

UC San Diego

UC San Diego Previously Published Works

Title

A novel active heads-up display for driver assistance.

Permalink

<https://escholarship.org/uc/item/21x1793b>

Journal

IEEE transactions on systems, man, and cybernetics. Part B, Cybernetics : a publication of the IEEE Systems, Man, and Cybernetics Society, 39(1)

ISSN

1941-0492

Authors

Doshi, Anup
Cheng, Shinko Yuanhsien
Trivedi, Mohan Manubhai

Publication Date

2009-02-01

Peer reviewed

A Novel Active Heads-Up Display for Driver Assistance

Anup Doshi, *Student Member, IEEE*, Shinko Yuanhsien Cheng, *Member, IEEE*, and
Mohan Manubhai Trivedi, *Senior Member, IEEE*

Abstract—In this paper, we introduce a novel laser-based wide-area heads-up windshield display which is capable of actively interfacing with a human as part of a driver assistance system. The dynamic active display (DAD) is a unique prototype interface that presents safety-critical visual icons to the driver in a manner that minimizes the deviation of his or her gaze direction without adding to unnecessary visual clutter. As part of an automotive safety system, the DAD presents alerts in the field of view of the driver only if necessary, which is based upon the state and pose of the driver, vehicle, and environment. This paper examines the effectiveness of DAD through a comprehensive comparative experimental evaluation of a speed compliance driver assistance system, which is implemented on a vehicular test bed. Three different types of display protocols for assisting a driver to comply with speed limits are tested on actual roadways, and these are compared with a conventional dashboard display. Given the inclination, drivers who are given an overspeed warning alert reduced the time required to slow down to the speed limit by 38% ($p < 0.01$) as compared with the drivers not given the alert. Additionally, certain alerts decreased distraction levels by reducing the time spent looking away from the road by 63% ($p < 0.01$). Ultimately, these alerts demonstrate the utility and promise of the DAD system.

Index Terms—Active safety, driver assistance systems, driver distraction, head movement tracking, human factors, integrated safety systems, intelligent driver-support systems.

I. INTRODUCTION

SAFETY is a major cause for innovation in automobile industries. Many new technologies are emerging to meet the increasing desire for safer vehicles and roadways.

One factor that plays a big role in road safety is excessive speed. Speeding is a significant cause of accidents and motor vehicle infractions. According to the National Highway Transportation Safety Administration (NHTSA) [1], 13 113 lives were lost in 2005 in crashes involving speeding. Indeed, 30% of all crashes involved speeding, involving a cost of approximately

Manuscript received April 16, 2007; revised October 20, 2007. First published July 29, 2008; current version published January 15, 2009. This work was supported in part by UC Discovery, by the Digital Media Innovations Program, and by the Electronics Research Laboratory, Volkswagen of America. This paper was recommended by Guest Editor A. Pentland.

A. Doshi and M. M. Trivedi are with the Laboratory for Intelligent and Safe Automobiles, University of California, San Diego, La Jolla, CA 92093 USA (e-mail: andoshi@ucsd.edu; mtrivedi@ucsd.edu).

S. Y. Cheng was with the Laboratory for Intelligent and Safe Automobiles, University of California, San Diego, La Jolla, CA 92093 USA. He is now with HRL Laboratories, LLC, Malibu, CA 90265 USA (e-mail: sycheng@ucsd.edu).

Color versions of one or more of the figures in this paper are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/TSMCB.2008.923527

\$40.4 billion each year in the U.S. alone. Furthermore, most of those crashes are at speeds under 55 mi/h, which are off of the highways.

For these reasons and more, auto manufacturers have begun implementing technology-based safety systems. Some of these state-of-the-art systems include collision warning and brake support, intelligent night vision with pedestrian detection, backup warnings and cameras, and lane departure warning systems. Despite this progress, it is not clear whether these systems can urgently and reliably warn the driver without distracting him or her from the road conditions. Fixed displays will not grab the driver's attention if he or she is looking away. Auditory (and haptic) displays may not be able to convey the same amount of information quickly and succinctly. Drivers may already know about impending danger, and they may be annoyed by systems that provide redundant warnings. Side-screen displays might take the driver's attention off the road.

We introduce and evaluate the dynamic active display (DAD), which is a unique large-area windshield display designed to actively alert the driver in critical situations. As a novel prototype developed in conjunction with Volkswagen, the DAD is able to use a laser to display dynamic visual icons nearly anywhere on the windshield. Within the author's knowledge, the implementation of such a wide-area windshield display in a real test bed is unprecedented. It allows for the real-world experimentation of concepts which were previously only testable in laboratory settings, thus moving beyond the realm of simulated studies.

The DAD can be used to provide context-specific alerts to the driver, and it is capable of changing the position and intensity of an alert, depending on the attention of the driver. This "active" alert thus makes decisions based upon the state and pose of the driver, vehicle, and environment.

The display is presented as an effective medium to communicate important information to the driver while minimizing distraction. As part of a quantitative evaluation of this system, we find that DAD demonstrates significant improvements in both effectiveness and the minimization of distractions as part of a driver assistance system.

This paper is organized as follows. Background and related works are discussed in Section II. Section III describes the instrumented Laboratory for Intelligent and Safe Automobiles—Passat (LISA-P) test bed and the capabilities of DAD. A comprehensive evaluation of DAD in a speed control experiment is described in Section IV. Conclusions and future research are discussed in Section V.

II. BACKGROUND AND RELATED WORKS

A. Background

1) *Modalities of Displays*: The driver can be informed of critical situations via several different modalities. Haptic interfaces include any sort of interface that will use force feedback or touch sensitivity. Examples could include resistance or shaking of the steering wheel or resistance in the brake and accelerator pedals. These have the advantage of being intuitive; they can also quickly inform the driver even if the driver is distracted, considering that the driver is usually in contact with the interface.

Audio interfaces may include voiced commands, such as those given by Navigation systems, or even simple beeps and sounds. Most vehicles are equipped with warning beeps to indicate if the driver has left his or her headlights on or if the driver is not wearing a seatbelt. The beeps are useful if the driver knows what the sound means, or if the sound occurs in conjunction with a visual cue. To convey more information in the auditory channel, as is done with voiced navigation directions, for example, requires more time.

Visual interfaces abound in the vehicular environment. Examples include the dashboard of the vehicle, showing the speedometer, tachometer, and side-screen monitors for navigation systems. Visual cues have the advantage of being able to quickly convey a wealth of information to the driver. However, there is a great deal of visual distraction in a vehicular environment; therefore, informing a driver using this modality could be a challenge.

