FATIGUE OF CAR DRIVERS - DETECTION AND CLASSIFICATION BASED ON THE EXPERIMENTS ON CAR SIMULATORS

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Abstract: - The paper discusses the problem of drowsiness and phenomenon of microsleeps of healthy drivers. It describes our experiments done on our driving simulators. First there is a brief description of simulator which was used for the experiments, its capabilities and necessary changes which we did so that it fits best the needs of such experiments. The paper presents requirements on the overall design of experiments performed on driving simulators. It describes requirements on the design of the testing tracks and our experiences with measurements. The results of classification based on EEG, video record expert analysis, steering wheel correction movements, lateral position and average velocity change trends and weaving and drive out from the lane are presented. Finally discussion on analysis methods used for investigation in driver's drowsiness is done.

Key-Words: - Driving simulators, car simulation, drivers' fatigue, sleepiness, simulator experiments

1 Introduction

The problem of sufficient attention of a human operator is still in the top of the interest when dealing with reliability of human operated systems [17]. In fact the human operator is generally considered as a weakest link of the HMI systems, unless those are operated fully automatically. There is very good progress in automation of the driving of transportation means in general but in the field of automotive industry (mainly in case of passenger cars) the human driver still plays indisputable role. Those facts imply that passenger cars will be operated by human drivers at least for next decade(s). From that reason there is still a strong need for reliable system which can monitor the level of human driver's vigilance (for example [1, 2, 10]). For development and further testing of such a system a huge amount measurements are required to be performed. Advanced driving simulators were approved to be very suitable for that task.

Sleep onset process ("hypnagogium") and its patterns in the EEG are generally known, but their measurements are mainly focused on people with sleep disorders, few on healthy people. We can say that certain part of demonstrable healthy people have slight (up to significant) abnormalities in their EEG. From that point of view it seems to be reasonable study this methodology (i.e. characteristic changes in EEG) with respect to each subject. Generally valid classification seems to be problematic and it will require certain knowledge about each particular user.

Our experiments, done on car simulators, consist of measuring (and synchronous recording) of majority of commonly used biological and technical signals used for fatigue detection (like trajectory, speed variability, steering wheel and pedals movements, ECG and heartbeat variability, EOG [1, 8, 9], EEG [4, 5, 6], driver's face video recording, driver's self report [3, 7] and reaction time on various stimuli). EEG shows to be a reliable indicator of drowsiness [11]. The amount of activity in different frequency bands can be measured to detect the stage of drowsiness or sleep (for example [4, 5, 6]). From our point view, the brain waves changes seem to be one of the most direct and fastest markers of the human vigilance level [14].

We did measurements of almost a hundred people in microsleep related experiments either with use or without use o car driving simulators and twice more in other kinds of experiments performed on car simulator with drivers equipped with EEG recording. Unfortunately their analysis is not always feasible and hard to be done automatically. Majority of studies reports significant changes in the alpha band, or/and delta and theta bands but sometimes their results are in contradiction. This could be caused by improper selection of analyzed data. Data from real drive are usually full of muscle and other artifacts. Even more the microsleep episode could be very short and their pattern in EEG changes fast, so it is not easy analyze data of different vigilance state. Our approach has been done on probands not interacting with car or simulator was to apply advanced analysis no pieces of data precisely adjusted with reaction time measures [12, 13] using only the 'clear' EEG data.

1.1 Sleepiness from medical point of view

Although sleep have attracted human interest since the dawn of history, it has only been in the last 30 years that physicians have recognized the importance of sleep related problems and sleep disorders, and no more than 20 years since objective diagnostic procedures have been routinely employed for their diagnosis. This rapidly growing field attracts physicians from diverse disciplines, such pulmonology, internal medicine, psychiatry, neurology, otolaryngology, pediatrics, and even dentists, all of whom are now becoming sleep physicians after appropriate training. A normal individua obtaining adequate sleep should be able to maintain wakefulness during the day with little to no difficulty. People with hypersomnolence, with microsleep, as opposed to fatigue, often fall asleep unintentionally. The tendency to fall asleep can be quantified both subjectively and objectively in general. Hypersomnolence results in several consequences, some of which resemble those of sleep deprivation. Microsleep is usually associated with sleep apnea syndrome. But similar behavior can be seen in shift workers or common people who are after sleep deprivation from any reason.

