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# Complex analysis of outputs from driving simulator experiments focused on drowsiness detection

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*Abstract:* - One of the most serious problems concerning car safety is a driver's attention decrease and fatigue which could lead to the micro-sleep. For development of a warning system, which is able to detect driver's inability to drive safely, it is necessary to have a complex knowledge about the processes inside driver's body and mind. From that reason it is needed to perform plenty of experiments. Our laboratory investigates in actual driver's state mainly using the means of brain activity measurements (EEG analysis) and other additional biological signals. The EEG measurements are very sensitive to environmental influences. On the other hand it is necessary to put the experimenting person into the environment which is as close to reality as possible. Usage of car simulation devices appears to be a good compromise. The paper describes design of the experiments, scenarios and tracks, based on a knowledge obtained from a good ample of already performed measurements. The paper also shows certain results form the analysis of biological signals (mainly EEG and ECG) correlated with analysis of the ride and subjective ratings.

*Key-Words:* - Simulated driving, Drowsiness, Micro-sleeps, EEG, Driving Simulators

## 1 Introduction

The human operator needs a constant vigilance to work reliably and safely [1] [3]. Unfortunately, humans cannot reliably classify their sate, mainly when they are extremely drowsy. In the *Joint Laboratory of System Reliability*, we work on projects dedicated to the analysis and prevention of the operator's attention decrease and micro-sleeps[1]. One of the very promising methods that can be successfully used for micro-sleep detection (and prediction) is the analysis of driver's EEG[2] signals.

The EEG signals arise from an activity of neurons of the thalamus and cortex. A normal EEG signals are quasi-periodic, but they are approximately of a sinusoidal shape. The amplitude of the EEG signal is usually between 10 and 100, which varies with frequency. The frequency range is from 0 Hz to 80 Hz, the effective range is limited approximately to 30 Hz. It's measured on the scalp of the driver's head. It is possible to say that we can (at least manually) detect from the EEG the actual driver's mental state (condition) and derive if he is about to fall into micro-sleep.

The final goal of this research is to design and to develop a real-time warning system, which could be used in real cars. Such a device should be used mainly by professional drivers, truck drivers and rail engine drivers. From that reason it is necessary to measure a big amount of people of different types and ages. The research in the field can still bring a lot of new knowledge, since the ways of reliable and objective detection of driver's state are not yet know. In a literature we can find mainly investigation dedicated to sleep diseases and influence of drugs or medicines. The analysis of brain waves of healthy people during getting sleep is not too interesting from the point of medicine and from that reason there are not so much up-to-date studies on this topic.

## 2 Drowsiness experiments

The experiments that has been done in our laboratory are aimed to find patterns in brain waves that determine human's drowsiness level. Those patterns will be than used as an input of an automatic classifier of an actual driver's state (i.e. level of his attention which could be paid on primary driving tasks). The most interesting from that point is finding patterns preceding a micro-sleep. The procedure of getting asleep was divided into four stages [1]:

1. ***vigilance***
2. ***relaxation***
3. ***somnolence***
4. ***micro-sleep (or first stages of sleep)***

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[1] Under the term "micro-sleep" we understand an event of total lost of driver's control over the car (which is similar to the sleep) for at most several seconds

[2] Electroencephalography

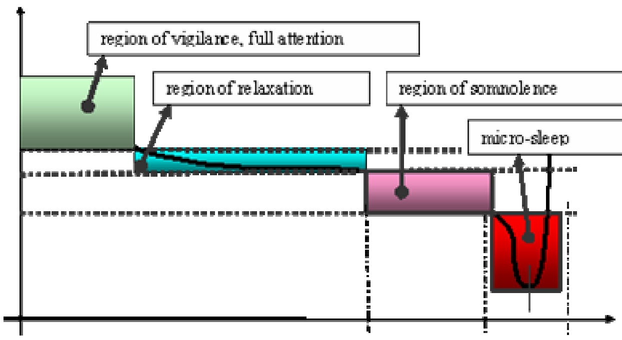



**Figure 1: Theoretical development of the micro-sleep [1].**

Micro-sleep development how described by our neurologists [1] shows picture Figure 1.

In a general case the above described stages have their specific images in the EEG (in frequency space). Such well recognizable patterns are achieved from the records measured on probands getting asleep in an armchair, relaxing, with closed eyes and without any disturbance (except a beep signal for reaction time detection). See figure 2, where four clear examples are shown. When the proband is forced to do some mental work (i.e. driving on a simulator) the situation becomes much more complex.