Several cars these days also use heads-up displays (HUDs) to convey information to the driver. As a subset of visual interfaces, HUDs are designed to present information to the driver, which is closer to his or her field of view. Thus, the driver does not have to look down to see the information but can spend more time looking at the road. It is important to note, however, that drivers will not be able to focus on the HUD and the road at the same time, which is due to the effects of parallax. Nevertheless, by presenting information that is closer to the normal field of view, HUDs require less effort on the part of the driver than other kinds of visual displays [2]; therefore, it may present an effective choice of conveying visual information.

2) *Types of Displays*: Moreover, independent of the modality, there can be several types of displays, depending on the criticality of the situation. A “static” display will constantly display information, regardless of the situation. This may be useful if the driver should be constantly aware of the information, as in speed or engine temperature. “Dynamic” displays monitor the state of the environment and the vehicle and change accordingly, potentially alerting the driver only if there is an impending event to be aware of. Navigation systems are certainly dynamic, as well as dashboard warning lights for “engine check” and others. Finally, an “active” display monitors the state of the driver and displays information in response to the state. The active display could infer the intent or focus of the driver and could determine whether displaying information would be useful or distracting. This also allows the display to change position or even modality, depending on the driver’s state.

Some types of displays are mature technologies and are thereby widely implemented in vehicles. However, the design of a “dynamic and active” display is an active research subject, particularly in terms of investigating the effectiveness and the robustness of the active display. These references are discussed in more detail in the following section.

B. Related Works

A majority of research into “active” interfaces has mainly focused on simulator-based experiments. Experiments conducted on such environments have evaluated various aspects of the active displays, including appropriate display timings [3], [4], positions [2], [5], and driver responses [6] and attitudes [7]. These have demonstrated the potential positive effects of the active HUD. However, it is difficult to draw conclusions for real-world situations based on simulated experiments, considering that there are many more variables present in real-world conditions. According to an NHTSA driver workload metrics report [8]

Some effects were observed in the laboratory which were not observed during driving. Until this is better understood, judgments on task effects should reflect a comprehensive evaluation approach that includes more than just laboratory testing.

This motivates the need for an implemented test bed to experiment in real-world conditions.

Sharon *et al.* [9] implemented an active interface for the purpose of “coaching” or giving feedback to driving students. The interfaces are auditory and haptic, however. Therefore, very limited information can be communicated in urgent situations. Takemura *et al.* [10] experimented with a test bed actively sensing the driver and environment states using cameras and potentially advising the driver with voice synthesis. Amditis *et al.* [11] proposed a test-bed solution for active visual displays using side-screen and dashboard displays. Petersson *et al.* [12] conducted experiments with camera-based systems to detect driver and environment conditions, with an active visual display in a side screen. Unfortunately, the side screen requires the user to look away from the road to gauge the information.

Furthermore, Liu and Wen [2] observed that truck drivers in simulators were able to control their speed better with speed information from a HUD rather than a heads-down display (HDD). Their study had shown that a savings of 0.8 to 1.0 s in driver reaction time can be achieved with the use of HUDs to display warning information over conventional HDDs. We present results of a similar comparison on actual roadways with a novel experimental laser-based HUD.

Our contributions are the motivation and introduction of a novel laser-based wide-area heads-up windshield display, which is capable of actively interfacing with a human as part of a driver assistance system. The DAD is a unique prototype interface that presents safety-critical visual icons to the driver in a manner that minimizes the deviation of his or her gaze direction without adding to unnecessary visual clutter. Furthermore, as part of an active safety system, the DAD “actively” presents alerts in the field of view of the driver—only if necessary, which

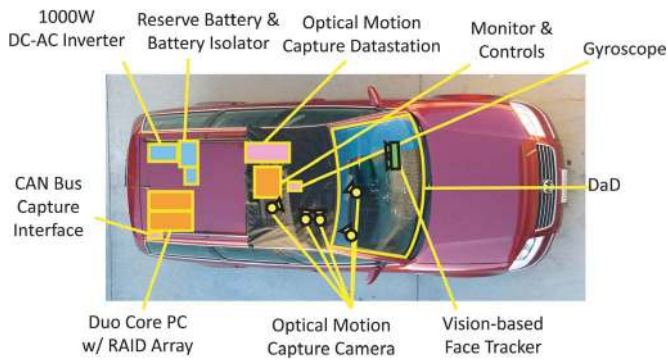


Fig. 1. LISA-P test bed.

are based upon the state and pose of the driver, vehicle, and environment. We examine the effectiveness of DAD through a comprehensive comparative experimental evaluation of a speed compliance driver assistance system, which is implemented on a vehicular test bed. Three different types of display protocols for assisting a driver to comply with speed limits are tested on actual roadways and compared with the conventional dashboard speedometer. Given the inclination, drivers who are given an overspeed warning alert reduced the amount of “time-to-slow-back-down” to speed limit by 38% ($p < 0.01$), as compared with drivers not given the alert. Additionally, certain alerts decreased the distraction levels by reducing the time spent looking away from the road by 63% ($p < 0.01$). Ultimately, each of these alerts exhibits strengths in complementing ways, demonstrating the utility and promise of the DAD system.

III. LISA-P TEST BED AND DAD ALERTS

The LISA-P test-bed setup is shown in Fig. 1. It is instrumented with a novel laser-based large-area windshield display whose capabilities are shown in Fig. 2. The DAD is capable of displaying alerts anywhere on the windshield via a blue-colored laser. Additionally, the LISA-P is outfitted with an optical motion capture system, a vision-based eye gaze tracker, and global positioning system (GPS) and controller area network (CAN) bus sensors to determine the state of the occupant and vehicle. A more detailed description of the LISA-P can be found in [13].

Considering that speeding is a leading cause of crashes, any manner of safely reducing speed from over the speed limits may be useful. In this light, a DAD-based speed compliance aid is presented and used to quantitatively analyze the safety and effectiveness of the DAD over having normal dashboard-based displays.

There are three proposed alert modes for this particular aid, whose designs were motivated by the strengths and weaknesses of human vision. The human eye can be divided into three regions based on acuity to different visual cues: the fovea and parafovea regions that subtend about 10° , which are both found in the macula, and the peripheral vision region, extending to 180° . Vision within the macula has the highest visual acuity, which is necessary for reading, watching television, driving, and any activity where visual detail is of primary importance.