2 Experiment setup

2.1 Simulator

Currently our laboratory use three simulators which are steady based ([15,20], see fig.1) and one motion based (still in development). The simulator which we used for this experiment is the steady based, fully interactive composed of full car body. It is equipped with system of measuring devices and in-car/out-car video recording system. The field of view was intently reduced to 80°, so that a portion of people suffering from simulator sickness is lowered (1%). See figure for the reference (fig.1). The simulator was originally built by German company VRtiment [18] and later on rebuild in our laboratory to better satisfy needs of our experiments.

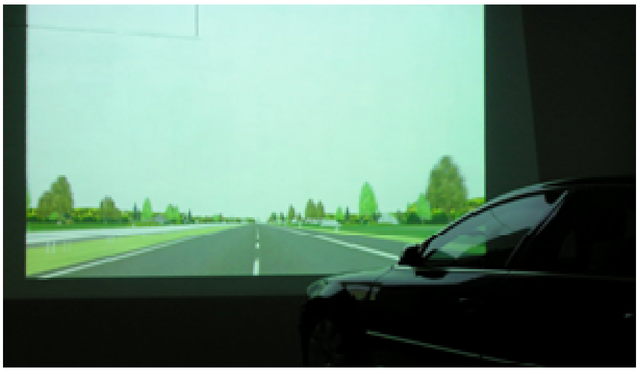


Figure 1: Compact simulator type I

Comparing to another type of drowsiness experiment, which was aimed to obtain driver's reaction times testifying of driver's vigilance level [20] which was conducted on our 'light' simulator, we preferred here to give the driver most realistic feelings from the car interior (this include also sound damping properties of the car cabin) and no distortion during the simulated driving.

2.2 Data collection

During all the measurements of the experiment the technical and psycho-physiological data were being collected [15]. All the data needs to be synchronized in a sufficient manner so that it would be possible to do a correlation analysis over them. The synchronization is realized via central logging application which gathers all the time trigging signals from all the measurement devices including the simulator all connected with RS232 links. This appears to be sufficiently precise [15]. Following data going into further analysis:

- *Technical data:*
  - *Trajectory and geometrically ideal path*
  - *Speed in sense of car heading*
  - *Steering wheel absolute angular position*
  - *Video record and its expert analysis*
- *Biological data:*
  - *EEG*
  - *EOG*
  - *Heart beats*
- *Questionnaire*

The next picture (fig. 2) shows the tested driver equipped with the EEG cap, EOG electrodes and heart beat recording.

Figure 2: The tested driver equipped with heart beat recording, EOG electrodes and the EEG cap

The measurement devices were developed by Alien technologies [21]. EEG was managed in standard 10/20 setup, heart beat electrodes were placed on both driver's wrists. The biological outputs were recorded with sampling rate of 128 or 256 Hz. The record from simulator is 100 Hz but for analysis it was reduced.

2.3 Testing cohort

The experiment was done in two stages. First one – the preliminary testing – used mainly for necessary methodology design. There were 39 person tested. The testing cohort consisted of drivers in between 20 and 39 years of mixed sex (82 % of males). Average age is 23.3 years and variance is 9.3 years. They are the common passenger car drivers with average driving experience but not professional drivers. They had to have normal EEG record and no apparent sleep related diseases. (Not all the drivers could be involved into EEG analysis because of artifacts appear in their record.)

All the probands have to pass preliminary tests. Except of adaptation laps on the simulator they had to pass anamnesis questioners and standard neurological test (equipped with EEG cap). Requirements on testing drivers can be summarized as follows:

1. *The experimentees were after at least 24 hour sleep deprivation*
2. *Experiment was peformed in the morning starting at 9 or 10 o'clock*
3. *They did not have consumed any drugs (alcohol, medicines…), coffee of other exciting agents.*
4. *The length of the drive varies between 2 and 2.5 hours, depending on development of his/her condition.*
5. *Before and after the testing drive the experimentees pass standard neurological tests including 3 types of mental load. Those serve mainly to recognize if the experimentee's brain is of "standard type" and to discover possible illnesses.*
6. *Before measurement they are asked to fill up detailed questioner concerning their sleep habits*
7. *Before and after the measurement they are asked to fill up testifying about their actual state*

2.4 Testing track

One of the most important factors which influences the usability of data obtained from experiments performed on a driving simulator is a design of testing tracks [15, 16]. Our approach follows standard setup of boring highway scenario with minimum or no interactive traffic. Such a setup should assure that all possible outer factors influencing the driver performance are diminished and all the driver's errors can be consequently considered to be caused with his/her inattention. This inattentiveness could be of several different origins but in the case of our experiment it's assumed that it is caused predominantly by drowsiness and/or microsleep occurrences. The tasks which the driver normally solves are reduced to speed-keeping and lane-keeping. From that reason the track consists of mainly almost straight parts and curvy parts which radius is minimally 1500m. Following table describes structural design of the whole testing track (Tab. 1).

