THE IMPORTANCE OF DRIVER STATE ASSESSMENT WITHIN HIGHLY AUTOMATED VEHICLES

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ABSTRACT

The EU-funded project HAVEit aims at the realization of highly automated driving for intelligent transport. Within the Joint System approach in HAVEit automation is adapted to the intentions and limits of both of the two members in a Joint system- the driver and a technical co- system. In order to evaluate driver’s performance capabilities it is necessary to online monitor his/her alertness and attention level. If the driver is detected as either drowsy or distracted it has to be decided how to bring him/her back into the loop by selecting the appropriate automation level. This paper presents an approach for online assessment of driver’s state by using a combination of direct measures (e.g. eye lid measurement) and indirect measures (e.g. driving performance measures). A differentiated set of parameters is described that reflects the underlying energetic and attentional processes within the evolution of driver’s state.

KEYWORDS

Driver state assessment, drowsiness, distraction, automation

INTRODUCTION

The importance of driver state assessment within highly automated driving

The EU-funded project HAVEit aims at the realization of highly automated driving for intelligent transport. The developed system should support the driver in overload as well as in underload situations by providing him or her several stages of automation from *driver only* to *assisted* (warnings or interventions in safety-critical situations), *semi-automated* (partial automation of the longitudinal control, e.g. Adaptive Cruise Control) towards *highly automated* (full lateral and longitudinal control).

Especially on higher levels of automation it is of utmost importance to ensure that the driver is in the loop when required so that he or she is able to react properly in a potential critical situation. Unfortunately, it can be expected that automation itself further promotes the development of drowsiness due to the changed role of the operator from an active interactor to that of a passive observer. The evolution of task related fatigue/drowsiness due to the low demands may be the result ([1]). Another problem of higher automation levels might be the subjectively perceived decrease in workload (see literature review in [2]). This may mislead the driver to interact more with other in-vehicle activities. Such distraction might clearly increase reaction time when system limits are reached on which the driver has to react (e.g. [3]).

Direct and indirect measures for online driver state assessment

To identify negatively influencing factors on the driver state, a Driver State Assessment (DSA) device is required which is able to detect mainly driver drowsiness/fatigue and driver distraction online in the vehicle (such devices should be distinguished from those that attempt to identify impaired drivers at trip onset, e.g. see [4]). From the past research within this area several indicators are known that seem suitable to online monitor driver's state. They can be divided into driver related (direct) and driving related (indirect) measures.

Driver related measures refer to *direct* measures of driver state. Most applicable for an online assessment are real-time analyses of the eye gaze and blink process ([5], [6], [7]). Direct driver monitoring techniques are generally using cameras looking to the drivers' face and associated image processing algorithms. For drowsiness detection, they usually refer to a combination of measures such as eye opening level, blink duration and blink frequency. The most often used measure is PERCLOS which describes the percentage of eye lid closure over time [6]. For distraction detection the head, face or gaze direction is used to derive if the driver is looking on or off the road.

Driving related measures are *indirect* activity and performance measures which can be used to draw conclusions about the driver's state. The most often reported effect is that lane keeping performance (e.g. measured by the standard deviation of lateral position SDLP or the number of lane crossings) is heavily impaired with increasing drowsiness (e.g. [8]) and visual distraction (e.g. [9]. The changes in steering activity can be summarized as the following: with increasing drowsiness or distraction the number of phases without micro-wheel adjustments increases (e.g. [10]). After a certain period when the steering error accumulated to a certain threshold the driver has to execute a strong and fast steering correction to keep within the lane boundaries (e.g. [11]).

Most authors recommend to rely on a combination of several measures to reach a higher prediction quality (e.g. [12], [6]). Systems using such indirect measures are for example Driver Alert Control by Volvo [13]) and Attention Assist by DaimlerChrysler [14]).

First approaches for combining direct and indirect measures were made in EU-Projects as SAVE [15] and AWAKE [16]. Especially for highly automated driving it seems necessary to combine the two approaches: On the one hand, it is essential to have direct data from a camera, as the number of available indirect driving related parameters will diminish with increasing level of automation. As the driver is released from performing parts of the driving task he is no longer required to make primary task commands, such as steering and activating the pedals. The resulting driving performance is then an effect of system interventions and is no longer related to driver's state. Nevertheless, also the direct driver monitoring has some constraints, e.g. tracking problems when driver is wearing sun glasses.