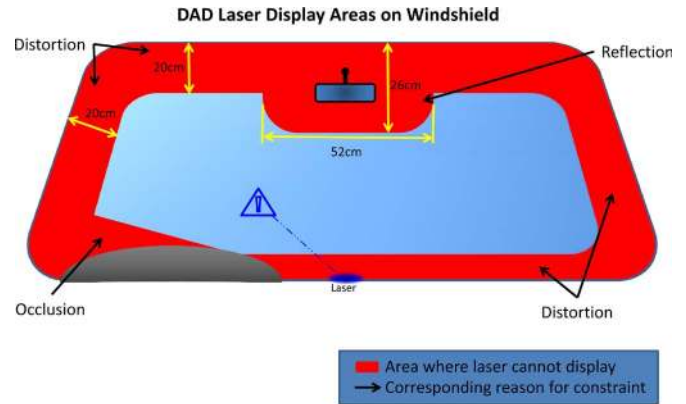


Fig. 2. LISA-P test bed. DAD display capabilities and limitations and the approximate location of alerts used for the speed control experiment. Within these limitations, the DAD is capable of drawing anywhere on the windshield.

The peripheral vision extends beyond it and has good motion detection and temporal resolution [14].

For critically important situations, a visual alert directly presented in the driver’s central visual field should be able to catch his or her attention immediately; however, this runs the risk of competing directly with the driver’s view of the road and surroundings. For the particular case of a speed limit or current speed alert, the more appropriate placement would be a secondary location where a driver has the option of taking notice if the situation does not demand complete concentration. Watanabe *et al.* [15] observed that the fastest response times to HUD warnings presented during videos of drives occurred when the warning was placed 5° to the right of the center of line of sight. Because of the fast response times and the secondary importance of the speed alerts, all alerts in our speed control experiments were placed approximately 5° diagonally to the bottom right from the center of the line of sight.

There is also a need to display alerts that grab the attention of the driver from the secondary location, particularly when the speed limit has been exceeded. Considering that the peripheral visual field is most sensitive to motion cues, we animate the alerts with zooming and bouncing effects for the purpose of attracting attention. The zooming enlarges the alert every other second, and the bouncing consists of a vertical location change that is similar to the motion of a rubber ball bouncing off the ground. Both take into account the apparent need for the driver to fixate upon the alert for a moment in order to recognize its meaning. The zoom consists of two sizes, with 1 s separating the times between the changing sizes. The bounce starts with high bounces for 0.5 s; however, for 1.0 s, the icon bounces only subtly until it finally comes to rest at the base location. Both allow for some time in which the icon is not or barely

moving for the eyes to fixate upon. Furthermore, the alerts were designed to be approximately 2 in tall, such that they were big enough to be clearly understood and yet small enough to prevent occlusions. The zoom doubles the size of the icon, whereas the bounce moves the icon approximately 2 in.

Considering that it is easy to measure amount of time spent over the speed limit (given the current speed and the speed limit), the speed compliance module is chosen over the other two modules for a quantitative evaluation of DAD. The following section uses this design methodology to determine the performance and safety of the DAD in a speed compliance experiment.

IV. DAD EVALUATION: SPEED COMPLIANCE EXPERIMENT

A. Experiment Details

We test four strategies of speed alerts; each driver is asked to drive the same route for each alert strategy. The alerts are presented in different orders for each driver, and the drivers are already familiar with the area. We measure the amount of time the driver spent above the speed limit, the ratio of time spent observing the alert or dash or the road in general, and the distribution of speeds measured for roads with various speed limits.

For each drive, we vary the display in one of the following four ways.

- 1) No display—No DAD alert is given.
- 2) Warning—A triangular exclamation point warning sign appears and bounces as soon as the driver exceeds speed limit.
- 3) Numbers—A textual alert constantly shows the driver's current speed and the road speed limit (e.g., 43/45). The text representing the driver's speed zooms in and out if the driver is above the speed limit.
- 4) Graphic—A graphical alert constantly shows a vertical status bar with the driver's speed and the speed limit clearly marked. The entire graphic bounces if the driver is above the speed limit.

A graphical representation is shown in Fig. 3.

On each of the four iterations (each using a different display condition) of the experiment, the subject is told to drive on a given road course lasting approximately 20 min. The route is carefully chosen to include a variety of situations and environments, as shown in Fig. 4. The speed limits vary from 15 to 65 mi/h, and the roads range from small local roads through campus to major highways. The distances were calculated such that approximately 3–4 min was spent driving in each speed range.

During the drive, speed limits are acquired by determining the current global position in longitude and latitude via GPS and by searching the list of road way points for the closest match. Associated with each way point is a speed limit that was manually annotated with the speed limit. The distance between each way point is approximately 0.1 mi. When the current position deviates from all way points by more than the width of the widest road, the speed limit is defaulted to a nonvalid value.

Head pose is measured by using a marker-based motion capture system, and eye gaze is measured by using a camera-

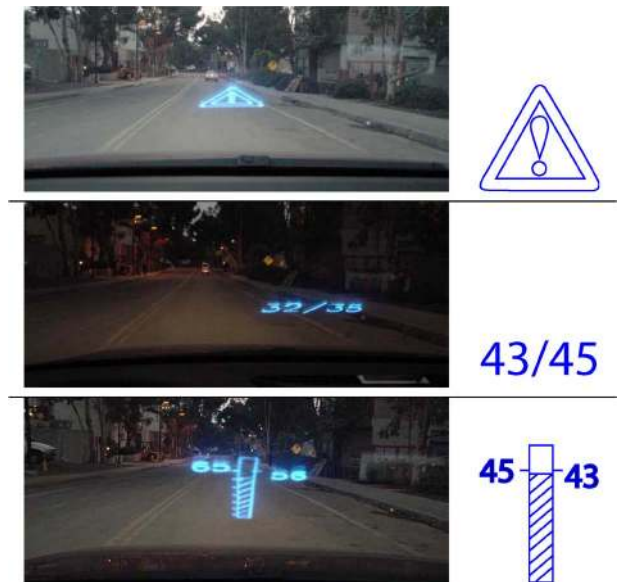


Fig. 3. Illustration of the three alerts used.

