Don't sleep and drive –
VW's fatigue detection technology

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Summary

This paper takes an in-depth look at an innovative driver state monitoring system, which VW has developed to assist drivers. The system is designed to help drivers manage their physical and mental resources properly when they are behind the wheel.

The article begins by explaining the motivation that led to the development of the system and then goes on to discuss the characteristics of the physical and cognitive states under observation as well as the system hardware and software components. The reader is given an insight into the empirical derivation of the prediction algorithm. The article also presents the results of the initial customer survey.

1 The human factor in car accidents

Human error is known to be a causal factor in many accidents. There are, however, various aspects of driver error, and an analysis of these aspects can be used to derive better engineering solutions for human-machine interaction. Various proposals have been put forward as the basis for an analysis of human error including Norman (1981), Rasmussen (1982) and Reason (1990). Human error is explained by shortcomings in perception, interpretation of information, decision-making, information recall and direct performance of an action. However, general physical and cognitive aspects such as attention and fatigue also play an important role, because they affect other cognitive processes. The driver's state has a crucial influence on performance reserves at any point in time and consequently on the conditions that determine the driver's ability to operate the vehicle safely.

Accident statistics provide grim evidence of the effects that driver fatigue can produce. The percentage of accidents caused by fatigue varies between 5 – 25 % depending on the individual study. One essential characteristic of these accidents is the disproportionate severity of injuries, as can be seen from the graph (Fig. 1). The explanation for this phenomenon can be derived directly from the effects of fatigue. When drivers are tired, they fail to take any action at all to avoid an accident (especially braking or steering). Fatigue impairs perception and the ability to make the decision to react, and it also degrades actual performance of the action(s).

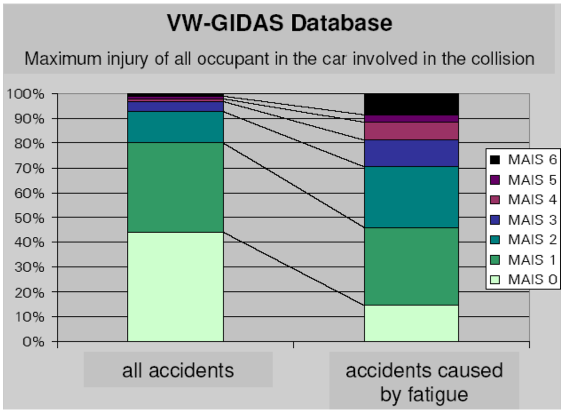

Fig. 1: Maximum injury in car collisions overall in relation to maximum injury in car collisions caused by fatigue

These facts motivated the research team at VW to investigate driver state recognition systems and look for suitable solutions to the problem.

1.1 Driver state recognition as an active safety measure

A whole range of improvements in vehicle design and the provision of airbags and safety belts as standard equipment are safety measures, which have helped reduce the effects of accidents on vehicle occupants in general and drivers in particular. However, it takes active safety measures to actually provide a chance of preventing accidents. Active safety systems, which have proven to be effective such as ESP and ABS help the driver control the vehicle. Driver state monitoring can also be regarded as an active safety measure, because the goal is to evaluate the driver's performance resources. It can provide prospective information to drivers about their condition, and the vehicle can automatically adapt to changes in the driver's performance capabilities. Other driver assistance systems can, for example, provide warning in a more timely fashion to give the driver more time to react.

There are difficulties with the methods that are used to assess the driver's state and the driver's fatigue level in particular. This in turn creates a problem when an attempt is made to test the suitability of fatigue recognition technology. At first, the answer to the question "what is fatigue?" appears to be quite straightforward. However, research on this phenomenon is still incomplete, and it is not possible at this time to provide an exact, quantitative assessment of fatigue. There is no generally accepted "golden rule" and no fatigue metrics that can be used to calibrate a fatigue recognition system (Bittner et al., 2000).

There are also limits to the effectiveness of attention monitoring systems in real-life driving situations. Monitoring the gaze position or head orientation is one plausible method, which can be used to assess visual attention and ensure that drivers have access to essential information. Ease-of-use considerations dictate that the assessment must take place without contact and without the need for calibration by the driver, and this presents an additional engineering challenge. One fundamental problem with this type of measurement is that "looking at something" does not necessarily mean, "being aware of something".

1.2 What do we mean by attention and fatigue

Attention is a concept, which we have all experienced and which seems plausible to us. However, it actually refers to a multi-faceted phenomenon. Attention is an essential prerequisite, which enables a person to select information, which is coming from the person's surroundings, process the information and control action (James, 1890). Attention can be focused intentionally in an attempt to locate information or unintentionally as a result of physical stimulus. Attention can be focused on one specific area, or it can be divided to a certain extent between several areas. Training and factors such as fatigue and motivation can influence the degree to, which attention and cognitive resources can be divided. Another aspect of attention is vigilance, which means maintaining focus. A person needs to be vigilant to perform a task over a long period of time. All of these factors are important for drivers, because they make available the cognitive and physical resources needed to carry out an activity.