Spectrum of EEG (by [5]) for the states of:

a) Vigilance (CE closed and OE opened eyes) b) Thinking (Raven's test)

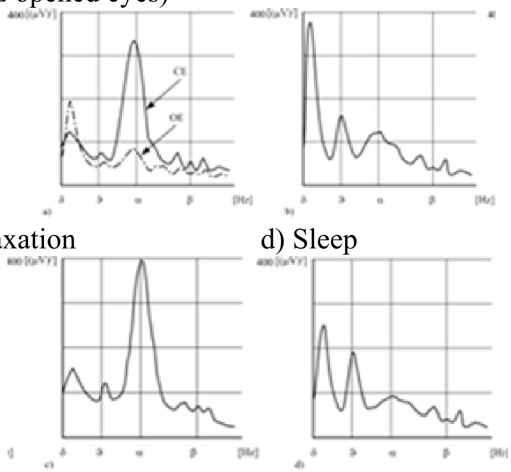



**Figure 2: Spectrum of EEG for different states [5].**

Experts form our laboratory work on different ways of analysis of the EEG - starting from classical frequency analysis, with advanced fuzzy classification [5], nonlinear methods like LLE (Largest Lyapunov exponent), chaotic attractors [4,8] or classification using neural networks [9].

# 3 Car simulator approach

The experiments on our driving simulators have been continuously performed for almost three years. The initial experiments used to be done using a very simple simulation device. It was composed from car simulation software and an advanced stock gaming steering wheel with pedals, force-feedback and a very large TV screen. Unfortunately the probands reported to by very confused with unrealistic driving feelings. They were too much excited by demanding driving which was far from the routine driving. This bad results resumed in usage of real simulators composed from real car parts and large screens.

## 3.1 Car simulators

Currently we have two simulators operating and one in development. All of them are based on the body parts of current middle class European passenger cars. A "compact" simulator was built by a German company VRtiment [6], second which we called "Light" was build in our laboratory as a prototype (its simulation engine is based on rebuilt old version of freeware car simulator [7]). We had to incorporate the simulation system into set of measuring devices and also support of creation of sceneries using real (GIS-based) data. The reason to create our own simulation device was that we had needed a very flexible system which could react on the sudden requirements of the experiment. A need to be adaptive, forced us to hold a development of car simulators in our hands. From the experiences from the prototype we designed new simulation device. This is now in development, it is based on distributed and modular architecture, so that it can offer larger field of usage than a micro-sleep research.

## 3.2 System for complex measurements

Our main focus is on the analysis of brain waves, since the brain is responsible for mental functions. It seems to be the most suitable direct and noninvasive method to be used in real life. Unfortunately the EEG analysis is very complex and time-dynamic. From that reason it is necessary to correlate it with other objective factors.

From the point of view of objectivity it is possible to subdivide measurements into two kinds; objective measurement and subjective measurement. Outputs from the simulator are included in set of objective measurement. These outputs combined with reaction time are basic inputs for analysis. From the simulator ride it is possible to measure also movements of pedals (throttle, brake) and movements of steering wheel. In addition to these simulator outputs it is possible to place additional devices in the simulator or on experimental driver.

## 3.3 Design of the testing tracks for fatigue/ micro-sleep experiments

From the real situations reported by many drivers (mainly professional ones) the micro-sleep usually comes when the driver goes on a calm highway. Critical moments are mainly those when the traffic is very low, the visibility low and the driver is not forced to solve more complex problems. The driving then becomes automated and driver loses control over the car. We took those experiences into account when designing the testing track and proposed following requirements on it:

1. *Simplicity. The track should be very simple to drive, so that the drive could use as few mental forces as possible. The relaxation state is a gate to the micro-sleep. Very easy curves or straight highway roads are recommended. We also discovered that the drivers are more relaxed on two or three-lane road. They perhaps do not feel to pay so much attention on car position as in the case of single-lane road.*
2. *Boring scenery. Variety of the objects on the scene always excites the driver.*
3. *Limited visibility. The main problems with drivers' fatigue occur during the night rides. It is hard to realistically simulate night conditions using common LCD projectors. From that reason we chose a day time but visibility was limited with a light fog (the heavy fog could fear and the driver would not relax).*
4. *Limited traffic. It could be very exciting for drowsy driver to solve any kind of traffic problems. From this point the best solution is to exclude traffic from the scenery. We tried the scenery with static sparse traffic in separate lane or contra lane only. But the best results we achieved when the testing track was without any traffic.*

The testing track is divided into two parts; easy and demanding one (Figure 3). Driver should keep the speed 90 km/h for easy track and 50 km/h. From the point of driver the easy track seems to be almost straight. A very light curvature was chosen so that the driver should all the time to pay his attention on steering. If not, they go out of their lane.

