Proceedings of the
2007 IEEE Intelligent Vehicles Symposium
Istanbul, Turkey, June 13-15, 2007

Active Heads-up Display based Speed Compliance Aid for Driver Assistance: A Novel Interface and Comparative Experimental Studies

Shinko Y. Cheng, Anup Doshi, and Mohan M. Trivedi
Laboratory for Intelligent and Safe Automobiles
University of California, San Diego
9500 Gilman Drive MC0434, San Diego, CA 92093-0434
{sycheng,adoshi,mtrivedi}@ucsd.edu
http://cvrr.ucsd.edu/lisa

Abstract

In this paper we introduce a novel laser-based wide-area head-up windshield display, and its evaluation for assisting a driver to comply with speed limits. The paper includes a comparative experimental evaluation with an instrumented vehicle of four different types of display protocols. The result is the Dynamic Active Display - Speed Control system, a part of the Dynamic Active Display concept of presenting safety-critical visual icons to the driver in a manner that minimizes deviation of his or her gaze direction without adding to unnecessary visual clutter. The experimental system make use of Global Positioning System (GPS) information to locate the vehicle on an annotated map with speed limits, the novel heads-up-display, and 3 biologically inspired alerts to present speed and speed limit information on this display. Each alert strategy is tested on actual roadways, and compared with the situation of having to rely only on the dash indicators. Given the inclination, drivers who are given an over-speed warning alert reduced the amount of "time-to-slow-back-down" to speed limit by 42% as compared to drivers not given the alert. The use of other alerts produced similar decreases. Ultimately, each of these alerts exhibit strengths in complementing ways, indicating that a combination of these alerts would provide the best strategy for promoting speed limit compliance.

Keywords: *Driver Assistance Systems, Integrated Safety Systems, Human Factors, Active safety, Intelligent Driver Support Systems, Eye Gaze Tracking, Head Movement Tracking, Driver distraction*

I. Introduction

Speeding is a significant cause of accidents and motor vehicle infractions. One potential solution could be using a "Heads-Up Display" (HUD) to warn the driver of their speed, and if they are in violation of the speed limit. Like the speed-limit reminders on local roads nowadays, simply alerting drivers of their actual speed vs. the current speed limit can surprise them into abiding by the law. The driver will think, "if the road sensor knew that I was driving faster, then other people might know I'm driving too fast; I'd better slow down."

Furthermore, Liu and Wen observed in [1] that truck drivers in simulators were able to control their speed better with speed information from a HUD rather than a HDD (heads-down display). The study had shown that a savings of 0.8s to 1.0s in driver reaction time can be achieved with the use of HUDs to display warning information over conventional heads-down-displays. We present results of a similar comparison on actual road-ways with a novel experimental laser-based HUD.

Our contributions are the results of an investigation in determining quantitatively the most effective alerts to allow a driver to control his or her speed. The result is the Dynamic Active Display - Speed Control system, a part of the Dynamic Active Display concept of presenting safety-critical visual icons to the driver in a manner that minimizes deviation of his or her gaze direction without adding to unnecessary visual clutter [2]. The experimental system make use of Global Positioning System (GPS) information to locate the vehicle on an annotated map with speed limits, a novel one-of-a-kind laser-based wide-area windshield heads-up-display, and 3 biologically inspired alerts to present speed and speed limit information on this display. Each alert strategy is tested on actual roadways, and compared with the situation of having to rely only on the dash indicators. Given the inclination, we show that drivers who are given an over-speed warning alert reduced the amount of "time-to-slow-back-down" to speed limit by 42% as compared to drivers not given the alert. The use of other alerts produced similar decreases. Ultimately, each of these alerts exhibit strengths in complementing ways, indicating that a combination of these alerts would provide the best strategy for promoting speed limit compliance.

II. DaD-SpeedControl

The design of the 3 alert modes were motivated by the strengths and weaknesses of human vision. For the following discussion, the human eye can be divided into 3 regions based on acuity to different visual cues: the macula which contains the fovea and parafovea subtends about 10°, and peripheral vision extends to 180°. Vision within the macula has the highest visual

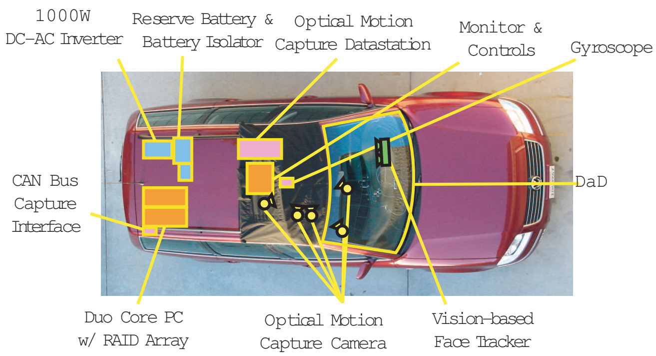


Fig. 1. LISA-P Testbed

acuity which is necessary for reading, watching television, driving and any activity where visual detail is of primary importance. The peripheral vision extends beyond it and has good motion detection and temporal resolution [3].