Fatigue is another phenomenon that influences a person's ability to perform a task on various levels. Hacker (1989) defined fatigue as a "state in which performance capabilities are temporarily impaired by continual activity demands which exceed the ongoing capacity to restore performance capabilities." A dangerous situation occurs when the driver of a vehicle suffers from psychological fatigue (temporary impairment of information acquisition and processing capabilities).

The effects of psychological fatigue manifest themselves in four categories:

(1) *physiological* (regulation of the vegetative and nervous system)

(2) *cognitive* (perception and information processing)

(3) *motor* (behavior)

(4) *subjective* (experience)

Changes in the first three categories are generally accessible for observation and "objective" measurement, but this is not the case for the subjective experience of a fatigued person. In addition, there is often no direct correlation between "objective" parameters and subjective experience ("Paradoxien des Müdigkeitsgefühls", Hacker, 1980, pp.70ff.).

Because the terms are not clearly defined, the boundary between the symptoms and the effects of fatigue is not well-defined. In practice, there is actually no need to make a theoretical distinction. The symptoms and effects of fatigue can be summarized as follows (Tab. 1; refer to FHWA, 1997):

Category	**Symptoms and effects of fatigue**
physiological	• reduced psycho-physiological stimulation
cognitive	• reduced alertness and vigilance • information processing and decision-making takes longer
motor	• reaction time increases when critical events occur • control reactions are more variable and less effective • reduced preparedness to react

Tab. 1: Classification of fatigue symptoms and effects

Brown (1994) believes that the main effects of fatigue are a progressive withdrawal of attention from traffic and what is happening on the road combined with a more risky approach to decision-making.

Brown (ibid) suspects that reduced alertness is most often the result of eyelid closure, which accompanies fatigue. He also describes another effect of fatigue on drivers as "driving without awareness" (DWA). When road and traffic conditions are not very demanding, the driver's attention is gradually diverted from traffic to distracting thoughts. This state of inattentiveness is caused by the fact that visual search behavior in the presence of highly repetitive and predictable visual stimulus is determined to an increasing extent by internal oculomotor control (top down) rather than by the actual task at any moment in time. Regarding the practical effects of this state, Brown (ibid) concludes that DWA will increase the probability of rear end collisions in particular, whereas the likelihood that the vehicle will leave the road without another vehicle being involved will increase if drivers close their eyes.

Knowledge about how fatigue progresses over time is vital for the development of a fatigue recognition system. Many studies have shown that driver fatigue occurs intermittently. There is not a linear increase in fatigue level when drivers with sleep deprivation are at the wheel for long periods of time. Instead, there is a sequence of episodes involving fatigue and reduced alertness with a general tendency towards increased fatigue (e.g. Hargutt & Tietze, 2001; Bittner et al., 2000; Richardson et al., 1997). These findings are in agreement with "classical" results from general fatigue research, which describe repeated short blocks or lapses during vigilance tasks interspersed between periods of normal performance (Warren & Clark, 1937).

The theoretical explanation for these observations is that fatigue does not develop as part of a passive process. What we actually see is interaction between deactivation processes and compensation processes. A driver can, for example, react when he realizes that he is getting tired and change the way he is driving to compensate for the (perceived or suspected) impairment of his ability to react. As a result, it is much more difficult to demonstrate a fatigue-related decrease in performance under realistic conditions than during "artificial" trials under laboratory conditions. According to Hockey (1993), people adopt a *performance protection strategy* when they are doing something that they perceive as being important. A modified action strategy can to some extent compensate for reduced performance capabilities. Determining where the limits of this ability to compensate lie is subjective and dependent on the situation. The limits vary and are difficult to predict.

As a result of interaction between the deactivation and compensation processes, fatigue manifests itself more as an increasing variability in performance than a steady decline in performance (Dinges & Kribbs, 1991).

The factors, which systematically determine the variation between alertness and blockages from one minute to the next remain unknown. Technology designed to recognize blockages in information processing and the activity of drowsy drivers must be designed to monitor changes continually (Dinges et al., 1998).

A fundamental problem in the validation of fatigue recognition technologies is the selection of a suitable criterion (Hartley et al., 2000). The difficulty stems from the fact that "fatigue" is a vague concept, which is used as a general term to describe phenomena, which result from a variety of factors. Literature published in English uses the following terminology in this context: "*fatigue*", "*sleepiness*", "*drowsiness*", "*microsleeps*", "*attention*", "*alertness*", "*vigilance*", "*hypovigilance*", "*performance variability*", "*error vulnerability*" etc. These terms or more or less used synonymously.