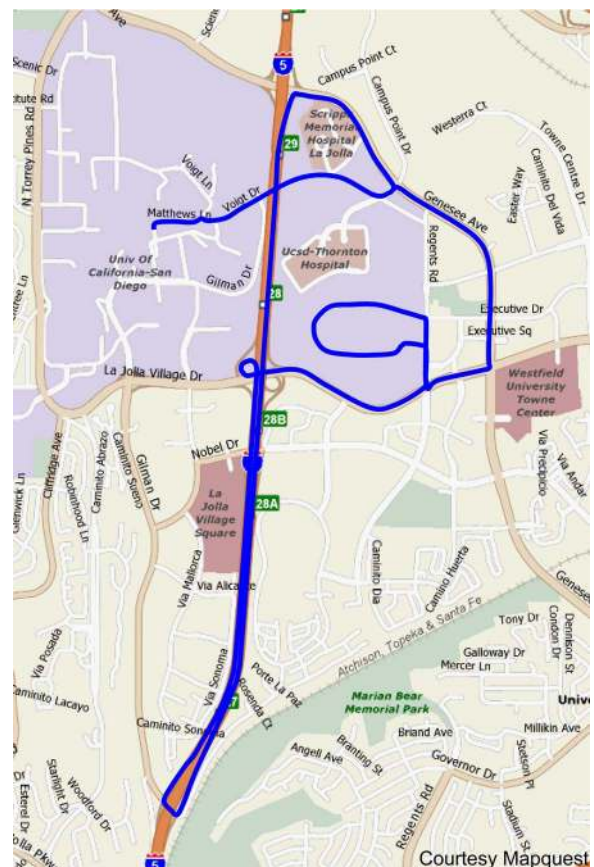


Fig. 4. Driving Test Path, which includes local roads, main roads, and highways, with speed limits ranging from 15 to 65 mph.

based eye tracking system. The vehicle speed data, as part of over 20 other vehicle parameters, are recorded via the vehicle's CAN bus and are passed as an input to the display module, to inform the subject of the speeds. A millisecond-accurate clock in the PC is used to time stamp all entries of data recorded. The setup for the experimental test-bed LISA-P is shown in Fig. 1.

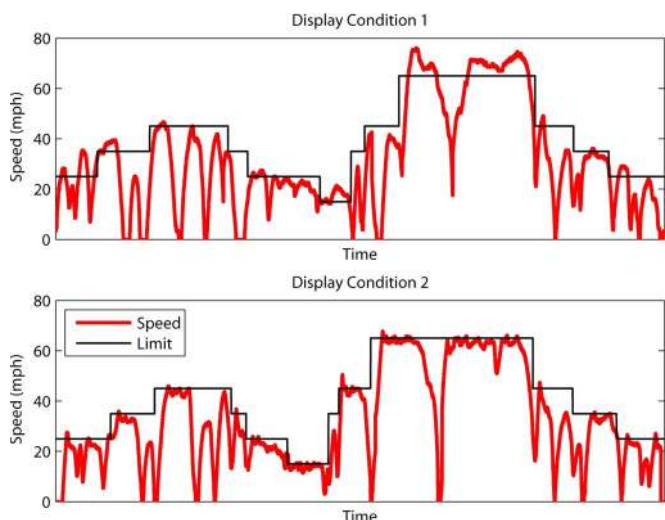


Fig. 5. Results of sample test run for (top) condition 1—no display and (bottom) condition 2—warning sign. The driver’s ability to maintain speed is clearly evidenced by the reduced amount of time accidentally spent over the speed limit in condition 2.

The subjects are asked to drive as they would normally but to pay particular attention to obey the speed limits. Each driver was familiar with the roads and path before beginning the drive. Data were collected from a total of 11 test subjects with varying experience levels, ranging from age 22 and 50, several with glasses, with a total of over 14 h of driving data. All drives were during the early evening hours, which are free from rush-hour traffic. Over the set of drivers, the order of the four display conditions was varied, hopefully mitigating the impact of any learning effects over the course of the study.

B. Results and Analysis

Plots of a sample drive showing speed versus time, and the corresponding speed limits, for display conditions 1 and 2 are shown in Fig. 5.

For each display condition, the driver was asked to drive normally, paying attention to speed limits. To analyze the ability of the driver to stay under the limit, one statistic measured was the “time to slow back down” or the average amount of time the driver spent over the speed limit before returning to under the limit. This measure was chosen to clearly represent how immediate were the effects of the different warnings. This measure also ignores route timing differences due to traffic lights, congestion, and environment changes, all of which would cause biases in other absolute measures such as “total amount of time spent over speed limit.”

The results are shown in Fig. 6, and the statistics are listed in Table I. With the second display condition, there is a clear drop in the amount of time it took each subject to return to driving below the speed limit once the warning was shown. For all test subjects, the caution symbol from the second condition caused a drop of 2.24 s in the average time to slow back down. We then normalize these times relative to the times of display condition 1 in order to better compare relative effects over each driver, arriving at the values shown at the bottom of Fig. 6. Using this normalized metric, we can conclude that, on average,

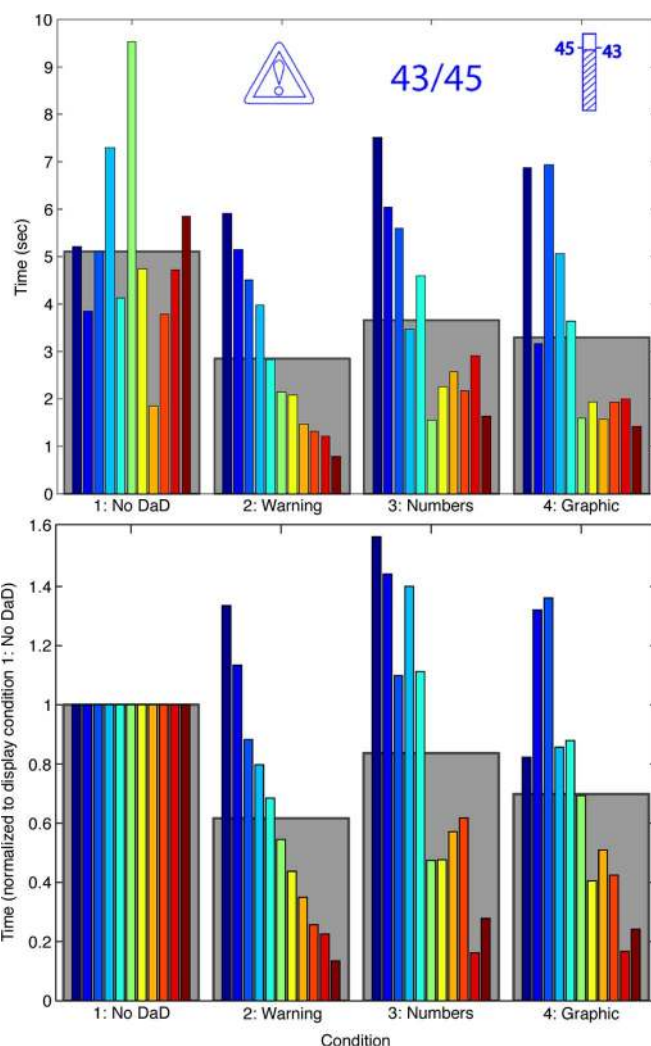


Fig. 6. Time to slow back down or the amount of time spent over the speed limit before slowing back down with different alerts. Each experiment consists of 4 trials by 11 different drivers. The overall averages are in gray, superimposed by the individual averages. The top plot represents the raw data, and the bottom plot shows the same data normalized by the values of condition 1—no DAD. See Table I for numerical figures.

TABLE I
AVERAGE “TIME TO SLOW BACK DOWN” WITH DIFFERENT ALERTS OVER ALL DRIVERS

Exp 1 - No Disp	5.09 sec
Exp 2 - Warning	2.85 sec
Exp 3 - Numbers	3.66 sec
Exp 4 - Graphic	3.28 sec

the second display condition caused a drop of 38% in the time to slow back down.

The other two warnings involving the displays of numbers and graphics were quite effective but not as much as the warning sign. As discussed later, this can be attributed to the two “active” signs being constantly displayed and thereby not catching as much of the driver’s attention when the drivers were over the speed limit. Additionally, their information takes a bit of time to process, compared with the static display which can be understood immediately.

To further understand these data, an analysis of variance (ANOVA) was performed on the normalized statistic “time to

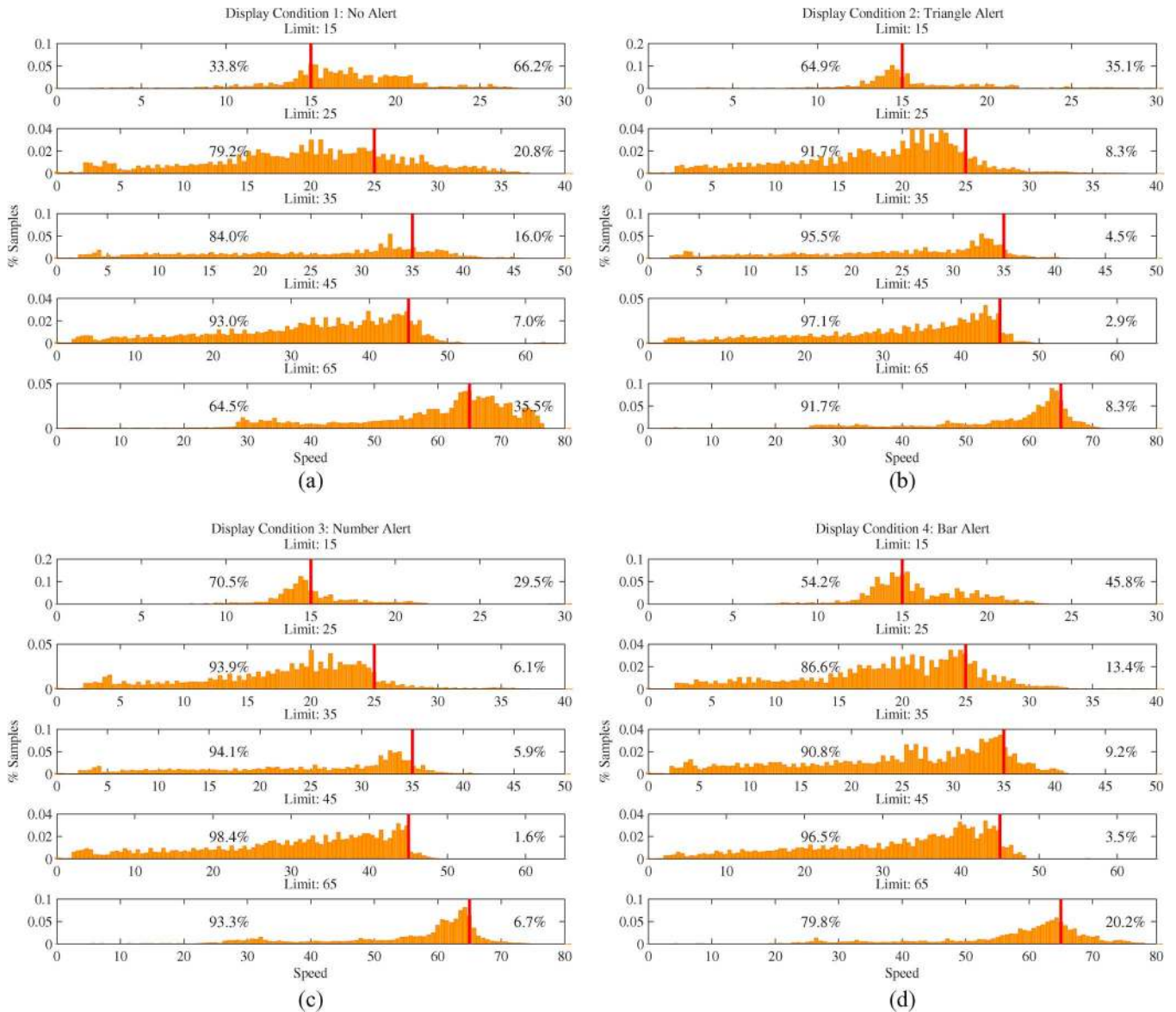


Fig. 7. Histograms of speeds for each section of road with the given speed limit. Significant differences can be seen by comparing over-speed cases across the 4 conditions, especially at 15 and 65 mph limits.

slow back down.” The test was conducted to ascertain whether the pattern shown at the bottom plot of Fig. 6 was a coincidence or whether the reduction in time in experiments 2, 3, and 4 actually represents general patterns. Analysis was done by comparing two conditions at a time using ANOVA, which is essentially equivalent to a t test. The analysis showed that the second display condition implies a statistically significant reduction in time to slow back down ($p = 0.0039 < 0.01$), whereas the third and fourth conditions did not have statistically significant effects. Based on the calculated confidence intervals from the 11 test subjects, we may conclude that 99% of the population would experience between 4.94% and 71.76% reduction in time to slow back down using this second display condition.