Table 1 Types of part and their lengths

Type of part	Length [Km]	[%]	Radius[m]
Straight	105,0	33,8	0
Left curve (light)	38,5	12,4	6500
Left curve (easy)	42,3	13,6	1500
Right curve (light)	66,5	21,4	6500
Right curve (easy)	58,2	18,7	1500
Total	310,5	100,0	x

3 Analysis

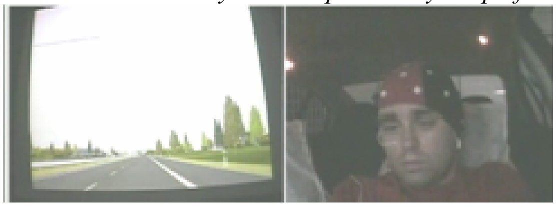
The above data were analyzed after an election process, where poor quality data, incomplete data and/or data being unfeasible to be classified using each particular method were excluded. All the probands' EEG records and anamneses were assessed by neurologists. Unlike in other type of experiments which we put reaction time (measured on brake) as a measure to which other measures were correlated [20] in the experiment being described here we do not rely on any direct measure of response time.

3.1 Expert video analysis of drivers and behavior

The offline expert analysis of a driver's face and hands video record had seemed to us very promising. Unfortunately, such an evaluation is very subjective either from the side of the expert or from the side of the subject. Because of this fact the expert evaluation serves mainly for finding specific patterns, which are further used in the EEG analysis. From the experience we decided to watch three significant patterns (fig. 3):

1. Drivers who are in high vigilance level - usually at the beginning of an experiment).

2. A "nod" off – when the driver gets into very short sleep and he/she is immediately woken up - usually drop of his/her head.



3. Serious lost of control. This state comes when the driver is so drowsy that he/she is unable to fight against upcoming sleep. Such a situation often ends by an accident.

Figure 3: Pictures of probands in different states of vigilance

3.2 Unintentional lane changes accidents

We performed several tens of measurements. Every record from simulation engine contains actual car position in each simulation step. We computed instantaneous differences from geometrically ideal path (reference curve) and founded the regions where the driver unintentionally deviated from his lane into contra lane or shoulders. Those events were then correlated with video record (facial expression). The parts where the drivers deviated intentionally were rejected from further analysis.

3.3 EEG activity

We tried to look for differences in alpha, theta and alpha/delta ratio between "drowsy" and "fresh driving". The result is quite uncertain. One of the reasons could be that many of samples had to be discarded due to the artifacts in EEG signal and it did not give enough representatives for good statistical analysis. This method of picking of the samples in time just before the stimulus perhaps suffers from significant aliasing. For statistical evaluation again a T-test was used. The following tables (Tab. 2) shows same examples of finding, there is in some cases significant of difference between "fresh" and "drowsy" driving on O1, O2, T5 and T6 electrode (10/20 system). It is possible to preliminarily conclude that some of drivers show increasing power of alpha bands which is accompanied with decrement of ration alpha/delta band. Unfortunately there is no statistically approvable difference which is static over the whole measurement. Note that sampling of analyzed samples was done for all the microsleep occurrences derived either from video record or trajectory analysis. Only those which were affected with artifacts were excluded from analysis.

Table 2: Significant increase (+), decrease (-) and no significant difference (x) on electrode O1, O2, T5, T6, columns mark proband evidence number

O1	8011	8056	8106	8403
θ	x	x	x	+
α	x	+	x	+
α/δ	-	x	x	x

O2	8011	8056	8106	8403
θ	x	x	x	+
α	x	+	x	+
α/δ	-	x	x	x

T5	8011	8056	8106	8403
θ	x	x	x	+
α	x	x	x	+
α/δ	x	x	x	x

T6	8011	8056	8106	8403
θ	x	x	x	x
α	x	x	x	+
α/δ	-	x	x	x

3.3 Trends of certain variables over the whole experiment

Because of the fact that the driver was not distracted by any stimuli, it is possible to classify trends in his/her behavior. The measurements of each one participant were pretty long. It took around 2 to 3 hours. When driving for such a time is recommended to make take a break in real life driving and off course in normal state of vigilance (i.e. without sleep deprivation). From that point it is possible to consider the experiment lap in the same manner as a drive period in reality.

