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PERFORMANCE SPECIFICATION DEVELOPMENT FOR ROADWAY DEPARTURE COLLISION AVOIDANCE SYSTEMS

Dean Pomerleau
Charles Thorpe

Robotics Institute
Carnegie Mellon University
5000 Forbes Ave.
Pittsburgh, PA 15213 USA
Email: pomerleau@cs.cmu.edu
Phone: (412) 268-3210
Fax: (412) 268-5570

Lloyd Emery

Office of Crash Avoidance Research
National Highway Traffic Safety Administration
400-7th St. SW Room 6220L
Washington, DC 20590 USA
lemery@nhtsa.dot.gov
Phone: (202) 366-5673
Fax: (202) 366-7237

SUMMARY

The Run-Off-Road Collision Avoidance Using IVHS Countermeasures program is a four year program sponsored by the US National Highway Traffic Safety Administration (NHTSA). The primary goal of the program is to develop practical performance specifications for roadway departure collision avoidance systems. This paper describes the results to date of our efforts to:

1) Characterize the problem of roadway departure crashes
2) Develop and test technology for preventing these crashes
3) Model countermeasure system performance
4) Develop preliminary performance specifications

RUN-OFF-ROAD PROBLEM CHARACTERIZATION

Run-off-road crashes are defined to be all single vehicle crashes where the first harmful event occurs off the roadway, except for backing and pedestrian related crashes. A statistical review of the 1992 General Estimation System (GES) and Fatal Accident Reporting System (FARS) databases indicate that run-off-road crashes are the most serious of crash types within the US crash population. These crashes account for over 20% of all police reported crashes, and over 41% of all in-vehicle fatalities (15,000 / year).

Some of the most important characteristics of roadway departure crashes are the following:

- They occur most often on straight roads (76%)
- They occur most often on dry roads (62%) in good weather (73%)
- They occur most often on rural or suburban roads (75%)
- They occur almost evenly split between day and night

Unlike many of the other crash types, run-off-road crashes are caused by a wide variety of factors. Detailed analysis of 200 NASS CDS crash reports indicates that run-off-road crashes are primarily caused by the following six factors (in decreasing order of frequency):

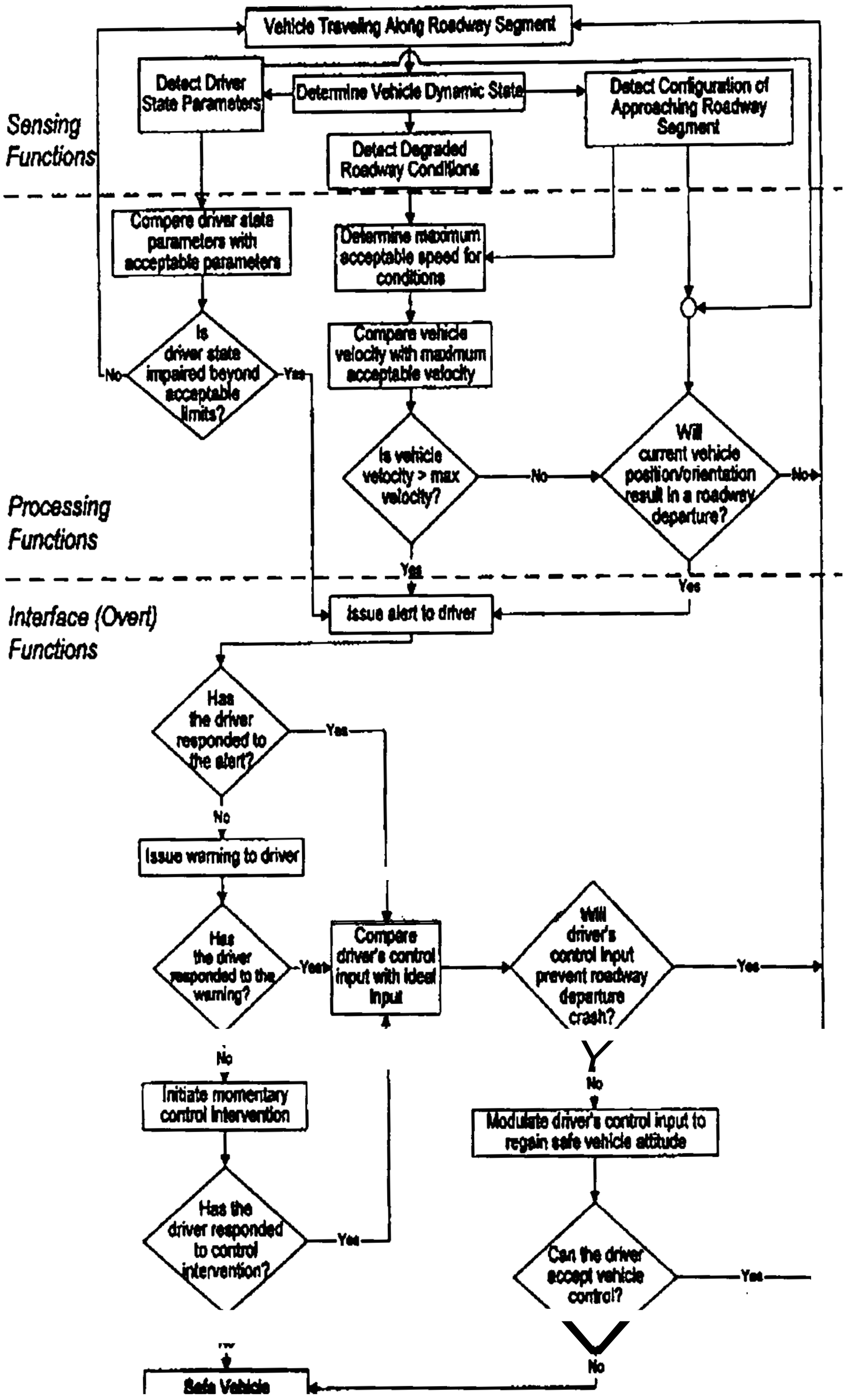
- Excessive speed (32.0%) - traveling too fast to maintain control
- Driver incapacitation (20.1%) - typically drowsiness or intoxication
- Lost directional control (16.0%) - typically due to wet or icy pavement
- Evasive maneuvers (15.7%) - driver steers off road to avoid obstacle
- Driver inattention (12.7%) - typically due to internal or external distraction
- Vehicle failure (3.6%) - typically due to tire blowout or steering system failure