For critically important situations, presenting a visual alert directly in the driver's central visual field should be able to catch the driver's attention immediately. Doing so however presents the driver with a visual cue that competes 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 seems to be a more secondary location where a driver has the option of taking notice if the situation does not demand complete concentration. Watanabe et al. [4] observed that the fastest response times to HUD warnings presented during videos of drives were highest at 5° from center, with the fastest response at right of center. Because of the fast response times and the secondary importance of which we believe the speed alerts should assume, all alerts in our experiments were placed approximately 5° diagonally to the bottom-right from center.

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. Since peripheral visual field is most sensitive to motion cues, we animate the alerts with zooming and bouncing effects for this 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, and one second separating the times between changing sizes. The bounce starts with high bounces, but for more than half the time the icon bounces only subtly until it finally comes to rest at the base location. Both allows for some time in which the icon is not or barely moving for the eyes to fixate upon.

III. Experiment Details

We test four strategies of speed alerts; each driver is asked to drive the same route for each alert strategy. We measured 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 Disp* - No HUD 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 (eg: 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 figure 2.

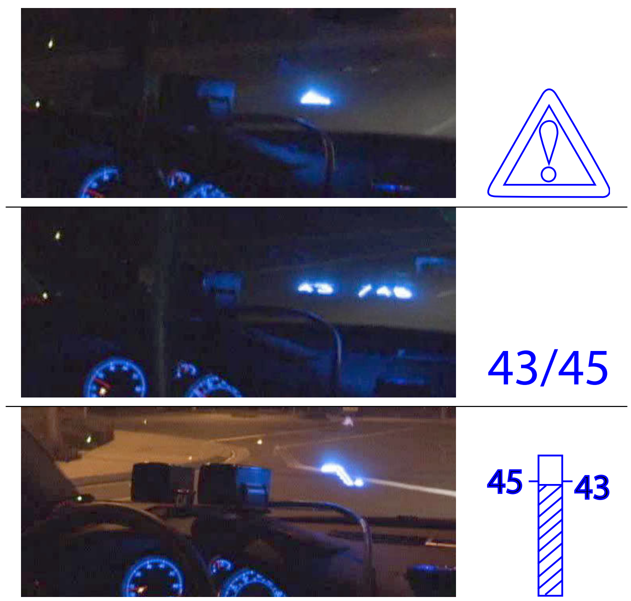


Fig. 2. Illustration of the three alerts used.

On each of four iterations of the experiment, the subject is told to drive on a given road course lasting approximately 20 minutes. This path is shown in Figure 3. The route is carefully chosen to include a variety of situations and environments. The speed limits vary from 15 to 65 miles per hour, and the roads range from small local roads through campus to major highways.

During the drive, speed limits are acquired by determining the current global position in longitude and latitude via GPS and searching the list of road way-points of 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 miles. 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 non-valid value.