At first, the answer to the question "what is fatigue?" appears to be quite straightforward. However, research into this phenomenon is still incomplete, and it is not possible at this time to perform an exact, quantitative assessment of fatigue level. There is no generally accepted "golden rule" and no fatigue metrics that you can use to calibrate a fatigue recognition system (Bittner et al., 2000).

2 VW's approach to (in)attentiveness and fatigue

As can be seen from the information presented in the previous sections, fatigue in general is a very complex phenomenon. It has been the subject of intense scientific study, and drowsiness at the wheel is a very familiar cause of accidents. Fatigue and the resulting microsleeps are merely a subset of the potential causes of accidents, which can be traced to a lack of fitness or performance capability on the part of the driver. From the pragmatic standpoint, fatigue and lack of alertness and the effects on driving may be summarized under the term inattentiveness. To put it another way, fatigue is one of a number reasons for inattentiveness (Brown, 1994). Inattentiveness is a major cause of accidents and can occur when the driver is reading traffic signs or talking with passengers in the vehicle. Unless an accident or dangerous incident occurs, the driver is unlikely to even notice the inattentiveness. That is one of the reasons why our customers perceive fatigue to be a more significant problem than inattentiveness. Nearly all drivers can remember a situation when they were driving while they were tired whether or not they had trouble controlling the vehicle as a result of fatigue. This means that a system that addresses the general problem of inattentiveness would be more effective in increasing traffic safety. Customers are more concerned with fatigue and microsleep, and media reports tend to reinforce this attitude.

To make a valid assessment or relatively reliable estimate of a driver's fatigue level and provide a timely recommendation for action to be taken before a dangerous situation arises, represents a significant challenge (see section 1). Deciding whether a driver is paying sufficient attention to traffic is far more complicated.

What is the best way to assist the driver, give him information about his condition and help him drive the vehicle? To find an answer to this question, we will start by using a pragmatic conceptual model. How, for example, can we tell whether persons attending a meeting are attentively following what is going on or instead have nearly fallen asleep? We can find out or at least make a reasonable assessment by watching their faces. Are they looking at the speaker's charts at the front of the room? Are they looking out the window or flicking through their notes with a bored expression of their faces? Do they already have "heavy" eyelids that open and close slowly and almost remain closed?

This tells us that one way to assess the fitness level of another person or a driver is to observe the face, head and eyes. We can draw conclusions about a driver's alertness if we can determine what seems to be holding the driver's attention, what direction he has turned his head in or where he is looking. If we can determine whether and how a driver's eyelids are moving or whether they are actually closed, we can assess whether the driver is tired. The VW approach is to transfer this human assessment capability to a technical system, which vigilantly observes the driver.

The on-board equipment needed to monitor and assess or estimate the driver's state is as follows:

- a **video sensor (camera)**, which can provide an image of the driver in all lighting conditions and with sufficient resolution, and **image processing software** as part of the camera, which identifies parameters such as eyelid opening, head position and gaze position.
- a **prediction algorithm**, which calculates or estimates the driver's fitness/fatigue level based on eye closure data
- logic or an algorithm, which accepts the various inputs and provides a suitable output to a **human-machine interface**.

Proposed solutions for a driver state monitoring system, the associated difficulties with the system and the resulting technical requirements are presented below. We will also describe our first on-board engineering prototype and what our customers think of this approach.

2.1 Video sensor (camera) and image processing

We use a video camera, which is suitable for vehicle-based applications to monitor the driver. The camera is positioned so that we can monitor the driver's head and especially the eyes. We want to measure the movement of the head, eyes and eyelids with the aid of the camera. The output should include parameters such as the position of the head with relation to the chassis, gaze position parameters and eyelid data. The change in eyelid spacing (the distance between the upper and lower eyelid) over time can be used to calculate the frequency and duration of eyelid motion and other parameters. Parameters derived from eyelid motion are then used to generate an estimate of the driver's fitness/fatigue level. An assessment of attentiveness is based on head and gaze position.

The on-board system also includes an image processor, which analyzes the images and performs the necessary calculations.

The way in which the camera is integrated into the vehicle is largely determined by the cabin design and the need to position the camera so that it can monitor the head and especially the eyes. The camera's location, orientation and field of view must be adapted to suit the particular vehicle.

Once the system is activated, the image processor reads the data that is sent periodically from the camera and performs the necessary processing steps. The processor must be able to calculate the parameters in real time. The system also includes light sources to provide adequate illumination under all ambient conditions.

The data from the system is fed into a fatigue monitoring system and the result (e.g. a warning) is passed onto a human-machine interface.

The observation camera system mounted in the cabin contains the following components:

- camera
- image processor
- light sources

Similar camera systems and video sensors are already being used in laboratory trials in a wide range of applications. The challenge is to adapt these systems to the vehicle and make them suitable for use in that environment. We also have to be able to produce sufficient quantities of the camera in high volume production.

