REAR-END COLLISION WARNING SYSTEM FIELD OPERATIONAL TEST - STATUS REPORT

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ABSTRACT

This paper provides an overview of a cooperative research program between General Motors and the National Highway Traffic Safety Administration to conduct a field operational test of a rear-end collision warning system. A description of the system architecture is also presented.

INTRODUCTION

In June of 1999, the National Highway Traffic Safety Administration entered into a cooperative research agreement with General Motors to conduct a field operational test of a limited fleet of passenger vehicles outfitted with a rear-end collision warning system integrated with adaptive cruise control.

This effort is being conducted under the U.S. DOT's Intelligent Vehicle Initiative, a research program focused on solving traffic safety problems through development and deployment of vehicle-based systems.

The rear-end collision warning system being developed for the field operational test will leverage knowledge and experience from internal development efforts of the program team members, as well as achievements and know-how developed during a previous cooperative program with NHTSA.

The prior program, known as the Automotive Collision Avoidance System (ACAS) Program, concentrated on developing a detailed understanding of overall collision warning system requirements and accelerating the development of key subsystems such as forward-looking radar systems and algorithms that use the radar data to identify targets in the vehicle's forward path, select the most threatening target, and decide when to issue an alert to the driver.

The ACAS Program also included activities to reduce the cost and improve the manufacturability of radar components and to understand the nature of driver interactions with rear-end collision warning systems.

The three-year ACAS Program, which ended in May of 1998, was funded by the Defense Advanced Research Projects Agency (DARPA) as part of the Technology Reinvestment Project (TRP). NHTSA was responsible for technical management and oversight of the program.

Research results from other NHTSA rear-end collision warning projects combined with technical advancements made in the ACAS Program formed the basis for going forward with the current operational test.

FIELD OPERATIONAL TEST OVERVIEW

The field operational test team, headed by General Motors Corporation, includes GM's primary partner Delphi Delco Electronics Systems, Delphi Chassis Systems and HRL Laboratories. The University of Michigan Transportation Research Institute (UMTRI) will manage and conduct the field operational test and analyze the field data. An independent evaluation of the field test will be carried out by The Volpe National Transportation Systems Center of Cambridge, MA. Program coordination and technical oversight is being provided by NHTSA's Office of Advanced Safety Systems Research.

The primary goal of the field operational test program is to demonstrate a state-of-the-art rear-end collision warning system and measure system performance and effectiveness using volunteer drivers driving on public roads in the United States. Data collected during the field test will also be used to estimate real-world safety benefits and obtain information of user acceptance.

The collision warning system design philosophy is to help the driver avoid crashes by providing warnings to the driver, rather than by taking active control of the vehicle. The rear-end collision warning system will provide warning signals to the driver in the form of an audible alert tone and visual display of an icon on a head-up-display when the driver needs to take action to avoid an impending rear-end collision.

