EYE TRACKING IN A COTS PC-BASED DRIVING SIMULATOR: IMPLEMENTATION AND APPLICATIONS

Chris Schwarz
National Advanced Driving Simulator
Iowa City, Iowa, US

Yefei He, Andrew Veit
National Advanced Driving Simulator
Iowa City, Iowa, US

ABSTRACT

An eye tracker has been integrated with the NADS MiniSim, a COTS PC-based driving simulator based on the large motion-based NADS-1. This work was motivated by increasing use of eye tracker data for both research and safety system simulation. Two new capabilities have been developed for the MiniSim. A gaze marker provides instantaneous feedback of the driver's gaze location on the visual display. Also, dynamic scenario triggers may be added to begin events when the driver's glance leaves the front scene. Meanwhile, eye-based algorithms have been developed for NADS studies; and one such algorithm has been ported to the MiniSim platform. These new capabilities broaden the utility of the MiniSim as a research platform. Additionally, they provide tools with which to creatively provide feedback to the driver/trainer both during and after a training scenario.

INTRODUCTION

It is often useful to track the location of a driver's gaze and measure performance indicators such as blinks or eye closures. Towards this end, a research-grade eye tracker has been integrated into the NADS MiniSim PC-based driving simulator. This enhances the utility of the simulator by: 1) adding eye tracker variables into the data collection stream for after action review (AAR) and data analysis, 2) augmenting the front visual display with a gaze position marker, and 3) allowing the integration of advanced eye-based algorithms from the NADS-1 simulator into the MiniSim environment.

A distraction detection algorithm has been implemented for NADS simulators based on a commercially-developed one that uses Percent gaze on Road Center (PRC) as a key metric. The flexibility of the PRC approach is described; and some details of the algorithm implementation are described.

We first present some details of the MiniSim setup and the eye tracker integration. Next we present algorithmic development work at the NADS for the detection of distraction and how it may be used in the MiniSim. Finally, we discuss future applications of the enhanced MiniSim for research, safety, and training applications. Of particular interest are the benefits and limitations of porting eye tracker technology to the MiniSim platform.

BACKGROUND

Eye trackers are established tools for research in driving simulation [1,2,3], and have been used at NADS for several years [4,5,6]. More recently, eye trackers have begun to be integrated into commercial systems for safety warning systems [7,8]. This too has been reflected in recent NADS studies. As a result, new eye tracker capabilities have been added to the NADS simulation environment.

Meanwhile, the MiniSim, a commercial off-the-shelf (COTS) PC-based simulator based on the NADS-1, has also enjoyed continued develop over the last couple of years. Through the convergence of these factors, an eye tracker capability was ported to the MiniSim and some new features were envisioned and implemented.

There are certainly challenges in working with eye tracker data. Measurement noise makes it difficult to pick out fixations and saccades [9]. Tracking fades in and out eroding confidence during some time intervals. The overall quality of tracking can vary dramatically from person to person; and some facial types are harder to track than others.

However, the benefits of eye tracker data outweigh the disadvantages. Notably, eye tracker data is a very non-intrusive form of psychophysiological data to collect; and for the driving task, it is arguably the most valuable as well.

The motivation for implementing eye tracking on the MiniSim comes from several factors. Though it was created

Presented at the **IMAGE 2011** Conference
Scottsdale, Arizona – June 2011

as a tool for rapid scenario development and testing, the MiniSim platform has evolved into a device that can be used for certain types of human subject driving simulation studies. As such, it will benefit from the capability to record eye data just as the NADS-1 and NADS-2 simulators do.

The MiniSim platform can be used as a low cost tool with which to test different driver vehicle interfaces (DVI). As current and future advanced driver assistance systems (ADAS) increasingly utilize new inputs, like eye data, an eye tracker equipped MiniSim can be used to test various forms of driver feedback in safety warning systems.

Finally, the MiniSim has been used in driver training workshops at the NADS Driver Safety Lab; and the eye tracker may prove to be an attractive new tool to train drivers and grade their performance.

NADS MINISIM

The NADS MiniSim™ is a software platform that is based on the real time subsystems and databases that have been developed for the NADS-1 and NADS-2 research simulators located at the University of Iowa's National Advanced Driving Simulator and Simulation Center. The MiniSim emerged from a need to create an alternative platform for the development of scenarios and study assets, since both the NADS-1 and NADS-2 were being used to conduct human subject studies. The architecture of the MiniSim is modeled after that of the NADS-1.