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

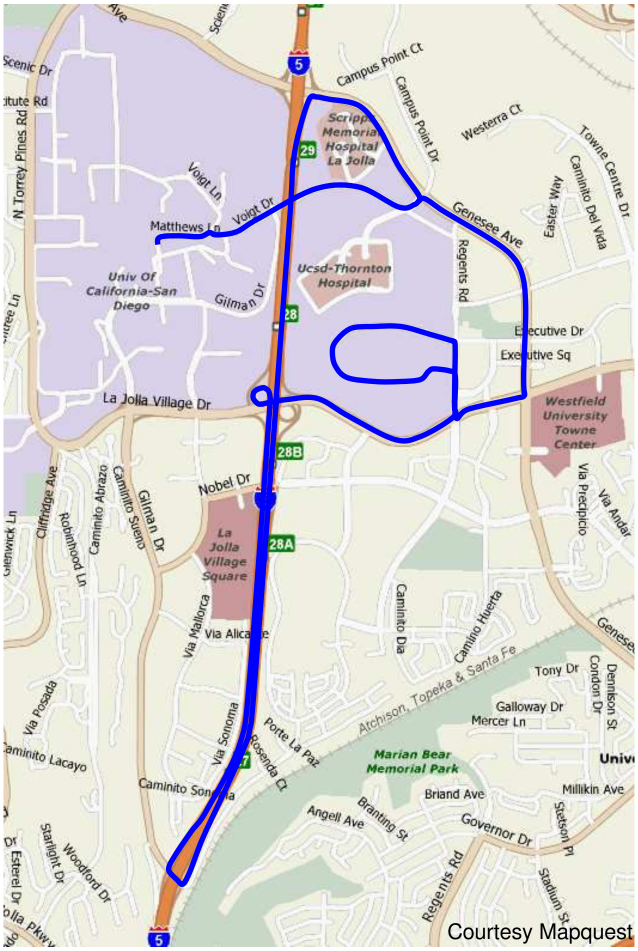


Fig. 3. Driving Test Path, which includes local roads, main roads, and highways, with speed limits ranging from 15 to 65 mph.

tracking system. The vehicle speed data, as part of over 20 other vehicle parameters, are recorded via the vehicle's Controller Area Network (CAN) bus, and 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 set up for the experimental test-bed LISA-P is shown in fig. 1.

The subject is asked to drive as they would normally, but paying particular attention to obey the speed limits. Data was collected from a total of six test subjects ranging from age 22 and 50, several with glasses, totaling nearly 8 hours of driving data. All drives were during the early evening hours, free from rush-hour traffic.

IV. Experiment Results

Plots of a sample drive showing speed vs. time, and the corresponding speed limits, for Experiments 1 and 2 are shown in fig. 4.

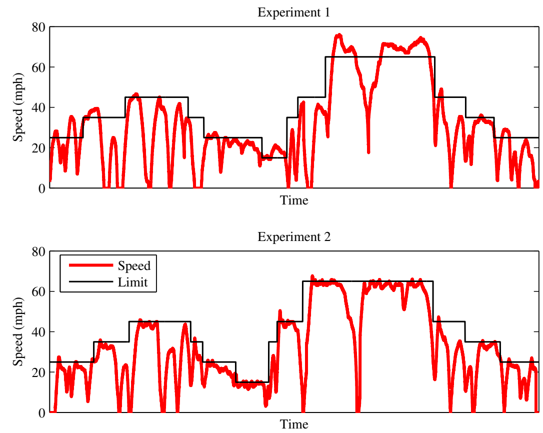


Fig. 4. Results of sample Test Run for Experiment 1 - No Display (top) and Experiment 2 - Warning sign (bottom). The driver's ability to maintain speed is evidenced clearly by the reduced amount of time accidentally spent over the speed limit in Experiment 2.

For each experiment, the driver was asked to abide by the speed limits. To analyze the ability of the driver to do so, one statistic measured was the "Time-to-slow-back-down" or the average amount of time the driver spent over speed limit before returning back 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. 5, and overall average numbers are listed in table I. With the second experiment, there is a clear drop in the amount of time it took each subject to return to driving below speed limit once the warning was shown. For all test subjects, the warning sign from the second experiment caused a drop of 2.67 seconds, or 42%, in the average 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 below, 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 driver's 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.

For each section of the route with a given speed limit, fig. 6 displays the histogram of speeds from all test subjects. Subjects found it more difficult to maintain speed limits at 15mph, as evidenced by the top graph in 6a. However comparing this across all four experiments shows the effectiveness of the HUD in reducing the amount of time spent over speed limit. The same result can also be clearly seen in comparing the histograms of the 65mph zones, where without the display there is a significant amount of time spent above the speed limit. These patterns demonstrate the effects of the DaD in assisting the subject to maintain their speed.

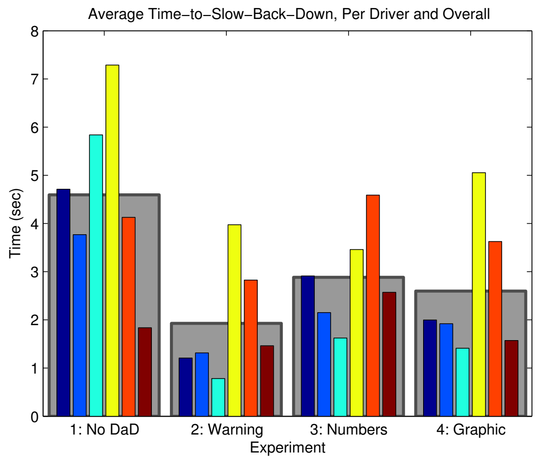


Fig. 5. Time to slow back down, or the amount of time spent over the speed limit before slowing back down with different alerts. Each experiment consists of 4 trials by 6 different drivers. The overall averages are in gray, superimposed by the individual averages. See Table I for numerical figures.

