Computer Analysis of Driver’s Trajectory
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Abstract: - The paper deals with evaluation of reliability of a human operator in the MMS (Man-Machine-System). In terms of controls the driver is a very universal and effective controller. In contrast to an unnatural controller the driver fatigue (both mental and physical) is reflected and it is reduces driver control abilities. The paper describes analyzing of driver trajectory and driver’s state monitoring with no signs of fatigue and with fatigue. The statistical analysis of driver trajectories is given and important characteristics of dynamic driver control actions are described. These are mainly Standard deviation, Allan deviation and Poincare distance.

Key-Words: - driver fatigue, MMS, driver’s state monitoring, analyzing of driver trajectory, statistical analysis, Poincare distance, Allan deviation

1 Introduction
Nowadays, the attention of researchers and specialized teams is focused on assessing the reliability of a human operator in the Man-Machine system (MMS). Man is far from reaching as high reliability as is the reliability of technical components of the system. Human capacities to perform activities flawlessly are very much restricted and limited by incoming fatigue. If a man is tired, far more frequent incorrect response, failure, mistakes and errors occur. There are many systems where the human failure may lead to emergency situations, harm or fatal injuries.

2 Fatigue and its symptoms
Human fatigue cannot in practice be measured using well defined units. There is no uniform methodology for assessing the degree of fatigue. It can discern several types of fatigue, depending on where fatigue occurs or what caused it.

Muscle fatigue is perceived as feeling the pain and is clearly identified.

On the other hand sensuous fatigue is in many cases not felt nor perceived by the affected person. There are the individual's subjective feelings, which are ambiguous and difficult to quantify. The most frequent example of this type of fatigue is visual fatigue. Mental fatigue manifests indifference to the assigned functions or attempts to interrupt work activities. These symptoms lead to inability to concentrate on the task performed; the thoughts are distracted to other subjects.

Fatigue caused by adverse factors has its origins in the environment. This is, in the case of a driver, particularly the excessive noise, vibrations etc.

Very dangerous manifestation of fatigue is a micro sleep decline of attention, which occurs when there is an excessive burden on the mental abilities mostly during monotonous activities. The micro sleep as well as a regular sleep is a very complex neurophysiological phenomenon; sleep as well as micro sleep is not fully understood yet. The micro sleep has a strongly individual character. It is influenced by both genetic and individual's overall fitness and health [1].

Any action that a person performs in the context of MMS can be affected by a fatigue. Specifically, when the driver is on the decline in attention and his psychophysiological alertness, vigilance and alertness decreases, which prolongs the reaction time and information processing time, therefore his control actions are less effective. Subjective feelings come with fatigue and slumber, leading to apathy and fixation on a single issue [2], [3], [4]. Each of these symptoms can lead to failure of drivers' activities and can result in a dangerous condition.

Monitoring driver fatigue is mostly done on drive-simulators, which are not completely identical with the conditions in the real traffic and driver
fatigue, there may be manifested in different ways and with different intensity.

3 Fatigue and changes the dynamic behavior

The fatigue leads to degradation of the control ability of a person, slows physiological processes and can be seen as an overall downturn of the organism. Fatigue can be also seen as change in the dynamic performance of the human element in the control system.

The aim of our research is to characterize this change, i.e. characterize control performance terms of driver-vehicle driving dynamics for both the tired driver and a driver in good condition.

Changes in the dynamic behavior occur at all levels of driver activities. It is shown that a wrong decision at a higher level of coordination or organization may not immediately be as dangerous as the wrong response at the lowest level of control. [5]. In connection with the evaluation of the fatigue factor, it is advantageous to monitor and analyze the driver's control actions under the control level in the MMS. Another reason is the feasibility of relatively simple measurements without the need to burden the driver's senses and his secondary activities. Changes in behavior, i.e. the driver fatigue, can be monitored in the form of measurable variables such as steering angle, lateral and longitudinal acceleration of the vehicle or the driver's reaction time.

From the perspective of control techniques are dynamic changes in driver behavior due to the change and the nature of the control action. The basic control circuit for monitoring dynamic changes is shown in Fig. 1. The circuit has a feedback compensatory status. The driver on the perception of the eye continuously monitors the current vehicle position \( y(t) \) and compares with the required position, \( y_r(t) \). Control actions \( h(t) \) chosen to minimize control deviation \( e(t) \) between the input and output signals. Feedback is closed through the human eye, is characteristic of systems with a human operator and cannot be disconnected. Compensation management is the nature of these systems and is always present [6].

The effectiveness and efficiency of control actions \( h(t) \) is reduced due to the increase of time delay and there will also be changes in driving dynamics:

- Driver’s trajectory will have a greater "disorder" and variations, than driving of calm and fresh person.
- Control process quality happens to be impaired, there will be greater disproportion between the desired and actual location of the vehicle on the trajectory \( y_r(t), y(t) \), and the value of the control deviation \( e(t) \) will attain higher values than driving of driver without fatigue.
- Frequency of control action is different interventions for driver within and without fatigue.

4 Analyses of driver’s trajectories

For successful monitoring and control ability of the driver and fatigue detection are essential to prepare a representative set of drivers driving within and without fatigue. Features of test runs were chosen so that drivers gave largely compensating control system of car see Fig. 1. It is a monotonous driving where the driver's main activity is to maintain optimum vehicle in the lane without the need to respond quickly to the environmental conditions with minimal interaction with other road users. Position of the vehicle on the road \( y(t) \) is continuously monitored by a camera and evaluated as the distance from the designated reference guide lines.

![System Driver - Vehicle Control level](image)

**Fig. 1: Control circuit in system Driver - Vehicle**
All experimental data were obtained in collaboration with Technical University in Prague, Faculty of Transportation Sciences - Laboratory of Telematics.