The main difference between the MiniSim and its larger cousins is the Scenario Control and Visual (SCNVIF) subsystem that uses a new image generator built on Open Scene graph. The network on the MiniSim is not based on SCRAMNet as in the NADS-1 and NADS-2, rather on local Ethernet and UDP packet transmission that feed intoe a virtual shared memory network. Additionally, the fundamental sampling rate on the MiniSim is 60 Hz, whereas the NADS-1 schedules processes at up to 240 Hz.

Configurations and Specifications

The MiniSim is a primarily a software platform, and as such the physical configuration of the system can be customized for different applications. Typical configurations are either a single or three-screen desktop, a car or truck quarter-cab with three large displays, or full cab system (see Figure 1). Visual display systems comprised of LCD, Plasma, and projectors have also been utilized, and different display geometries are supported through viewport settings.

Figure 1 Three Screen Quarter Cab MiniSim

Driver input devices that are currently supported include Logitech G27, ECCI Trackstar 6000, HAPP Controls UGCI, and Measurement Computing USB Analog/Digital IO boards. These devices allow either the simpler desktop configurations, or the instrumentation of quarter or full cabs. Some MiniSim users have even built their own cabs; and CANbus interfaces to OEM hardware can be supported through a custom subsystem as well. A separate virtual instrument cluster LCD is generally used with the MiniSim (see Figure 2), but for desktop systems it can be omitted and a speedometer overlayed on the bottom of the forward display.

Figure 2 Typical MiniSim Instrument Panel

The performance of the MiniSim, like all real-time simulation systems, is dependent on both the complexity and detail of the simulation itself and the processing capability of the hardware being utilized. As such, a compromise is generally reached between the desired performance, simulation complexity, and the cost that can be tolerated to accomplish the task. A typical MiniSim PC has the following specifications:

- Windows 7 Pro 64 bit
- 6 Gb RAM
- NVIDIA GeForce GTX 580
- NVIDIA GeForce 9500GT

- Intel i7 Quad-Core 3.0 GHz processor

The GTX 580 is used to drive three front channels through a Matrox Triple Head Adapter and to drive the Instrument panel display. At 60Hz frame rate, this hardware is capable of driving three forward channels at 1280x1024 resolution, and the instrument panel display at 1366x768 for a complex night-time scenario with dynamic lighting. If more resolution is required for the front channels, such as 1920x1080, a separate rendering PC is required for each channel.

The MiniSim software interface is the primary method a user interacts with the simulator. The interface runs on the same PC as the MiniSim, but is typically displayed on a separate display, out of the view of the driver.

Figure 3 MiniSim Operator Station

EYE TRACKING AT NADS

Eye tracking has been used at the NADS for the better part of a decade primarily as a research tool. Currently, NADS utilizes a research grade eye tracker from Seeing Machines with faceLab 5.0, as well as a commercial grade head tracker called DSS, also from Seeing Machines.

For Research

FaceLab provides a large number of variables to the researcher about the subject's gaze, head, blinks, saccades & fixations, world objects, and tracking confidence levels. These variables are typically used in NADS data analyses to calculate glances at specific locations in the car, gaze time on and off the road, reaction time of gaze back to the road after an event, as well as others. The advantages of the research eye tracker are the plethora of variables that are logged and the ability to manually configure the device for different faces, as required. Moreover, there is a choice to log real-time data or 'accurate' data that includes additional calculated measures such as Perclos.

In Vehicle Systems

Recent projects though have been characterized by dual-use utilization of the eye tracker for both the collection of research data as well as to support the implementation of safety warning algorithms. Such systems are increasingly finding their way into production vehicles, often beginning with the heavy truck market [7]. Eye data can be used to detect various forms if impairment such as drowsiness [10,11,16] and distraction [12-17].

Software Architecture

The NADS simulators use a modular design that consists of multiple subsystems. Subsystems exchange simulation data with each other via the underlying communication layer. The list of simulation data variables is pre-defined. The eye tracker is integrated into the NADS simulation environment by creating a new eye tracking (ET) subsystem. This process is very similar in the context of the NADS-1 and MiniSim simulators.