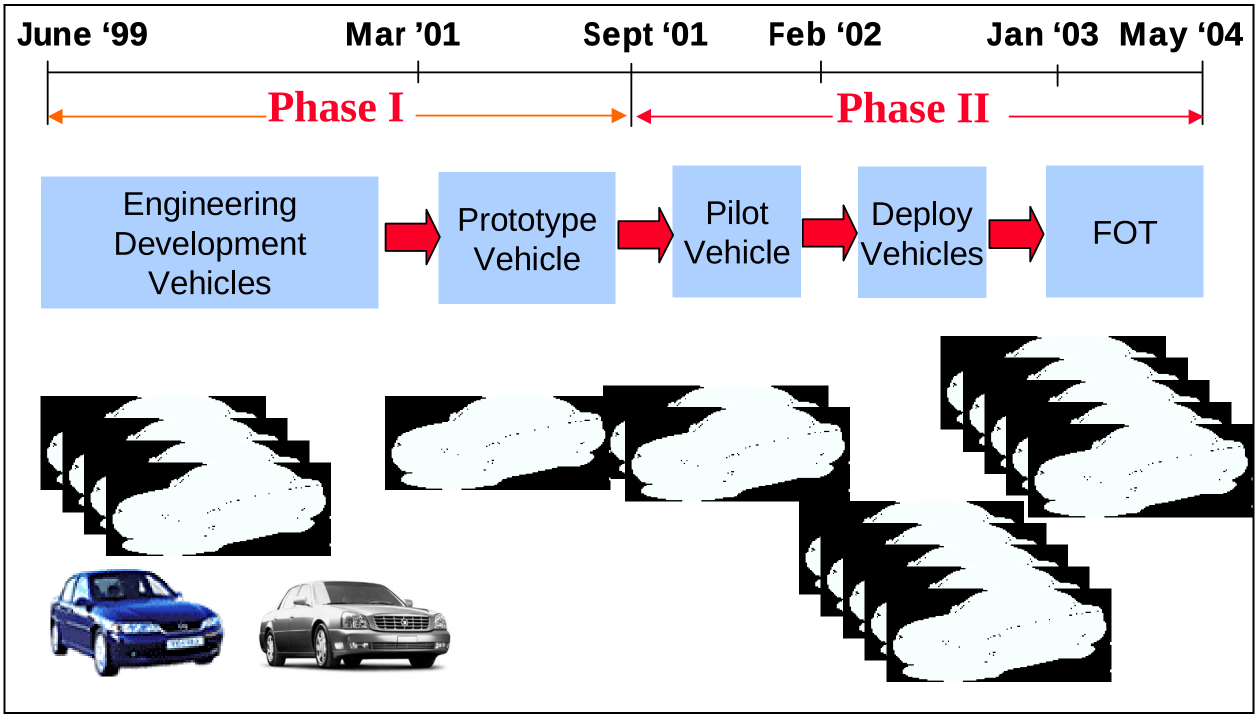

Figure 1. Program Timing and Development of Test Vehicles

An adaptive cruise control system will be integrated with the rear-end collision warning system which will provide a warning to the driver when action is required to avoid a rear-end collision when using the adaptive cruise control system.

The five-year program consists of a 2-year development phase during which refinement of vehicle subsystems and software will continue and will be integrated into a prototype test vehicle. Several engineering development vehicles (EDV) have been developed to allow team members to fine tune and rigorously test each subsystem prior to integration with the other subsystems. Toward the end of the first program phase, subsystems developed on the EDVs will be integrated into a prototype vehicle. The prototype vehicle will be be thoroughly tested to verify that all subsystems are operating properly as individual units, as well as an integrated system.

At the beginning of the second program phase, two pilot test vehicles will be developed for further testing and validation. The pilot test vehicles will bebased on the prototype vehicle built in Phase I. Once the vehicle design has been validated using the pilot test vehicles, a fleet of ten vehicles will be outfitted with a rear-end collision warning and adaptive cruise control system. The operational test vehicles will then be given to volunteer drivers to drive over a period of several weeks. Data collected from onboard vehicle instrumentation will be analyzed and used to determine system effectiveness, estimate potential safety benefits and obtain information on the driving experiences of the volunteer drivers.

Post-test questionnaires and focus group meetings will be used to obtain additional information on driver experiences and acceptance of this next-generation safety technology. The operational test will last approximately one year. The timetable for the vehicle development is shown in Figure 1.

COLLISION WARNING SYSTEM OVERVIEW

System Architecture

During the first year of the program, overall system functional requirements were developed and the system was partitioned into subsystems or "blocks" The functional requirements were allocated to the subsystems, and interfaces between the subsystems