2.1.1 System components

2.1.1.1 Camera

A camera is mounted in the cabin to supply a video signal, which provides an image of the driver's head, the area around the eyes and certain facial features to the image processor. The camera is connected directly to the processor's video input, and it must meet certain technical requirements including for example adequate resolution, frame rate and sensitivity.

The field of vision must include the driver's face in all seating positions if possible without the need for any camera adjustments. The camera must be able to accommodate variations in the size, possible seating positions and posture of different drivers. Body sizes can range from the 5% female to the 95% male. Possible body and head posture must also be taken into account. The camera must offer a certain depth of field because the distance between the camera and the driver can vary depending on the driver's seating position. The camera's peripheral field of view also must be defined.

Additional simulation and in-vehicle testing are required to arrive at a precise definition of the required field of vision. Fig. 2 shows a sample study.

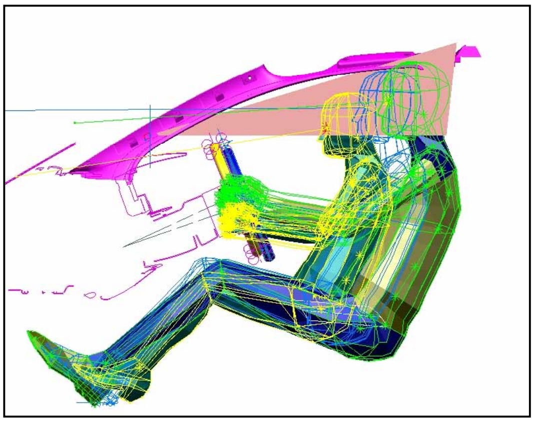

Fig. 2: Example - camera integrated in the A-pillar, Volkswagen Phaeton

2.1.1.2 Light sources

Light sources are needed to ensure sufficient illumination of the object under all ambient conditions. They must be adapted to suit the size and shape of the particular vehicle. The amount of light emitted in the visible spectrum must be so low that the driver does not notice it. The light sources must be safe for the eyes, and they must comply with applicable legislation.

2.1.2 Image processing functional requirements

The cabin-mounted camera system must essentially perform the following functions:

- It must detect whether someone is sitting in the driver's seat.
- It must determine the approximate position of the driver's head in space (x,y,z).
- It must provide current eyelid opening data in millimeters for both eyes. Minor latency is acceptable if an exact eyelid opening value is required.
- A status value should be made available with very low latency. The status should include data on the driver's current position, approximate orientation and eyelid opening status.
- The system must reliably flag measurement dropout or errors.
- It should provide data on head position particularly on the x-y axis (left and right rotation) over a wide range and within a relatively small angular drift. Head orientation in the x-z axis (nodding) over a small range is also important.
- Using the head position as the basis, the next step is to determine the gaze position relative to a fixed, defined cabin element. Qualitative differentiation is required to determine whether the driver is looking at the instrument panel (multi-function control, radio, etc.), looking out at traffic through the windshield on the driver's side, looking through the windshield on the passenger side or looking out the side window. Testing must be carried out to check whether it is possible to reliably determine when the driver is looking at the inside or outside mirrors.
- Capability to perform additional functions such as driver identification would increase customer benefit.

Only specific operational criteria will be added to this long list of requirements.

2.1.2.1 Operational criteria

The functional requirements must be fulfilled in a variety of situations. These operational criteria are essentially divided into ambient criteria and person-related criteria.

2.1.2.2 Ambient criteria

The system must continue to operate reliably regardless of ambient lighting conditions. It must be able to handle the full range of light intensity that is likely to occur during vehicle operation, ranging from total darkness to direct sunlight. The system must also be able to handle rapidly changing lighting conditions (e.g. travel along a tree-lined road with sunlight from the side). On systems that operate in the near-infrared range, consideration must be given in particular to near-infrared interference and the effect of the windows in the target vehicle.

The system is designed for use on the road. Typical vibration must not impair system reliability or cause system failure.

During vehicle testing, the system must operate in the standard test temperature range without any restrictions.

2.1.2.3 Person-related criteria

There must be no dependence on the driver's physical appearance including hair style. Ethnic origin (Asian, African or Central/South/North European/American), sex, make-up and prosthetic changes to the person's face must not affect system performance. We should attempt to provide unrestricted functionality for persons wearing glasses, and this is currently the most difficult image processing challenge. Reflections from the lenses or frame cause errors during image processing and evaluation. The system must be able to measure eyelid spacing through glasses even in unfavorable lighting conditions. It has to accommodate different styles of glasses and lens types (mineral glass, plastic and tinted/untinted lenses) and prescriptions. The only exception relates to sunglasses that filter out a significant amount of infrared light.

