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Diagnostic fusion for in vehicle Driver vigilance assessment

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Abstract: Driver impairment in broad terms is one of the most common causes for traffic accidents. In the context of impairment, decreased vigilance, fatigue and inattention are major factors accounting for driver errors. The real time detection and assessment of driver impairment through non-intrusive driver monitoring system is a real challenge. Within this paper, after an extended state of the art of the existing technologies and systems a Driver vigilance monitoring system, based on the fusion of physiological, behavioural and contextual information is described. This system has been implemented on a vehicle and real conditions experiments have been performed on motorway.

Keywords: ADAS, Driver vigilance, diagnostic, image processing, fuzzy logic

1 INTRODUCTION

In September 2001, the European Commission has published a White Paper which ambitious objective is to reduce of about 50% the road fatalities in Europe by 2010. (European commission, 2001, 2005). Currently about 40 000 persons are killed and 1.5 million wounded each year on European roads. This number shows that a minimum of one EU citizen over 200 will be wounded in a traffic accident each year. In order to reach the objectives set by the European commission, various efforts have been dedicated to the integrated safety that's includes accident prevention, risk mitigation, and assistance management.
Literature shows that about 90 % of the accidents are due to an intentional or non intentional Driver behavior (Treat *et al* 1977, Sabey, B. E. *et al.* 1975). For example, they can be related to a bad perception or a bad knowledge of the driving environment (obstacle, .); to a low training ("Sunday" drivers, young drivers, etc); to driving errors due to distraction (telephone, chatting, external attractors, advertisements, . .); to an over working load (driving in difficult conditions, in complex conditions, . . .) or an under working load (monotonous driving conditions on motorway for example); to reduced physiological (drowsiness, sleepiness, . .) or physical (old people, elderly drivers) conditions, etc. Among the problems that impact on traffic safety, the Driver's physical and psychological states play an important role. The assessment of the Driver vigilance[•] state has attracted wide interest both in basic research and in solutions to the development of driver monitoring systems. This interest has been reinforced these last years thanks to technologies becoming more and more mature (Boverie S., 2002.*)*

[•] The term "driver vigilance" encompasses all the situations in which the driver's alertness is diminished, and therefore when the driving task cannot be maintained at an adequate level of performance. It is a consequence of stress, fatigue, alcohol abuse, medication, inattention, effects of various diseases.

The objective of this paper is to propose a general overview of the Driver Monitoring System (DMS) that has been developed by Continental.
Section 2 presents the state of the art of the current developments. In section 3 the DMS principles are introduced as well as the functional and physical architectures. Section 4 is dedicated to the detailed description of the various modules that are included in the DMS. At last section 5 presents some experiments and results achieved with the DMS system in real driving situation.

2 STATE OF THE ART

A major focus of research over the 15 last years has been "driver impairment" as a cause of road accidents. In the 1990s, the US National Transportation and Safety Board paid attention to driver fatigue as one of the most important causes of road accidents (National Transportation and Safety Board of US 1999). Horne *et al* (1999) stated that 10-20% of all accidents is related to driver fatigue. Boussuge, J., (1995) 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 (Garder, P, 1998). To conclude, a French survey reveals that drowsiness is among the main causes of fatal accidents, with excessive speed and alcohol. Furthermore, accidents related to driver impairment 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.
In the 1970's and 1980's extensive research was carried out to identify and describe issues as well as countermeasures were planned to tackle the problem. Profiled road markings serve as a good example of countermeasures that have been tried out, but without clear and consistent impacts on accidents. Also, laws were enacted in the whole EU-area for controlling professional Drivers driving times.