Furthermore, one could divide the population of test subjects into “compliant” and “noncompliant” groups. The “noncompliant” drivers (consisting of the first four in Fig. 6) exhibited no clear pattern in response to any of the alerts ($p = 0.10 > 0.01$). Interestingly, there was no clear common trait among these

noncompliant drivers, as they were of varying age, gender, and backgrounds. The rest of the drivers were extremely responsive to all the alerts ($p = 0.000082 < 0.0001$) and could be labeled as “compliant.” Thus, while we can conclude that the warning, display condition 2, causes a 38% overall average drop in time to slow back down ($p < 0.01$), we can also identify that some users may be “noncompliant,” in which case they are less likely to respond. As discussed later, the active nature of the DAD could allow the system to identify such noncompliant drivers by analyzing historical responses and accordingly adjust or remove the alerts.

C. Driver Distraction: Pose Analysis

By analyzing the driver’s behavior, it becomes possible to gauge the distraction level of the alerts and determine whether they were taking the driver’s focus away from the road. Automatic analysis of pose and gaze can be done by using the

LISA-P test-bed setup with the motion capture system and the near-infrared vision-based gaze tracking system. We can use these to determine whether the HUD kept the driver from taking his or her attention off the road, ostensibly to look at the dashboard when the driver has drifted above the speed limit. This would determine the drivers' attention and distraction level in response to various visual cues, which has implications on the safety of the alerts.

1) *Eye Movement and Head Pose*: Several of the studies mentioned in Section II-B focus on systems monitoring the driver, particularly eye gaze tracking systems [8], [10], [12]. However, although modern eye gaze trackers have become extremely sophisticated, they still suffer under fast-changing in-vehicle conditions [16]–[18]. Indeed, others who have measured eye gaze in vehicles have usually tracked eyes in more stable lighting environments. NHTSA [8] also conducted a thorough study into driver workload metrics, using eye gaze as a measurement tool. However, in that study, the eye gaze patterns were manually marked up by humans after the data were recorded in order to achieve more accurate results.

We found that, after automatically collecting marked eye gaze data, these were not accurate or robust enough to draw systematic conclusions. Specifically, many of the drivers in the current experiment wore glasses, which, under strong illumination changes, heavily affect the performance of the eye tracker, effectively serving as occlusions. Moreover, when the driver turns his or her head out of range of the eye tracking cameras, the gaze estimates are no longer valid. Finally, the eye gaze tracking system was cumbersome in that it required training for each individual subject, and slight errors in training would decrease the accuracy of the gaze estimates.

We determined that head pose estimates were reliable and, thereby, a better estimate of the attention and distraction levels of the driver. The marker-based head pose estimation system used in these experiments, in comparison, is extremely accurate and precise [19]. It does not suffer under lighting changes, considering that it is based on detecting infrared reflections off of the markers placed on the head. With the LISA-P instrumented with this powerful measurement tool, we were able to draw reliable data on driver reactions to the DAD alerts.

2) *Distraction Results*: The input head pose data use labeled calibration data as a reference to cluster into three regions: looking “up,” or forward at the windshield; “down,” or at the dashboard; and “at DAD,” at the specific location of the DAD alert. These classes are shown in Fig. 8. To calibrate the regions, several subjects were asked to look around each region, and the measurements were labeled and stored. Input data were then clustered by using an L_2 norm-based nearest neighbor classifier.

Considering that each driver is unique in reaction speeds, the absolute amount of time spent looking in each direction is not a very reliable metric, particularly because the times being considered are so quick. Therefore, for each driver, we considered the relative amount of time spent looking in each direction with an alert (display conditions 2–4), compared with the time spent when there was no alert (display condition 1). In other words, we measured the time in each direction with alerts as a percentage of the time in each direction without alerts.

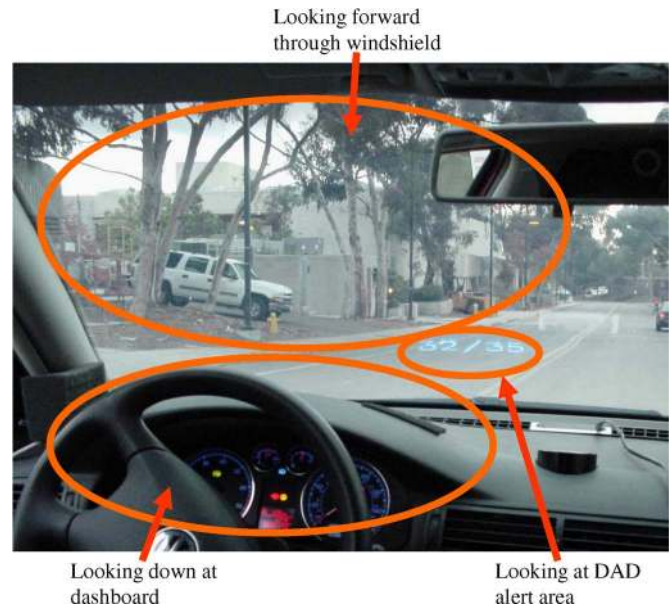


Fig. 8. Head pose estimates are classified into three clusters, with each corresponding to a certain region in front of the driver, namely: “up,” “down,” or “at DAD.”

TABLE II
NORMALIZED RATIOS OF TIME SPENT “LOOKING” IN EACH DIRECTION WHILE ABOVE THE SPEED LIMIT, WITH VERSUS WITHOUT ALERTS, WHICH ARE AVERAGED OVER ALL DRIVERS

Alert Type:	1: [no alert]	2:	3: 43/45	4:
Ratio of time spent “looking down” with & without alert	1.00	3.40	0.37	0.31
Ratio of time spent “looking at DAD” with & without alert	1.00	6.80	1.37	5.50
Ratio of time spent “looking forward” with & without alert	1.00	0.95	1.10	1.03

This normalized metric provides greater insight into the relative glance patterns of the drivers over each condition.

Results of each display condition are shown in Table II, again noting the behavior while the driver was traveling beyond speed limit.

The effects of the warning in display condition 2 can be clearly seen, in that the driver was not warned of his or her current speed so the driver had to look down to the dash to find out how much he or she needed to brake. This notion is verified by the head movements during display conditions 3 and 4, in which the speed was dynamically displayed to the driver, precluding the need to look down.

