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PRESENTING AUTHOR
Family Name: Bekiaris
Given Name: Evangelos
Department: Hellenic Institute of Transport
Address: 6th km Charilaou - Thermi Road
City: Thermi, Thessaloniki
State/Province: State/Province:
Telephone: 30/31/481265
Facsimile: 30/31/481269
Email: abek@certh.gr

Presenting Author’s Organisation:
Centre for Research and Technology Hellas

Co Authors:
Wevers, Amditis
Mr. Kees
Title (Prof/Dr/Mr/Mrs/Ms/Miss): Mr.
Department: Navigation Technologies B.V.
Address: De Waal 15
City: Best
State/Province: NL-5684 PH
Telephone: +31.499.331.585
Facsimile: +31.499.331.410
Email: kwever@navtech.nl

Wevers, Amditis
Dr. Angelos
Title (Prof/Dr/Mr/Mrs/Ms/Miss): Dr.
Department: Institute of Communication and Computer Systems
Address: 9, Iroon Politechniou str.
City: Zografou
State/Province: 15773
Telephone: +30/1772398
Facsimile: +30/1 7723557
Email: angelos@esd.ece.ntua.gr

Wevers, Amditis
Title (Prof/Dr/Mr/Mrs/Ms/Miss):
Department:
Address:
City:
Telephone:
Facsimile:
Email:

Wevers, Amditis
Title (Prof/Dr/Mr/Mrs/Ms/Miss):
Department:
Address:
City:
Telephone:
Facsimile:
Email:

Wevers, Amditis
Title (Prof/Dr/Mr/Mrs/Ms/Miss):
Department:
Address:
City:
Telephone:
Facsimile:
Email:
ADVANCED DRIVER MONITORING – THE AWAKE PROJECT

Dr. Evangelos Bekiaris
CERTH/HIT, 6th km. Charilaou – Thermi Road, 57001 Thermi, Greece
Tel. +30 31 498265, Fax +30 31 498269, e-mail: abek@certh.gr

Kees Wevers
Navigation Technologies B.V., De Waal 15, NL-5684 PH, The Netherlands
Tel.: +31.499.331.585, Fax: +31.499.331.410
E-mail: kwever@navtech.nl

Dr. Angelos Amditis
Institute of Communication and Computer Systems of the National Technical University of Athens, Microwave and Optics Laboratory
9, Iroon Politechniou Str., 15773 Zografou, Greece
Tel. ++301 7722398, Fax: ++301 7723557
E-mail: angelos@esd.ece.ntua.gr

ABSTRACT

Recent research indicates that driver hypovigilance (or under-awakeness) is a major cause of road accidents. The objective of the AWAKE project, co-funded by the IST programme of the European Commission, is the development of an unobtrusive and reliable in-vehicle system to monitor the driver and the environment, for real-time detection of hypovigilance, based on multiple parameters. Continuous (instead of discrete) event related driver monitoring, effective system personalisation based on driver characteristics, and consideration of the actual traffic situation will enhance the reliability of the system and minimise the false alarm rate. In case of hypovigilance the system will provide an adequate warning to the driver. Several warning levels will be used, depending on the (estimated) level of driver hypovigilance, and the estimated level of traffic risk. This paper presents the general concept, the design process and the modules of the AWAKE system.

INTRODUCTION

A major focus of research over the last few years has been “driver hypovigilance” as a cause of road accidents. National Transportation and Safety Board of US has during the 1990s paid attention to driver fatigue as one of the most important causes of road accidents [18]. 10-20% of all accidents is related to driver fatigue [19]. More precisely:

- [2] found that fatigue and/or drowsiness of the driver caused around 30% of accidents in French highways in the period 1979-1994, whereas about 40% of fatal accidents on US highways are sleep-related [3].
- 1% to 10% of all accidents in the U.S.A. seem to be directly related to sleepiness [4].
- Regarding heavy vehicles crashes [5] estimated that in the USA fatigue-related crashes constitute 0.71%-2.7% of all crashes involving trucks and 15% to 36% of all crashes fatal to the truck driver. [3] estimates that fatigue is a factor affecting 30-40% of heavy truck crashes in US.
- [6] and [7] establish that a good detection of fatigue alone could concern between 40% and
60% of the crashes with one vehicle and 37% of truck drivers fatalities.

- Expected involvement in such accidents of trucks is 4.5 times greater than for passenger vehicles due to exposure, operational life and night driving [7].