3.3.1 Average speed trends

As one of the measures which could testify about the development of driver's actual vigilance level and consequently about his/her ability of safe driving we can consider keeping of required car speed. The drivers were instructed to keep the speed of 130kph. Moreover they are periodically (approximately each 700 m) evoked by common traffic sign 130kph. Over the all testing track are approximately 450 traffic signs.

Unlike the real-life situation the drivers had no reason to deviate intently form predefined speed, over more we excluded any situation requiring speed changes from the experiment. There were no traffic, no obstructions, sharper curves, all the time "free to drive" highway scenario and consequently no objective reason for speed fluctuation except of driver's inattention. Even those, all the tested drivers demonstrated slight fluctuation of the speed and general trend. We can differentiate 4 groups of drivers' behavior:

- *Continuous increase (fig. 4)*
- *Steady behavior or decrease (fig.5)*
- *Driver cannot keep the speed in 'reasonable' boarder / goes much faster than required*
- *Experiment was interrupted – excluded from analysis*

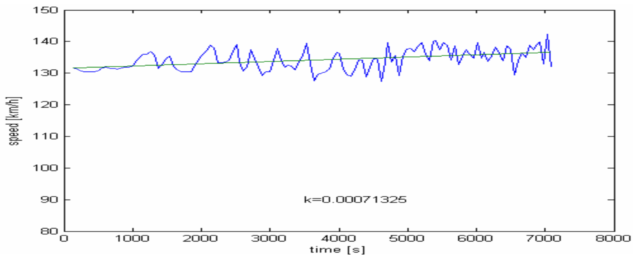


Figure 4: Average speed trends (increasing trend)

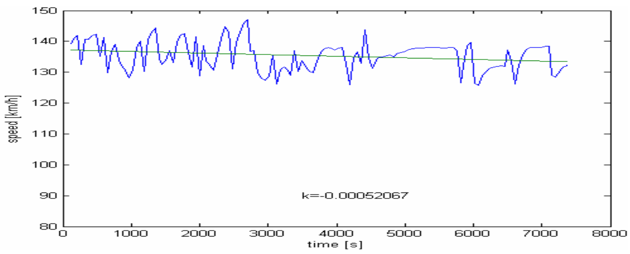


Figure 5: Average speed trends (non-increasing trend)

The following table (Tab. 3) approves that there is a general increasing trend in average speed within a majority of tested drivers. The experiment, which had been interrupted during the measurement (due to any reason) were excluded from final evaluation.

Table 3: Percent occurrence of groups

Continuous increase	Steady behavior or decrease	Driver cannot keep the speed
60,87%	17,39%	21,74%

3.3.2 Steering wheel correction movements

Number of correction movements done by driver on the steering wheel was counted with respect to time. The following graphs (fig. 6,7) show a percentage of the fast corrections (bigger than modus of all corrections) related to all instant corrections. From a linear regression analysis it is possible to derive that 81,48% shows increasing trend in this measure meanwhile only few drivers (18,52%) showed decreasing trend. This approves the hypothesis that the correction movements are more apparent and faster with drivers' drowsiness (expected to be getting worse during experiment) [19].

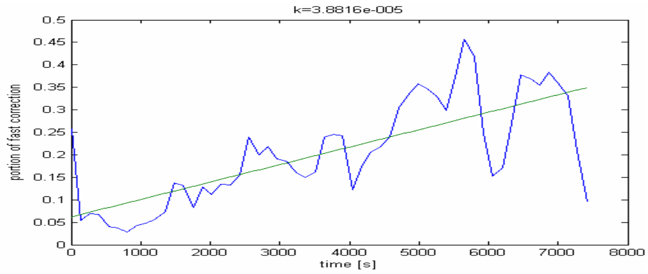


Figure 6: Examples of ratio of fast and slow steering corrections during the whole measurement (increasing trend)

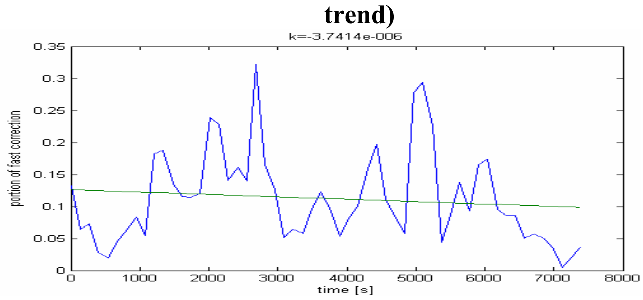


Figure 7: Examples of ratio of fast and slow steering corrections during the whole measurement (non - increasing trend)