We can draw from these results that the alert type from display condition 3 caused the least distraction. The driver spent only 37% of the normal time looking down, and the time spent looking forward through the windshield increased by 10%. This amount of time is particularly important when considering that every second is precious when it comes to avoiding accidents. An ANOVA implies that the increase in forward-looking time might not be as statistically significant, whereas the time spent looking down is indeed a pattern, with $p = 0.0034 < 0.01$.

V. DISCUSSION AND CONCLUDING REMARKS

A novel interface for communicating information to a driver was introduced, and its motivations over other interfaces were presented. As part of an active driver assistance system, the DAD is a unique and demonstrably capable display.

Results were presented for a series of experiments conducted to discover the most effective and least distracting class of alerts using a HUD to assist a driver in maintaining speed. Head pose data were analyzed to determine the effects of the alerts on the driver's attention and focus.

The overall results in Table I show that the warning display that appears in the driver's peripheral vision while he or she is driving above the speed limit is most effective in assisting the drivers to maintain speeds within or below the limit. With the warning display, the driver tended to speed only 62% as much compared with a conventional speedometer. ANOVA implies that these results are indeed general patterns, with $p = 0.0039$. In addition, results from the head pose data imply that the warning display actually increased the time looking away from the road; however, the numerical display decreased the time looking down by 63% overall ($p = 0.0034$).

These results were echoed by the test subjects themselves. Among the most prevalent comments were that the warning display was the most helpful because it caught their attention better than the active displays and was able to inform them that they were driving above the speed limit without causing them to move their focus away from the road. They did have to look down to gauge their speed more often, which could ultimately decrease safety. The numerical display allowed them to concentrate on the road more, as they did not have to look down to see their speed; however, it was not effective enough in grabbing their attention while drifting above the speed limit. Finally, the graphical display took a bit of time to register the information; therefore, it did not prove as useful, even though it was effective in slowing the drivers down.

One possibility to improve the utility of the alerts would be to combine the better aspects of each of them. The warning sign would prove more effective if the speed was also displayed in the driver's field of view. This kind of alert would still have the ability to do the following: 1) quickly grab the driver's attention; 2) include information about how much to slow down; and 3) allow the driver to maintain focus on the road. At the same time, the alert could recognize, based on the current driver's responses to recent alerts, whether the driver is "noncompliant," which, as was explained earlier, decreases the likelihood of responding to the DAD. If this is the case, it may be wise to dynamically remove alerts to reduce distractions and annoyances.

The active capabilities of DAD could also be useful in several other situations, including backup warning and navigation aids. Future experiments will evaluate the usefulness and critical safety improvements in using these systems. It would also be interesting to consider the problem of overlaying objects or destinations with an alert on the windshield, which would require accurate calibration and registration mechanisms.

It is interesting to note that certain displays can increase distraction, whereas other displays decrease distraction.

Design would thus become paramount in considering safe driver assistance systems. The ability of the DAD to test and implement many different designs and placements of alerts is thereby quite valuable. Considering that it is an active display, the DAD can even adjust its display types and information to suit a particular driver.

The DAD system has the potential to play a clear role in improving driver assistance systems. This alert modality can decrease distraction levels by alerting drivers without taking their gaze off the road. It also can actively alert the driver only if necessary, which is based on the state and pose of the driver, vehicle, and environment. The experiments conducted in this paper quantitatively show the improvements in the drivers' abilities to control speed, as well as decreased distraction levels, using the DAD—speed control system in real traffic conditions with the LISA-P test bed. Future research includes harnessing the capabilities of DAD in improving and analyzing intelligent driver assistance systems.

ACKNOWLEDGMENT

The authors would like to thank J. Camhi and Dr. A. Stoschek for helping them instrument the very first prototype of the large-area windshield display in their LISA-P test bed, E. Murphy-Chutorian for his assistance with software libraries, and the test subjects for their invaluable input and assistance in their experiments. The authors would also like to thank the reviewers for their insightful comments.

REFERENCES

- [1] NHTSA National Center for Statistics and Analysis, *Traffic Safety Facts: 2005 Data—Speeding*, 2006, Washington D.C.: U.S. Dept. Transp., Nat. Highway Traffic Safety Admin.
- [2] Y.-C. Liu and M.-H. Wen, "Comparison of head-up display (HUD) vs. head-down display (HDD): Driving performance of commercial vehicle operators in Taiwan," *Int. J. Human-Comput. Studies*, vol. 61, no. 5, pp. 679–697, Nov. 2004.
- [3] S. Nagirir, Y. Amano, K. Fukui, and S. Doi, "A study of a personally adaptive driving support system using a driving simulator," *R&D Rev. Toyota CRDL*, vol. 39, no. 2, pp. 24–33, 2004.
- [4] G. Abe and J. Richardson, "Alarm timing, trust and driver expectation for forward collision warning systems," *Appl. Ergon.*, vol. 37, no. 5, pp. 577–586, Sep. 2006.
- [5] M. Wittman, M. Kiss, P. Gugg, A. Steffen, M. Fink, E. Poppel, and H. Kamiya, "Effects of display position of a visual in-vehicle task on simulated driving," *Appl. Ergon.*, vol. 37, no. 2, pp. 187–199, Mar. 2006.
- [6] B. Okombi-Diba, M. Okuwa, Y. Uchiyama, A. Kozato, and T. Hongo, "Evaluation of a night driver support system: Driver eye movement behavior," in *Proc. SICE Annu. Conf.*, Aug. 4–6, 2004, vol. 1, pp. 795–801.
- [7] B. Donmez, L. N. Boyle, J. Lee, and D. McGehee, "Drivers' attitudes toward imperfect distraction mitigation strategies," *Transp. Res., Part F Traffic Psychol. Behav.*, vol. 9, no. 6, pp. 387–398, Nov. 2006.
- [8] L. Angell, J. Auflick, P. Austria, D. Kochhar, L. Tijerina, W. Biever, T. Diptiman, J. Hodgsett, and S. Kiger, "Driver workload metrics project: Task 2 final report," U.S. Dept. Transp., NHTSA, Washington, D.C., Tech. Rep. DOT HS 810 635, Nov. 2006.
- [9] T. Sharon, T. Selker, L. Wagner, and A. Frank, "Carcoach: A generalized layered architecture for educational car systems," in *Proc. IEEE Int. Conf. Softw.—Science, Technology Engineering*, Feb. 2005, pp. 13–22.
- [10] K. Takemura, J. Ido, Y. Matsumoto, and T. Ogasawara, "Drive monitoring system based on non-contact measurement system of driver's focus of visual attention," in *Proc. IEEE Intell. Veh. Symp.*, Jun. 2003, pp. 581–586.
- [11] A. Amditis, H. Kubmann, A. Polychronopoulos, J. Engstrom, and L. Andreone, "System architecture for integrated adaptive HMI solutions," in *Proc. IEEE Intell. Veh. Symp.*, 2006, pp. 388–393.