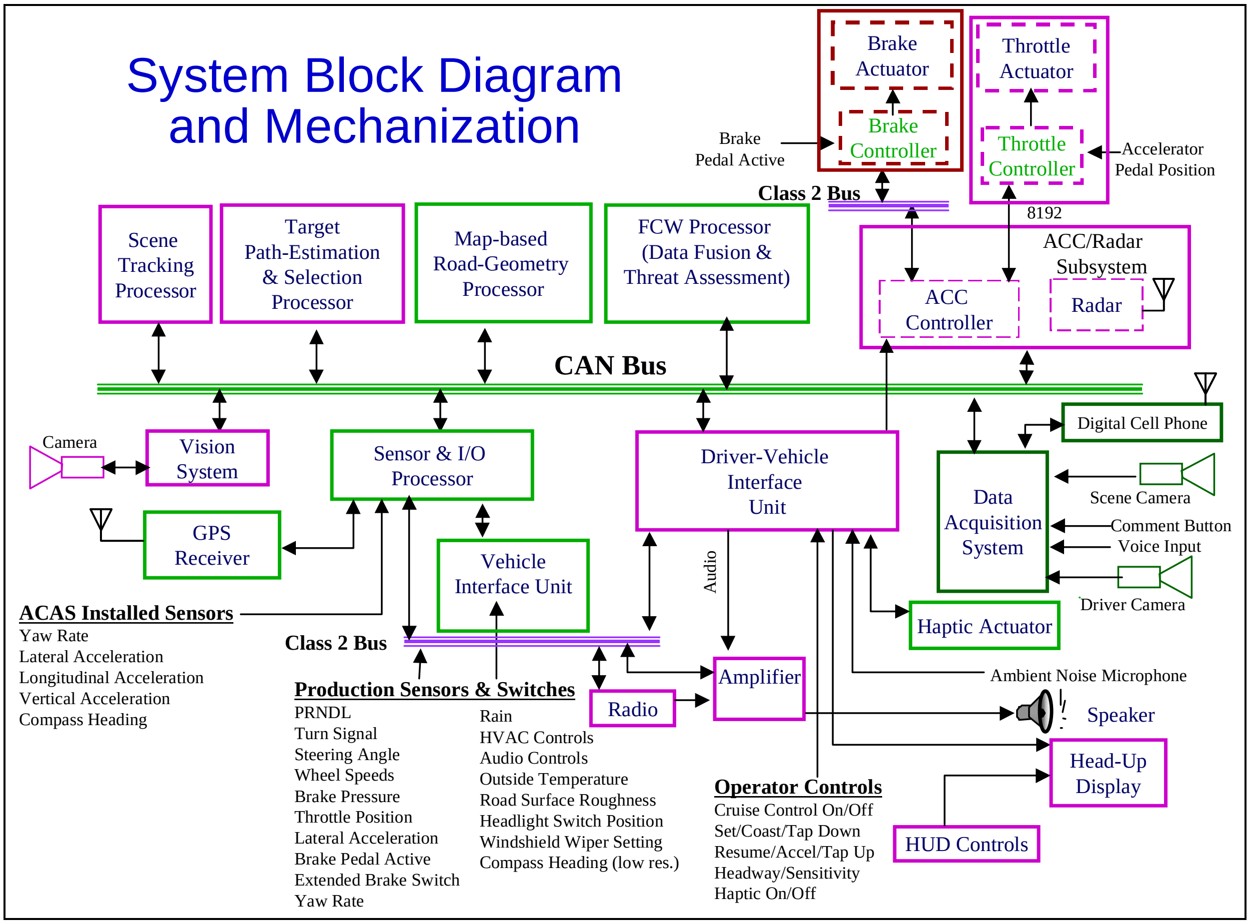

Figure 2. System Block Diagram and Mechanization

were defined and documented in an interface control document. The result of the process is the system architecture shown in the block diagram of Figure 2. This architecture will be initially implemented on the prototype vehicle and subsequently used in the pilot and deployment vehicles.

The system architecture adopted by the program team is built around the Controller Area Network (CAN), a high-speed serial communications protocol developed by the automotive industry and now an ISO Standard. The CAN bus will be the primary pipeline for transferring data between various subsystems and system components. In addition, a GM Class 2 bus and low-speed serial bus will provide links to vehicle-based systems such as the brakes and throttle. CAN bus access to data from standard vehicle sensors and switches, as well as special-purpose sensors will be provided through a GM Class 2 bus, Vehicle Interface Unit and a Sensor and I/O Processor.

Integrated Vehicle Radar

The forward-looking radar that will be used in the field operational test will be an all Microwave Monolithic Integrated Circuit (MMIC) design, allowing the transceiver and antenna to be integrated into a single unit. This development was pursued to improve reliability and enhance overall system performance. By the end of the first program phase, the integrated transceiver/antenna design will be completed and prepared for further testing and installation on the operational test vehicle fleet.

The rear-end collision warning (CW) and adaptive cruise control (ACC) systems will be integrated systems. They will be integrated in that the same radar will be used to detect, track and report objects for both the CW and ACC systems.

A forward-looking, millimeter wave radar will detect and track objects in the vehicle's forward path and report this information to the ACC and CW subsystems for subsequent processing. The ACC subsystem will use this information to adjust the throttle, downshift, or apply the vehicle's brakes. The CW subsystem will use it to inform the driver how closely they are following the vehicle in front of them, or to issue a cautionary or imminent crash alert.