COUNTERMEASURE FUNCTIONAL *GOALS*

Through careful analysis of causal factors, we identified two primary functions for the roadway departure countermeasures to be tested in this program, which we termed “longitudinal” and “lateral” roadway departure warning. The goal for the longitudinal warning function is to detect when the vehicle is traveling too fast for the upcoming roadway segment. The longitudinal warning system utilizes vehicle dynamic state and performance data in combination with information about the current pavement conditions and upcoming roadway geometry to determine the maximum safe speed for the vehicle. If the vehicle’s current velocity exceeds the safe speed, a sequence of driver interface functions is triggered to alert the driver of the danger and avoid a crash. The longitudinal warning system is designed to prevent those run-off-road crashes caused by excessive speed and lost directional control.

The lateral warning system is designed to detect when the vehicle begins to depart the road. It utilizes data about the dynamic state of the vehicle, in combination with information about the geometry of the road ahead to determine if the vehicle’s current position and orientation will likely lead to a roadway departure. If the likelihood of departure exceeds a threshold, a sequence of driver interface functions is triggered to alert the driver of the danger and avoid a crash. The lateral functional sequence is designed to prevent those run-off-road crashes caused primarily by driver inattention and driver relinquishes steering control.

Note, the longitudinal and lateral functions do not address all the causal factors for roadway departure crashes listed above. Other functions, such as direct driver impairment detection, forward obstacle detection (to prevent the need to depart the roadway to avoid an obstacle) and vehicle component failure warning (to warn the driver of mechanical problems which could result in a roadway departure crash) could be investigated as a means of preventing run-off-road crashes. Since these areas are being widely investigated by others **(5),** they were eliminated from the scope of this program.



TESTS OF EXISTING TECHNOLOGY

Having identified longitudinal and lateral warnings as the primary functions our run-off-road countermeasure should perform, the next step in the program was to test existing technology for performing these functions. Since no complete systems for performing either the lateral or longitudinal warning function were commercially available for testing, we leveraged previous technology developed at CMU to prototype and test four complete countermeasure systems, three lateral and one longitudinal system. Tests of these systems were conducted both on a testbed vehicle, and in simulation on the Iowa driving simulator. Highlights from these tests are given below (for more details, see 1, 2, 4, 8, 9).

IN-VEHICLE TESTS

The three lateral warning systems all used a video camera to track roadway features and determine when the vehicle was starting to departure from the road. One of the systems, called AURORA, used a downward looking video camera to track lane markings next to the vehicle. Laboratory and in-vehicle tests of the AURORA system indicate that it can estimate the lateral position of the vehicle with about 1cm accuracy. Tests showed AURORA to be relatively insensitive to ambient lighting and road condition. However AURORA is limited to roads with distinct painted lane markings, and has difficulty when the markings are severely degraded, obscured or missing. Also, downward looking systems like AURORA do not have forward preview capability, resulting in occasional false alarms when negotiating curves.