TABLE I. Average time-to-slow-back-down with different alerts over all drivers.

Exp 1 - No Disp	4.595 sec
Exp 2 - Warning	1.929 sec
Exp 3 - Numbers	2.885 sec
Exp 4 - Graphic	2.597 sec

A. Eye Movement

With eye movement and eye gaze data, the analysis can be taken a step further. It becomes possible to ascertain when the driver drifted above the speed limit, whether the HUD kept the driver from taking her eyes off the road, ostensibly to look at the dashboard. This would determine drivers' attention and distraction level in response to various visual cues, which has implications on the safety of the alerts.

Modern eye-gaze trackers have become extremely sophisticated, yet still suffer under fast-changing in-vehicle conditions[5], [6], [7]. Specifically, many of the drivers in the current experiment wore glasses, which under strong illumination changes heavily affect the performance of eye trackers, effectively serving as occlusions. To avoid this issue an off-the-shelf eye tracking system was modified to harness near-IR lighting, with several infrared illuminators mounted around the vehicle to light up the scene. In the low-light conditions of our experiment, the effect of this set-up was to create a more stable lighting environment. The outdoor near-IR lighting changes would then not have much effect inside the vehicle.

However several issues were encountered upon analysis of the collected data. Of primary importance was that it was not clear how accurately or confidently the eyes were tracked. The tracks qualitatively looked to be on target, with the exception of periods of glare or occlusions. Without a strong measure of accuracy, though, the eye gaze data could not yet prove to be conclusive. Additionally, the eye tracking system was not calibrated in "world" coordinates with the windshield and dashboard. This precluded knowledge of absolute gaze estimates in world coordinates. To get around this a simple experimental step was conducted to find the threshold dividing between the classes of "glancing up" and "glancing down", which was then used to classify the eye gaze data.

The numbers in fig. 7 represent the average percentage of time in which the driver was "glancing down" while drifting above the speed limit. A detailed pattern does not seem to emerge, across all drivers, implying that more test data is needed to ascertain specific patterns.

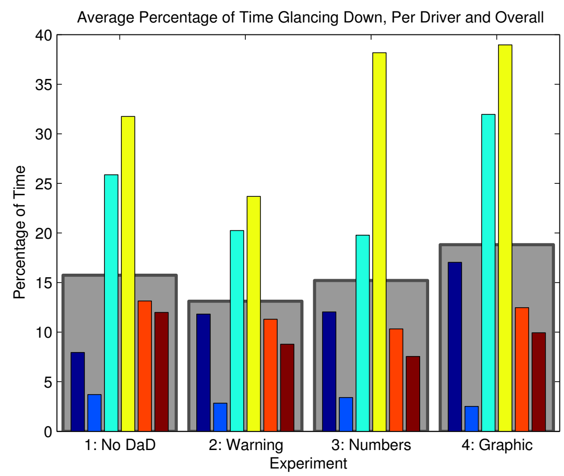
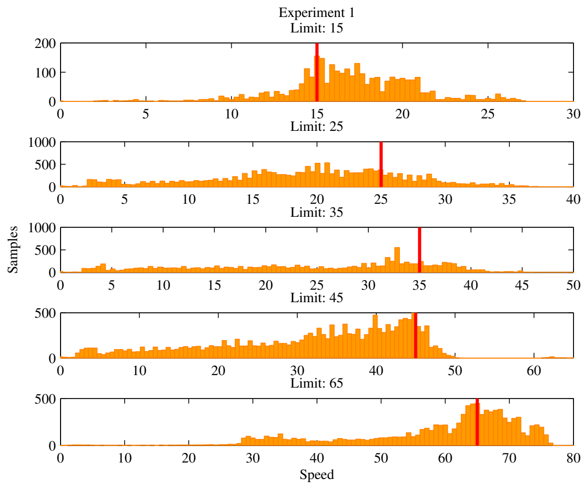