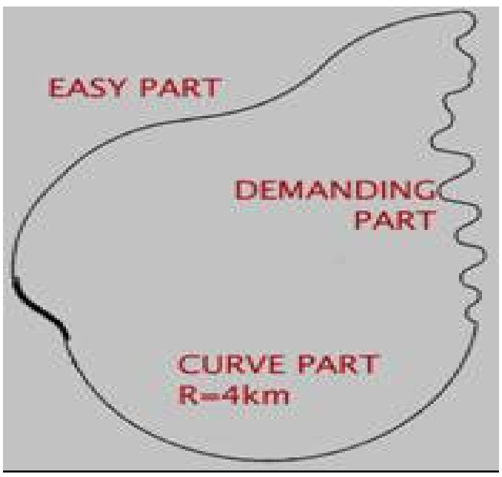



**Figure 3: Top view of the testing track**


**Figure 4: Proband stopping on red lights**

The above picture (Figure 4) shows the tested driver in action. The driver stops on a red signal. The semaphore has only red and green lights and the lights are multiplied for better visibility.

## 3.4 General experiment setup

The experiment was done in a following way; in the beginning of the measurement the driver is usually excited by the initial (reference) test. After the driver gets deeper into driving (immerses into the virtual reality) he/she becomes kind and more and more relaxed. Surprisingly, a majority of the testing person accommodated very early (not more than a half an hour) to new environment and overcame differences between car simulator and real car. It appears to be different when doing other kind of experiments with fresh drivers where the initial adaptation rounds are necessary. We also experienced very low portion of probands suffering from a simulator sickness (1%). We could explain it by the fact that people after sleep deprivation are less sensitive to the "bad" factors. We set up following general requirements:

1. *The probands were after 24 or 36 hour sleep deprivation*
2. *They did not have consumed any drugs (alcohol, medicines…), coffee of other exciting agents*
3. *The length of the drive varies between 2 and 2.5 hours, depending on development of his/her condition.*
4. *Before and after the testing drive the probands pass standard neurological tests. Those serve mainly to recognize if the proband's brain is of "standard type" and to discover possible illnesses. Secondly the reference measurements are used to study differences between a standardized brain load and a uncertain load caused by driving.*

## 3.5 Stopping on red signal

The driver was instructed to stop as soon as they had recognized the red signal on the semaphore. The semaphores are placed more or less equidistantly in straight segments, before curves. The red signal on the track is randomly generated when the car approaches the semaphore. The distance is randomly selected over the length of B (on the picture Figure)

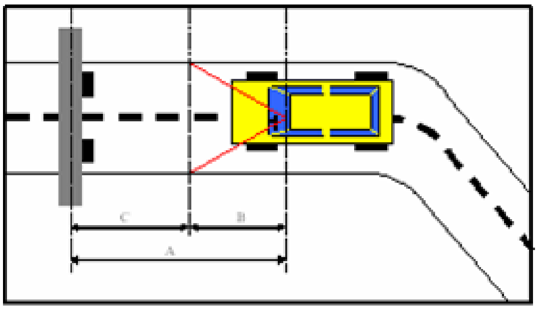


**Figure 5: A - distance of good recognition, C - minimal safe stopping distance, B – random difference**

### 3.6 Self reported state

The probands were instructed to report their actual state when asked by the crew. Usually they were asked every time after stopping on red signal but also during a kind drive (whenever the dispatcher felt that driver's state had changed apparently). They were instructed to answer only on demand, so that they should not keep in mind any more information then the driving itself and/or keeping an eye on the semaphores. Such a concept gives us a possibility to precisely correlate reaction time and other measures with self reported state of drowsiness.
The state was classified according driver capabilities of safe driving and subjective feeling of drowsiness. The table with the scale was also placed on a steering wheel. Scale is as follows:

1. *I feel fine/fresh & driving does not make me any problems.*
2. *I feel drowsy & driving does not make me any problems.*
3. *I feel drowsy & I notice some problems with driving.*
4. *I feel very drowsy & I need excessively concentrate to drive correctly.*
5. *I experienced 'blackouts' & losing of control over the car.*

States 1 and 5 were reported rarely. ('1'- because the driver came already drowsy). A plot of its progress is in section 3.9.

### 3.7 Expert analysis of drivers face and behaviour

The offline expert analysis of a driver's face and hands from 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.