2.1.2.4 Measuring eyelid opening

Precision measurement of eyelid movements is a basic prerequisite for determining the driver's fatigue level. The distance between the eyelids is used for example to calculate lid opening and closing speeds, eyelid closure time and blinking frequency. It is also used to determine how wide the eye is opened and other parameters. The system must provide the current distance between the eyelids for both eyes at the camera frame rate. Output must not exceed a defined latency level.

2.1.2.5 Accuracy

The image-processing unit should be capable of detecting the position of the eyelid edges with an accuracy of less than one pixel. Variation in measurement errors is particularly critical. Rapidly changing measurement errors create major problems during fatigue monitoring. Key parameters such as eyelid opening speed are derived directly from the distance between the eyelids, and false discontinuity on the blinking curve leads to very critical measurement errors. Measurement errors that remain constant over time are somewhat less critical. A small, constant offset or factor on eyelid opening data can be tolerated.

2.1.2.6 Quality indicator

It is important that the system is able to recognize and flag unavoidable dropout and large measurement inaccuracies to ensure that the downstream unit that monitors fatigue and detects head and gaze position does not misuse the data or misinterpret it. A differentiated, conservatively designed quality indicator should be used for this purpose.

2.1.2.7 Determining the 3-dimensional position of the driver's head

In a number of applications, it is important to know the approximate position of the driver's head. If possible, there should be no need for ranging sensors other than the camera. When these criteria are met, the camera image along with biometric assumptions (e.g. spacing between the eyes) can be used to determine the approximate distance of the face from the camera. The distance and the position of the face in the camera image can then be used to determine the other two coordinates.

2.1.2.8 Status output

The system should provide a status signal, which is output in real time or nearly so. This is necessary to achieve reliability and an alarm rate, which is acceptable to the customer in a number of situations, which occur when the vehicle is in traffic.
The table below (Tab. 2) shows a sample status value:

Status	Description
Base view	The face of the driver is in the field of view. Both eyes are detected in the camera image
Blink	The face of the driver is within the field of view. The eyes are closed
Turn out of range	The driver has turned his head. The head is still in the field of view, but the eyes are not visible from the camera, and the distance between the eyelids cannot be determined
Occlusion	The eyes are covered by an object, but they are otherwise within the field of view
Lateral out of range	The driver has moved to the side out of the camera's field of view
No person	No one is within the camera's field of view
Measurement error	The face is in the field of view, but the eyes cannot be located

Tab. 2: Output of the driver state

2.1.2.9 Reliability of the status value

The "Blink" status is used to trigger a warning as soon as the driver's eyes have been closed for a certain length of time. Latency must be minimal in order to provide timely warning to the driver. The fatigue level is determined by measuring the distance between the eyelids (see section 2.1.2.4). Latency is less critical here.

The "Blink" status must be highly accurate. If "Blink" remains set for a defined length of time, a downstream unit (a suitable HMI) will warn the driver. Long blinks will lead directly to a driver warning. If the "Blink" status erroneously indicates a long blink, a false alarm would be sent to the driver. The "Blink" status must never lead to a warning if the eyelids were not actually closed for the defined length of time. However, long blinks should always be detected if possible. 95% of long blinks should be detected using the "Blink" status.

This issue presents also a big challenge for the image processing functions. The requirements placed on other status values are less stringent.

2.1.2.10 Calibration

The system design must ensure that no calibration is needed over the system's lifecycle. However, automatic calibration without the need for user intervention is acceptable. There should also be no need for calibration during installation or service. The camera lens aperture angle should ensure that there will be an adequate field of view despite the usual installation tolerances.

2.1.3 Sensor tests and outlook

The requirements we have outlined for an on-board video sensor used for driver state monitoring are partially taken from a standard specification list, which applies to any new electronic component or system, which is to be integrated into a vehicle during the course of the development process. VW has also conducted a large number of tests in-house on video sensor prototypes (Fig. 3 shows an example).

Without going into the details of the trials, we would at this point like to briefly explain some of the problems that still need to be resolved before we can consider widespread use of this technology in vehicle applications.

The sensor system should work with drivers who are wearing glasses. Current image processing systems on prototype sensors have the disadvantage that they generate false interpretations or reflections coming from the lenses or frames. These reflections can be confused with the reflections, which normally come from the pupil, for example, at a time when the eye behind the lens may actually be closed. The frame can be misinterpreted as the upper or lower edge of the eyelid. This could lead to generation of false data relating to the spacing between the eyelids or the gaze position.

Fig. 3: Prototype of a video sensor in a VW car

The availability of the sensor signal in all lighting conditions poses another problem. What we are talking about here is lighting conditions that are related to the weather conditions, time of day (sun low on the horizon at sunrise or sunset) or ambient conditions (e.g. rapid transition between light and shadow on tree-lined roads) and differences in lighting conditions that are related to geographical location.