3.3.3 Trajectory to lane center position

In the research of driver drowsiness on simulators the trajectory keeping and weaving are frequently analyzed. Lane departure is very useful when finding serious driver's state but not suitable for statistical analysis. We looked mainly for overall variance. From the contemporary research it is also possible to say that the movement of car within the lane borders (originated in steering wheel movements) could be promising marker [19]. It is possible to conclude that majority of tested driver's shows increase of "weaving" around geometrically ideal trajectory, corresponding with increase of drowsiness. It is up to 3 times greater in amplitude comparing with non-drowsy ones. Very drowsy drivers demonstrate much higher amplitude of necessary steering corrections by the end of measurement than relatively fresh in the beginning of measurement. The following graph (Fig. 8) shows example of trajectory fluctuation around geometrically ideal path ('weaving') during the time of whole experiment.

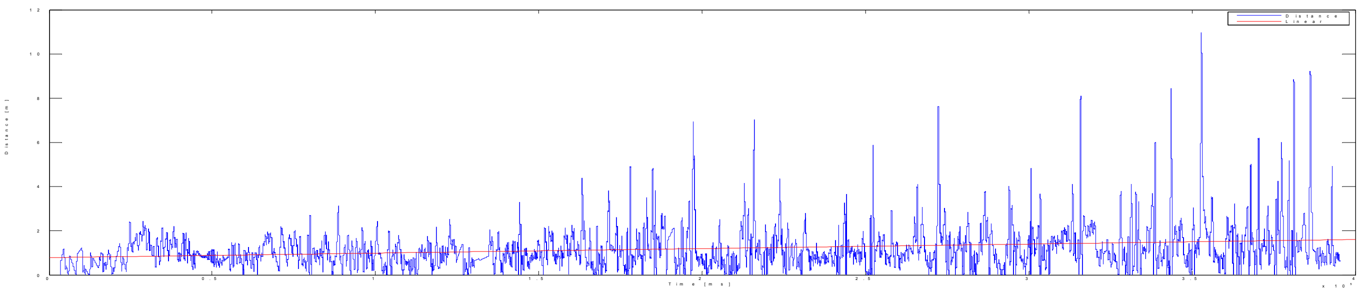


Figure 8: Deviation of a car trajectory from geometrically ideal path during the whole experiment. (Blue curve instant deflection in absolute value; Red – linear regression)

4 Discussion and conclusion

The expert analysis of face video record gave very good and objective results. Unfortunately people behave very differently and have generally diverse behavioral patterns from one another when drowsy. Even more those are different over the time for same people. Values which averagely change with time spent with driving ('trends') which we can see for example in average speed can also give us interesting results as long as we know that they are not influenced with outer factors. This is hard to be applied in real cars. The EEG shows different features in assessment of drowsiness levels when experiments are done without a mental load and when performed on driving simulator. More over it proves much faster dynamics in this case. It leads to notion that simple criteria dealing replacements of basic rhythms are applied from neurology are hardly applicable here.

Concerning the testing virtual track, proposed design in general satisfies well the needs of the experiment. One problem is coupled with long and totally strait parts, where the simulated car can drive correctly without any driver's effort. It serves well for experiments with traffic light stimuli [20] but here we can hardly detect driver's inattention. Therefore for further measurements those long straight stages are not suitable until the road model could provide dynamics of real car driving.

We tried to use several methods of classification of the driver's abilities of safe driving with minimum distractions, so that he/she can drive under condition close to real-life conditions when the danger of microsleeps is highest. Unfortunately it seems that those criteria do not 100% match the criteria for assessment of driver's vigilance. Sometimes the driver can drive safely and with sufficient attention paid on driving even if very drowsy and vice versa. It could be explained by different driver's skill and personality. We must of course take into account error caused be different ability to adapt to different type of car (than the driver use normally), even more question of adaptation on virtual environment can influence results a lot.

From that reason it is should be better to take into classification mainly those measures which do not directly depend on technical aspects of driving itself, but they rather derive driver's state from independent measures. From that point the EEG measurement combined with some other objective measure has great potential mainly thanks its directness and reliability. This of course requires such a device to be as less annoying as possible (ideally touch-less or at least equipped with one or two dry electrode) so that it would be accepted by users.

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