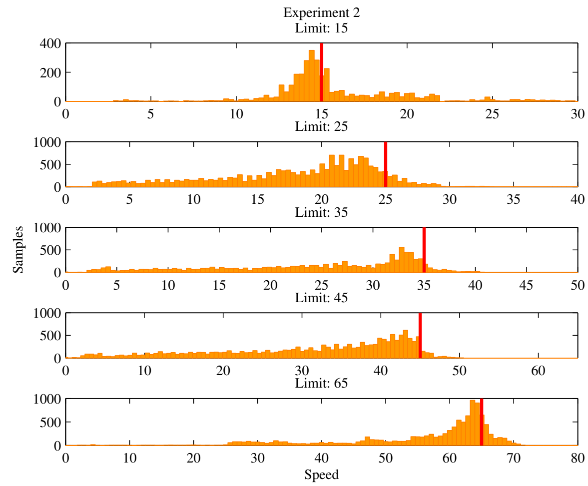
Fig. 7. Amount of time spent glancing down, while above speed limit, with different alerts. Each experiment consists of 6 trials by different drivers. The overall averages are in gray, superimposed by the individual averages.

B. Head Movement

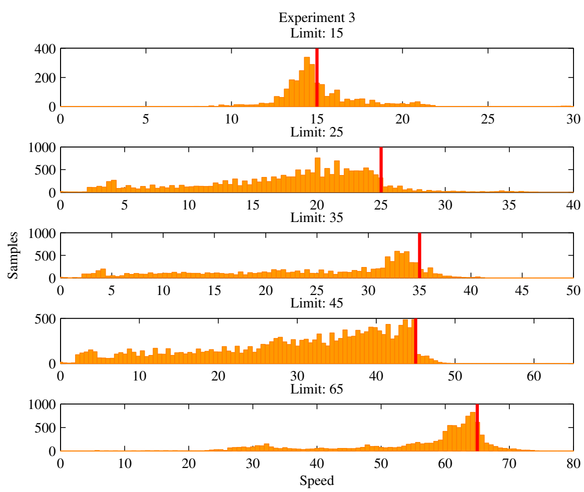
The marker-based head pose estimation system used in these experiments in comparison is extremely accurate [8], but only when calibrated correctly to the world coordinate frame. A sample result from a successfully precise calibration is shown below for one of the trials. The corresponding input head pose data uses the labeled calibration data as a reference to cluster into three regions: Looking "Up," or at the windshield, "Down," or at the dashboard, and "At DaD," at the specific location of the DaD alert. Results of each experiment are shown in Table II, again noting the behavior while the driver was traveling beyond speed limit.



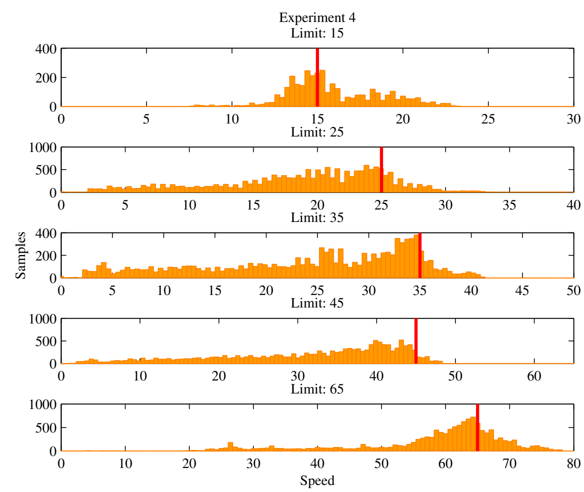
(a) Experiment 1: No DaD Display



(b) Experiment 2: Warning



(c) Experiment 3: Numbers



(d) Experiment 4: Graphic

Fig. 6. Histograms of speeds for each section of road with the given speed limit.

TABLE II. Percentage of time spent "looking" in each direction while above the speed limit.

Looking...	Up	Down	At DaD
Exp 1 - No Disp	99.81%	0.15%	0.03%
Exp 2 - Warning	96.65%	2.26%	1.09%
Exp 3 - Numbers	99.82%	0.09%	0.09%
Exp 4 - Graphic	98.91%	0.00%	1.09%

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

More tests would need to be conducted before conclusively stating findings based on the head pose. However because the calibrated marker-based head-pose estimation system is so accurate, this is a good preliminary representative for more general results.

V. Discussion and Concluding Remarks

Results are presented above for a series of experiments conducted to discover the most effective and safe class of alerts using a HUD to assist a driver in maintaining speed. Additionally, eye gaze and head pose data was 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 which appears in the driver's peripheral vision while they are above the speed limit is most effective in assisting the drivers to maintain speed limit. With the warning display, the driver tended to speed only 42% as much time as compared to without a display, and 67% and 74% as much time compared with active numerical and graphical displays, respectively. However results from the head pose data imply that this sort of display has the potential to be more distracting, as it causes the driver to look away from the road more often to check speed on the dashboard.