Experimental driver’s trajectories for driver within and without fatigue on the highway at night (D1 - D16), in the tunnel (T1 - T13) and simulator (S1 - S16) were subjected to statistical, probabilistic and frequency analysis. Based on the results and their comparison significant properties that are sufficiently strong and that affect dynamic changes in the driving path were selected. These properties we assume to reveal changes in the nature of driving due to fatigue and can be used to indicate dangerous drop in control performance of the driver.

Statistical analysis of sets of driver’s trajectories for driver with and without fatigue showed that the major characteristics describing the driver's control actions are mainly characteristics of the distribution of $\sigma$, $All$, $Po3$ defined by the equations (1.1), (1.2), and (1.3):

- Standard deviation:
  $$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (y_i - \bar{y})^2}$$ (1.1)

- Allan deviation:
  $$All = \sqrt{\frac{\sum_{i=1}^{N-1} (y_{i+1} - y_i)^2}{2(N-1)}}$$ (1.2)

- Poincare distance:
  $$Po3 = \sqrt{\frac{1}{N-2} \left( y_{i+2}^2 + y_{i+1}^2 + y_i^2 \right)}$$ (1.3)

Allan deviation $All$ is a characteristic indicating the degree of stability or the degree of variation of the observed characteristics (vehicle position $y(t)$ relative to the reference line) in the short time interval $t$. Unlike standard deviation $\sigma$, which is obtained by comparing each sample $y_i$ with an average of $\bar{y}$, the Allan deviation $All$ is based on comparison of each of the two adjacent samples $(y_{i+1}, y_i)$. Parameter value of $All$ depends on the step size between samples. For such analysis it is necessary to perform equidistant sampling, moreover this analysis can only be compared with the same trajectory step sampling, see Fig. 2.

Poincare distance $Po3$ is the characteristic that falls into the category of non-linear methods of examination. The average distance of points In Euclidean space $E(x, y, z)$ the average distance of points is evaluated by projections of three consecutive samples $y_{i+2}, y_{i+1}, y_i$ to the coordinate axes of $E(x, y, z)$, distance from the system center is evaluated. The driver’s trajectories in different environments (highways, tunnels, and simulator) are shown in Fig. 3. Consequently in the figure 4 there are shown statistical analyses of the sets of drives of non-fatigued drivers. Formulas for calculation of skewness and kurtosis are provided below:

- The coefficient of skewness:
  $$a = \frac{1}{N \cdot \sigma^3} \sum_{i=1}^{N} (y_i - \bar{y})^3$$ (1.4)

- Coefficient of kurtosis:
  $$ex = \frac{1}{N \cdot \sigma^4} \sum_{i=1}^{N} (y_i - \bar{y})^4 - 3$$ (1.5)

The actual deviation of a car from the reference line is denoted with the symbol $Y_i$. Obtained characteristics of distribution and shape $a$ (1.4) and $ex$ (1.5) for drivers without fatigue D1 - D16, T1 - T13, S1 - S16 provide very different values, see Fig. 4 and therefore their value cannot be used to conclude whether changing the nature of driver behavior is due to the fatigue or it is a standard drive.
Fig. 3: Statistical characteristic – Poincare distance $Po3$

Fig. 4: Statistical analysis of the set of drives of non-fatigued drivers, parameters of position and shape of distribution
5 Load driver’s trajectories and their analysis

Experimental simulations with fatigued drivers were performed with same set of drivers. Test drivers have repeatedly drove distance of 30 km throughout the day, there was a time lag of at least 2 hours between the drives. The experiment was designed to monitor changes in the person driving characteristics depending on time of day and also to monitor emerging driver fatigue.

To detect dangerous driver behavior, which may have its cause even rising fatigue, it was attempted to continuously monitor the driving performance and to evaluate the trajectory in short sections so that the sub-sections overlap. With the proposed algorithms, the values of selected statistical and probabilistic characteristics were compared with the corresponding performance for driver without fatigue. In Fig. 5 are provided two periods during the drive of the driver OS where one of the drives is clearly affected by fatigue. For purposes of monitoring sections of 200 m have been used.

![Graph showing drive trajectories](image)

**Fig. 5: Drive trajectories**

The result of continuous probabilistic analysis in the form of frequency histograms of lateral variations of the vehicle $y_i$ is shown in Fig. 6. Histogram of trajectory classes for driver without fatigue is balanced in all sections of driving. However the trajectory for driver within fatigue shows clear disbalances in the histogram. Distribution function of the lateral variations shows that the driver has problems with keeping the car on the road. Course deviations of the side distribution function $F(s)$ of the vehicle on the road carry very good information about how the changing dynamics driving the driver. Curves of distribution function $F(s)$ of the individual sections are shown in Fig. 7. Differences in waveforms $F(s)$ between driver within and without fatigue are distinct.

6 Conclusion

In many cases fatigue has a hidden or indirect impact on the accident rate, which is not logged. The Czech Republic has a similar research and analyses are performed. Yet it is clear that the resulting traffic accidents not only lead to significant financial and material losses, but also lead to loss of human lives.

Fatigue factor is certainly reflected in the dynamic behavior of the driver while driving. Analyses of test runs of the monotonous nature...
aimed at compensating the driving behavior of drivers showed differences depending on the environment and time of day. Prerequisite for correct interpretation and evaluation of changes in driver behavior is knowledge of the values of important characteristics for driver without and with fatigue.

Currently, prediction process for detection of hazardous driver performance is being developed. As the best statistical characteristics for identification of the dynamic change in driving performance seem to be the Allan deviation and Poincare distance.

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References: