Driver monitoring system as Road Focus Reminder

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ABSTRACT

Human errors due to distraction are a direct cause or a contributing factor in a majority of vehicle crashes and impacts. Visual-manual secondary tasks are critical according to naturalistic driving studies. NHTSA’s recently proposed Design Guidelines with purpose to limit potential driver distraction from secondary, non-driving-related, visual-manual tasks performed on integrated electronic devices.

With external cameras and radars, some of the crashes caused by distraction can be mitigated or even avoided thanks to active safety functions. An attention sensor could increase the effectiveness of such systems and generate positive side effects. Moreover, such a sensor will be useful in future cars with partially or fully automated driving.

A prototype system for real-time measurement of driver visual attention has been developed by Autoliv. The sensor was installed in 10 vehicles by ÅF-Technology (ÅF) and Volvo Car Corporation (Volvo Cars), and used in everyday traffic. Drivers/users were Volvo Cars employees with a company car leasing contract. Cars were also equipped automatic emergency braking; adaptive cruise control and lane keep assist.

The overall aim of the project was to evaluate the possibility to influence the driver’s visual behavior toward a reduction of critically long glances away from the road. For this purpose a naturalistic driving study / Field operational test was carried out with an online warning alerting the driver if s/he was looking away from the roadway for too long. The experimental protocols used was within group ABA design, meaning data was collected in three phases, baseline, treatment and repeated baseline. This allows for testing the effect of warnings compared to no warnings, and a possibility to see if the effects of warnings persist after removal.

In addition to analysis of distraction warnings, uniquely broad naturalistic data about driver glance behavior has been collected. Data show great similarities to previous studies where video clips of driver collected in naturalistic settings have been manually annotated for eyes-off-road, indicating a basic level of validity.

It was shown that driver off road glance duration is dependent on among other things, driving speed, daylight, use of Adaptive Cruise Control (ACC), lead vehicle presence and weekend or weekday driving. There was also a tendency of reduced number of warnings when the distraction warning was active, compared to baseline performance.

KEY WORDS

Driver monitoring, Distraction, Active Safety, Automated Driving
INTRODUCTION

Human errors such as distraction are a contributing factor in a majority of vehicle crashes and impacts. According to Lee, Young and Regan (2009) driver distraction “is a diversion of attention away from activities critical for safe driving toward a competing activity”. In a review article of naturalistic driving studies, Dingus et al. [11] discussed the risk of near crashes and driver tasks. All tasks with higher odds ratio than 2 were visual-manual. Furthermore, most of the riskiest tasks required multiple steps to complete and required multiple glances away from the roadway.

Based on scientific evidence, NHTSA recently proposed a first phase voluntary Driver Distraction Guidelines to promote safety by discouraging the introduction of excessively distracting devices in vehicles. The NHTSA Guidelines recommend devices to be designed so that tasks can be completed by the driver while driving with glances away from the roadway of 2 seconds or less, and a cumulative time spent glancing away from the roadway of 12 seconds or less.

Active safety, enabled by forward looking cameras and radars [6, 7], will play a crucial role in reducing serious and fatal injuries. Insurance Institute of Highway Safety concluded in their status report July 3, 2012 [8] that automatic braking already significantly reduce crash claims. According to Strandroth et al [9] car occupant fatalities may be reduced by up to 50% from 2010 to 2020 given a high implementation of automatic braking, lane keep assist and electronic stability control (in combination with median barriers on rural roads etc).

Forward collision warning, automatic braking, lane departure warnings and lane keep assist address situations where the driver is inattentive to what’s happening in front of the car without actually knowing about the visual state of the driver. There are numerous reasons (e.g. adaptive settings, transitions to and from automated driving modes) to monitor not only the environment outside the car but also the driver. The driver can be monitored by information about braking or acceleration response or hands-on-steering wheel. The next step should be distraction sensors. Driver cameras in research vehicles have been used extensively in order to capture eye-blinking and gaze, [5, 10].