Whether or not we will see this type of system in future cars depends to a large extent on our ability to find satisfactory vehicle-based solutions, which meet the requirements described above and which eliminate the current problems.

2.2 Prediction algorithm

We will now take a look at the methodology, results and conclusions from trials, which were conducted at VW to determine the driver's state, and his fitness/fatigue level in particular, using eye closure data. An appropriate prediction algorithm was developed and tested in a vehicle application.

2.2.1 Methods and results

The behavior of drivers suffering from extreme fatigue was investigated in a driving simulator during the first phase of the project. In addition to looking at other driving parameters, the study focused on blinking and identification of fatigue indicators.

The pilot study, which ended in 2002, demonstrated a significant correlation between blinking parameters and fatigue. These results were validated in another trial. The wealth of data available from these trials was used to develop a fatigue prediction algorithm, which is based on driving and eye parameters.

In parallel, a prototype sensor was tested and evaluated. Up to that point, complex video analysis was needed to accurately detect blinking. The sensor was designed to perform this function automatically. A prototypical sensor was used to detect blinking. Raw data from the sensor was processed and parameterized during the project.

The algorithm was intended to provide accurate state evaluations for all drivers if possible. The fatigue behavior of a variety of persons was studied at different times. A broad, varied sample of drivers was selected for the study, which roughly represented the population of persons holding driving licenses in Germany. Trials were conducted at various times during the day to ensure that parameter differences, which are related to time of day were identified. Monotonous travel on a freeway was selected to maintain strict control of simulated situations and conditions. Otherwise it would not have been possible to relate parameter differences to a single cause. Thus the results of the study can be generalized to apply to various test persons and times of the day, but it is only valid for a monotonous stretch of freeway.

A third goal was to establish additional fatigue criteria, which were missing from the pilot study. For algorithm training, prediction variables that can be established in the vehicle have to be linked with a fatigue or alertness level criterion. Since no generally valid measurement standard for fatigue exists, three different criteria were established to compensate for the advantages and disadvantages of each criterion. Firstly, the drivers taking part in the study were asked to assess their level of alertness. Secondly, following training on a defined set of observation criteria, neutral observers used video analysis to evaluate driver fatigue. The third “objective” standard was measurement of brain activity (EEG), which was applied in some tests.

A total of 83 persons, who were specifically selected from a large database containing information from responses to an ad campaign, took part in the series of experiments. The participants appeared for testing at three different times during the day: 8 A.M., 1 P.M. and 10 P.M. Each person drove for about two hours on a monotonous stretch of freeway.

The data collected during the experiments was processed and parameterized to provide a basis for prediction models (prediction algorithms), which use a variety of mathematical methods.

The methods used in experiment 1 include:

- threshold analysis
- a C5 decision tree
- multiple regression

These methods were used to construct the prediction algorithms. The approach taken was to use half of the test persons to “teach” the algorithms. The other half was used to test the quality of the predictions. The prediction is retrospectively based on all data collected during the preceding 60 seconds, and it is re-calculated every second (frequency = 1 Hz). Sensitivity and specificity criteria taken from signal detection theory (Green & Swets, 1966) were used to assess the quality of the prediction. To calculate the quality of the prediction, the output of the algorithm is categorized into correctly detected, missed, correctly rejected and false alarm events. Specificity gives an indication of the extent to, which an event was only and exclusively detected when a microsleep phase actually occurred. It can also be expressed as a percentage value for correctly categorized event-free time segments. Sensitivity is a ratio of the number of correctly identified events compared to the total number of events expressed as a percentage.

$$Specifity = \frac{correct\_rejection}{correct\_rejection + false\_alarms} \bullet 100\%$$

$$Sensitivity = \frac{hits}{hits + mis\sin gs} \bullet 100\%$$

Algorithms in this study should have a maximum value for sensitivity and specificity.

Fig. 4 below shows how results were classified. It indicates when a prediction is counted as a hit, false alarm, correct rejection or missing in relation to the 5-minute prediction interval.

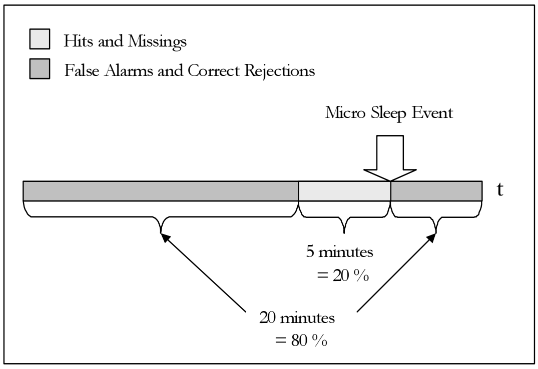

Fig. 4: Evaluation of driver’s fatigue recognition algorithm

Prediction algorithms were developed and tested on the basis of this methodology. The best results were achieved when the results of different algorithms were merged into one consolidated algorithm. This is discussed in more detail in the next section.

