Road edge departure on curve
- Approaching curve at excessive speed

Jersey Barrier
Vehicle Characteristics
Lane Change/Merge Blind Spots

SUV
Delivery Truck
Transit Bus
Tractor Trailer
Vehicle Characteristics
Rear End Collision: Vehicle Platform Type Affects Regulated Maximum Stopping Distance

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>FMVSS</th>
<th>Stopping Distance</th>
<th>Equivalent Uniform Deceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Car</td>
<td>135</td>
<td>230 ft from 62 mph</td>
<td>.56 g</td>
</tr>
<tr>
<td>Bus</td>
<td>105 or 121</td>
<td>280 ft from 60 mph</td>
<td>.43 g</td>
</tr>
<tr>
<td>Heavy Truck (with air brakes)</td>
<td>121</td>
<td>355 ft from 60 mph</td>
<td>.34 g</td>
</tr>
</tbody>
</table>
Driver Characteristics – Strongly Influence Performance Requirements

• Demographic Factors – age, gender
• Physiological Factors – vision, hearing, reaction time, sleep patterns
• Background – experience, training
• Attitudes, Beliefs, Habits – driving style and habits, intentions
• Driver Profiles – impaired driving, aggressive vs. cautious drivers, capacity-limited
Structured Systems Strategy and Technical Approach

• There are multiple technical challenges in integrating sensor and wireless systems for collision avoidance

• The technologies and marketplace are dynamic and will evolve

• OEMs may take different approaches to integration

• Battelle, Telcordia and Automotive Insights advocate two thrusts
  – Strong, structured systems development strategy built around clearly defining the collision scenarios and the performance requirements to avoid or mitigate collision
  – Technology development in core topics critical to the successful implementation of wireless systems for collision avoidance including
Outline of Structured Systems
Strategy and Technical Approach

1. Define Scenarios for Collision Avoidance Technology
   1. Auto Highway – (Ferrence et al Objective Test Scenarios for IVBSS)
   2. Auto Urban
   3. Delivery truck
   4. Tractor-trailer

2. Establish a baseline set of countermeasure functional requirements based on the defined scenarios

3. Define Performance Parameters to support the baseline functional requirements
   1. Characterize Driver Performance Range
   2. Characterize Vehicle Performance Ranges
   3. Derive Performance Requirements (range, latency, etc.) for Comprehensive Driver Awareness and Assistance System (technology independent)
   4. Derive Performance Requirements for Design Specific Systems
      - Sensor Based
      - Wireless Communication
Outline of Structured Systems Strategy and Technical Approach

4. Develop System Architecture for Integrated Sensor and Wireless
   1. Hardware / Software
   2. Interfaces
   3. Constraints

5. (Optional) Technology update of existing technologies
   1. Give each technology option a chance for a technology refresh to get the best capabilities it can, given the newly developed performance and functional parameters established.

6. Conduct Technology Assessment against Performance Requirements
   1. Sensor Systems – IVBSS
   2. Wireless Communication Systems

7. Technology Design Tradeoff Studies
   1. Cost-benefit tradeoff design study of sensor and wireless comm systems
   2. Assess alternatives and Select Design solutions
   3. Finalize Design
Outline of Structured Systems Strategy and Technical Approach

8. Design Implementation & Integration
   1. Develop test procedures for all selected technologies and subsystems
   2. Implement enabling systems
   3. Fabricate Sub-systems
   4. Test and document sub-system conformance to needed functions and performance.
   5. Establish integration environment for multi-party subassembly integration and acceptance verification (testing).
   6. Integrate Sub-systems

9. System Test & Evaluation
   1. Establish system verification enabling facilities, Test Track facility setup to enable functional and performance testing of key parameters.
   2. Establish system verification procedures
   3. Test system and document conformance to needed functions and performance
   4. Address anomalies found during testing
   5. Establish a verification record and update functional and performance criteria as necessary.
Technology Development Needs

• Driver requirements for awareness and assistance systems
• Vehicle platform based performance requirements
• V2V wireless systems development for collision avoidance
  – DSRC communication
  – Heartbeat application
  – System architecture and design
    - 4.3.3.1 Protocols for V2V and V2I Communications and Applications
    - 4.3.3.2 Interoperability and Standardization
    - 4.3.3.3 Digital Certificate Management
    - 4.3.3.4 Security and Privacy Management
    - 4.3.3.5 Remote OBE Provisioning
  – Positioning technology performance and optimization
• HMI data arbitration
Technology Development Needs
Driver Requirements

• From a driver’s perspective, the critical need is
  – To provide drivers with information that they need and want.
  – Warnings and alerts should be managed & prioritized and—in a broader sense—should be integrated into the existing information systems within the vehicle.

