DEVELOPMENT OF A DRIVER SITUATION ASSESSMENT MODULE IN THE AIDE PROJECT

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Abstract: The Driver Situation Assessment module developed in the EU-funded FP6 integrated project AIDE (Adaptive Integrated Driver-vehicle Interface), provides a real time diagnosis of a number of driver parameters in order to enable different adaptive driver-vehicle interface functions. It is composed by: (1) The Driver Characteristics Module that personalises the HMI of in-vehicle ADAS/IVIS, according to driver static characteristics, the context of and his/her preferences and residual abilities, (2) the Driver State Degradation Module that evaluates the evolution of the driver's drowsiness, (3) the Cockpit Activity Assessment Module, focused on secondary task activities, that monitors aspects of the driver's activity and (4) the Driver Availability Estimator that assesses the driver's "level of availability" to receive and process information, according to the requirements of the current driving task.

Keywords: ADAS, Feature Extraction, Hypovigilance, Driver Behavior, Driver Profile Personalization, Intelligent Agents

1. INTRODUCTION

Drivers are faced to an increasing information flow provided by an increasing number of on-board functions (not only related to the driving task) and in a near future of the massive introduction of driver assistance systems (navigation systems have opened the door). On the other hand the driver is not always in good situation to receive and understand the messages that are given to him by the vehicle/system. Major reasons are his current status: physiological state (tired, absent minded …), his profile (young/old, long driving experience …); But also to a complex traffic environment that requires all his attention, and sometimes to external non traffic related solicitations as for example advertisement on the road. In this context several questions need to be answered: how to avoid the driver overloading by a "disparate" information flow? What information should be delivered, when and how? How to avoid interference between different pieces of information? And, on an even more general level, how to avoid the negative impact of these information sources on the driving task?

As an "Adaptive" and "Integrative" information manager, AIDE should contribute to solve these problems by implementing a set of adaptive interface functions. These could include, for example, delaying non-critical information in demanding driving situations and adapting the timing and intensity of warnings to the driver state and/or characteristics.

In the proposed AIDE architecture, the control of the adaptive interface functions is centralised to the so called Adaptive Interface Module (AIM), containing the ICA (Interaction and Communication Assistant) function. Two primary modules have been defined with the purpose of computing in real time a set of parameters needed for enabling the AIDE adaptive interface functions: The Traffic and Environment

Risk Assessment module (TERA) and the Driver Situation Assessment (DSA) module. The TERA monitors and measures activities both inside and outside the vehicle in order to assess the external contributors to the environmental and traffic context. This module is further described in (Polycronopoulos, *et al,* 2005).

The focus of the present paper is the Driver Situation Assessment (DSA) module. The role of this module is to provide the AIM with real-time information on driver characteristics, state and activity.

2. DSA ARCHITECTURE

DSA module functional architecture (see figure 1) comprises the following sub-modules:

- The Driver Characteristics (DC) module
- The Driver State Degradation (DSD) module
- The Cockpit Activity Assessment (CAA) module
- The Driver Availability Estimator (DAE) module

The input of these modules will be provided by a shared sensor array. All these sensors already exist as prototypes or products. Nevertheless some adaptations and specific processing (algorithms and software developments) will be necessary to take into account the specificity of the application. The outputs of the sub-modules are fused and a DSA set of criteria is estimated in real time. This value could be also a matrix of values that could be also changed dynamically. The outputs of the different units will be also available separately.

In the remainder of the paper, the DSA sub-modules are described in further detail.