Indicator models were developed during the 2002 pilot study. Parameters and their fatigue-dependent variation were systematized. Experiment 1 was then conducted to develop algorithms to predict an immanent sleep event. Experiment 2, which followed in 2003/2004, was conducted essentially to repeat the testing and improve the reliability and validity of the algorithms that were developed during the previous experiment. A further experiment was conducted in 2004 to study the effect of warnings on the prediction quality.

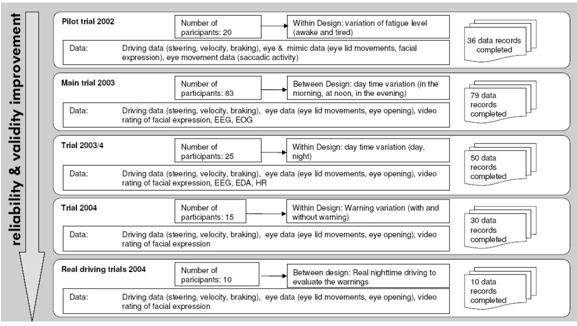

Fig. 5: Empirical basis of driver's fatigue recognition algorithm

2.2.2 On-board implementation

Tests under real driving conditions were carried out to evaluate the data processing and algorithm framework. The general framework is shown in the diagram below (Fig. 6).

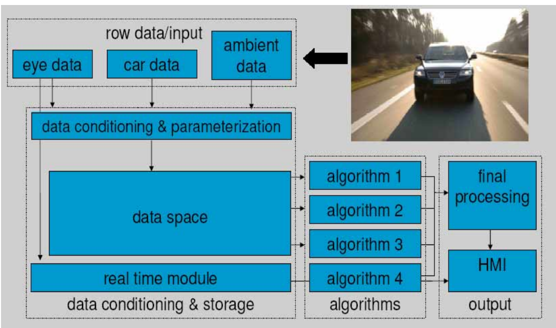

Fig. 6: Framework of driver's fatigue recognition algorithm

Eye data captured by the video sensor was fed into the system. Eye opening as a function of time and the parameters derived from that data are used during calculation of the fitness/fatigue level. Data smoothing has to be performed in order to generate meaningful parameters from the raw data signal. Then compensation must be added for missing input data. After these steps are performed, the quality of the input data is adequate to detect blinking events (event detection). A check should be made to determine the extent to which data from the left and right eye vary. Once eye closing events have been identified, they can be parameterized (the duration of the blinking event or speed at which the eyelid is opened can be determined). The quality of the measurement performed on each blinking event can then be evaluated. The quality assessment is performed during algorithmic processing. Once the significant statistical values per event for the preceding minute have been generated, the data is exported to the data pool and is available to the algorithm modules for further manipulation.

Vehicle and ambient data are placed on the CAN bus (**C**ontroller **A**rea **N**etwork) and fed into the framework. Vehicle data is used to determine activity patterns, which can then be used to perform an additional check of the fatigue prediction. Ambient data such as the time is used to generate the prediction depending on what time of day it is. The prediction takes into account circadian rhythm (our internal time-dependent clock).

Initial development of the prediction algorithm took place under controlled conditions in the simulator. The effect of warnings and feedback on drivers and on the validity of the prediction was also tested in the driving simulator before a test series was carried out on the road.

The results of evaluations conducted on the newly developed warning system under actual conditions were encouraging. The calculation of the quality indicator as well as feedback from test drivers who gave an assessment of the warning system indicate that at the current stage development the system is already producing satisfactory results and is something that customers would like to have.

In principle, the algorithm is transferable to actual behavior in traffic. It is still difficult to capture eye data without error when the driver looks away. This problem was discovered under real-world conditions where more stimuli were present. It did not occur in the carefully controlled environment of the simulator.

It also became clear that the way fatigue progressed under actual road conditions was different from what was observed in the simulator. Drowsiness came on significantly faster in the simulator if the assessment is based on the final fitness value of the prediction algorithm. Subjective self-assessment by the participants indicated that the fatigue level increased over the course of the test drive. Sensitivity and specificity calculated on a minute basis were both above 90 %. These results show that the prototype delivers satisfactory performance.

There is however still scope to improve detection of eye behavior for persons who are wearing glasses. It is also clear that it is not possible to develop an algorithm, which can be used to predict the fitness/fatigue level for the entire driving population. Some drivers do not exhibit the type of behavior, which indicates fatigue to a sufficient extent, and this makes it impossible to develop a universally valid assessment. Results of the testing completed so far indicate that the fitness/fatigue level could be predicted for about 80% of the participants. Ways in which a warning could be issued to the rest of the drivers when microsleep incidents occur are outlined in Section 2.3.