We stated several different criteria to classify driver's state. From the experience we decided to watch two significant patterns:

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

Above described patterns give us a starting point for analyzing the parts of our records preceding this fatal moment and describe processes in driver's body (mainly brain) which leads to it (See next paragraph). Such a selection gives us the best source of data for a general statistical classification [3].

### 3.7 Analysis of EEG

The basic continuous analysis was done from the segment preceding the inquiry for the driver's actual status was made. A reliability of the analysis of brain waves is dependent on a quality (clearness) of recorded encephalogram. Main problems are caused by muscle tension artifacts which are much stronger than any potential arising from the brain. In other words; the EEG record cannot be reliably analyzed when the signal is affected by muscle artifacts. From that reason we equipped the proband with EOG electrodes scanning his/her eye blinks, so that it is possible easily detect clean pieces. The next picture (Figure 6) shows a screenshot from the recorded drive. The video record consists of four pictures, two focused on the proband, one shows a view of the track and last one is an online view of the driver's EEG. Such an arrangement allows straight forward correlation between the brain waves and the driver's appearance.


**Figure 6: Video record with EEG, the proband just goes out of the road due to a micro-sleep**

The following graphs (Figure 7, Figure 8) show a detailed view on EEG bands from the drive just before accident. It starts after the last driver's apparent movement is detected and its duration is around 40 seconds. We can see that the delta arises and alpha drops from its initially high value (The Alpha/Delta Ratio expresses it well [4]). From such behavior we can suggest the relaxation to somnolence (or micro-sleep) transition.

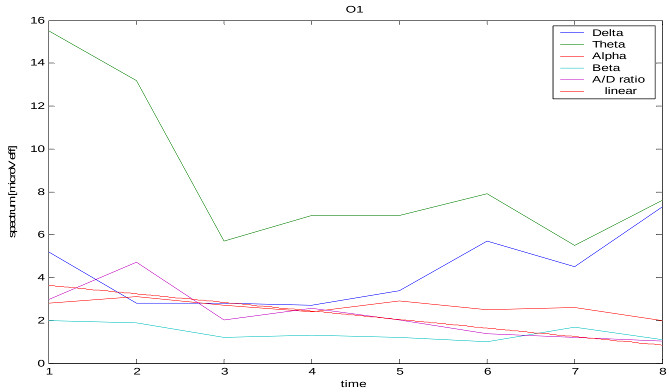



**Figure 7: EEG frequency analysis before the accident (T5 electrode)**

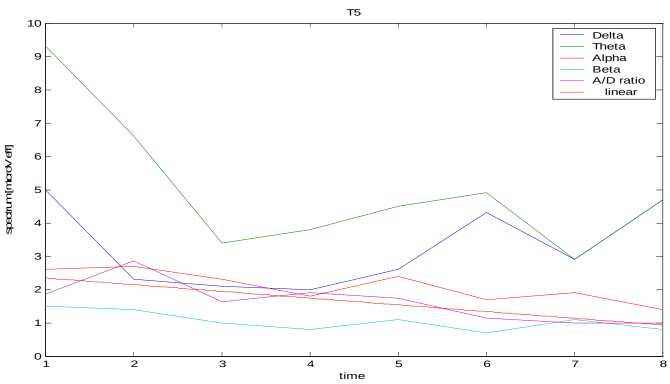


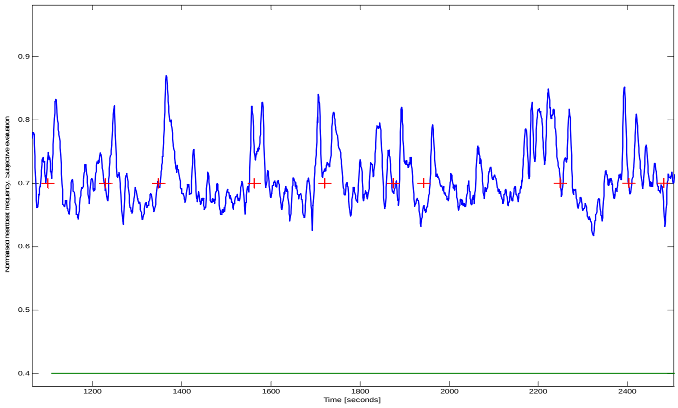

**Figure 8: EEG frequency analysis before the accident (O1 electrode)**

The overall course of the EEG (namely Alpha/Delta Ratio) during the whole simulated drive is in the section **3.9.**