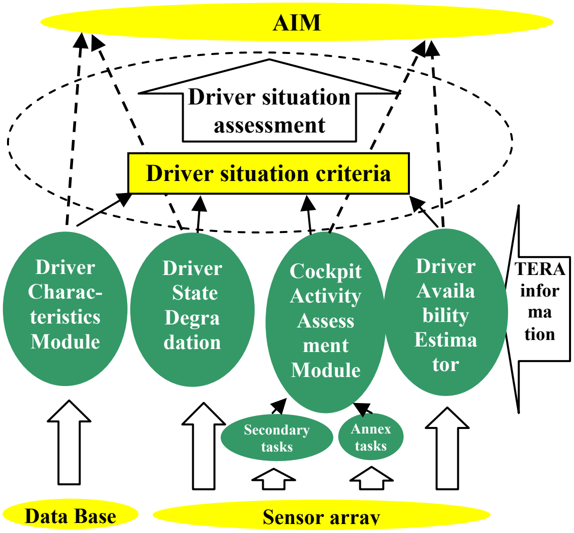

Fig.1: DSA functional architecture

3. DRIVER CHARACTERISTICS MODULE

The aim of this module is to personalise the HMI of a car based on the driver's unique characteristics and preferences. The Java Agent Development framework (*JADE)*, will be the basis for building the DCM. The driving ability is not static but evolves dynamically, according to many parameters, as skills, workload, psychological factors, etc. as defined in the DRIVABILITY driver behaviour model theory (Bekiaris, *et al*, 2003). Thus, real-time monitoring is needed, as many parameters change from day to day. Intelligent Agents are used for the learning and personalisation of the driver behaviour and preferences. JAVA is the appropriate programming language for Intelligent Agents development and suitable for graphical user interface applications.

Initially, a User's Profile Configuration Agent will support different "types of users". The user him/herself will chose his/her type, residual abilities and preferences regarding posture, interface elements, etc. A user-friendly and cost-effective, in-vehicle interface for input of this profile by the user will be also developed.

A Customisation Agent will monitor the user's driving behaviour and preferences / actions, by keeping and processing the user's driving habits, i.e. average lateral position in the lane, average headway, typical speeding and braking pattern, preferred seating position, average use of radio and mobile phone, other services, like navigation, requested often, etc. This Agent will help to predict user needs that are not explicitly mentioned (i.e. long reaction times) and based upon stochastic algorithms, will evolve with the user.

The user profile is divided in three possible types: the static, the semi-dynamic and the dynamic ones. Consequently, the requirements for input parameters that will compose the module are divided in the same categories. Examples of each profile type include the driving experience, language, etc. for the static profile, type of user (tourist, commuter, etc.) for the semi-dynamic and finally, driver habit (TTC, TLC, etc.) for the dynamic one. A simple database is not sufficient, as dynamic parameters such as reaction time, cannot be known by the user but must be calculated by the system and also, are individual-based, i.e. different per driver, even for drivers of the same age and experience.

Furthermore, software development will enable smart card data acquisition and storage of a driver, to be used also in other equipped cars.

4. DRIVER STATE DEGRADATION MODULE

4.1 General context and state of the Art

The objective of the DSD module as part of the general AIDE system is to monitor Driver vigilance state degradation and more specifically "asleep at wheel" situations. The DSD is based on multi-sensorial approach combining information from different sources and natures (Santana et al, 2003).

4.2 General concept

The DSD module includes several levels (figure 2). The sensing level includes various sensors and their associate processing units, (i.e. image processing).

- The Data pre-processing level that extracts pertinent parameters and discriminate information from the various measurements provided by the sensing level.
- The diagnosis unit(s), that estimates and provides the evolution of the driver state.

4.3 The sensor level

Sensor level includes existing on-board sensors, and/or dedicated non-intrusive sensors prototypes (i.e. Eyelid sensor). In addition Additional information to assess driver physiological state should be addressed. This information should be extracted from existing sensors currently dedicated to other applications (see Table 1).

	Functionality	Sensor or subsystem	Diagnostic
Vehicle behavioural information	Vehicle lateral position, time to lane crossing and lane tracking	Lane tracking system based on vision machine	Behavioural diagnostic
	Vehicle longitudinal control TTC	ACC system based on radar or lidar technology	
Driver behavioural information	Driver behaviour	Steering wheel angle	
	Driver postures and attitudes, driver activities in relation with driver state degradation	Vision machine and foil sensing devices integrated in the seat	Physiological diagnostic
Physiological information	Eyelid movement	Eyelid sensor, based on vision machine	

Table 1: Sensor/subsystems required for driver status understanding and modelling