The faceLAB software is so configured that during run time, it not only writes eye tracking data to the local hard drive, but also streams the real-time portion of the data onto the local Ethernet. The ET subsystem, which resides on a different computer on the network, retrieves those real-time data during the simulator run, and publishes them to the communication layer. They are then collected together with other simulation data and automatically frame synchronized.

Not all outputs from the eye tracker are available for streaming in real-time. However, such data can be synchronized during post-drive data analysis using the eye tracker frame number, which are stored in both the eye tracker data files on the local hard drive and in the main driving simulation data file.

MiniSim Integration

As in the NADS-1 simulator set up, the NADS MiniSim also employs a subsystem-based architecture. An eye tracker subsystem almost identical to the NADS equivalent is created to receive eye tracking data from the faceLAB software through local Ethernet connection. The architecture of the MiniSim is shown in Figure 4; and the eye tracker subsystem fits into the optional CUSTOM subsystem shown in the figure.

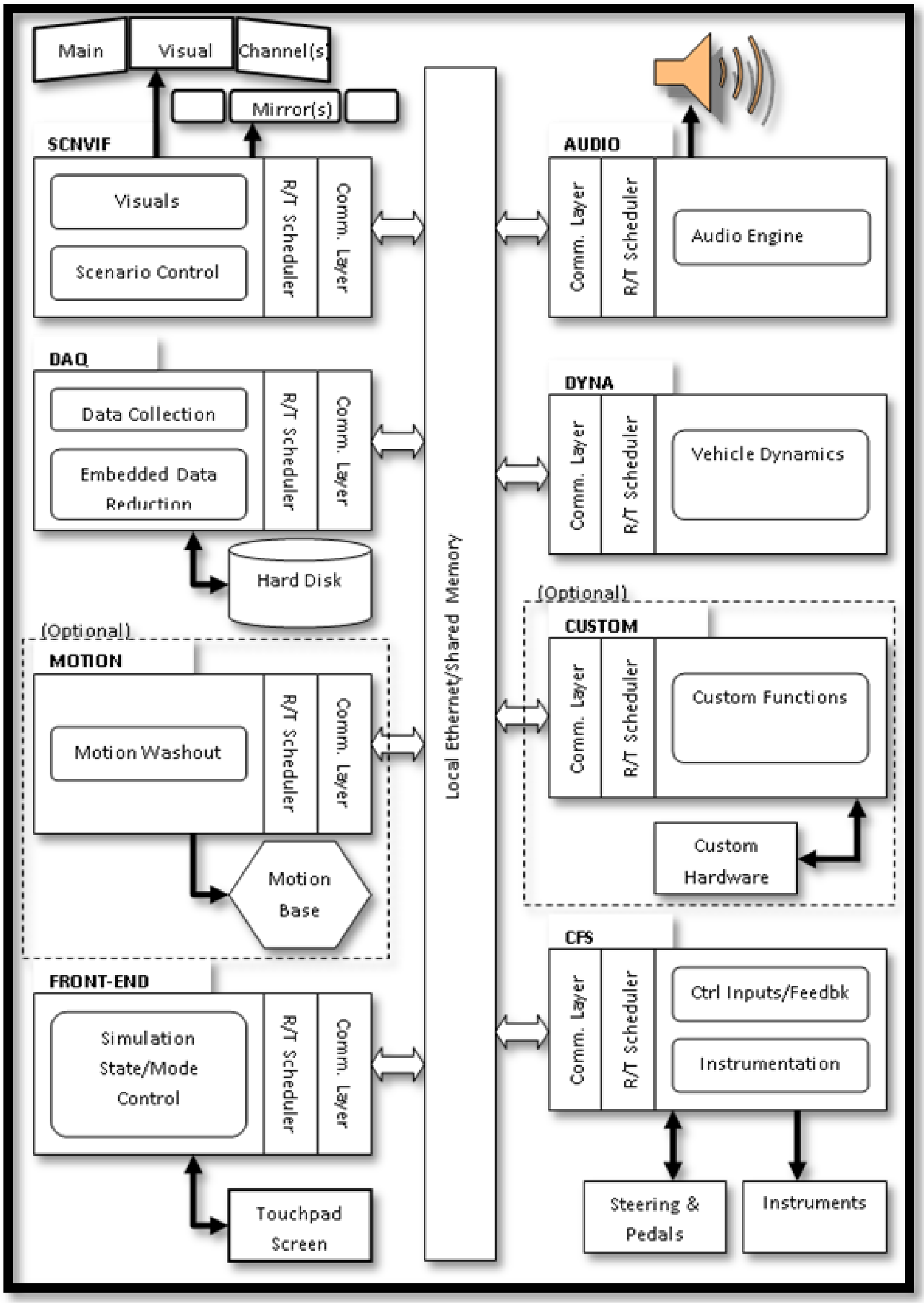

Figure 4 MiniSim Architecture

NEW CAPABILITIES DEVELOPMENT

The real-time eye tracking data are not only used for post-drive analysis on driver behavior and performance, they can also be used to interact with the driver at run time. Two such applications have been implemented on the MiniSim. The first provides instantaneous visual feedback to the driver and researcher using gaze markers on the display screens. The second is to trigger scenario events based on gaze direction.

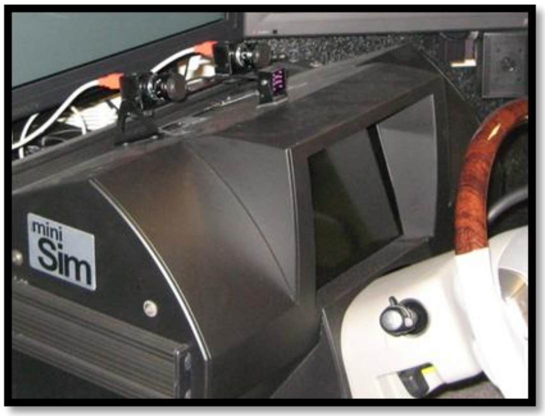

Figure 5 FaceLab 5.0 on Quarter Cab MiniSim
(courtesy of Linda Boyle at University of Washington)

Gaze Marker

Among the real-time eye tracking data that are relayed to the driving simulator data flow are variables that determine the gaze vectors of the driver, which include eyeball center position and gaze rotation. Eyeball center position is an array of six floats that specify the x, y and z coordinates of the right and left eyeball, respectively, in the world coordinate system of the eye tracking device. Gaze rotation is an array of four floats that specify the pitch and yaw angles of the gaze vectors of the right and left eye, respectively.