Given the known limitations of forward-looking radar systems, one of the key technical challenges facing collision warning system developers is the ability to effectively deal with "real-world" driving scenarios, such as driving on curved, multi-lane roadways. Knowledge of the upcoming road curvature, as well as the vehicle's forward path, will go a long way toward improving overall system performance.

Approaches to this problem usually begin with identifying and understanding the troublesome scenarios and developing techniques to augment the radar system's performance with additional sensors and processing.

The system architecture for the collision warning system being field-tested includes sensing systems such as the Forward-Vision System, and processing modules such as Target Path Estimation and Selection, Map-based Roadway Geometry, and Scene Tracking, to address this issue and improve system reliability and robustness.

The Data Fusion module in the Forward Collision Warning Processor uses techniques based on applied probability and information theory to "fuse" or combine information from these processing modules to provide the best estimate of the upcoming roadway geometry, predict the vehicle's forward path and identify threatening targets in the vehicle's forward path.

The Data Fusion module also estimates the level of driver distraction for use by the system's Threat Assessment algorithm to modify expected driver reaction time and braking intensity based on the reported environmental conditions.

Target Path Estimation and Selection

In order to ensure proper operation, the CW and ACC systems require identification of both stationary and moving target vehicles that are in the forward path of motion of the following or "host" vehicle. The overall performance of these systems is directly affected by its ability to properly predict the host vehicle's forward path and successfully carry out the "in-path" target selection process in the presence of various types of driving behavior (e.g., in-lane weaving and drift, lane change maneuvers, etc.) and roadway conditions (e.g., straight roads, curved roads, and curve entry/exit, etc.) that are encountered in everyday driving.

The current approach is to use four complementary host vehicle and roadway state estimation techniques. These techniques are based on: (a) a forward-looking vision system, (b) map-matching using host vehicle location provided by the Global Positioning System (GPS), (c) scene tracking using information from radar returns, and, (d) host vehicle yaw-rate to estimate road curvature and host vehicle state. Each of these techniques is briefly discussed in the remainder of this paper.

Forward Vision System

The forward-looking vision system examines the forward driving scene and predicts the geometry of the roadway ahead of the vehicle. This helps the radar system distinguish between targets which are in the vehicle's forward path and those which are not. An accurate determination of the forward roadway geometry, along with the vehicle's steering angle and lateral position in the lane, are necessary to predict the vehicle's projected forward path and, more importantly, to correctly select only those targets that are in the vehicle's forward path. In this way, valid targets, such as moving or stopped vehicles in the forward path of the vehicle, are recognized and invalid targets, such as trees, sign posts, guardrails or parked vehicles which are on the edge or off the road and out of the vehicle's forward path, are rejected.

A video camera mounted behind the windshield of the vehicle will look out at the forward road scene to estimate road shape, lane width, vehicle heading and lateral position of the vehicle in the lane. Three universities are working with the Malibu, CA based Advanced Electronics Division of Delphi-Delco Electronics (DDE) Systems to refine their respective approaches for developing a reliable, real-time model of the road geometry ahead of the vehicle. The teams include the University of Pennsylvania, Ohio State University and the University of Michigan-Dearborn. A formal down selection process will be carried out to determine the approach that will be identified for further development and integration with the other vehicle subsystems.

Map-Based Roadway Geometry Processor

Another technique being employed to improve the path prediction and target selection process includes the use of differential global positioning system (DGPS), dead reckoning, and digitized road maps.

In this approach, path-prediction is achieved by continuously estimating the location of the vehicle on the roadway, matching the vehicle's position to roadway coordinates stored in the map database, tracking the path traversed by the vehicle and extracting the upcoming roadway geometry from the map database.

DGPS information is used to compute vehicle heading and distance traveled. However, in recognition of the reality of GPS outages and its effect on system reliability, DGPS has been augmented with dead reckoning sensors, such as wheel speed, odometer reading, compass and differential wheel sensors to compute the heading and distance traveled by the vehicle.

Scene Tracking Processor

The scene tracking processor exploits kinematic information about objects which is available from the radar returns and uses this information to enhance the process of determining whether preceding vehicles are in the projected forward path of the following vehicle.