Furthermore, accidents related to driver hypovigilance are more serious than other types of accidents. An impaired driver will not take evasive action prior to a collision, and if a cruise control is used, the vehicle will keep its speed until a major impact. [9] concludes that the reductions in traffic crash losses from reducing crashes attributable to driver impairment far exceed reductions from any other potential countermeasure.

The circumstances in which drowsiness-related accidents usually happen should be taken into account, namely late-night hours, with a smaller peak in the mid-afternoon. Young drivers have no increased risk during the afternoon. Drivers over 45 on the other hand have fewer night time crashes, with a peak at 7 a.m., and are more likely to have such crashes during the mid-afternoon [11]. For this reason, the age groups specifically prone for such accidents are being focused within AWAKE. For example, [11] estimates that drivers younger than 30 account for almost two thirds of drowsy driving crashes, despite counting for only about one-fourth of licensed drivers. 20 is the age of peak occurrence of drowsy-driving crashes, whereas both the 18-24 and 25-39 age groups are over-represented in fall-sleep crashes. Data like the above will guide the user groups synthesis of the project pilots.

In addition, the problem might be also directly related to the introduction of various Advanced Driver Assistance Systems (ADAS) in the next years in the market. Automated or even assistive driving systems may also induce fatigue and stress to the driver caused by prolonged driving under monotonous driving conditions. In other words, cases of driver hypovigilance may be well enhanced due to the introduction of ADAS. And yet, ADAS technology may well be the right answer to fight this same problem.

Thus, the objective of AWAKE is to increase traffic safety by reducing the number and the consequences of traffic accidents caused by driver hypovigilance. In order to achieve this objective, AWAKE intends to develop an unobtrusive, reliable system, which will monitor the driver and the environment and will detect in real time hypovigilance, based on multiple parameters. The system will achieve enhanced reliability and minimised false alarm rate, by supporting continuous, instead if discrete, event-related driver monitoring, strong system personalisation to driver characteristics and traffic situation awareness. In case of hypovigilance, the system will provide an adequate warning to the driver, with various levels of warnings, according to the estimated driver’s hypovigilance state and also to the estimated level of traffic risk. This system will operate reliably and effectively in all highway scenarios.

**STATE OF THE ART**

Various prototypes and systems for monitoring driver impairment have been developed until now, without any outstanding market success. Most of them either base their detection on single driver characteristics (i.e. eyelid movements, eye closure, steering grip force), on physiological measurements of the driver (such as EEG, EOG, ECG, muscle activity) or on behavioural characteristics (such as vehicle speed, lane position, etc.). Very few attempts have been made on combining all above indexes in a complementary way. Yet, these few attempts have shown promising results, even if they have not as yet solved the problem in its entity.

The most promising efforts so far include:
• Nissan anti-drowsiness system that monitors driver’s eyelid movements and in case drowsiness is detected warns the driver by audio signal and at a second stage releases menthol scent and cold air to awake the driver. It also includes an automatic braking option.

• Mitsubishi Driver’s View Detector uses two dash-mounted cameras to monitor and analyse eye position and blinking. If drowsiness is detected, a warning sound is generated.

• Within SAVE EU project (System for effective Assessment of driver state and Vehicle control in Emergency situations - TR 1047) an eyelid sensor has been developed for driver hypovigilance detection. This sensor has high detection rate under the condition that the driver does not wear glasses. Furthermore, detection rate is influenced by environmental lighting conditions and even by the driver’s driving style (i.e. when putting the hands on the steering wheel). Still, under optimal conditions, detection rate of up to 95% can be achieved [10]. AWAKE is the follow-up of SAVE project.

• [11] has evaluated various techniques for ocular measurements as the basis for alertness management. They have compared two EEG algorithms, a head tracker device, two wearable eye-blink monitors with a video-based scoring of eye closure by trained observers. The results suggest that the MICRODAS system using the PERCLOS algorithm is the best of these technologies in simulation studies and can be used to detect hypo-vigilance under the condition that it will be automated in a computer algorithm. The false alarm rate of the algorithm has been reported to be 0.5% and the miss-rate 19.73% by [12]. A follow-up [13], however, using real world driving data was inconclusive in relating the algorithm results to the prediction of driver hypovigilance. They have found a false alarm rate of 1.6% but a miss-rate of 37.2%.

• The Spanish ADS (Anti-Drowsiness System) detects driver drowsiness by monitoring steering grip pressure at the steering wheel, warns the surrounding traffic (by blinking the headlights and acoustic alarm) and automatically cuts off the vehicle’s fuelling to stop it, in case driver drowsiness is detected. No reliability or market data on this system are available.