The origin of the eye tracker's world coordinate system is located between the two eye tracking cameras, with the x axis pointing to the right when looking into the cameras, the y axis pointing upwards, and the z axis pointing toward the driver. The position and rotation of the MiniSim's display screens are measured in advance and stored in a configuration file accessible to the simulator software.

Figure 6 Gaze Markers on Front Display

The intersection points of the left and right eye gaze vectors against the planes formed by the displays are calculated at run time, and if they lie within the boundary of the screens, a gaze marker is rendered at each intersection point on the corresponding display screen. The gaze vector values require filtering before they are used to calculate the location of the gaze markers due to measurement noise, otherwise the markers will appear jittery.

It is interesting to note that the two gaze markers do not coincide exactly. This may depend somewhat on the focal length of the viewing plane, which is currently close enough that some visual accommodation is required. It would be acceptable to average the two locations and display a single gaze marker as well.

Dynamic Events

The faceLAB software allows the user to create a world model that contains objects with fixed locations, such as the display screens. The ID of the objects intersecting with the gaze vectors are reported as part of the real-time eye tracking data. The LCD display rendering the virtual instrument panel is created as an object in the world model.

Scenarios can be created which, for example, force an autonomous vehicle in front of the ownship vehicle to brake when the driver looks into the instrument panel, i.e. when the eye tracker reports a gaze vector intersecting the instrument panel object. This gives the researcher useful tools to plan surprise events in study scenarios.

Identification of Gaze Objects in Scene

The eye tracker cameras and the driver are in the physical world, while the objects rendered in the driving environment are in a virtual world. However, the two worlds are fused together; and the common reference point is the driver. Therefore, coordinates expressed in the eye tracker's coordinate system can be converted into global coordinates in the virtual environment. This includes the eyeball center location and the gaze rotation, as well as the display screen position and rotation. The latter is in fact already used in the virtual environment as it determines the viewing frustum. The gaze vectors can then be projected into the virtual environment to perform intersection checks against objects of interest, such as vehicles, pedestrians, and signs.