![Figure 1 A driver with, a) eyes on the road and, b) without eyes on the road](image)

In the current project, a camera was detecting whether the driver’s eyes were on or off the road, see Figure 1. This information was assessed and used to trigger a warning after prolonged visual driver distraction. The main objective was to evaluate the feasibility of anti-distraction warnings, based on an Eyes-On-Road sensor, by comparing baseline visual distraction to treatment (with anti-distraction warning) visual distraction. As a
remark, the Eyes-On-Road sensor is robust in nature and its output can be used to change the performance of other active safety systems such as forward collision warnings, lane keep assistance, or automatic emergency braking systems.

TECHNOLOGY

The concept for driver distraction warning, Driver Monitoring System (DMS) used in this study has been envisioned in the research community for some time. The DMS uses an infrared camera, and a computer vision algorithm identifies if the drivers’ gaze is directed towards the road ahead or elsewhere. The consecutive or cumulative eyes-off-road-time is recorded and when it reaches a critical level, e.g. 3 seconds, a distraction event is triggered/recorded, upon which the driver is notified with an audible and visual alert. Variations of this concept have been evaluated in short simulators studies. There has also been implementations and evaluations in instrumented cars \[3\] but usually over a limited time span. The current paper describes an effort to evaluate a distraction warning in a field setting over a somewhat extended period.

The road area for Eyes-on-road detection is defined as a rectangular\(^1\) area +/-10° to the left and right of a center line through the drivers’ seat, and +/-7° up and down from the horizon. (Figure 2) If the driver is looking inside this area, the eyes are classified as Eyes-on-road, if looking outside the area, the eyes are classified as Eye-off-road, thus providing a Boolean signal. The integral of this Boolean signal is the duration of the current eyes-off-road glance.

The EOR system is a vision system, consisting of a computer, a camera unit with an interface box, and two separate IR illumination modules\(^2\), (see Figure 3). The camera provides images for further image analysis in the software. It consists of further sub-components, housing, lens, filters, and imager. There are also a number of support and communication systems, for e.g. synchronization of light sources with the exposure time in the imager.

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\(^1\) In practice, the detection area takes on a more oval shape

\(^2\) Prototypes for the light sources were confirmed to comply with eye safety standard IEC-SS/EN62471 by laboratory tests performed at SP in Borås. SP report, MTk3P08460 issued 2014-01-07, (item Light source 4: Oslon 940 with 23°small reflectors 8 mm).
The EOR software is developed as a concept demonstrator by Autoliv Research. The general idea is to detect drivers’ eyes with a high degree of reliability and robustness, and from there classify whether or not the eyes are directed towards the road. Drivers’ eyes are detected by a combination of detection algorithms and tracking. The algorithm can detect and track two eyes independently. The location and size of each detected eye is logged along with other eye-related information.

METHODS

A field test of such a DMS system was performed with 13 drivers, over the course of 6 months. 10 company lease cars were equipped with the system for 6 months, to evaluate the effectiveness of a distraction warning. The study was designed as a within group repeated baseline (A-B-A) design. The first two months the system was collecting data silently (baseline phase), the following two months the warning was activated (treatment phase), and in the final two months the warning system was once again silent (baseline 2). The three periods—baseline, treatment and reset—were ten, eight and four weeks duration respectively. Distraction warning algorithms were active during all three phases, but HMI was only active during the treatment phase. The purpose of this design was to assess any behavioral changes from the distraction alert, and if such changes remained after the warning was removed. A simple HMI was developed and activated when the test fleet entered the treatment phase. Its purpose was to draw drivers’ attention back to the road when the system detected inattention. Data collected from the cars included normal kinematic parameters, (speed, acceleration, driver inputs etc.) as well as position and driver distraction state and eyelid opening from the EOR system.