• Dozer’s alarm from Australia detects driver’s drowsiness by measuring the inclination angle of driver’s head. No reliability or market data are available for this system too.

• A steering grip detector developed within SAVE project (TR 1047) had a rather low detection rate (60%), when used as stand-alone sensor for drowsiness detection. Furthermore, a head-rest sensor developed in the same project seemed to be useful to detect sudden loss of control by the driver (i.e. fainting, heart attack) but has low correlation to vigilance detection [10].

• Head pose and gaze-direction tracking system developed by an Australian University (ANU) and Volvo [23], estimates fatigue through measuring head-pose, gaze-direction, eye closure and blinking. The system is not yet in the market (is announced for 2001 but without specified price). Its setup process requires 10 minutes for an environment with controlled lighting, but in-vehicle lighting conditions are rapidly and constantly changing. It still requires a few markers on the driver’s face.

- SAMOVAR Project (V2007 - Safety Assessment Monitoring On-Vehicle with Automatic Recording) concentrated on low cost in-vehicle electronic system for recording vehicle data and driver behaviour, in relation to driver’s performance of the driving task (i.e. speed choice, traffic signal violation, lane keeping), but did not result in any specific correlation of them to driver’s hypovigilance.

- DETER (V2009 - Detection, Enforcement and Tutoring for Error Reduction) project has been based on DRIVE I projects AUTOPOLIS (V1033 - Automatic Policing Information Systems), DREAM (Feasibility of Driver Monitoring) and GIDS (V1041 - Generic Intelligent Driver Support Systems). All projects targeted driver vigilance detection by monitoring driver’s behaviour, concerning speed, headway, violation of traffic law. For this they used strategies like electro-encephalograms, electro-oculograms, off-line video camera analysis of driver’s face, etc. No actual system resulted from them.

- Daimler Chrysler [14] has developed a detection algorithm that uses lateral position, steering wheel angle and longitudinal speed data, jointly analysed to detect driver’s drowsiness. This
algorithm has been validated in simulator and field studies with drivers of private cars and heavy vehicles. This system has been proven feasible but is not fully developed yet.

- SafeTRAC [24] is a new system from USA (just marketed), which claims to effectively monitor driver drowsiness in over 97% of all highway driving conditions with less than 1 false alarm every 8 hours of driving. It is based on a lane tracking system. The system requires white lane markers to operate and does not operate under night time rain conditions. Its reported false alarm level of 1 false alarm every trip (a professional drives typically 8 hours per journey) is still too high and the environmental restrictions seem too severe.

An abundance of systems have tried to detect on-line driver monitoring by the measurement of driver’s physiological measurements, such as EEG, ECG, EOG signals, cerebral, cardiac and pulmonary activities. As two typical examples the following are mentioned:

- Toyota has developed an anti-drowsiness system, that detects driver drowsiness by physiological driver measurements through a wrist device at driver’s left hand (like a watch) and warns the driver by alarming sounds (first stage), vibration of the driver’s seat (second stage) and even automatic braking (third stage). Driver’s wiring has been reported to be particularly disliked by the users.
- Atlas Researches from Israel has developed a family of relevant monitors, called NOVAalert, that employ electromyography for monitoring driver’s wrist activity (by a wireless wrist detector) and warning the driver by vibratory stimulus, to increase muscle activity if he/she slows the pace or reduces isometric levels below a relevant criterion.

Such systems however target more driver alertness maintenance than monitoring.

**AWAKE OBJECTIVES AND INNOVATIONS**

From the above cases as well as from analysis of the most significant drawbacks mentioned in the literature, AWAKE Consortium has concluded that:

- A multi-sensor approach, combining driver’s physiological and behavioural (traffic task related) parameters is the only feasible way of successfully filtering driver, traffic, environment-caused disturbances and “noise” to any single sensor.
- Driver wiring and the use of obtrusive sensors has to be excluded due to their low user acceptance. Also, systems requesting often feedback by the driver should be avoided for the same reason (i.e. to perform a task in order to prove he/she is awake or to keep the driver awake for longer).
- There is a necessity to develop a continuous diagnostic algorithm instead of a discrete one, allowing for incremental learning and sufficient personalisation to the particular driver characteristics.
- There is a need for on-line environmental condition adaptation of the detection algorithm, based on the actual traffic conditions.
- Driver warning should be modular and multimodal, to force the driver to understand the danger and react to it, without causing him/her panic. If the surrounding traffic situation permits it, high levels of warning should be avoided to reduce user’s disturbance.
- System intervention (for autonomous vehicle control) is feasible but still too far from the market (due to the associated high failure risk of any subsystem and its enormous cost), and thus can not be effectively supported yet.
- A uniquely defined unit will not be able to cover all types of users and problems. For example, Sleep Apnea Syndrome (SAS) patients may accept more strict detection and warning strategies
than professional drivers, who in turn would tolerate much more than passenger vehicles drivers, and especially young ones. Thus, a modular and configurable system should be targeted.

