An Adaptive Driver Alert System Making Use of Implicit Sensing and Notification Techniques*

Gilbert Beyer[1], Gian Mario Bertolotti[2], Andrea Cristiani[2], and Shadi Al Dehni[1]

[1] Ludwig-Maximilians-University Munich,
Programming and Software Engineering,
Oettingenstr. 67, 80538 Munich, Germany
{gilbert.beyer,shadi.aldehni}@ifi.lmu.de
[2] Università di Pavia,
Dip. Informatica e Sistemistica,
Via Ferrata 1, 27100 Pavia, Italy
{andrea.cristiani,gianmario.bertolotti}@unipv.it

Abstract. In this paper we present an adaptive driver alert system that uses passive techniques for extracting psycho-physiological features from the user, and a head-up display actuator that hands preprocessed information about the driving behavior back to the user. The paper starts with background information on driver inattentiveness. That followed we present our conception of an adaptive loop with a view to improve the driver's attention. We give an overview on current research on sensor and actuator techniques that support our adaptation strategy attaining data about user drowsiness and distraction. Then we describe a suitable hardware and software solution for the proposed system, using a head-up display and vision-based sensor techniques. We close describing first tests of our system in the lab and road tests with a Ferrari car.

Keywords: driver assistance systems, sensor-actuator supported interaction, psycho-physiological sensing, computer vision, adaptive control, implicit interaction, adaptive user interfaces, head-up displays.

1 Introduction

Driver alert systems have the purpose to shift the driver's attention back to the driving task after being shifted away from it by an event, activity, object or person inside or outside the vehicle [1]. Driver distraction is one form of driver inattention. It can be either caused by the driver himself, by the vehicle condition, or from environmental factors like the traffic situation [2]. For user-centric adaptive sensor-actuator systems, distractions are of special interest, that whether derive from the driver's psycho-physiological state (such as fatigue or drowsiness) or manifest themselves in the long-term behavior and repeated reactions to distractions caused by secondary tasks or social situations (such as continuously looking away from the driving direction when conversing with the co-driver).

* This work has been partially sponsored by the EC project REFLECT, IST-2007-215893.

P. Sénac, M. Ott, and A. Seneviratne (Eds.): MobiQuitous 2010, LNICST 73, pp. 417–424, 2012.

According to official statistics, car drivers' fatigue is one of the causes of roughly 1% serious accidents. Anyway, it is presumable that the real number is even higher, since in this kind of analysis it is often impossible to determine the effective cause of the crash. Some European studies say that 24-33% of fatal crashes are due to driver's fatigue [3,4]. In the United States about 100000 accidents are caused by drivers falling asleep [5]. Distractions caused by the driver's behavior or by persistent external influences are another important cause of crashes. Examples for such distractions are searching an object under the seat, adjusting the car stereo or all kinds of passenger-related distractions [6,7]. The NHTSA reports that driver distraction is the cause of 40% of accidents in which involved cars go off road.

The given examples show that, in order to increase the safety of the driver and the passengers, systems which also monitor such long-term distractions would be useful. We here propose an adaptive driver alert system dealing with such problems making use of implicit sensing and notification techniques.

2 Design of an Adaptive Driver Alert System

The system we propose monitors persistent or long-term distractions, to be able to react in an anticipatory way and notify the driver gradually and in a gentle way before the driving situation even gets critical. In the following we first describe the overall adaptation idea of our system, and then deduce the requirements of sensors and actuators that can realize such an adaptive driver alert system.

2.1 Adaptation Strategy

Our basic idea is a feedback loop where the level of driver's distraction is attained by measuring indicators such as drowsiness and eyes-off-the-road time with the help of vision sensors, and is regulated by implicit visual actuators in the viewing direction. Implicit feedback means in this regard, that the feedback is given long-term: If the driver has continuously shown signs of drowsiness or distraction over a certain time period, he is given a visual notification of his long-term behavior. According to [2], every modality (vision, hearing, touch) has its own temporal behavior, and we propose that for long-term notification unobtrusive visual information in the viewing direction is most suitable.