- [12] L. Petersson, L. Fletcher, and A. Zelinsky, "A framework for driver-in-the-loop driver assistance systems," in *Proc. IEEE Intell. Transp. Syst.*, Sep. 2005, pp. 771–776.
- [13] S. Y. Cheng and M. M. Trivedi, "Turn intent analysis using bodypose for intelligent driver assistance," *Pervasive Comput.*, vol. 5, no. 4, pp. 28–37, Oct.–Dec. 2006.
- [14] M. Rizzo and I. L. Kellison, "Eyes, Brains, and Autos," *Arch. Ophthalmol.*, vol. 122, no. 4, pp. 641–645, Apr. 2004.
- [15] H. Watanabe, H. Yoo, O. Tsimhoni, and P. Green, "The effect of HUD warning location on driver responses," in *Proc. Int. Transp. Syst. World Congr.*, 1999, pp. 1–10.
- [16] X. Liu, F. Xu, and K. Fujimura, "Real-time eye detection and tracking for driver observation under various light conditions," in *Proc. IEEE Intell. Veh. Symp.*, Jun. 2002, pp. 344–351.
- [17] P. Wang, B. G. Matthew, J. Qiang, and W. J. Wayman, "Automatic eye detection and its validation," in *Proc. IEEE Workshop Face Recog. Grand Challenge Experiments (CVPR)*, Jun. 2005, p. 164.
- [18] J. Wu and M. M. Trivedi, "A binary tree for probability learning in eye detection," in *Proc. IEEE Workshop FRGC CVPR*, 2005, vol. 3, p. 170.
- [19] A. D. Wiles, D. G. Thompson, and D. D. Frantz, "Accuracy assessment and interpretation for optical tracking systems," in *Proc. SPIE—Medical Imaging, Visualization, Image-Guided Procedures, Display*, 2004, vol. 5367, pp. 421–432.
- [20] M. M. Trivedi and S. Y. Cheng, "Holistic sensing and active displays for intelligent driver support systems," *Computer*, vol. 40, no. 5, pp. 60–68, May 2007.
- [21] M. M. Trivedi, T. Gandhi, and J. McCall, "Looking-in and looking-out of a vehicle: Computer-vision-based enhanced vehicle safety," *IEEE Trans. Intell. Transp. Syst.*, vol. 8, no. 1, pp. 108–120, Mar. 2007.
- [22] J. McCall and M. M. Trivedi, "Driver behavior and situation aware brake assistance for intelligent vehicles," *Proc. IEEE*, vol. 95, no. 2, pp. 374–387, Feb. 2007.
- [23] K. W. Gish and L. Staplin, "Human factors aspects of using head up displays in automobiles: A review of the literature," U.S. Dept. Transp., NHTSA, Washington D.C., Tech. Rep. DOT HS 808 320, Aug. 1995.
- [24] A. Doshi and M. M. Trivedi, "A comparative exploration of eye gaze and head motion cues for lane change intent prediction," in *Proc. IEEE Intell. Veh. Symp.*, 2008.
- [25] E. Murphy-Chutorian and M. M. Trivedi, "Head pose estimation in computer vision: A survey," *IEEE Trans. Pattern Anal. Mach. Intell.*, 2008.



Anup Doshi (S'03) received the B.S. and M.S. degrees in electrical and computer engineering from Carnegie Mellon University, Pittsburgh, PA, in 2005. He is currently working toward the Ph.D. degree in the Laboratory for Intelligent and Safe Automobiles, University of California, San Diego, La Jolla.

His research interests include computer vision and machine learning for applications in driver assistance and intelligent vehicles, human-computer interfaces, and surveillance.



Shinko Yuanhsien Cheng (S'05–M'07) received the Ph.D. from the University of California, San Diego, La Jolla, in 2007.

He is currently with HRL Laboratories, LLC, Malibu, CA. His research interests include computer vision systems, human-machine interfaces, articulated body modeling, volumetric scene reconstruction, human body pose and structure recovery, human activity recognition, intelligent transportation systems, and intelligent vehicles.



Mohan Manubhai Trivedi (S'76–M'79–SM'86) received the B.E. degree (with honors) from Birla Institute of Technology and Science, Pilani, India, and the Ph.D. degree from Utah State University, Logan.

He is a Professor of electrical and computer engineering and the Founding Director of the Computer Vision and Robotics Research Laboratory, University of California, San Diego (UCSD), La Jolla. He has established the Laboratory for Intelligent and Safe Automobiles, UCSD, to pursue a multidisciplinary research agenda. His team is currently pursuing

system-oriented research in distributed video arrays and active vision, omnidirectional vision, human body modeling and movement analysis, face and affect analysis, and intelligent driver assistance and active safety systems for automobiles. He regularly serves as a consultant to industry and government agencies in the United States and abroad.

Prof. Trivedi served as the Editor-in-Chief of the *Machine Vision and Applications Journal* from 1996 to 2003 and on the editorial boards of several other journals. He is currently an Associate Editor of the *IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS*. He served as the Program Chair for the IEEE Intelligent Vehicles Symposium (IV 2006) and will serve as the General Chair for the IEEE IV 2010 in San Diego. He serves on the Executive Committees of the University of California Digital Media Innovation Program and of the California Institute for Telecommunication and Information Technologies [Cal-IT2] as the Leader of the Intelligent Transportation and Telematics Layer at UCSD. He serves as an Expert Panelist for the Strategic Highway Research Program (Safety) of the Transportation Research Board of the National Academy of Sciences. He has an extensive publication record, and two of his recent papers coauthored with his Ph.D. students have won the Best Paper Award. He was also a recipient of the Distinguished Alumnus Award from Utah State University and of the Pioneer Award (Technical Activities) and the Meritorious Service Award from the IEEE Computer Society.