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. However 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, and so it did not prove as useful, even though it was effective in slowing the drivers down.

A possibility to improve the safety and effectiveness of the alerts would be to combine the better aspects of each of the alerts, or have a combination of alerts. 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 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.

The Dynamic Active Display system thus has the potential to play a clear role in driver's assistance and safety systems. The experiments conducted in this study quantitatively show the improvements in drivers' abilities to control speed using the Dynamic Active Display - Speed Control system in real traffic conditions with the LISA-P testbed. Future experiments involve adjusting the alerts to improve safety, and improving the collection of head pose and eye gaze data to more accurately gauge driver responses.

Acknowledgments

This work was partially supported by a grant from UC Discovery, Digital Media Innovations Program and from Volkswagen of America, Electronics Research laboratory. We would like to give special thanks to Jaime Camhi and Dr. Arne Stoschek in helping us instrument the very first prototype of the Large Area Windshield Display in our LISA-P testbed. We thank Erik Murphy-Chutorian for developing software libraries to utilize the Display. And we thank the test subjects for their invaluable inputs and assistance in our experiments.

References

[1] 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. of Human-Computer Studies*, vol. 61, no. 5, pp. 679–697, 2004.

[2] M. M. Trivedi and S. Y. Cheng, "Holistic sensing and active displays for intelligent driver support systems," *IEEE Computer Magazine, Special Issue on Human-centered Computing* in press, May 2007.

[3] M. Rizzo and I. L. Kellison, "Eyes, Brains, and Autos," *Arch Ophthalmol*, vol. 122, pp. 641–645, Apr. 2004.

[4] H. Watanabe, H. Yoo, O. Tsimhoni, and P. Green, "The effect of hud warning location on driver responses," in *International Transportation Systems World Congress*, 1999, pp. 1–10.

[5] X. Liu, F. Xu, and K. Fujimura, "Real-time eye detection and tracking for driver observation under various light conditions." in *Proceedings of IEEE Intelligent Vehicle Symposium*, June 2002, pp. 18–20.

[6] P. Wang, B. G. Matthew, J. Qiang, and W. J. Wayman, "Automatic eye detection and its validation." in *Proceedings of the IEEE Workshop on Face Recognition Grand Challenge Experiments (in Conjunction With CVPR)*, June 2005.

[7] J. Wu and M. M. Trivedi, "A binary tree for probability learning in eye detection." in *Proceedings of the IEEE Workshop on Face Recognition Grand Challenge Experiments (FRGC) in conjunction with CVPR 2005.*, vol. 3, 2005, pp. 170– 170.

[8] A. D. Wiles, D. G. Thompson, and D. D. Frantz, "Accuracy assessment and interpretation for optical tracking systems," in *SPIE Proceedings on Medical Imaging, Visualization, Image-Guided Procedures, and Display*, no. 5367, 2004.

[9] S. Y. Cheng, S. Park, and M. M. Trivedi, "Multi-spectral and multi-perspective video arrays for driver body tracking and activity analysis," *Computer Vision and Image Understanding* in press, 2007, doi:10.1016/j.cviu.2006.08.010.

[10] S. Y. Cheng and M. M. Trivedi, "Turn intent analysis using body-pose for intelligent driver assistance," *IEEE Pervasive Computing, Special Issue on Intelligent Transportation Systems*, vol. 5, no. 4, pp. 28–37, October-December 2006.

[11] M. M. Trivedi, T. Gandhi, and J. McCall, "Looking in and looking out of a vehicle: Computer vision-based enhanced vehicle safety," *IEEE Transactions on Intelligent Transportation Systems*, January 2007.

[12] J. McCall and M. M. Trivedi, "Driving behavior and situation aware brake assistance for intelligent vehicles," *Proceedings of IEEE, Special Issue on Advanced Automobile Technologies*, February 2007.

[13] K. W. Gish and L. Staplin, "Human factors aspects of using head up displays in automobiles: A review of the literature," U.S. Department of Transportation, National Highway Traffic Safety Administration, Tech. Rep. DOTT HS 808 320, August 1995.

[14] G. Johannsen, "Auditory displays in human-machine interfaces," *Proceedings of the IEEE*, vol. 92, no. 4, pp. 742–758, April 2004.