On the sensing side, with regard to the long-term feedback visualization that we propose, the analysis of properties is of special interest that are not indicating immediate but gradually increasing driver distraction. In this work we focus on drowsiness (eyes-closed time and frequency) and distractions caused by secondary tasks or social situations in the car, that express themselves in repeatedly looking away from the driving direction (eyes-off-the-road time and frequency). The eyes-closed time is attained via an accordant algorithm, and for the eyes-off-the-road time we currently use the head position of the driver.

In a further step we combine this data on the user state with information on the car state. The purpose of such a combination shall be explained by the information value of the head position recognition: Looking right to the co-driver while driving fast on a curvy country-road can be classified as risky behavior, while looking right while waiting at a crossing is allowed (or may even be required, e.g. before turning into a road). To determine the car state, telemetry data such as velocity, lateral and longitudinal acceleration are taken from the CAN-Bus. An accordant analysis component combines this telemetry data and the psycho-physiological data of the user state, producing new decisions about the driver's behavior. The output of the combined states is visualized by an appropriate visualization in the driving direction.

2.2 Sensor-Actuator Support of the System

For the long-term visual actuator we propose to use a head-up display. The term head-up display (HUD) usually describes a transparent display that presents information without requiring the user to look away from his usual viewpoint. This viewing situation is innate to activities where an essential primary task requires the full attention of the viewer, like the driving task where user is required to look most of the time on the road, to not miss critical events in the driving environment.

The basic idea behind our adaptive head-up display actuator is a transparent windshield visualization that adapts to the combined user-car state. The feedback on the driver is then carried out by presenting implicit information in the viewing direction. In contrast to explicit, attention-grabbing warnings this information should be unobtrusive, consisting of rather ambient, continuously changing visualizations at the bottom of the windshield. Once the driver has understood the meanings of these ambient visualizations, they should influence his situational awareness and bring him to adapt his driving style accordingly.

On the sensor side, we decided to use cameras, as vision-based techniques operate non-invasively and support unobtrusive, implicit interaction. In last years many works have dealt with the development of car safety systems that employ sensor technologies that are "intrusive". For example to detect the vigilance level of drivers, mostly physical sensors or electrodes are used that must be positioned on the body of the subjects to attain the needed information (e.g. electromyogram, respiration, skin conductance monitoring, electro-oculography). Electro-oculography (EOG) has been used to study spontaneous eyelid closure, providing a series of interesting parameters that can be taken as indicators in fatigue diagnostics and in drowsiness detection [8]. Although techniques like EOG provide very detailed information about one's vigilance level, they could hardly be used in real systems, since they are intrusive, and not easily performed in a non-laboratory environment. Recent studies have shown that also non-intrusive techniques can be used to extract information related to drivers' vigilance level. Video-cameras and image elaboration algorithms, for example, are now broadly used to detect the face and the eyes of a subject, in order to detect driver's inattention [9]. The analysis of drivers' behavior, through the elaboration of car telemetry data, is another technique which can give important clues about pilot's vigilance level. Experiments conducted in simulated environments showed, for example, the existence of a relationship between drowsiness and driving "errors".

3 Related Work

In literature, a number of papers describe camera-based systems for detecting driver's inattention. Most of reported results show very good performances while tests are performed in simulated conditions or in laboratory environments (see [10] as an example). Few of presented systems have been tested in real vehicles.

While dealing with the study of driver vigilance level, it is important to mention the AWAKE project (System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation) [4], since it is probably the main reference for researches in this field. They proposed a multi-sensor approach to the problem, since the system monitors eyelid closures through a camera, and it also acquires information from a steering grip sensor, a lane tracking sensor. Furthermore gas/brake and steering wheel signals are used as indicators of the driver behavior. To close the loop, a "Driver Warning System" is used to warn the driver through visual and haptic means according to the type of AWAKE warning. In this case, visual elements are located at an external box on top of the dashboard or at the rear view mirror. Other works suggest that visual information or alarms are provided to the driver by means of HUDs, allowing him to keep his eyes on the road [11]. There already have been proposals for adaptive HUDs in automobiles that visualize the state of the car or that adapt the amount of items to be displayed by only showing the most useful information at any time [12,13]. Yet these works did neither deliver detailed answers on how such feedback information should be presented, nor what kind of data should be processed for that purpose.