THE APPROACH FOR ONLINE DRIVER STATE ASSESSMENT IN HAVE-IT

In the following chapters the approach for Driver State Assessment (DSA) in HAVEit is described in its general principles. The goal is to develop a software module that works online in the vehicle and provides output with reference to driver's state (drowsiness and distraction). Together with a situation assessment that estimates the objective task demands, the general safety-criticality of a situation and the need for automation can be estimated (e.g. the driver is distracted and is approaching a critical driving situation). This information can then be used by a so called Mode Selection Unit (MSU) to decide upon the suitable automation level and appropriate warning strategies.

A multi-level concept of driver state assessment

Driver State Assessment within HAVEit means the monitoring of the driver in order to draw conclusions on his/her current state (long-term reduced arousal and short-term inattentiveness). For the online assessment both direct and indirect parameters will be used. Direct information about the driver will be derived from a camera based system (DMS) provided by Continental Automotive France (CAF) which observes driver's eye movements, blinking patterns and gaze direction. Indirect driver monitoring means the analysis of driver's activity and performance measures that correlate with increasing drowsiness or distraction.

It is stated, that driver monitoring has to be carried out on multiple levels with reference to the underlying energetical and attentional processes that occur in different time frames and correlate with different states and performance levels [7]. It is assumed that a differentiated set of indicators is required to reflect this multi-level concept (see figure 1).

The development of drowsiness is assumed to be provoked by the increasing consumption of energetic resources that are available for performing a certain task (e.g. [17]). The following levels of this resource consumption have to be distinguished: In the "alert" state full resources are available. The driver's behaviour is not influenced in any way. On the next "slightly drowsy" or "low vigilance" level some resources have to be invested to maintain a certain arousal level. This should be measurable by first physiological changes, e.g. in the blinking pattern. Driving performance will still remain uninfluenced on this level (e.g. [7]). Therefore, no indicators will be derivable from driving behaviour on this state. However, some other factors for a reduced activity that promote vigilance decrements can be considered here.