Two video-based lateral systems with forward preview capabilities were also tested, the ALVINN and RALPH systems. These two systems adapt their processing to the features available, and can therefore handle roads on which the lane markings are degraded, obscured, or missing. These two systems detect the road ahead of the vehicle in the video image, and can therefore anticipate curves better than AURORA. However, as systems with forward looking sensors, they are somewhat more sensitive than AURORA to harsh weather and lighting conditions. Tests showed that ALVINN can handle reduced visibility from rain and/or fog down to about 300m, but below that visibility level, performance begins to degrade. Other difficult situations for forward looking systems like ALVINN and RALPH are when the sun shines directly into the camera at dawn and dusk. Locating the road at night, using only headlights for illumination, was not a problem for these forward looking systems. Overall, in over 15,000 miles of on-road tests, the RALPH system was shown to be capable of locating the position of the road ahead of the vehicle to a distance of approximately 60m with an accuracy of about 12cm on a wide variety of road types and environmental conditions, including day, dusk, night, sun, rain and snow.

However, there are situations in which the performance of the vision systems degrade. Driving into the setting sun can cause the CCD camera to saturate, creating problems for the forward looking systems. Glare off wet pavement from headlights or streetlights at night can create spurious road features which can confuse the vision systems. In the next phase of the program, we hope to investigate combining vision data with digital maps to make finding the vehicle's position on the road easier, as well as investigate non-vision sensors (primarily laser based) for lane position detection.

The longitudinal system developed and tested for this effort was designed to warn of excessive speed when approaching curves. The system consists of a Differential GPS for determining the vehicle's current position, and a digital map for estimating the distance to the upcoming curve and its severity. If the system detects that the vehicle is traveling too fast to safely negotiate the upcoming curve, it triggers an audible or tactile warning.

Experiments with the longitudinal system indicate that most of the technology exists for providing a reliable warning of excessive speed when approaching curves. Differential GPS can provide accurate and reliable estimates of the distance to an upcoming curve. Commercial digital maps, although currently not quite detailed enough, have the potential to provide the necessary geometric information regarding curve sharpness and superelevation. Tests of a system that combines information from GPS and digital maps show that is possible to provide reliable and highly repeatable warning signals (within 0.5 seconds) when approaching curves at excessive speed.

The biggest missing component for a general longitudinal countermeasure is an effective means of measuring degraded road conditions. Infrastructure-based pavement monitoring systems exist, but are expensive and provide data that is only valid in a local region. Simulation results of vehicle-based methods for inferring the coefficient of friction between the tires and the road appear promising, however these methods require the vehicle to encounter the degraded pavement before it can be detected. Further research is needed before a longitudinal countermeasure capable of handling all roadway conditions can be deployed. Fortunately, analysis of the national crash database indicates that only 10% of run-off-road crashes caused by excessive speed occur on snowy or icy roads. The remainder occur on pavement which is dry (64%) or wet (26%). A system that can simply detect whether the pavement is wet or dry has the potential to prevent most speed related roadway departure crashes.

DRIVING SIMULATOR TESTS

A crucial functional goal of all collision countermeasures is to effectively interact with the driver. A system must be capable of conveying the danger of collision to driver in a manner that elicits an appropriate response in emergency situations, and does not significantly increase the driver's workload during normal driving. Tests on the Iowa driving simulator suggest several interface configurations can achieve these goals. These tests included auditory warnings in the form of a tone, and/or haptic (tactile) feedback through the steering wheel (lateral system) or brake pedal (longitudinal system). Visual feedback was not considered since this form of interface would almost certainly be ineffective for a drowsy or distracted driver, and could potentially interfere with visual assessment of the situation just when such assessment is most crucial.

In general, neither the lateral nor the longitudinal countermeasures appear to significantly increase driver workload during normal driving. Either haptic or auditory interfaces appear to be viable means of providing the driver with feedback. However, the combination of both modalities can result in driver overload. Directional feedback, which provides information about the appropriate driver response, is preferred by drivers, and appears to provide at least some performance benefit. Early onset of warnings seems to have a beneficial effect on collision avoidance maneuvers, particularly for the lateral countermeasure. However the less frequent feedback from late onset warnings was subjectively preferred by the test subjects.

In probably the most striking findings of the Iowa simulator experiments, 31% (5 / 16) of the control subjects without road departure countermeasure support crashed when presented with a lateral disturbance (a simulated wind gust) while distracted from the drive task. In the same circumstances, only 8% (4 / 48) of the driver's with lateral countermeasure support were unable to avoid a crash. These result suggest that lateral countermeasures may indeed be effective at preventing roadway departure crashes. Unfortunately, such dramatic results were not observed in the longitudinal experiments, where none of the 64 subjects crashed due to excessive speed through curves. This was probably due to the conservative driving style of subjects in the simulator and the difficulty of creating dangerous longitudinal roadway departure situations in the simulator.