4 Hardware Prototype

The proposed hardware solution consists of a web camera as sensor device and a head-up display as implicit information device. The camera is installed near the viewing direction of the driver to get optimal image details of the required facial features. Several positions were evaluated, and the position behind the steering wheel was figured out as the most applicable as it doesn't constrain the driver's view on the road (see Fig. 1a). For the head-up display a hardware solution was designed that fits the demands of the cockpit of our test car, a Ferrari California. To physically integrate the adaptive HUD, an additional device had to be designed. Display technologies that can be used in HUD systems include different kinds of emissive displays (e.g. LED) or backlit LCDs, that reflect the screen image towards the windshield or special transparent reflective surfaces attached to the windshield. The first idea was to use such flat panel screens, but the available products showed hardly to fit into the narrow space between the windshield and the dashboard of the Ferrari. Other problems were low brightness and the presence of backlight glow in the reflected image. Another

Fig. 1. a, Camera sensor position behind the steering wheel. b, Head-up display projection hardware below the windshield. c, Icon for visualizing the eyes-off-the-road state.

idea was to use a micro projector and let it beam directly onto a reflective surface attached to the windshield, but here the driver could be blinded by the direct light of the beamer lens. The best solution showed to be a setup where the projector beams the light through a channel (to prevent backlight reflections) towards a highly reflective surface that in turn reflects the image towards the windshield (see Fig. 1b and 1c).

5 Implicit Sensing Software

This section describes the algorithms that have been developed in order to detect potentially dangerous situations related to drowsiness and distraction while driving. They use image elaboration techniques to detect and measure the duration of driver's eye blinks and to monitor his head position.

5.1 Drowsiness Detection

We developed an algorithm which combines the Viola-Jones [14] and the template-matching techniques to track one eye of the subject. At the beginning, the first technique is used in order to identify the driver's face within the acquired frames, defining a rectangular area which contains it. That area becomes the region of interest inside of which the eyes will be searched for. To reduce the computational load, only the right eye is tracked. Once again, the Viola-Jones algorithm is used to identify a rectangular region enclosing the eye. Then, an area A centered on the eye position previously found and double-size with respect to the eye rectangle is defined (Fig. 2).

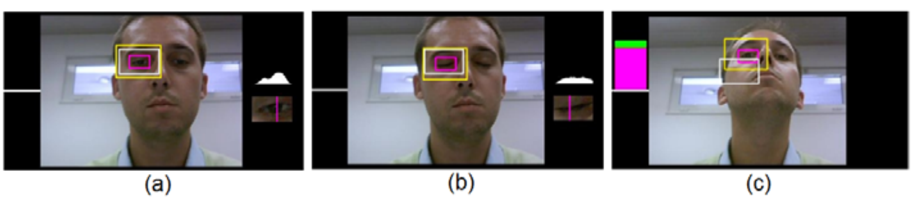

Fig. 2. The A area (delimited by the largest rectangle) is the region of interest in which a combination of Viola-Jones and template-matching techniques is used to detect driver's eye. In (a) subject's right eye is found (smallest rectangle); in (b) an eye blink is correctly identified; in (c) the algorithm detects that the subject has moved his head up with respect to previous frame.

The Viola-Jones algorithm is applied to A: if the eye is found, then a copy of it is saved and used as a template; if not, a template-matching technique is used, basing on last saved template. If a certain number of wrong matchings occur, then a re-initialization procedure is performed. Subsequently, the eye image is converted to grayscale and thresholded, obtaining a binary picture. The latter is further processed to eliminate the gaps generated by pupil reflections and to reduce the noise due to shadows or portions of eyebrows. The vertical projection histogram of the resulting image is then elaborated to determine the pupil's position and the eye openness level. An eye which remains closed for more than a pre-defined amount of time (which is about 500 ms) is considered as an indicator of possible drowsiness (the driver could be falling asleep). If this event occurs frequently, the system gives the driver a visual notification in form of an icon on the head-up display. Only if the driver is closing his eyes for a critical period (e.g. 1s) the system will react by giving a proper audio alarm.