AWAKE will strive to meet the above requirements for an optimum detection system by a series of innovations in its specifications, design and development, prominent among them being:

1. Development of a multi-sensor system, including the most promising detection sensors developed so far, such as an eyelid camera, a steering grip sensor, a lane tracker and other vehicle-related parameters monitoring sensors. For this the best existing sensors in Europe (all available to the Consortium) will be further optimised.
2. Follow-up in parallel of the most promising stochastic and deterministic (knowledge-based) approaches for data fusion of the above sensor data.
3. Extension of the current diagnostic methods to take into account continuous diagnostic capabilities (incremental learning).
4. On-line personalisation of the diagnostic algorithm.
5. Introduction of ambient intelligence to the diagnostic module, according to the traffic environment and driver’s attention to it (through gaze analysis).
6. Development of a warning strategy that combines acoustic, visual and haptic elements and is parametric to driver’s vigilance state as well as to the estimated traffic situation.
7. Emphasis on cost-effective and viable solution to the market, using to the maximum extent readily available sensors and other ADAS subsystems.
8. Emphasis on legal, standardisation and insurance issues, to guarantee unobstructed marketing of the developed system.
9. Parametric specifications that match the particular preferences of the target user cohorts (such as young drivers, professional / heavy vehicle drivers, shift workers and people suffering from sleep disorders) and the whole spectrum of application fields (small to luxury passenger cars, heavy vehicles).

THE AWAKE SYSTEM

The system will consist of the following modular components:

A Hypovigilance Diagnosis Module (HDM) that will detect and diagnose driver hypovigilance in real-time. Based on an artificial intelligence algorithm this module will fuse data from on-board driver monitoring sensors (eyelid and steering grip data) and data regarding the driver's behaviour (lane tracking, gas/brake and steering position data). The HDM will be adapted to the specific driving characteristics of the user by continuous driver monitoring and expert-based adaptation. The goal is to achieve a (correct) diagnosis level over 90% and a false alarm rate below 1% in all highway scenarios.

A Traffic Risk Estimation Module (TREM) that will assess the traffic situation and the involved risks. It will match, following a deterministic approach, data from an enhanced digital navigational map, a positioning system, an anticollision radar, the odometer, and a driver's gaze direction sensor. This module is not designed as a complete new system to estimate traffic risk, but rather as an expert combination of existing ADAS technology. The output of this module will be used by the HDM to re-assess the state of the driver, and by the Driver Warning System to determine the adequate level of warning.

A Driver Warning System (DWS) that will use acoustic, visual and haptic means. The module will use inputs from the HDM and the TREM to determine the adequate warning level for a certain
situation.

A Hierarchical Manager (HM) which will be able to perform self-diagnosis, and which will co-ordinate the other system components.

Mentioned system components and sensors will be integrated in one single unit (the AWAKE unit) suitable for use in real-life automotive applications (in terms of cost, size, weight and robustness). In the project three prototype systems will be developed, and tests will be performed with a middle and an upper class passenger car, and with a heavy vehicle demonstrator, so as to cover all relevant applications areas.

EXPECTED IMPACTS OF AWAKE

Traffic crashes constitute one of the largest public health problems in industrialised countries. In the USA almost half of the deaths of 19-years-olds are caused by traffic crashes, and the total number of pre-retirement years of life cost because of traffic crashes is approximately equal to deaths caused by the combined effects of the two leading diseases, cancer and heart diseases [9].

Over 30% of accidents may have as primary or secondary cause the driver impairment, due to a variety of reasons. Also, almost 30% of accidents could be avoided by means of reducing the driver related reaction time by just 0.5 sec (through warning by AWAKE system).