In the ACAS program, the use of yaw-rate was investigated to predict the roadway curvature in front of the vehicle. Studies revealed that while yaw-rate does provide a measure of vehicle state, it alone does not provide a reliable measure of the road curvature ahead of the vehicle.

In the scene tracking approach, the trajectories of the preceding vehicles and roadside objects are used to estimate the upcoming roadway curvature, distinguish between in-lane and adjacent lane vehicles, and determine the heading of the host vehicle in its lane.

Driver-Vehicle Interface

A collision warning system will be of little value if it fails to effectively get the attention of the driver and unambiguously inform them that action may be required to avoid a potentially hazardous situation.

The driver-vehicle interface (DVI) for the GM system will consist of a combination of visual, auditory and possibly haptic display. The primary driver interface will be a visual display, consisting of a high resolution, reconfigurable, full-color head-up-display (HUD). The DVI auditory display will include a tonal alert which is generated within the DVI hardware and delivered over the vehicle's sound system. Provisions for a haptic cue have also been included.

Human factors experiments are currently underway to assess alternatives for the visual display format and message content of the HUD, as well as the characteristics of the tonal alert and haptic cue.

Three visual display formats are being considered:

(1) a single-stage imminent crash alert which would unambiguously cue the driver that corrective action is required,

(2) a multistage warning, with the initial stage providing a lower level preparatory warning cue to the driver that an emergency response may be necessary,

(3) a continuous display of information to the driver regarding the safety of their current vehicle-following behavior, taking into account vehicle kinematic information, and combining this with an imminent crash alert.

The auditory alert developed by the Crash Avoidance Metrics Partnership (CAMP) has been selected for use with the visual display formats being considered. Electronics to remap and adapt the existing steering wheel controls to support the ACC and CW functions is under development.

Data Acquisition System

The data acquisition system that will support the field operational test will collect information about the vehicle state, the ACC and CW systems, the driver and the forward scene. During the first program year, UMTRI's efforts have focused on understanding the complete collision warning system and its interface requirements.

Drawing upon its extensive field test experience from the NHTSA-sponsored Intelligent Cruise Control

Field Operational Test, UMTRI has developed a conceptual design for the data acquisition system and its interfaces to the test vehicle. A preliminary list of recorded variables was developed and strategies for recognizing critical events, and capturing data from these events have been established. The architecture for the overall data storage and retrieval system has also been defined.

Early in the program, a "rapid prototype" data acquisition system was constructed and installed in one of the EDVs to support some limited testing. The purpose of the testing was to demonstrate the ability to reliably extract and record radar system data and vehicle signals from the EDV's CAN bus. The recorded data was analyzed by UMTRI to obtain some early experience with multi-target radar data and to confirm readiness for handling later tasks of data collection.

CONCLUSIONS

This paper provided an overview of a cooperative research program to conduct a field operational test of a prototype rear-end collision warning system and adaptive cruise control under real-world driving conditions. The prototype vehicle architecture was was outlined, and approaches to address several technical challenges were also discussed.

Rear-end collisions account for almost 28% of all crashes, primarily resulting in property damage and congestion. The most common causes of rear-end crashes are driver inattention and following too closely, factors this program is hoping to address and alleviate by making drivers more aware of their car-following behavior or issuing a warning that action may be required to avoid an imminent collision.

ACKNOWLEDGMENTS

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PROGRAM INFORMATION

Copies of the Automotive Collision Avoidance System Field Operational Test - First Annual Report, the ACAS Program Final Report and the CAMP Final Report are available in printed and electronic form from NHTSA, http://www.nhtsa.dot.gov.

Requests for copies of the reports should be directed to NHTSA's Office of Publications Ordering and Distribution, (202) 366-1566. Technical questions on the field operational test program should be referred to Jack J. Ference of NHTSA's Office of Vehicle Safety Research or Ronald C. Colgin, Ph.D. of GM. Mr. Ference may be reached at (202) 366-0168 or via E-mail at jference@nhtsa.dot.gov. Dr. Colgin may be reached at (810) 986-4775 or via E-mail at ronald.c.colgin@gm.com.

REFERENCES

"Automotive Collision Avoidance Systems (ACAS) Program Final Report", August 2000, DOT HS 809 080.

"Automotive Collision Avoidance System Field Operational Test - First Annual Report", December 2000, DOT HS 809 196.

"Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems - Final Report", August 1999, DOT HS 808 964.