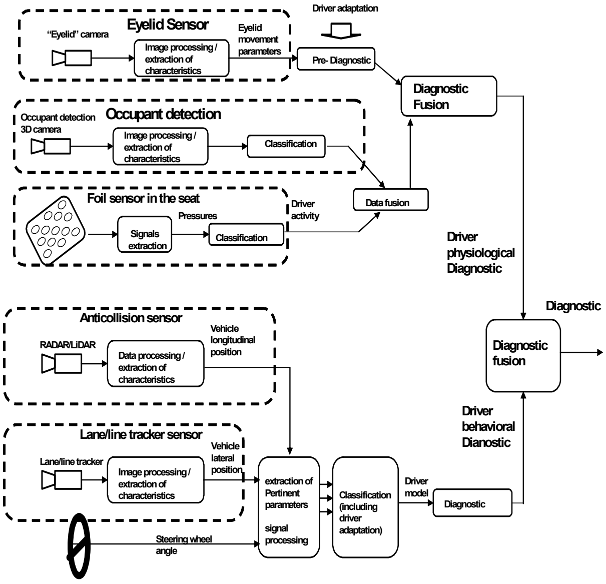

Fig. 2: Driver monitoring system Detailed architecture

4.4 The Data pre-processing and the diagnostic

The Data Pre-Processing "feature extraction", is really fundamental. Because loosely informed composite signals would definitely lead to a bad diagnostic whatever the discrimination module one can use. Feature extraction is usually not easy. Various things, but mainly intuition may guide it. The classical process to achieve this task is first to start with a well representative database (with a sufficient quantity of observations from the different classes). Secondly, various treatments may be applied on these data also based on intuitive and/or logical ideas: classical statistic, signal processing, frequency analysis, energy distribution, time-frequency analysis, and so on.

From the parameters issued from the pre-processing two diagnostic are performed: a physiological diagnostic and a behavioural diagnostic that are then fused to provide an evaluation of the driver's state level degradation.

- Feature extraction for driver physiological state assessment is mainly concerned with blink detection and eyelid closure time (duration, frequency). The diagnosis is based on the occurrence of long blink (over 300 ms) and eye closure (over 500 ms).
- Feature extraction for driver behavioural state assessment is mainly based on a statistical analysis of the signals and on the use of driver's "Correction Time" in order to characterize his/her vigilance state. The idea behind this "Correction time" is to use both the lateral position signal and the steering wheel angle signal in order to compute the time between a change in the lateral position and the reaction of the driver moving its steering wheel. In addition parameters related with vehicle longitudinal control like Time to Collision can also be used. A behavioral diagnostic is issued from by classifying this information

One of a basic assumption of this multi-sensorial approach was that the fusion of each stand alone diagnostic, would improve drastically the final diagnosis. In consequence each individual diagnostic should be able to guarantee a very low false alarm rate (high specificity rate) even if it cannot reach a low non-detection rate (high sensitivity rate). Then the basic principle of the diagnostic fusion is to use a logic "OR" aggregation to maximize the detection rate. Each stand-alone diagnosis delivers a three levels hypovigilance diagnosis:

- Level 0 means that the driver is alert
- Level 1 means that the driver is hypovigilant or DROWSY
- Level 2 means that the driver is strongly hypovigilant, this state is called SLEEPY.

In addition the output is set to -1 when the diagnosis is not available. Based on the global "OR" fusion rule 5 rules were derived (Table 2).

	Unavailable	Alert	Drowsy	Sleepy
Unavailable	Ok	Ok	Drowsy	Drowsy
Alert	Ok	Ok	undefined	Drowsy
Drowsy	Drowsy	undefined	Drowsy	Drowsy
Sleepy	Drowsy	Drowsy	Drowsy	Drowsy

Table 2: Diagnostic fusion:

Rule 1: if one of the diagnoses is 2 a drowsy situation is detected.

Rule 2: if only one diagnosis is available, the output is defined by the valid diagnosis.
Rule 3: If one diagnostic is DROWSY and the other ALERT, the output is UNDEFINED.
Rule 4(5): If the 2 diagnostics are DROWSY (ALERT) the output is DROWSY (Ok).

5. COOKPIT ACTIVITY ASSESSMENT MODULE

5.1 Objective

The objective of the CAAM (Cockpit Activity Assessment Module), as part of the general AIDE system, is to monitor aspects of the driver's activity that are relevant for adaptive interface functions to be implemented in the AIM module. The CAAM focuses on secondary task activities, and could this be viewed as a complement to the DAE module, which focuses on primary task aspects.