EYE-BASED ALGORITHMS

In addition to these new capabilities implemented specifically on the MiniSim, an eye-based algorithm was also ported from the NADS-1 environment, where they were implemented for a NHTSA study. This section generally describes the features of the eye-based algorithm.

Percent Road Center

A relatively simple and robust eye tracking measure that can be calculated in real time is called percent road center (PRC) [8,12,17]. The PRC is a useful measure for quantifying driving performance during normal driving with or without secondary tasks, and under various forms of impairment. PRC is defined as the percentage of gaze data points during some period of time that fall within a circular area around the center of the road. Generally only fixations are counted in the PRC calculation. The location of the road center is calibrated during the drive by accumulating the driver's gaze into a two dimensional histogram and finding the most common point.

PRC is an attractive measure because of its simplicity. It does not require an underlying world model or gaze objects to be defined. Nor does it concern itself with the problem of detecting glances at areas off the road, such as mirrors or instrument panels; rather, it focuses on the somewhat easier problem of monitoring gaze towards the front roadway. The measure can be calculated over a running time window ranging from a few seconds to a minute or more; or it can be calculated over a fixed window that has been identified as an event or a task. The size of the road center circle can also vary, usually having a diameter of 16-20 degrees. The shape can also be elongated to one side or the other depending on certain conditions. If the driver is rounding a curve, then his gaze would be expected to drift to follow the curve, and may leave the center area; however, it may be compensated by using the car's angular rate to detect curves and turns.

Algorithm Elements

A multi-distraction detection algorithm that is based on the PRC measure was developed [8] since PRC has been shown to be sensitive to both visual and cognitive types of distraction [12]. This algorithm, along with a set of visual and auditory alerts, was used as the basis of an algorithm implemented in the NADS for a NHTSA-funded distraction study. This section presents in general terms the various elements of the distraction algorithm. The assumption about PRC-based measures is that they are more accurate when the vehicle is at speed and there are safety penalties for looking around too much. For this reason, the algorithm is only activated when a speed threshold of 25 mph was exceeded. Moreover a small hysteresis band of two miles per hour was implemented to prevent dithering in the algorithm switching.

Long Glances

The detection of long glances away from the roadway is an important part of detecting distraction. A glance of more than two seconds away from the road center is likely linked to a visual distraction and is certainly undesirable. The PRC measure classifies glances as either being in the road center area or off road. In the absence of good tracking, the assumption is towards on-center glances; thus, spurious alerts will not be given in the event of tracking degradation or hardware failure.

Glance History

While long glances may be sufficient to diagnose driver distraction, they are most definitely not necessary. The driver may exhibit signs of distraction is more complex and subtle ways. For this reason, another measure was used to detect visual distraction. The glance history is related to the PRC value in a running window of some length, but not concerned with the length of any one glance. The running PRC during normal driving should be in the vicinity of 80%. Distraction is detected if the value of the running PRC drops below some threshold, indicating that the percentage of gaze time off the road has increased to an unacceptable level. Once a distraction alert is issued, the running PRC is reset back to a nominal value so that the driver has a 'clean slate'. Hopefully the alert brought the driver's attention back to the road and PRC will not drop again.

It can be seen that the glance history is a more subtle measure for the detection of distraction, but that it is more difficult to determine an appropriate level at which to issue a warning. There is an interplay between the length of the running window over which PRC is calculated and the PRC threshold at which an alert is issued. A longer window will filter the PRC measure more causing it to change more slowly. In this case, one might raise the threshold for distraction to a value closer to 80%.

Another subtlety that is considered by Victor [9,12] to improve the robustness of the measure is to allow for visual time sharing (VTS) between locations. This occurs quite often during driving when the driver alternates glances between the front road and some other location, such as a mirror or an instrument cluster. This behavior reduces the running PRC, but is not indicative of distraction; rather, it is an orderly and safe strategy for dealing with a secondary driving task. VTS can be detected by looking for a pattern of falling and rising PRC calculated on a shorter time window. When VTS is detected, the glance history window is reset back to its nominal value, giving the driver another 'clean slate'.