MATHEMATICAL MODELING

In order to evaluate the performance of alternative countermeasures and develop performance specifications for roadway departure collision avoidance systems, a sophisticated analytic tool, called RORSIM (Run-Off-Road SIMulator), was developed for the project by Battelle Memorial Institute to model sequences of events that occur during these crashes. RORSIM includes all relevant system parameters, including the vehicle, roadway, driver, environment, sensors and in-vehicle countermeasures. RORSIM is an extension of a commercial vehicle modeling system called VDANL, from Systems Technology Inc.

The potential effectiveness of alternative lateral countermeasure systems was estimated using RORSIM by comparing their performance to that of an existing roadway departure countermeasure, roadside rumble strips. Like the electronic lateral countermeasures tested in this effort, the rumble strips provide feedback to the driver when the vehicle begins to drift off the road. The results of simulations with RORSIM indicate that the electronic countermeasures can significantly reduce the vehicle’s maximum lane excursion during near roadway departure crashes relative to roadside rumble strips, which have already been shown to prevent up to 70% of run-of-road crashes. This enhanced effectiveness is due primarily to the ability of the electronic countermeasures to anticipate the road departure prior to the vehicle actually departing its travel lane, and therefore provide additional time for the driver to respond.

Mathematical modeling was also conducted for longitudinal countermeasures. The analysis indicates that an estimate of the distance to the upcoming curve with an accuracy of better than 40ft is necessary if the countermeasure is to provide an accurate and timely warning of excessive speed. This result implies that non-differential GPS may be adequate to warn the driver of the presence of a curve ahead, but differential GPS may be required if the countermeasure is to provide warning of excessive speed. These analyses also showed that errors in the estimate of available side friction of less than 0.15 can lead to a 10% error in the estimated safe speed for a curve. This suggests more research is necessary to determine a quick and accurate method of estimating available friction.

PRELIMINARY PERFORMANCE SPECIFICATIONS

The results of the above tests and simulations were used to generate preliminary performance specifications for potential run-off-road countermeasure systems. In order to be as comprehensive as possible, the performance specifications were generalized to be technology independent whenever feasible. Concrete values were provided for those performance specifications where the tests and analyses provide specific minimum performance criteria. A total of 60 specifications were developed, addressing sensing, processing and interface functions. A representative sample of these specifications is provided below.

Sensing Specifications:

- The system shall operate in all reasonable environmental conditions.

- The system shall be capable of operating over the range of typical road types, including those without lane markings, and on those where the lane markings are worn or in some other way degraded.
- In the rare conditions where countermeasure performance is significantly degraded due to extreme environmental conditions, the countermeasure shall recognize the situation, discontinue operation and communicate its status to the driver.
- The system shall measure vehicle speed to within **4** fps.
- The system shall measure the vehicle's lateral position to within 0.1 ft.
- The system shall be able to function on curves as sharp as 200 ft radius.

Processing Specifications:

- The system shall estimate the upcoming road curvature to within 10%.
- The system shall estimate the distance to an upcoming road feature, such as curve entry, to within 20ft.
- The system shall quantify the danger of lane departure and trigger a response if the danger exceeds some threshold. The danger may be measured in terms of time remaining until departure, the magnitude of the corrective maneuver required to avoid a crash, or some other measure.
- The decision algorithm shall consider the expected driver reaction time in determining when to trigger an alarm. The assumed total reaction time shall be no less than 1.5 s, including the time required by the countermeasure, the driver, and the vehicle.

Driver Interface Specifications:

- Warning signals shall not be so intense **or** complex as to overload driver.
- If possible, the system shall indicate appropriate driver response.
- If active braking is employed, it shall not impair the driver's ability to steer.
- The system shall not prohibit the driver from making safe lane changes, driving on the shoulder to avoid obstacles in the travel lane, or stopping beside the road for a vehicle or passenger emergency.

REMAINING WORK

The Phase I results of the program are very promising: it appears effective roadway departure countermeasures are possible using existing technology. However several open questions remain, and will be addressed in Phases II and III of the program. First, we will test improvements in the countermeasure technologies to improve their effectiveness. In particular, tests will be performed to evaluate alternative methods for sensing degraded roadway conditions, an important causal factor for roadway departure crashes not addressed in Phase I of this program. **Also** in the area of improved technologies, the team intends to test adaptive countermeasures, which modify their processing to accommodate variations from one driver to the next. This should reduce the frequency of false alarms, which could otherwise significantly reduce driver acceptance and system effectiveness. Evaluation of these techniques will require relatively extended tests by a number drivers.

The second focus during the remainder of the program will be on the development and application of improved techniques for estimating system effectiveness. The comparison with real data collected for roadside rumble strips performed for Phase I provided valuable insight into potential countermeasure performance, and extensions of this technique to account for more aspects of countermeasures. Finally, the results of these tests and analyses will be used to refine, quantify and validate the preliminary performance specifications developed as part of Phase I.

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