The aspects of driver activity to be monitored will be determined by the adaptive interface functions that CAAM is intended to support. Moreover, if the AIDE project, the specification of the adaptive functions is still underway, so the exact requirements of the CAAM are yet to be determined. However, some potential adaptive functions supported by the CAAM could still be envisioned at the present stage:

Adaptation of warnings: When the driver is engaged in a secondary task, warnings (e.g. forward collision and lane departure warnings) are given earlier and/or with higher intensity. If the driver's activity (e.g. mirror checking behaviour) indicates that (s)he intends to change lane, warnings may be adapted accordingly (e.g. lane departure warnings may be disabled).

Task scheduling: If an application wants to present a very-low-priority message while the driver is performing some other activity, the message could be delayed until the driver has finished the task.

Gaze-contingent displays: Displays (and other HMI I/O devices) could change their appearance and content if frequently used/looked at.

The realisation of these types of adaptive functions will require different parameter outputs from the CAAM. Some of these parameters could also potentially be used as input to other modules. The following section describes the CAAM output parameters currently envisioned, and the general methods proposed to compute them.

5.2 CAAM output

In-vehicle activities may be broadly categorised into (1) visual and (2) cognitive (although, in practice, purely visual tasks are probably rare). Visual activity is indicative of non-driving-related (or secondary-) tasks such as operating the radio, keeping an eye on children in the back seat and looking at commercial signs on the road side, but also driving-related tasks such keeping track of surrounding traffic and looking for road signs. The detection of visual activity can naturally be achieved on the basis of eye- and/or head movement patterns. Tasks not requiring visual activity, e.g. talking to passengers or on the mobile phone, operating an in-vehicle system through a voice- or haptic interface, thinking or daydreaming, may still induce cognitive activity. Although the detection of cognitive activity is not as straightforward as for visual activities, it is clearly feasible, as further described below.

Visual activity: Several visual activity parameters could be relevant for adaptive interface functions. Perhaps the most straightforward measure is the gaze direction, which simply represents the momentary gaze angle. This could be mapped onto world model in order to identify the real-world areas where the driver is looking (the point of regard).

For some adaptive applications, a measure of the portion over time that visual attention is directed away from the road centre can be useful. One way to compute a short-time frame measure of average visual distraction is by means of the Percent Road Centre (PRC) measure (Victor and Johansson, in preparation). PRC represents the proportion of glance time spent towards the road centre region, and is based on identification and modelling of the road centre gaze cluster.

Visual scan patterns, together with acceleration and steering patterns, may also be used to infer the intent of the driver, e.g. to perform manoeuvres such as lane change or overtaking. To this end, sequences of mirror/road glances, accelerations and steering manoeuvres could be modelled statistically, e.g. by Hidden Markov Models. (Oliver, 2000) for an example of previous work in this area. This work will be done in close collaboration with the TERA development (see Polycronopoulos, *et al.*,2005).

Cognitive activity: In experimental work, effects of cognitively loading activities are commonly measured by some type of event detection metric. However, for obvious reasons, these metrics are not feasible for the real-time applications considered here. As indicated by much recent research, cognitive workload, also leaves other distinct behavioural signatures, in particular increased gaze concentration towards the road centre (Recarte and Nunes, 2003; Östlund, *et al.*; 2004), reduced lane position variation (Östlund, *et al.*, 2004) and increased number of small corrective steering wheel movements (Boer, 2000). These parameters can be measured unintrusively and computed in real time. An example of data illustrating the gaze concentration effect, based on data collected at VTEC (Victor and Johansson, in preparation), is given in Figure 3.

The gaze concentration effect could be quantified online by the PRC measure mentioned above (where the PRC value is expected to increase during periods of cognitive load), although other metrics are also possible (e.g. standard deviation of gaze angle). The ocular analysis will be complemented by analysis of steering micro corrections and lane position variation. The result from these analyses will be weighted together, possibly by statistical techniques, in order to obtain the final cognitive workload measure. Alternative ocular metrics of cognitive and visual distraction will also be considered.

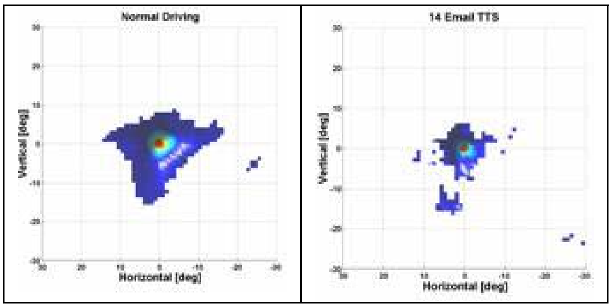

Fig. 3: Spatial density plots for gaze data during baseline driving (no task, left) compared to a cognitively loading condition (listening to an email message read by text-to-speak, right), adopted from Victor and Johansson (in preparation).