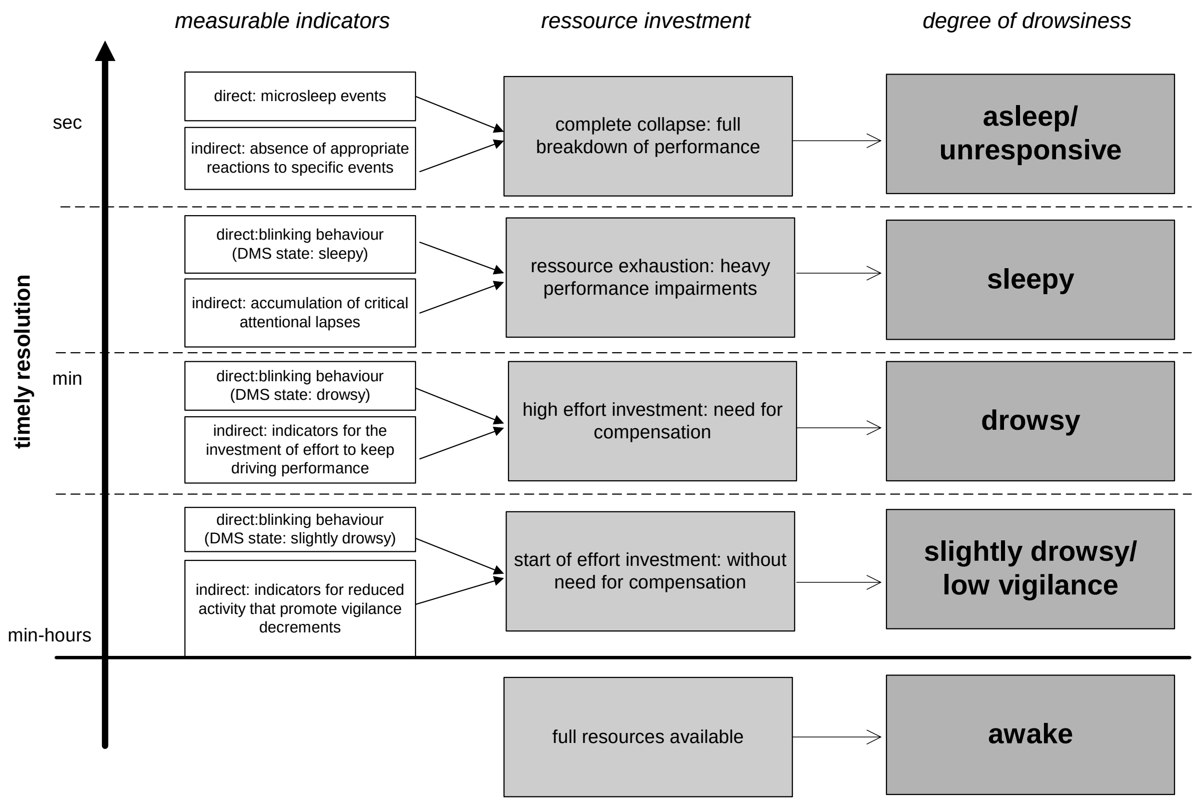

Figure 1: The multi-level concept of drowsiness detection in Driver State Assessment based on several differentiated levels of resource consumption and the correlated degree of drowsiness

Such factors are for example time-on-task (the relative risk for having a sleepiness accident increases heavily after 8 hours driving, [18]), time-of day (e.g. driving at night implies a 4-fold accident risk for a sleepiness accident, [19]), automation level (with increasing automation level the risk of promoting drowsiness increases, e.g. [1]) and the road type (e.g. very low demands on highway promote the development of reduced vigilance compared to driving in the city or on rural roads).

On the next “drowsy” level the driver has to invest a high effort to stay awake and to maintain an adequate driving performance. This effort can be measured again by the observation of physiological parameters, namely the blinking pattern (a higher frequency of medium and long blinks). On this level also first hints from the observation of driving behaviour (over longer time intervals) will be available. On a higher level, energetic resources are exhausted and performance capabilities are exceeded. This “sleepy” state will be observable in even more longer blinks and the accumulation of single critical attentional lapses in driving. On the final level, a complete collapse of the energetic system occurs accompanied by a full breakdown of performance. The driver has fallen asleep und does not longer respond to critical driving situations and e.g. take-over requests by the system.

The observation of distraction can only be made within a short-term range of several seconds where it has to be monitored, whether the driver is not looking at the road and/or is operating some other activities inside the vehicle (e.g. navigating within a complex information system, using the cell phone). It can be expected that the distraction level increases when performing more demanding tasks for a longer time interval. Countermeasures should especially consider situations where the driver is distracted and- in addition - high demands of the driving situation emerge. Due to the limited scope of the paper the approach of driver distraction detection is not further described here.

Derivation of suitable indicators from direct driver monitoring

The indicators for direct driver monitoring will come from the driver monitoring system (DMS) by Continental France that provides an online diagnostic about the evolution of driver’s drowsiness and information about visual distraction (eye on/off road; see figure 2). The function includes a monocular vision system with a CMOS camera looking to the face of the driver. A set of algorithms implemented in a distant processing unit analyzes the image flow provided by the camera in real time. It extracts information about the driver's eyelid, blinking patterns (blink duration, closing and opening durations, blink amplitude) and head position.

Figure 2: CAF Camera for direct driver state assessment

The diagnostic and decision making algorithms analyze the driver's blinking process in a given time frame and provide multi-level information in relation to the evolution of the driver state. Four different classes are used to describe the driver drowsiness level: alert, slightly Drowsy, drowsy and sleepy. They have been selected in accordance with physiologist expertise and the agreement of ergonomic engineers. The visual distraction assesses the driver distraction through the real time analysis of the head pose (eyes on/off the road).

Derivation of suitable indicators from indirect driver monitoring

For the parameter identification from indirect driver monitoring already existing data from a driving simulator study were re-analyzed. Data from 23 drivers driving for 5 hours under monotonous driving conditions (car follow, low curvature, no other traffic etc.) were available. As reference measure for drowsiness the internal WIVW drowsiness score developed by Hargutt [7] was used. It classifies every single blink as either "awake", "hypovigilant", "drowsy" or "sleepy". All classified blinks are then averaged over a certain time window to reach a continuous drowsiness score from 0 to 3. For the algorithm development within HAVEit three distinct classes of drowsiness were defined to separate between an "awake", "drowsy" or "sleepy" driver.