• Integration an especially important topic for driver information systems that serve an active safety function, such as any device that generates continuous, real-time information, as well as auditory, visual, or haptic warnings.
Technology Development Needs
Vehicle Platform

- Performance requirements for systems depend upon a number of variables, including
  - Driver
  - Collision scenario
  - Vehicle characteristics
  - Awareness and Warning strategy
  - System design
    - Wireless
    - Sensor
    - Integrated combination
- Structured systems approach necessitates fundamental precompetitive work to develop solid performance requirements across primary vehicle platforms.

Pass Car Stopping Distance
Bus Stopping Distance
Heavy Truck Stopping Distance

Look ahead distance to avoid forward collision

Blind Spots

Distance to the Lead Vehicle, ft

Closing Speed, mph
DSRC Hilly Terrain Test Results – DSRC Link Limited to Line of Sight

- DSRC Link performance
  - Predictable based on the line-of-site between the RSE and the test vehicle.
  - Communication link was lost when the line-of-sight was obstructed.
    - Crested Roadway
    - Occluded Curve
- DSRC link range more likely limited by nearest obstruction than radio signal propagation.
- Radio Null not Observed. Combination of reflective surfaces and obstructions limiting range to under 300 meters.
DSRC Urban Canyon Test Results

V2I Affected by Urban Canyon, but V2V is not

• Vehicle to Infrastructure
  – The height of the urban canyon affected the performance of the DSRC I-V radio link
    - The effective range generally increased as the height of the urban canyon increased.

• Vehicle to Vehicle
  – The height of the urban canyon did not affect the performance of the DSRC V-V radio link
  – The effect of the radio null point was observed in all the urban canyon test sites.
Positioning Technology Performance and Optimization

• V2V and V2P applications will require high levels of positioning accuracy.
  – At least 1m, “which lane” accuracy required
  – 10 cm, “where in lane” accuracy preferred

• Manufacturers indicate that technology is evolving rapidly and costs are coming down, such that low cost, high accuracy systems are likely to be available when needed for broader deployment.

• Further work is needed to specify the dynamic performance requirements for cost effective positioning systems and verify the performance of available systems in vehicle safety applications.
Summary

• The Combination of Sensor and Wireless Based Technologies Offer the Most Promising Solution for Enhancing Vehicle Safety:
  – Better Cost and Performance Balance
  – Enhanced Performance Capabilities
  – Shorter Time to Market
  – Gradual and Phased Deployment

• The Problems to be Addressed are Complex:
  – Multiple Collision Scenarios
  – Multiple Environments: Urban, Highway, Hot, Cold, Wet, etc
  – Diverse Players: Drivers, Different Types of Vehicles from Different OEMs, Pedestrians, Road Infrastructures, etc

• The Technologies are Individually Complex and Evolving:
  – Effective Convergence and Integration of Technologies is Even More Complex
Summary (cont.)

• Solutions Require Strong, Structured Systems Strategy Built Around:
  – Clearly Defining the Collision Scenarios and Performance Requirement Metrics for Commercial Optimization, Now and in the Future
  – Systematic Investigation into Essential Technologies and Technology Map

• Technical Limitations of Sensor Based Autonomous Systems Include:
  – High Vehicle Costs
  – Discrimination of Threats From Non-threats is Problematic
  – Nuisance Warnings are Difficult to Avoid

• Serious Technical Challenges Remain for Effective Implementation of Wireless Systems for Collision Avoidance:
  – DSRC Performance and Optimization for Vehicle Safety
  – Better Design of Essential Safety Applications (e.g. “heartbeat”)
  – VII System Architecture and Design for Safety:
  – Positioning Technology Performance and Optimization for Vehicle Safety
  – HMI Data Arbitration Algorithms
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