In the 1990's supported by the improvement of the sensor technology and the increasement of the computers processing power new approachs for solving driver impairment problems emerged, among them monitoring driving environment, vehicle movements, Driver status and behaviour. In Europe, basic work for Driver monitoring was carried out in the EU funded project, DETER-EU (Brookhuis, 1995) and next in PROCHIP /PROMETHEUS program (Estève et al, 1995). In the SAVE-project (SAVE 1995), a solution for all types of driver impairment monitoring was proposed by means of sensor fusion. Then in the AWAKE project (AWAKE 2000), a multi-sensor system has been set up. It combines information provided by an eyelid sensor, a lateral position sensor, a steering grip sensor and additional data available on the vehicle like steering wheel movements, vehicle speed and other behavioural parameters. More recently the SENSATION project (SENSATION 2005) aims at promoting novel micro and nano sensors and related technologies, of low-cost and high-efficiency, for physiological state monitoring. The focus of the work was the detection, the prediction and the management of the sleep and wakefulness states and their boundaries, stress, inattention and hypo vigilance. Within this project some specific automotive sensors have been developed. For example:

- A low cost CMOS image sensor allowing an accurate and high speed (200 Hz) measurement of eyelid opening.
- A posture (seat, foil-based) and capacitive micro sensors for measurement of Driver's activity parameters.

Among the other systems that have to be considered, we can mention:

- Toyota system, that detects driver's drowsiness through an eyelid camera mounted at the right side of the rear-view mirror and warns the driver through an in-vehicle navigation screen and acoustic sounds.
- Nissan system, based also on eyelid analysis, combined with facial image analysis of the driver.
- SAFETRAC system of Carnegie Mellon University, based on vehicle's position on the lane (video images)
- The Optalert system that consists in glasses equipped with a fully integrated vision sensor that analyzes the eye blinks with a high frequency rate. (Johns M.*et al* 2005)
- Most recently and certainly one of the first systems proposed in serial mass production vehicle by PSA was the AFIL system based on the analysis of the vehicle lane departure. (Riat J.C., 2005).

3 DMS principles

The DMS system intends to detect and to diagnose, in real-time the degradation of the driver's vigilance because of drowsiness or sleepiness.

From the state of the art, several indicators can be used in order to perform this diagnostic. Basically the physiological measurements give the most reliable information (i.e. Electro-encephalogram (EEG) and electro-oculogram (EOG)). Nevertheless it is not easy to measure them with non intrusive systems.

Eyelid motions, by means of the blink duration, the closing speed and some other blink related parameters are recognized to be one of the most pertinent indicators.

It is also of interest to observe the vehicle behaviour in order to assess the Driver's ability to drive (e.g. lateral control and longitudinal control performances).

In addition some contextual information can be considered. It is well known that Drivers' vigilance changes depend on the time of the day. Statistics show that some periods of the day are strongly related with the maximum occurrence of accidents (between 2:00 and 6:00 AM for example). These periods are defined by the chronobiological rhythms.

At last it is also well accepted that the trip duration has a direct influence on the driving performance.

One of the basic assumptions was that the diagnostics issued from each of this individual information are not reliable enough to guarantee a high level of performance. Nevertheless their fusion should compensate the individual gaps to provide more robust information. Furthermore, the addition of complementary in-vehicle and contextual information should also contribute to the improvement of the diagnostic.

Within the DMS, several diagnostics are calculated; a physiological diagnostic based on the eyelid motion observation and a behavioural diagnostic based on the observation of the vehicle lateral control behaviour. They are fused with additional in-vehicle and contextual information to provide a final decision about Driver's vigilance state (Tattegrain Veste H.*et al* , 2005). This final decision includes four levels representing the current Driver state (i.e. Normal, Medium, Critical, and Dangerous).

The overall DMS functional architecture is presented in

Figure 1.

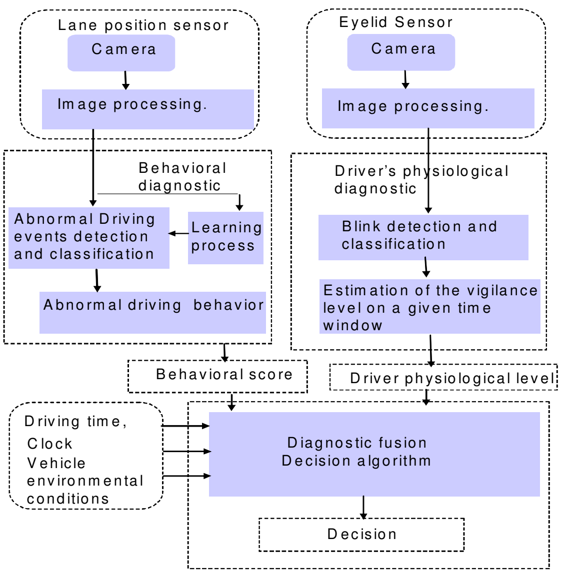

Figure 1: DMS functional architecture

The DMS includes several processing levels:

- The sensing level that provides measurements and signals from the various sensors. This level includes both smart sensors (e.g. camera sensor + image processing). *Table 1* is listing the various inputs that are used to perform the on-line diagnostic. Some of them are currently available in the vehicle on the various communication buses (in-vehicle information). Others like eyelid activities and lane positioning are provided by a new generation of smart sensors based on video processing
- The data processing, "feature extraction, filtering, detection and classification", level that extracts pertinent and discriminated variables from the various measurements provided by the sensing level.
- The diagnostic units - i.e. physiological and behavioural diagnostics - that estimate the evolution of the Driver state.
- The decision level fuses the information of the physiological and behavioural diagnostics but also takes care of the environmental and the contextual information. It provides the final assessment about the Driver state.

INPUTS	
Driver Monitoring information	**In vehicle information**
Eyelid activity	Vehicle Velocity
Eyelid measurement quality index	Trip duration[3]
Lane positioning information	Clock
Lateral offset [1]	Vehicle Width
Driving Lane position on the road [2]	Steering wheel angle
Lane width	Right and left indicators
OUTPUTS	
Driver State diagnostic rated on four levels	Eyelid measurement quality index

[1] Distance between the middle, longitudinal axis of the vehicle and the right border of the lane; [2] Indication of the vehicle position on the road/lane; [3] Indicates the time elapsed from the beginning of the trip, without any stop.

Table 1 : Input and output variables

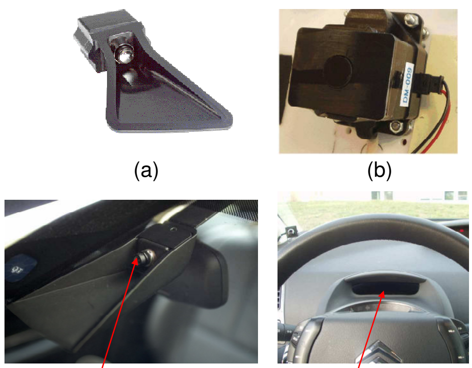

Figure 2: Video sensor a) for vehicle lane positioning b) for eyelid monitoring

The eyelid sensor (ELS) consists of a camera implemented in the vehicle dashboard and looking to the driver face. The eyelid sensor includes a processing unit that process in real time the Driver's face image and extract the eyelid movements (see *Figure* 2a) (Boverie *et al,* 2008).

The lane positioning sensor consists of a camera implemented into the vehicle (see *Figure* 2b), behind the windshield and near by the central rear view mirror. This camera is looking ahead. The images provided by the camera are processed in real time in a dedicated computer that estimates the position of the vehicle in the lane.
The in-vehicle information is available on the car communication buses (CAN bus).

4 Description of the modules

The DMS includes 3 main modules, the Driver's physiological diagnostic, the behavioural diagnostic and the decision making modules (see

Figure 1).

4.1 Driver's physiological diagnostic

Among the most relevant physiological symptoms that are related with Driver's hypo vigilance the eyelid movements are obviously some of the most pertinent.
The Driver's physiological diagnostic estimates the evolution of the Driver's state degradation by analyzing the eyelid activity measured by the Eyelid Sensor (ELS) (Boverie S., 2002; Boverie S., *et al* ,2005).
The physiological diagnostic outputs four physiological states: Alert (Level 0), Slightly Drowsy (Level 1), Drowsy (Level 2), and Sleepy (Level 3); based on the analysis, on a sliding time window ΔT_1, of the Driver's blink process.
The blink process is deduced from a real time reconstruction of the eyelid motion provided by the eyelid sensor. It includes several steps (for more details report to Boverie et al 2008):

- The initialization phase that aims to detect the driver's face and eyes in the image provided by the camera
- The feature tracking that focuses on some features of interest like eyebrow, eye corner, nostrils
- The eye opening measurement that estimates the eyelid opening using a model of the eyelids.
- The blink detection and duration measurement
- The blink classification that uses fuzzy subsets. Currently four blink categories are used, respectively, *Short, Long, Very Long* and *Sleepy* blinks.
- At last the physiological state is estimated by analyzing the nature of the various eye blinks observed on ΔT_1. Each of the state is characterized by the occurrence of some blink categories. For example the Sleepy state is characterized by one or two *Sleepy* blinks. For the Alert state the blink duration on ΔT_1 must always be *Short*.

4.2 Behavioural diagnostic

The main concern of the behavioural diagnostic is to detect abnormal driving behaviours and to distinguish between safe and unsafe driving (Boverie S.*et al*, 2002). Of course the cause for abnormal driving is not only drowsiness. It can also be due to lack of attention, fatigue, etc. Nevertheless the diagnostic issued from those observations is very complementary to those delivered by the physiological diagnostic module and can be used to reinforce or relax it.

Different information can be used to perform this diagnostic, depending on the task the Driver has to perform; lateral control, lane keeping, longitudinal control, frontal distance keeping, etc. . . .
The aim of this module is to focus on lane keeping task performance, among those the driver has to perform. (lateral control of the vehicle),
One of the main results of SAVE (1996) and AWAKE (2000) projects was the evidence that each driver has a personal way to drive and, furthermore, that each driver reacts differently to hypo-vigilance. This entails the necessity to personalize the diagnostic for each Driver. Another main assumption is that only learning of vigilant state is possible.
From the available information, a simplified model of how the each Driver behaves in vigilant conditions is set up. The deviations from this model indicate some driving performance reduction and then a degradation of the Driver state.
The Vehicle Behavioural diagnostic includes several processing steps:

- The Learning Process; the inter Driver driving behaviour variability entails a need for personalization. The learning module records, analyzes and models some parameters characterizing the way of driving for each Driver, in normal driving conditions. These parameters are learned during the first ten minutes of the trip (*reference period).*
- The abnormal driving event detection and classification is performed by comparing the current data acquisition and derived variables to the characteristic variables issued from the learning process. It uses a set of predefined deterministic *if – then* rules that have been established from on-road experimentation.
- The abnormal driving condition is achieved by analyzing the number, the frequency and the distribution of the detected abnormal events. A set of rules deduced from on-road experiments and databases has been set up. The output delivered each ΔT_2 by the behavioural diagnostic module is a 3 level behavioural score [0, 1, 2] from normal to dangerous situation.

4.3 Decision making unit

4.3.1 Fusion of the physiological and behavioural diagnostics

The fusion of the Driver's physiological and Behavioural diagnostics uses a fuzzy rule based approach. The output of the diagnostic fusion describes the general state of the Driver. This diagnostic is performed iteratively on a sliding time window, ΔT_3 ($\Delta T_2 \leq \Delta T_1 \leq \Delta T_3$). The diagnostic fusion principles are summarized in *Figure 4*.
The inputs of the diagnostic fusion are the number of occurrences of each physiological states/behavioural scores on ΔT_3. For the Driver physiological diagnostic only levels 1, 2, 3 are considered. Level 0 that corresponds to the "Driver Alert" situation has no influence on the fusion. For the Behavioural diagnostic only scores 1 and 2 are considered. Score 0 that corresponds to a *normal* situation has no influence on the fusion.

Thus the fuzzy diagnostic system has 5 inputs X_1, X_2, X_3, X_4, X_5 and one output.

3 fuzzy subsets, *Small, Medium, and Big* are used for describing each of the input.
4 fuzzy subsets Normal, Medium, *Critical* and *Dangerous* are used for describing the output (Figure 3).

$$X_1 = nb \;\; of\, occurence \;\; of \;\; Physiological\; level\, 1 \;\; on\; \Delta T_3$$
$$X_2 = nb \;\; of\, occurence \;\; of \;\; Physiological\; level\, 2\; on\; \Delta T_3$$
$$X_3 = nb \;\; of\, occurence \;\; of \;\; Physiological\; level\, 3 \;\; on\; \Delta T_3$$
$$X_4 = nb \;\; of\, occurence\; of \;\; Behavioral\; score\, 1 \;\; on\; \Delta T_3$$
$$X_5 = nb \;\; of\, occurence\; of \;\; Behavioral\; score\, 2 \;\; on\; \Delta T_3$$

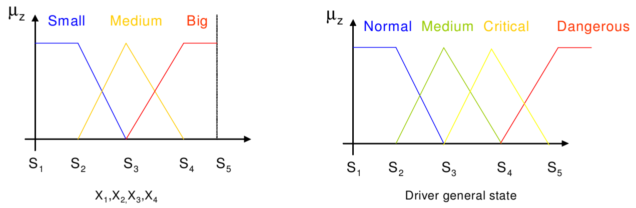

Figure 3: Input/-output membership functions

The inference engine includes a set of 16 expert rules. These rules are directly deduced from human expertise. In those rules the predominance has been given to the physiological diagnostic. The behavioural diagnostic is currently used to reinforce or relax the physiological one. In that set of rules the situations where the physiological or the behavioural diagnostic are not available are considered. In those cases the only available diagnostic is considered. An example of such rules is given hereafter:
When physiological and behavioural diagnostics are both available:

$$rule_i = if\; ((X_1)\;\; is\, Small \;\; or\;\; X_1\; is\; Medium)\; and\; (X_2) is\, Medium$$
$$and\; (X_4)\; is\, Small\; and\; (X_5)\; is\, Small)$$
$$Then \;\; diagnostic \;\; fusion\; level\; is\; Medium$$

When only the behavioural diagnostic is available:

$$rule_j = if\; ((X_5)\;\; is\, Big\; Then \;\; diagnostic \;\; fusion\; level\; is\; Critical$$

In the premises the *And* & *Or* connectors are using the min and max operators:

$$\mu_{A \wedge B}(x,y) = \min(\mu_A(x), \mu_B(y)) \quad and \quad \mu_{A \vee B}(x,y) = \max(\mu_A(x), \mu_B(y))$$

The fuzzy implication is using the popular Mamdani operator: $\mu_R(x,y) = \min(\mu_A(x), \mu_B(y))$

The fuzzy inference is given by:

$\mu_{B'}(y) = \sup_{x \in X} \min(\mu_{A'}(x), \mu_R(x,y))$ In our case the A' subset is reduced to a singleton x_0. Then with the Mamdani implication the inference becomes:

$$\mu_{B'_i}(y) = \min(\mu_A(x_0), \mu_R(y))$$

All the rules are linked with an OR operator. The final output is given by: $\mu_{B'}(y) = \max_{i=1,N} \mu_{B_i'}(y)$ Where, N is the number of rules.

The defuzzification is done with the "center of Gravity" method. The defuzzified output of the diagnostic fusion is a four level diagnostic [0, 1, 2, 3] from Normal to Dangerous situation.

4.3.2 Contextual information

The contextual information (time of the day and trip duration) is aggregated in order to provide a global “Context Information”. 3 fuzzy subsets are used to describe the trip durations (*Small, Medium, Long*) and only two for the time of the day (*Normal, Critical*). The output is described by 3 fuzzy subsets (*Normal, Medium, and Critical*). The fuzzy operators are the same then formerly. Six expert rules have been set. An example of such rules is given hereafter:

$$rule_i = if\ \left(\left(trip\ duration\right) is\ Medium\ and\ \left(time\ of\ \ the\ day\right) is\ Critical\right.$$
$$Then\ Context\ \ is\ Medium$$

4.3.3 Final diagnostic

The contextual information is used to modulate the decision provided by the fusion of the behavioural and physiological diagnostics. For example if the Driver’s general state is diagnosed as *Critical* and the context information is *Normal*, then the decision making will set the final decision to *Critical*. But, if the contextual information is *Critical* then the final decision will be set to *Dangerous*.
The output of the diagnostic fusion is a four level output [0, 1, 2, 3]. Where 0 corresponds to the normal situation while 3 corresponds to *Dangerous* situation.

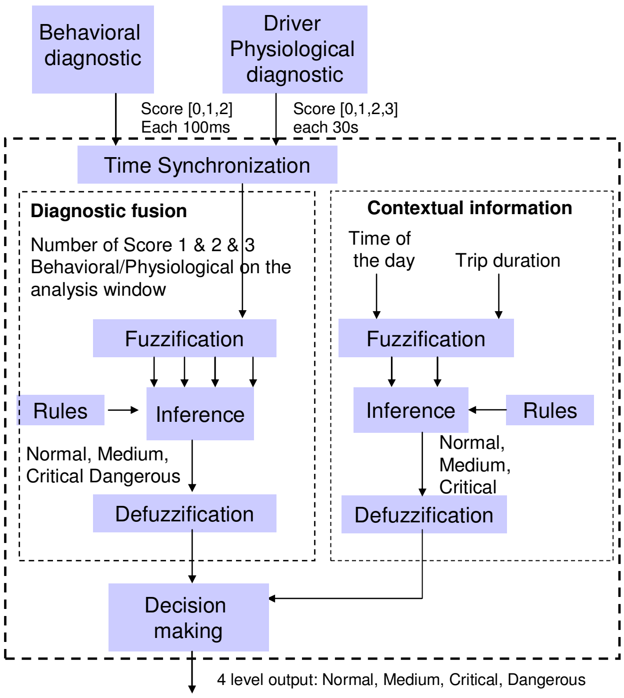

Figure 4: Decision making module architecture

5 Experimental results

The validation of the DMS module has been performed with experimental vehicles, on motorway, in real driving conditions, with 12 drivers (D01 to D12) following a strict experimental protocol. Each driver drove about 360 km for each experiment. Drivers were instrumented with physiological sensors (electrodes) that recorded their EEG and EOG. During the experiments a technical supervisor and a medical team (a doctor) accompanied the drivers. The following data were recorded:

- Vehicle behavioural parameters: steering wheel angle, lateral position;
- EEG and EOG signals;
- Driving fault recorded by the technical supervisor.
- Diagnostic provided by the Driver Monitoring System

In addition, two cameras recorded the scene in the cockpit and ahead the vehicle.

From the physiological data (EEG and EOG) an off-line analysis provided a Physiological Expertise on the Driver State. This expertise was used as a reference to evaluate the performance of the system.

Figure 5 shows the experimental vehicle architecture. It includes the sensing and processing devices needed for performing the diagnostic and. recording in real time the situation inside and outside the vehicle.
The algorithms run on a PC laptop.