Calculation of parameters

As measure of lane keeping performance the following parameters were calculated:

- Standard deviation of lateral position, SDLP [m]
- Number of lane crossings, lane_cross_n

For the analysis of driver's steering activity the steering wheel angle is processed with 1 Hz. Then Steering Wheel Reversals (SWR) are identified (events where the direction of the steering wheel movement is reversed by a small finite angle). The following parameters are extracted from this measure:

- time difference time_diff between SWR [sec] (mean, number above a certain threshold)
- amplitude difference amp_diff between SWR [°],(mean, number above a certain threshold)
- steering wheel velocity sw_v [°/s], (mean, number above a certain threshold)

Indicators for the drowsy state

Results from the re-analysis reveal that suitable indirect parameters for detecting the "drowsy state" will be the standard deviation of lateral position (SDLP) and several parameters from steering activity averaged over a longer time interval.

SDLP observed in a 2.5 min interval correlates highest among the large set of observed parameters with the mean WIVW drowsiness score (also averaged over 2.5 min intervals). Mean correlation across all subjects was r=.563 (sd: r=.187), more than 50% of all drivers show correlations higher than r=.50. In the next step, it was analyzed how good the parameter might be for classification of distinct drowsiness states ("awake", "drowsy", "sleepy"). In figure 3 upper left it can be seen that the parameter SDLP increases linearly from awake up to sleepy. Therefore, it seems to be useful to identify also beginning performance decrements in the "drowsy" state.
Also quiet promising for online detection of the "drowsy" state are the mean amplitude of SWR, the mean time difference between SWR and mean steering wheel velocity. With increasing drowsiness the driver makes more seldom but larger steering wheel corrections with a higher velocity. Again these parameters seem to be able to cover the whole range of drowsiness, including also the detection of the "drowsy" state. Figure 3 lower left shows the linear increase over the 3 states "awake", "drowsy" and "sleepy" for the mean velocity of SWR.
However, when using these indicators to predict the individual state of each driver (derived from the WIWV drowsiness score) by defining some absolute thresholds (e.g. SDLP >.30m) – it seems that these intermediate stage of drowsiness will be very difficult to detect. Even after an intensive testing of suitable thresholds, only 30% correct classifications could be revealed. This might be due to the high variability between the drivers. It turned out that the reference

of the data to an individual baseline (the first 10 minutes of the drive) lead to slight improvements. For the DSA module it has to be concluded that a baseline-measurement would be useful. However, the prediction of the drowsy state solely based on indirect driving parameters will be not good enough to give clear recommendations on countermeasures. Instead, the consideration of direct driver monitoring is inevitable on this state.