5.2 Head-Position Detection

The eye test described in the previous subsection is made only when the face of the driver is about still and directed forward. The identification of this "rest" posture is performed by averaging the eye location over last n frames. Then, the eye status test is performed on a region which is centered in this location. Vertical and lateral positions of the eye within this region give an indication of how much the pilot's head is tilted and turned. This information is used to assess the driver's level of attention: if his head is up/down or left/right turned, the system assumes that he is not paying attention to the street (e.g. when being distracted by a passenger). If this event occurs frequently, the system gives the driver a visual notification in form of an icon on the head-up display that gradually inclines in brightness (see Fig. 1c). Only if the driver looks away for a critical amount of time, i.e. his head is up/down or left/right turned for more than a pre-defined time-out, the gentle visual information will be intensified by an immediate audio warning by the car speakers.

6 Experiments and User Analysis

Three kinds of experiments have been carried out in order to test the adaptive driver alert system. Tests to evaluate performances of implicit sensing algorithms are described in subsection 6.1. Driver observations in a simulated driving environment and testing sessions of the adaptive head-up display on a Ferrari California are reported in subsection 6.2.

6.1 Passive Sensing Performance Tests

The performance of our passive sensing algorithms has been tested in two different environments: a laboratory room, and the Ferrari California car. During the experiments, performed in daylight conditions except for the lab environment (which was lighted only by a fluorescent light), the tester, a 25 years old male, was asked to "behave normally" while driving the car or while sitting at a desk, in front of a PC screen. A Hercules Classic Silver USB web-camera (maximum 30 fps, resolution 640 x 480) was connected to a Dell Vostro 1310 notebook (Intel® Core 2 Duo T8100 (2.1GHz), 2GB RAM, NVIDIA GeForce 8400M GS, Windows XP™). Our preliminary tests focused on the recognition of slow/fast blinks and the accuracy of tracking of slow/fast head movements. Slow blinks were correctly identified in 99.1% (room) and 98.3% of cases (in the Ferrari California car), while fast blinks were clearly detected in 98.6% (room) and in 97.3% of cases (in the Ferrari California car). Slow head movements were correctly detected and tracked in 99.7% (room) and in 99.0% of cases (in the Ferrari California car), while fast head movements were correctly identified and tracked in 96.1% (room) and in 96.0% of cases (in the Ferrari California car).

Results showed different kinds of errors: the tracking is not performed correctly in successive frames; shadows or occlusions hamper the eye/face detection; blinks are not recognized; particular head positions cause erroneously detected blinks. Performed tests are just preliminary; nevertheless, obtained results are promising and further experiments (with more testers, lighting conditions) are already planned.

6.2 Driver Observations in the Lab and Driving Tests at Ferrari

To develop our adaptive sensor-actuator solution and to be able to perform preliminary user tests in the lab, a driving simulator was build. This driving simulator consists of two seats, a steering wheel mounted to a console, a plasma display to visualize a driving simulation, and a web camera connected through USB to obtain psycho-physiological data from test persons (see Fig. 3a). To obtain telemetry data that we later get in road tests from the CAN-Bus of the car, we used and adapted a suitable driving simulation [15]. With the driving simulator we performed first user tests. Therefore we invited employees and students to the lab and let them perform test runs that confronted them with route sections of different degrees of difficulty and demands for attentiveness. These tests showed that test persons in most cases adapted their driving behavior according to the adaptive visualizations.

The adaptive head-up display could be tested and refined during an onboard installation and testing session on a Ferrari California. The in-car version of the HUD was installed at an applicable position below the windshield. Several test runs were conducted with a professional test driver, and the driver was surveyed during and after the test runs on the quality of perception of the icons during different driving and lighting conditions. These tests produced significant findings that poured in the refinement of the hardware, the improvement of the HUD position and the visual representation. For practical and security reasons however, we were not able to conduct realistic user tests on drowsiness in the lab and during test drives.