Concentrated Gaze

Cognitive distractions are unusual in that they are not linked to increased visual demand in another location. Nevertheless cognitive distraction can result in inattentional blindness, which has been attributed as a cause of some accidents involving talking on cell phones. Cognitive distraction may present as an *increase* in the running PRC. This is because there is a drastic drop in a driver's attention to *other* areas of the scene. In other words, their normal scanning pattern is disrupted during a period of increased cognitive workload, leading to a greater vulnerability to unexpected events.

The PRC window used for detecting cognitive distraction is somewhat longer than that used for visual distraction, as cognitive tasks develop over a longer time period. A five second long glance to send a text is a visual distraction. An engrossing five minute telephone conversation with a friend is a cognitive distraction.

Data Fusion

The multi distraction detection algorithm was modified for use in the NADS-1 simulator in the context of the NHTSA experiment. An expanded sensor suite was available for use in the study. In addition to the faceLab product, a commercial head tracker from Seeing Machines, called DSS, was installed. Finally, seat sensors were available to monitor driver weight shifts. These three sensors, along with simulator variables like vehicle speed, were fused to create a more robust algorithm.

The data fusion methodology was to use eye tracker signals for gaze rotation when the tracking was available. During bad tracking, the algorithm used the head tracker for a more general estimate of the driver's location of gaze. If neither the eye or head trackers were tracking, the seat sensors were evaluated to detect significant shifts in the seat to one side or the other. If a shift was detected, the gaze was classified as off-road. On the other hand, if no shift was detected then the algorithm was frozen until such time as one of the devices regained their tracking quality. This approach was helpful in the distraction scenarios that required the driver to turn their head around and look towards the back seat.

The MiniSim port only included the eye tracker portion of the algorithm, so the data fusion functionality was not needed. However, it is available to be used in future MiniSim sensor enhancements.

CONCLUSIONS AND FUTURE WORK

There are several potential benefits of adding an eye tracker to the MiniSim PC-based simulator. First, the MiniSim has been used in research studies; and the possibility to now incorporate eye tracking, either in a safety warning system or for data reduction and analysis, is quite attractive. For example, it is extremely useful to know when the operator looks at the instrument panel or mirrors; and the eye tracker can be configured with world models of these objects to detect glances in their direction.

Another application is driver education. NADS hosts driver safety classes for commercial fleets; and eye tracker data may be useful in rating performance and making specific suggestions for improvement. Similarly, there is great potential to incorporate eye tracker data into other training and simulation activities. Glance information could be useful post-drive in AARs, as well as to dynamically and adaptively add content during the drive.

Eye tracking on the MiniSim platform presents some different challenges when compared to the NADS-1 application. A smaller field-of-view (FOV) means that the driver's gaze will more often be completely off the display screens, and the researcher will be forced to interpret what this means.

In the future, the head position of the driver can be used to adjust the offset between the head position and the own vehicle cab, which currently is a static value. With a dynamic head position offset, the effect of motion parallax can be simulated, adding to the list of depth cues provided by the driving simulator [18]; thus increasing visual realism, and providing the driver with such abilities as looking *around* virtual mirrors. Moreover, identification of central field of view of the driver should make it possible for the visualization system to use aggressive and precise level-of-detail control of rendering content, taking advantage of the disparity of human visual acuity between foveal view and peripheral view [19].

Additionally, algorithm efforts for recent NADS-1 studies have been ported to the MiniSim. Current and recent algorithm work has been focused on distraction and drowsiness detection; and they may be useful for that purpose on the MiniSim as well. However, there is also interesting potential to adapt eye-based algorithms for training applications. Instead of using road center as the center of a gaze circle, some other area or object in the FOV could be used. Performance grading could depend on the driver spending a minimum of gaze percentage on specified gauges and locations in addition to attending safely to the road center during task training.

ACKNOWLEDGMENTS

The authors would like to acknowledge the helpful discussion and cooperation of Trent Victor at Volvo during the algorithm selection and implementation process. This work was partially funded under NHTSA contract DTNH22-06-D-00043, Task Order 0007.