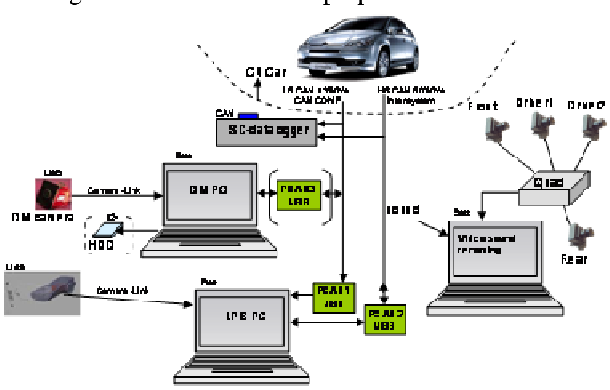

Figure 5: Experimental vehicle architecture

Figure 6 shows the influence of the trip duration information on Driver D10 final DMS-diagnostic. The experiment began at 2:45 PM and its duration was about four hours (only the 4:30 PM to 5:45PM part of the experiment is reported). On the left side figure the diagnostic fusion is reported without the contextual information. Some level 1 diagnostic are appearing. On the right side figure the contextual information is considered. After 2hrs driving, the contextual information is classified has MEDIUM. That’s has a direct influence on the DMS diagnostic increasing the output level from 0 (normal=green) to 1 (medium= orange) and for some of the previous level 1 to level 2 (Critical=red) depending on the value extracted from the defuzzification process.
Figure 7 presents, for Driver D09, a comparison between the the diagnostic achieved by fusion of the physiological, and behavioral diagnostics and the Physiological Expertise provided by the medical staff using EEG and EOG analysis. We can notice that the degradation of the driver state all along the experiment is well detected by the Driver’s Physiological diagnostic. Furthermore the Behavioral Diagnostic detects some critical situations that correspond to unexpected trajectories of the vehicle and then to a driving performance reduction. In that figure, four areas (a, b c, d) have been highlighted. In areas a), c) and d) the physiological diagnostic is detecting a degradation of the driver’s state. This degradation is confirmed by the

behavioral diagnostic that reaches several times level 2. Consequently the final diagnostic is set more times to higher values. In area b) the physiological diagnostic doesn't detect any important degradation of the driver state while the behavioral diagnostic detects some driving performance degradation. As stated in 4.3.1 the role of the behavioral diagnostic is to reinforce the decision taken by the physiological diagnostic. That is well illustrated in these results were it can be seen that the physiological diagnostic is predominant.

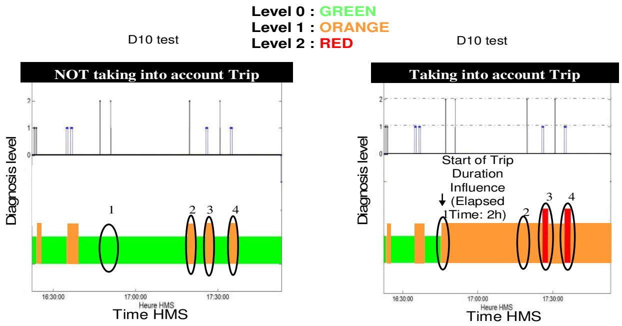

Figure 6: Influence of the trip duration on the DMS diagnostic

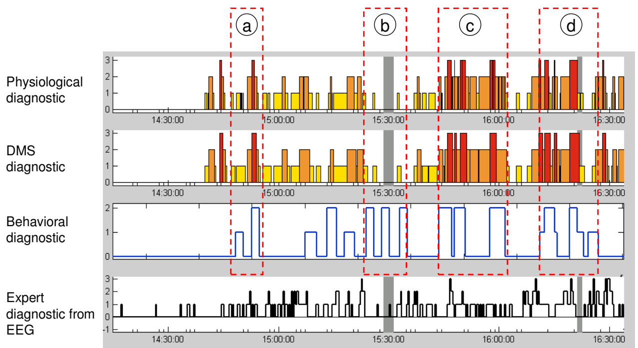

Figure 7: Comparison of experimental results for driver D09

6 CONCLUSION

Driver vigilance monitoring is a complex problem that requires a user accepted system able to measure and interpret the symptoms independently of driver's characteristics, way of driving and environmental conditions. During the last decade Continental has been strongly involved in the development of new concepts and solutions for Driver Monitoring. It has been a key actor in related Eu projects EU projects like SAVE, AWAKE, SENSATION.

In this paper a new and innovative approach that promotes multi-sensorial techniques has been proposed. The fusion of driver's and vehicle behavioural information as well as contextual information is obviously very promising. The experiments performed in real driving conditions with normal drivers have proven its efficiency.

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