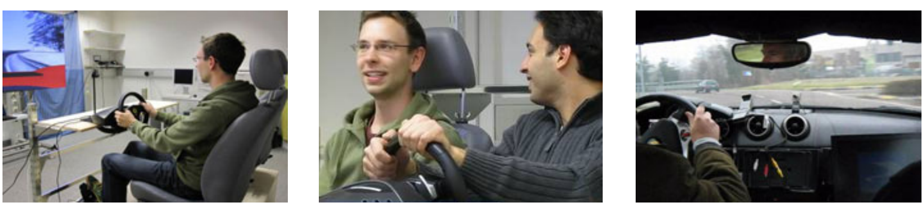

Fig. 3. a, Driving simulator with camera sensor. b, User tests in the lab. c, Testing of the adaptive head-up display in the Ferrari car.

7 Prospects and Future Work

In this paper we presented an adaptive driver alert system making use of passive, camera-based sensor techniques and implicit windshield visualizations. We presented the overall concept of our adaptive loop, hardware solutions to realize an unobtrusive loop on the sensor and the actuator side, and software algorithms that can measure the required features of user inattentiveness. We deployed a prototype system and observed users in a lab environment as well as during tests on the road.

These first tests with our prototype show that the overall concept of our adaptive driver alert system works quite well, properly detecting potentially dangerous driving behaviors and making the driver aware of them through gentle alert signals.

A field study of the prototype will be the next step in investigating the properties of the system. Moreover, we'll test our implicit sensing software with a nightvision webcam, in order to make our adaptive driver alert system efficient also during nighttime.

References

1. Treat, J.R.: A study of precrash factors involv. in traffic acc. HSRI, Research Rev.10 (1980)
2. Riener, A.: Sensor-Actuator Supported Implicit Interaction in Driver Assistance Systems. Vieweg+Teubner Verlag, Wiesbaden (2010)
3. Streff, F., Spradlin, H.: Driver distraction, aggression, and fatigue: a synthesis of the literature and guidelines for Michigan planning. Ann Arbor 1001, 48109 (2000)
4. A.C. (IST 2000-28062): Awake-system for effective assessment of driver vigilance and warning according to traffic risk estimation (September 2001-2004)
5. Bergasa, L., Nuevo, J., Sotelo, M., Barea, R., Lopez, M.: Real-time system for monitoring driver vigilance. IEEE Trans. on Intell. Transp. Systems 7(1), 63–77 (2006)
6. Stutts, J., Feaganes, J., Reinfurt, D., Rodgman, E., Hamlett, C., Gish, K., Staplin, L.: Driver's exposure to distractions in their natural driving environment. Accident Analysis and Prevention 37(6), 1093–1101 (2005)
7. Sheridan, T.: Driver distraction from a control theory perspective. Human Factors 46(4), 587 (2004)
8. Ingre, M., Åkerstedt, T., Peters, B., Anund, A., Kecklund, G.: Subjective sleepiness, simulated driving performance and blink duration: examining individual differences. Journal of Sleep Research 15(1), 47–53 (2006)
9. Bergasa, L., Buenaposada, J., Nuevo, J., Jimenez, P., Baumela, L.: Analysing Driver's Attention Level using Computer Vision. In: ITSC 2008, pp. 1149–1154 (2008)
10. Ji, Q., Yang, X.: Real-time eye, gaze, and face pose tracking for monitoring driver vigilance. Real-Time Imaging 8(5), 357–377 (2002)
11. Karvonen, H., Kujala, T., Saariluoma, P.: In-Car Ubiquitous Computing: Driver Tutoring Messages Presented on a Head-Up Display. In: Ikeda, M., Ashley, K.D., Chan, T.-W. (eds.) ITS 2006. LNCS, vol. 4053, pp. 560–565. Springer, Heidelberg (2006)
12. Dienelt, M.: Adaptive Informationsdarstellung für ein Head-Up Display. In: Stary, C. (ed.) Mensch & Computer 2005, pp. 1148–1158. Oldenbourg Verlag, München (2005)
13. Blanco, V., Goldthwaite, F., Baumert, D.: Adaptive heads-up user interface for automobile (2007), http://assignments.uspto.gov/assignments/q?db=pat&pub=20070194902
14. Viola, P., Jones, M.J.: Rapid Object Detection using a Boosted Cascade of Simple Features. In: IEEE Computer Society Conf. on Computer Vision and Pattern Recog., vol. 1 (2001)
15. Wymann, B.: TORCS, The open racing car simulator (2010), http://torcs.sourceforge.net/