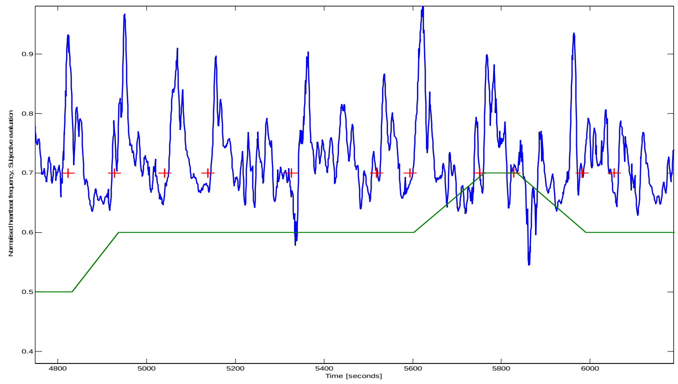
## 3.8 Heart beat frequency

From results derived from the whole experiment we can say that in majority of cases the average heart beat frequency is of slightly increasing frequency. This phenomenon could have several explanations. One could be that the task more demanding with more fatigue or it could be connected with circadian rhythms (decreasing frequency was achieved mainly during afternoon experiments).

If we take more detailed view of its evolution, it is possible to see evident differences in the look of sections where the self-rating is good and where it is bad. If the state is "more drowsy", we can see much steeper and bigger ascent than during state reported within "less drowsy" values. The next two graphs show such a comparison (Figure 9).




**A**




**B**

**Figure 9: The normalized heart beat frequency: (A) – self rating 2, (B) – self rating 3-4**

This feature appears to be another objective factor which could be used. It could be hardly used for classifier in real cars, but it can give us valuable information about driver's actual state which is used for development of EEG based classifier.

## 3.9 Complex analysis

The following picture (Figure 10) shows a complex view on analyzed technical and biological output from the drive on a simulator. It consists of the following analyzed outputs:

1. *Dark blue – heartbeat frequency*
2. *Light blue – deviation from the ideal path*
3. *Black – reaction time*
4. *Green – Alpha/Delta ratio*
5. *Violet – Self rating*
6. *Red crosses – Red light signal*

From the overall look of this graph it is possible to say that the investigated measures are do not correlated in global. From the graphs with complex analysis we can see that there is a big dynamics inside process of drowsiness and that we should investigate it in specifically defined subsections (see Appendix for additional graphs). Generally we can successfully correlate a deviation from the ideal path and the self rating, but for example reaction time and heartbeat frequency are usually of a rising trend.

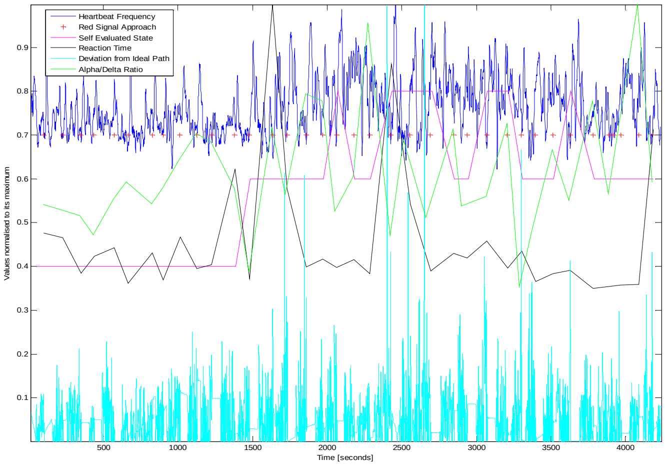



**Figure 10: Complex analysis of proband #7**

## 4 Conclusion

We approved that the realistic interactive driving simulators are necessary for the investigation of driver's drowsiness with use of the EEG analysis. The driver should be occupied with the work which is as close to the real driving as possible, because the experiments done without such a load show different results. From this point of view the requirements on the car simulator device are weaker than for other kind of measurements. The moving platform for such a kind of experiment is not necessary but it could bring more muscle artifacts into measurement.

The complex analysis which correlates different indirect measurements can overcome the problems with uncertainty of the results of each of the separately used methods. More over, involving the EEG into the final evaluation procedure gives us very direct view on the actual driver's brain state with which the results of other indirect methods can be justified. The main problem of usage of EEG is its complicated automated analysis and a machine interpretation.

In this paper we did not want to give any statistical results (since from the experience we know that it will be necessary to measure several hundreds of drivers to get generally valid results) but to show the promising ways for further investigation of driver fatigue mainly with use of EEG analysis.

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# Appendix

Two different probands of ages 26 and 27 years after more than 24 hour sleep deprivation. (Appendix to the article 3.9)