Over the years many different distraction warning algorithms have been presented that usually were developed for a single hardware setup and tested only within a limited research project. Majority of published algorithms were never compared to alternative algorithms and are therefore of unknown value. Many algorithms rely on detailed information such as exact pitch/yaw gaze angle (and sometimes also head angle). In some cases a model of interior is used to assign different criteria based on what a driver could be looking at, for example “AttenD” algorithm [3]. These limitations significantly reduce the number of applicable warning algorithms that were feasible to adopt for EOR study with a limited binary eye state signal as the only algorithm input.

RESULTS

A crucial part of EOR sensor data analysis was data filtering and glance detection. On a sensor level, the output includes a binary On/Off-road signal for each eye as well as a number of signals that can be used for data quality estimates. The overall data filtering was very similar to the one used in the distraction warning.

For preliminary validation, data quality was compared to previously published datasets that have established characteristic glance distributions. In particular when compared to the distribution reported by Hada, [4] (see Figure 4) there is very good agreement with the EOR sensor data. It is important to consider that previous datasets typically were manually annotated from video and therefore:

- have less issues with noise in the data;
- may cover limited or different set of driving conditions;
- may have different definition of a glance start-stop compared to EOR sensor algorithm.
At aggregated level, the Eyes-On-Road sensor data appears to be suitable for relative comparisons and trend analysis. As the data is not verified on the per-glance level, it is not recommended to draw conclusions about the absolute values observed in the data.

Figure 4 Eye glance data from Hada, H. (1994) with an overlay from EOR dataset.

Off road glance duration speed dependence

Eyes-On-Road FOT provides sufficient amount of data to study speed dependence of eye glances. When filtered by speed in 10 km/h bins and using only daylight condition (very important to control for) the smallest amount of data for a histogram was always above 5000 glances and for speeds above 50 km/h there are at least 15000 glances used for distribution fitting and mean values.

Figure 5 Mean off road glance duration per vehicle speed.

Figure 5 shows how there is a clear trend for average off-road glance duration decrease as the speed increases. Notably at speeds under 20 km/h drivers are about 2 times more likely to have glances longer than 3 seconds away from road than at speeds > 90 km/h. Arguably, the speed 30 km/h is the lowest speed where glance durations are still comparable to durations of glances at high speeds. This observation is very important when glance behavior is compared without controlling for proportion of data at lower and higher speeds between conditions.

To evaluate the possibility to influence the driver’s visual behaviour toward a reduction of critically long glances away from the road the mean Eyes-off-road glance duration was observed. In the treatment condition a
reduction of mean glance duration was expected compared to the baseline conditions, but the results were quite the opposite with progressively longer off-road-glance durations as the study continued. This quite unexpected finding needs further investigation – is this representative for actual driver behavior or an artefact of unknown origin? Nevertheless, looking for the reduction of long glances off road to be visible on a global scale is probably to expect too much. Looking locally at data collected within the first minute following a warning event, having removed events with bad sensor diagnostics, the distributions are very similar across conditions.

![Figure 6](image.png)

*Figure 6 Mean duration of glances off-road in different conditions and two speed ranges (daylight only).*

**DISCUSSION**

This research aimed to evaluate the possibility to influence the driver’s visual behaviour toward a reduction of critically long glances away from the road. A global effect of warnings could not be found in glance duration data, but the data collected during the project is to our knowledge unique in the world in terms of the amount of reasonably good quality eye glance data from naturalistic driving. The collected data will be used in continued traffic safety research.

Some highlights:

- a machine vision based sensor for driver visual (in-) attention can be deployed in a vehicle and read driver attention status continuously in daily traffic situations
- the eyes off road glance distribution comparisons suggest very good match to previously published eye-glance data that was collected in similar situations but annotated manually.
- The collected dataset provides unique insights into driver glance behavior which will be presented in upcoming publications from the project partners.

Although there are some encouraging results regarding the effect of the distraction warning, the usefulness of a distraction alert is yet not conclusively determined. It may well be the case that the effect wears off quickly, or over an extended time, when the novelty of the distraction warning has worn off. Still, the driver attention status information can be used also for contextual adjustment of other driver support features (for example FCW & LKA systems), or for assessment of driver readiness to drive in automated driving transfers of control.
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