REFERENCES

[1] D.L. Strayer, F.A. Drews, W.A. Johnston, 2003, "Cell Phone-Induced Failures of Visual Attention During Simulated Driving", *Journal of Experimental Psychology: Applied*, vol. 9(1), 23-32.

[2] T.W. Victor, J.L. Harbluk, J.A. Engström, 2005, "Sensitivity of Eye-Movement Measures to In-Vehicle Task Difficulty", *Transportation Research Part F:*

Traffic Psychology and Behaviour, vol. 8(2), 167-190

[3] A.T. Duchowski, 2007, *Eye Tracking Methodology*, Springer-Verlag, London, England, 185-186, 244.

[4] E.N. Mazzae, T.A. Ranney, G.S. Watson, J.A. Wightman, 2004, "Hand-Held or Hands-Free? The Effects of Wireless Phone Interface Type on Phone Task Performance and Driver Preference", *HFES Proceedings: Surface Transportation*, vol. 5, 2218-2222.

[5] D.C. Marshall, R.B. Wallace, J.C. Torner, M.B. Leeds, 2010, "Enhancing the Effectiveness of Safety Warning Systems for Older Drivers: Project Report", NHTSA Report DOT HS 811 417.

[6] J.D. Lee, D. Fiorentino, M.L. Reyes, T.L. Brown, O. Ahmad, J. Fell, N. Waard, R. Dufour, 2010, "Assessing the Feasibility of Vehicle-Based Sensors to Detect Alcohol Impairment", NHTSA Report DOT HS 811 358.

[7] L. Barr, S. Popkin, H. Howarth, 2009, "An Evaluation of Emerging Driver Fatigue Detection Measures and Technologies", FMCSA Final Report: FMCSA-RRR-09-005.

[8] P. Larsson and T.W. Victor, 2005, "Method and arrangement for interpreting a subject's head and eye activity", United States Patent Application Publication, Pub. No. US2005/0073136 A1.

[9] P. Larsson, 2003, *Automatic Visual Behavior Analysis*, Master's thesis: ISRN LITH-ISY-EX-3259-2002. Linköping University, Linköping, Sweden.

[10] R. Grace, V.E. Byrne, D.M. Bierman, J.M. Legrand, D. Gricourt, B.K. Davis, J.J. Steszewski, B. Carnahan, 1998, "A Drowsy Driver Detection System for Heavy Vehicles", *Proceedings 17th Digital Avionics Systems Conference*, vol. 2(I36), 1-8.

[11] A. Eskandarian, R. Sayed, P. Delaigue, J. Blum, A. Mortazavi, 2007, "Advanced Driver Fatigue Research", FMCSA Final Report: FMCSA-RRR-07-001.

[12] T.W. Victor, 2005, *Keeping Eye and Mind on the Road*, Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Social Sciences 9, Uppsala University, Uppsala, Sweden.

[13] Y. Liang, M.L. Reyes, J.D. Lee, 2007, "Real-Time Detection of Driver Cognitive Distraction Using Support Vector Machines", *IEEE Transactions on Intelligent Transportation Systems*, vol. 8(2), 340-350.

[14] B. Donmez, L.N. Boyle, J.D. Lee, 2008, "Mitigating driver distraction with retrospective and concurrent feedback", *Accident Analysis & Prevention*, vol. 40(2), 776-786.

[15] K. Kircher, A. Kircher, C. Ahlstrom, 2009, *Results of a field study on a driver distraction warning system*, VTI, Swedish National Road and Transport Research Institute, Linköping, Sweden.

[16] K. Kircher, A. Kircher, F. Claezon, 2009, *Distraction and drowsiness- a field study*, VTI, Swedish National Road and Transport Research Institute, Linköping, Sweden.

[17] L. Fletcher, A. Zelinsky, 2009, "Driver Inattention Detection Based on Eye Gaze Road Event Correlation", *The International Journal of Robotics Research*, vol. 28, 774-801.

[18] J.E. Cutting, 1997, "How the Eye Measures Reality and Virtual Reality" *Behavior Research Methods, Instruments, & Computers*, vol. 29(1), 27-36.

[19] W.S. Geisler and J.S. Perry, 2002, "Real-Time Simulation of Arbitrary Visual Fields", *Proceedings of the 2002 Symposium on Eye Tracking Research & Applications*, 83-87.