5.3 CAAM sensor input

The computation of the output parameters described above will make use of a number of different sensor inputs. The main sensor to be used is an unintrusive camera based system that measures 3D eye- and head movements in real time. For examples of existing systems of this type, Seeing Machines (Longhurst 2002) and Smart Eye (Smart Eye 2004). However, other information available from the common AIDE sensor array will be used as well, e.g. steering wheel- and lane position data, microphone and HMI input (e.g. button presses). Moreover, input from other modules may be used, e.g. traffic situation assessment from the TERA (Traffic and Environment Risk Assessment).

6. DRIVER AVAILABILITY ESTIMATOR

6.1 Objectives

The aim of this module is to assess the driver's "level of availability" to receive and process information, according to the requirements of the current driving task (i.e. road infrastructure of the moment, goal followed at this time, current driving actions carried out). This module will be focused on the analysis of the primary task activities (i.e. driver's actions on vehicle controls). Previous works done in CEMVOCAS EU-project (Bellet, *et al,.* 2002) had shown that it's possible to partly assess the driver's availability level by considering data coming from "basic" sensors which reflect the driver's actions on vehicle controls (e.g. pedals, steering wheel, blinkers, etc) and the dynamics of the car (e.g. vehicle speed). After this project, new diagnosis algorithms has been developed in order to have a more robust and a more "rational" technology using a more logic approach (based on segmentation trees and decision rules). It is now more easy to integrate new parameters in order to increase the quality of the "availability" diagnosis (i.e. robustify good diagnosis and test solutions for correcting errors).

The aim of the present work is to continue the development of these rule-based algorithms and to increase its performances by using new sensors providing information on current driving situation. Three main kinds of sensors and data seem more particularly relevant:

- Cartographic data (by using a standard Data Base of a navigation system) for positioning vehicle and knowing the driving context (current road infrastructure)
- Navigation (if guidance mode is active) for driver's activities prediction and potential availability state prevision.
- Perceptive information coming from external sensors (i.e. global diagnosis generate by the Traffic and Environment Risk Assessment module or information coming from TERA sub-modules).

6.2 Methodology

From a methodological point of view, 4 main steps will be carried out for DAE prototype design and development.

The first step will be focused on data acquisition (with end users and in real driving conditions). Several drivers (around 20) will drive an experimental car (equipped with DAE sensors) on a urban, rural and motorway route. During this driving phase, objective parameters will be collected by sensors and recorded (i.e. drivers action on controls, dynamic of the car, and GPS values for vehicle localisation on cartographic Data Base). On the other hand, video cameras will record (a) the front view of the road scene, (b) the rear view of the road scene, (c) the driver's face, and (d) the dashboard. Immediately after the driving phase, drivers will be interviewed (using the video as a support) with the aim to collect their opinion concerning their own availability state in each driving situation they had found themselves during the drive.

These end users "availability opinions" will be used (**step 2**) in order to develop DAE diagnosis algorithms. They are based on segmentation trees approach to decompose the driving situations in homogenous phases using the sensor data. Then, a high level, based on decision rules, which take into account the semantic data (cartographic) and the temporal evolution of the situation, make the final decision. At this level, the aim is to develop software being able to propose an availability diagnosis by using information coming from sensors (driver's activities and data coming from navigation system).

The third step will concern the 1st prototype performances evaluation. The aim will be to assess the DAE capacities to automatically propose an availability diagnosis in conformity with the end-user's opinion. On-desk tests, by using real data collected during the first experiment, will be run to evaluate the **DAE effectiveness** (rate of good diagnosis and errors analysis). This evaluation will permit to enhance strong and weak aspects of the 1st prototype and therefore to optimize the final prototype ready to be tested in real diving conditions.

Then, DAE Prototype will be installed on vehicle for on-board & real time tests.