2.3 Other applications for a camera mounted in the cabin to monitor the driver

For this group of less-predictable drivers we are looking at various scenarios and strategies to generate a benefit from the fatigue/alertness assistant.

One possibility is to develop a long blink or doze-off alarm (please refer to section 2.1.2.8). The fatigue/fitness level can be used to produce a warning before the driver falls asleep. In contrast, the long blink or doze-off alarm does not produce an alarm until the eyes have remained closed for a predefined length of time. A high frequency is not needed to determine the eyelid spacing sequence. The system needs “only” to determine whether the eyes are open or closed. However, this decision must be made in a very short time, because a warning must be transmitted to the driver as quickly as possible. The danger for the driver and others becomes acute once the eyes have closed. False alarms are not acceptable, because this would significantly reduce confidence in the system and thus customer acceptance. This scenario places high demands on the image processing function, which must be very precise and accurate. Other scenarios, which make use of the camera in the cabin to monitor the driver, are shown in Fig. 7. The goal is to provide more information on the driver’s alertness by determining the head orientation and gaze position.

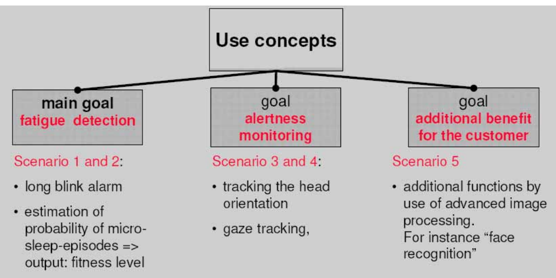

Fig. 7: Use concepts for an in-cabin camera

These use concepts will not be presented in more detail in this paper because the applications are still under development.

3 What does our customer want? Some results of a customer opinion survey

It takes more than a demonstration of technical feasibility to achieve a successful transition from a research project to a product strategy and from there to volume production. Creating a link to the customer and the market is at least as important, and this is why we used marketing techniques to include customer preferences and requirements in the project. In collaboration with our market research and product marketing teams, we designed and carried out an online questionnaire-based survey. The advantage of this type of study is the ability to survey a large number of customers in a relatively short period of time. The disadvantage is that, despite the use of today’s computer and animation technology, the respondents only get a virtual impression. The customers have not used the product or experienced its features, and they can only evaluate the concept. The responses do, however, provide information about expectations associated with the product. They also identify any aversion to this type of technology and shed some light on the reasons behind this attitude.

In the summer of 2004, a standardized online interview was used to survey 431 Volkswagen and Audi drivers in all product segments. The table below (Tab. 3) shows the details of the interview sample.

SEGMENTS	A	B	C	D	MPV/A-MPV	NFZ	TOTAL
Targeted sample size	80	80	80	40	80	80	**440**
Actual sample size	83	83	82	37	81	65	**431**
Sex Male (Female) [%]	59 (41)	71 (29)	66 (34)	84 (16)	62 (38)	89 (11)	**70 (30)**
Ø Age [years]	29	33	36	49	35	42	**36**
Private car (business car) [%]	78 (22)	84 (16)	74 (26)	54 (46)	86 (14)	60 (40)	**78 (22)**

Tab. 3: Sample population

In very general terms, the goal was to solicit opinions from our customers on the alertness/fatigue assistant. Various usage models were presented (refer to Fig. 7). Scenario 1 was given the working title “doze off alarm”, Scenario 2, calculation of the fatigue/fitness level, was called the “fatigue detector”, Scenarios 3 and 4 together were called “alertness assistant”. The scenarios 1 and 2 were the best accepted ones by the customers surveyed, because they were expected as the most helpful functions. The approval level for the alertness assistant was also high, but clearly behind the doze off alarm and the fatigue detector. Respondents were allowed to select more than one item. Another question is whether customers accept the idea of having a camera in the cabin to monitor the driver. They were specifically asked whether they would accept a camera to assess fatigue/alertness and if necessary infrared light sources in the vehicle as well. Over 80% of customers surveyed think that a camera and the necessary infrared lighting in the vehicle are a good idea. This means that only a minority of those surveyed rejected the concept.

Finally, we can say that there is demand for a fatigue/alertness assistant in markets where there is high customer acceptance of technology, such as Germany. There is a need to take a critical look at the expectations that customers place on this type of system. Customers have indicated that the doze off alarm is more important than the fatigue detector. This function should be available on the system to ensure that customers believe that it will provide tangible support.

Authors' note:

The technical requirements and specifications regarding fatigue detection and monitoring outlined in this paper reflect current thinking based on research activities conducted to date. These requirements are subject to change based on ongoing and future research and development efforts in technical disciplines as well as in the behavioral and medical sciences. The development of such systems is necessarily an iterative process that can be described only in broad terms. Individual results over time will determine the nature and content of specifications that can form the basis of production systems.

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