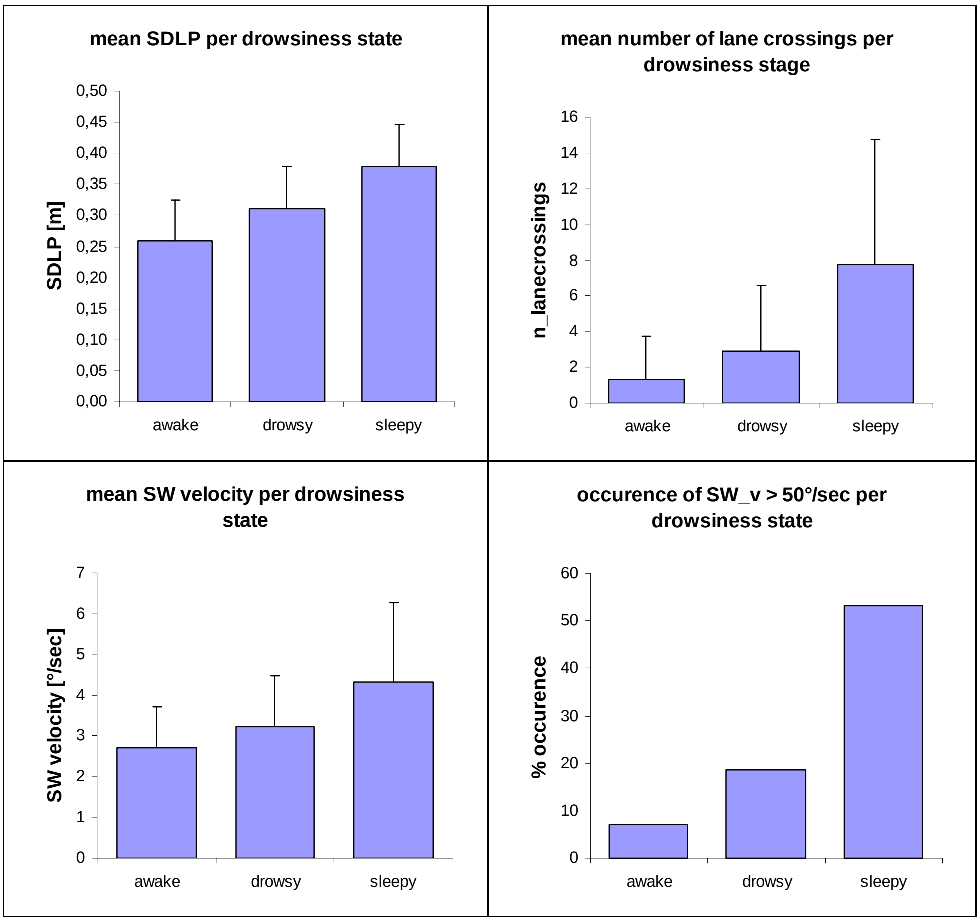

Figure 3: mean SDLP, mean number of lane crossings, mean steering wheel velocity, occurrence of steering wheel velocities > 50°/sec per discrete drowsiness state from the driving simulator study

Indicators for the sleepy state

For the detection of the sleepy state it proved to be promising to observe if several critical attentional lapses accumulate within a certain time interval. E.g. the number of lane crossings rises heavily especially at the sleepy state (see figure 3 upper right). The driver seems to be no longer able to maintain a safe lateral control. Also high steering wheel velocities > 50°/sec (sw_v_50_n) reflecting very fast steering corrections (according to e.g. [20]) occur only on higher drowsiness states and therefore seems to be a reliable indicator for a really sleepy driver (see figure 3 lower right).

Taking into account these two parameters to predict the sleepy state, the prediction rate is quiet high. 70% of all sleepy drivers can be correctly detected. Again, it is expected that the inclusion of direct driver monitoring will lead to better prediction rates.

Factors influencing the confidence of the output

The reliability of the used parameters within the algorithm is dependent from various factors: The output of the direct driver monitoring is mainly influenced by the face tracking quality (e.g. the system has some problems when the driver is wearing sunglasses). The reliability of indirect driver monitoring is dependent from the sensor availability (e.g. are lanes detected, does the distronic sensor and the steering wheel sensor deliver signals?) and the current automation level. Another important factor is the currently executed driving manoeuvre. Especially lane changes and driving sharp curves will be affect lane keeping performance and steering activity. The conclusion is that especially the indirect monitoring components within the module require a manoeuvre detection and classification in order to decide which parameters can be considered in the algorithm and which not. In contrast, the direct driver monitoring is much less dependent from specific driving manoeuvres.

CONCLUSION AND OUTLOOK

To sum up, the main principles for the Driver State Assessment module within HAVEit can be summarized:

- A parallel situation assessment together with driver state assessment for the estimation of the safety-criticality of the situation
- A multilevel concept for driver state assessment with reference to the underlying energetical and attentional processes
- A differentiated set of suitable parameters with reference to their specific prediction quality of separate distinct states
- A fusion of direct and indirect measures for driver state assessment
- A baseline-measurement especially for the calculation of indirect parameters for the drowsy state
- A manoeuvre detection and consideration of current automation level for the evaluation of the confidence of single parameters (especially indirect driving performance measures)

In the ongoing project, the algorithm development will be further specified and validated in driving simulator studies. The development of drowsiness (measured by expert observations and subjective ratings) and distraction will be compared with the output of the DSA module. It will be tested if a classification into several stages of drowsiness and distraction is possible and how the two information sources direct and indirect driver monitoring should be weighted within a fused component for driver state assessment. Furthermore, the effects of countermeasures will be evaluated to give recommendations for the decisions of the Mode Selection Unit (whether and how to change the Automation level).

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