The **step 4** will concerns "full-scale" tests (i.e. in real driving conditions) will be carried out for evaluating its performances (effectiveness & efficiency levels) and the interest of this system, from the point of view of end-user (satisfaction level). An example of "full-scale test" could be to send information (e.g. phone call, vocal message….) during complex driving situations. Following a "turning" experimental plan, delivering messages will be controlled - or not - by DAE module. In other words, either the messages will be delivered immediately (no control over diffusion by DAE), or they will be postponed (in compliance with the DAE diagnosis). At the end of the journey, drivers will be asked to give their opinion (whilst looking at the video taken during the driving task) concerning (a) the quality of the diagnosis done and (b) the appropriateness of this diagnosis to their own potential requirements in terms of information management.

7. CONCLUSION

A key contribution of the AIDE project is to enable "ambient intelligence" to enter into the driving environment without compromising road safety. An important goal of the adaptive integrated driver-vehicle interface to be developed is to resolve the conflict between, on the one hand, access to multiple in-vehicle information services and applications while driving and, on the other hand, road safety. The diagnostics, given by the different modules of the DSA are essential to manage the interaction between the in-vehicle systems and the driver. The DCM will translate the driver data (static, dynamic and context-oriented), according to the AIDE driver models, into specific information and warnings, adapting both info presentation media and timing; thus offering the best service to each user within each context of use. The DSDM monitors the driver vigilance state of degradation in terms of driver's ability to receive information. The CAAM module is intended to estimate how much a driver is engaged with secondary tasks. The distraction level is computed with computer vision system, which is assisted by the whole AIDE sensor array. The DAE module takes into account the driving task needs in term of driver availability to receive messages. For example, a non urgent information could be delayed in demanding situations (when the driver is not available).

The present decomposition of DSA Module allows all teams involved in this part of the project to introduce their specific and different knowledge acquired during previous projects. Each team has performed work on driver monitoring using different and complementary approaches. The combination of these approaches into a unified AIDE DSA module is expected to be a key achievement of the project.

Moreover, the use of the criteria and diagnosis given by the DSA modules are already taken into account in the design scenarios as DVE conditions (Bolovinou, *et al,* 2004).

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REFERENCES

Bekiaris, E., Amditis, A., Panou, M., "DRIVABILITY: A new concept for modelling driving performance", In: Cogn Tech Work, Vol.5, N.2/June 2003, pp.152-161, Springer0Verlag London Ltd, ISSN: 1435-5558.

Bellet T., Bruyas MP., Tattegrain-Veste H., Forzy JF., Simoes A., Carvalhais J., Lockwood P., Boudy J., Baligand B., Damiani S., Opitz M (2002) "Real-time" Analysis of the Driving Situation in Order to Manage On-board Information. *e-Safety Conference Proceedings, Lyon.*

Bolovinou A., Polychronopoulos A., Amditis A., Engström J., Holger K., Placke L., Andreone L., Deregibus E., Kompfner P.,Robertson-P.(2004) *Deliverable AIDE WP3_1-R1-V2-AIDE design Scenarios*

Longhurst, G. (2002). Understanding Driver Visual Behaviour. *Traffic Technology International. Annual Review 2002.*

Oliver, N. M. (2000) Towards Perceptual Intelligence: Statistical Modelling of Human Individual and Interactive Behaviours. *PhD Thesis, Massachusetts Institute of Technology, MA.*

Östlund, J. Carsten, O., Merat, N., Jamson, S., Janssen, W., Brouwer, R., Mouta, S., Carvalhais, J., Santos, Harbluk, Engström, J., Johansson, E., de Waard, D., Brookhuis, K., Anttila, V., Sandberg, H., Luoma, J. (2004) Deliverable 2 - HMI and Safety-Related Driver Performance. *Human Machine Interface And the Safety of Traffic in Europe Project GRD1/2000/25361 S12.319626*

Polycronopoulos, A., Amditis, A., and Andreone, L. Real Time Environment and Traffic Supervision for Adaptive Interfaces in Intelligent Vehicles. IFAC 2005.

Recarte, M.A and Nunes, L.M. (2003). Mental workload while driving: effects on visual search, discrimination and decision making,. *Journal of Experimental Psychology: Applied*, Vol. 9, No. 2.

Santana A., Jamme B., Boverie S., Giralt A., Poulard H., Thomas J. (2003) "Driver vigilance monitoring – New developments within the AWAKE project" *SICICA'03, Aveiro, Portugal.*

Smart Eye. (2004). Smart Eye White Paper. Available: www.smarteye.se

Victor, T and Johansson, E. In prep. Using eye movements to measure driving information loss while performing secondary tasks.