The above reasoning allows to believe that a successful application of the AWAKE concept will have important impact on road safety, namely it may seriously reduce accident rate. Still, this is far from certain. Although no model exists which can predict the actual safety effect of a new intervention, the results of previous interventions suggest some fairly stable patterns. Thus, better brakes and handling, poor-weather vision and drowsiness detection are expected to lead to faster driving, faster cornering, faster speeds under low visibility, and longer-duration driving [9].

Hence, only after the behavioural effects of AWAKE system have been studied (in its pilots) the actual impact to traffic safety will be estimated. If we do not consider possible negative effects (i.e. from over-reliance to the system), hoping to avert them by proper system implementation, we may result in erroneous assumptions.

On the other hand, the introduction of other ADAS into traffic (such as obstacle avoidance, vision enhancement, route guidance and lane keeping) may well induce subjective fatigue and stress or boredom to the drivers, leading to even more monotonous driving conditions. Thus, the need for driver monitoring and drowsiness detection systems will be further enlarged.

The implementation of AWAKE system would have other benefits too. In the [Intelligent Speed Adaptation pamphlet of AVV, 1997] it is mentioned that an accident reduction by 21% means a reduction in fuel consumption and carbon dioxide emissions by 11% while nitrogen oxide emissions would be reduced even more, by 15%, as accidents have as indirect impact traffic jams and a temporal decrease of the networks capacity. Hence, an eventual accident reduction by AWAKE system will also be accompanied by positive environmental impact.

The total cost of crashes in EU is 50 billions Euros [High Level Group Report, 1991]. Worldwide, more than half a million people are killed each year in traffic crashes. Approximately one person in 200 in the world’s population dies from injuries received in traffic crashes while about 15 million people per year are injured in traffic crashes worldwide. This means that the average citizen of the 7
world has about one in seven chance of being injured in a traffic crash sometime during one's life. Furthermore, it has been estimated [NHTSA, 1989] that the average vehicle has about a 20% probability of being involved in some type of crash per year.

More specifically, according to [4] sleep-related accidents in the USA are annually associated with more than 23,000 fatalities, more than 2 million injuries and cost over 56 billion Euros.

In economic terms this means that:
- Around 70 billion Euro are spent each year on medical treatment of injured people in accidents [4] and thousands man-years of work are lost. These numbers are bigger than the Gross Product of several EU countries!
- Social funds of magnitude also of billions Euro are devoted yearly to medical services and rehabilitation for people, becoming temporarily or permanently disabled due to accidents.

A large proportion of all the costs are paid directly, or reimbursed, by insurance companies, which therefore have a very significant interest in traffic safety enhancement.

In [9] two levels of monetary value of crashes are defined:
- **Economic values**: include actual monetary loss, like medical care, legal services, vehicle repair/replacement, lost productivity.
- **Comprehensive values**: include both monetary loss and a valuation of less tangible human consequences, such as “pain and suffering” and loss of life or disability.

Furthermore, the high monetary cost of the drowsy driver crash problem is presented. For heavy vehicles the per-crash costs are even higher than these for passenger cars. The results are presented below.

<table>
<thead>
<tr>
<th>Economic estimates of the US drowsy driver crash problem in $ [9]</th>
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<tbody>
<tr>
<td>Total annual US monetary cost</td>
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<tr>
<td>Economic values</td>
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<tr>
<td>Comprehensive value</td>
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<tr>
<td>Per-police-reported crash cost</td>
</tr>
<tr>
<td>Economic values</td>
</tr>
<tr>
<td>Comprehensive value</td>
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<tr>
<td>Crash cost per 100 million vehicles miles of travel</td>
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<tr>
<td>Economic values</td>
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<tr>
<td>Comprehensive value</td>
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<tr>
<td>Crash cost per registered vehicle annually</td>
</tr>
<tr>
<td>Economic values</td>
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<tr>
<td>Comprehensive value</td>
</tr>
<tr>
<td>Crash costs per vehicle produced over a full operational life</td>
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<tr>
<td>Economic values</td>
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<tr>
<td>Comprehensive value</td>
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The benefit to the economy throughout Europe is therefore obvious, even if AWAKE manages finally to prevent only a limited number of incidents, as, for example, a mere 5% reduction to road casualties means about 2,500 less deaths and 75,000 less injuries per year, which sums up to around 500 MEuro gain annually for the European economy. Also since accidents due to loss of vigilance
tend to be more severe than the average, that figure may be even an underestimation of the actual economic gain.

SAVE project has proved that such a system is feasible by integration and fusion of a wide rage of sensors and that it works properly under restricted scenarios. AWAKE Consortium is determined to develop it for actual highway applications.

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