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Nonconventional methods of assessing fatigue – practical aspects

***Abstract**. An analysis of selected modern methods of human fatigue assessment was carried out, taking into account various aspects, including non-metrological ones. We took into account 11 publications from recent years. We analysed application possibility of the methods using a common set of criteria. We correlated the result of this analysis with four selected professional groups. The paper is an attempt to answer the question about the possibility of practical use of nonconventional methods at selected workplaces.*

***Streszczenie.** Przeprowadzono analizę wybranych nowoczesnych metod oceny zmęczenia człowieka z uwzględnieniem różnych aspektów, w tym nie-metrologicznych. Wzięliśmy pod uwagę 11 publikacji z ostatnich lat. Przeanalizowaliśmy możliwości praktycznego wykorzystania metod, biorąc pod uwagę wspólny zestaw kryteriów. Wynik tej analizy skorelowaliśmy z czterema wybranymi grupami zawodowymi. Artykuł jest próbą odpowiedzi na pytanie o możliwość praktycznego wykorzystania metod niekonwencjonalnych na wybranych stanowiskach pracy. (**Niekonwencjonalne metody oceny zmęczenia – aspekty praktyczne**).*

Keywords: fatigue assessment, fatigue and reduced attention, work safety, PERCLOS
Słowa kluczowe: ocena zmęczenia, zmęczenie i obniżenie poziomu uwagi, bezpieczeństwo pracy, PERCLOS

Introduction

Employee fatigue is one of the basic factors influencing work efficiency and safety at every workplace [1]. In particular, there are many professions such as drivers or surgeons, where the consequences of employee fatigue can be very dangerous. Practical methods of fatigue assessment for selected workplaces are known. However there are many innovative ideas for non-standard and nonconventional methods to assess the degree of fatigue, attention and concentration of a person - ideas sometimes treated by some researchers as science fiction solutions. It is worth considering the practical aspects of such solutions and the future of fatigue assessment methods.

The detection of human fatigue is a complex and very difficult metrological task [2]. Typically, many different methods are used to identify the degree of fatigue. The analysis of brain activity in electroencephalography (EEG) is recognized as a very good identifier of fatigue state [3]. However, in non-laboratory applications, this is not a practical solution. Review publications on driver fatigue [4, 5] show how many different methods can be effective. These papers describe fatigue detections based on EEG, EOG analysis, measures of driver's state included PERCLOS, yawning and mouth shape, head position; the measures of driver performance included lane cracking (also lane vision depending on the position of the vehicle), tracking of distance between vehicles, and most importantly steering wheel movement control.

An interesting review of research on the diagnosis of fatigue is the paper [4]. The Authors analyzed 97 papers, most of them from 2000-2019. They presented a good guide to methods that use EEG, with particular emphasis on analyzes of electrode selection in 10-20 system for fatigue identification. They also presented methods where other non-invasive sensors are used. They conclude that the methods that use eye-related parameters seem to be the most promising for the future.

Most often, in review publications, metrological aspects are discussed and the methods used (and their effectiveness) are compared. Application aspects are considered in practice by companies that produce specific solutions. In particular, automotive companies in the case of methods of analyzing driver fatigue. It is worth paying attention to the fact that many of the published methods intentionally targeted at selected and specific professions (e.g. drivers) could be used practically for many other, different professional groups. However, such analyzes are very rarely carried out and are not published in practice.

The aim of the paper is to presents a short review of nonconventional methods of fatigue assessment, taking into account the practical aspects of using at selected workplaces.

Selected modern nonconventional methods

Modern research concerning fatigue shows the possibility of using analyzes related to many different parameters and features. In this study, we took into account 11 publications from recent years (6 from 2020-2021 and 5 from 2011-2018). The methods of fatigue recognition described in these articles can be divided in terms of the use of the part of the worker's body, which are related to parameters that are analyzed (and evaluated).

- **Eye**. PERCLOS (Percentage of Eye Closure) is a well-known measure of the condition of the eye that can effectively identify fatigue. The publication [6] is one of the newest works in which this method was used. The Authors use image segmentation and simple geometric relationships to analyze eyes opening and closing ratio (EOCR). PERCLOS is so common measure, it's hard to be considered unconventional. However, due to very frequent use, it has been included in this review as a kind of reference point.
- **Eye and mouth**. The trend of research presented in recent years is to combine analyzes of various parameters that indicate fatigue. An interesting combination is the combination of the PERCLOS type measure and the measure identifying yawning. In [7], the Authors use a tiny convolutional neural network to select the appropriate regions of the face, and then analyze the condition of the eyes and mouth using an appropriate feature vector. In [8], the convolutional neural network was also used, but this is probably the first time when both mouth and eye information is classified into a single model at the same time. The Authors of [9] proposed method based on deeply-learned facial expression analysis. They use multi block local binary patterns (MB-LBP) and Adaboost classifier and detected 24 facial features. The Authors of [10] analyzed the dynamic changes in facial expression. In the statistical analysis, they used the KSS (Karolinska Sleepiness Scale) and ORD (Observer Rating of Drowsiness) scales. They effectively

identified fatigue based on the image of the eyes (PERCLOS), and the images of the mouth and the eyebrow.

- **Hand**. The paper [11] describes a model for recognizing hand muscle fatigue. The Authors used novel polynomial Hammerstein model of neuromuscular system for muscle fatigue classification. The proposed fatigue analysis is dedicated to surgeons, but it is worth considering the fact that hand muscle fatigue can also be a problem for drivers and machine operators or even office workers.
- **Mouth and hand**. Yawning is widely recognized as an essential feature of fatigue. However, it is worth adding to this analysis of hand movement (covering the mouth or touching the face). Such an approach is described in one of the latest articles on yawning and fatigue [12].
- **Head and hand**. The Authors of [13] identify fatigue using heartbeat signal and respiratory signal. But they proposed an unusual way of collecting these signals – Doppler radar. Finally, due to problems with noise, they added a smart bracelet for heart beat signal collection.
- **Face and facial skin**. The Authors of paper [14] identified fatigue on the base of facial skin temperature. They used an infrared thermography device and measured forehead skin temperature (FHT) and nasal skin temperature. The FHT is highly correlated with tympanum temperature and blood flows. The result of experiments suggests that FHT can allow recognizing the drowsiness.
- **Facial skin and eye**. The Authors of paper [15] identify fatigue using the classic method based on PERCLOS. However, information about the condition of the eye is obtained in a very unusual way. A tension sensor has been applied - rectangular grid-patterned sensor (RGPG) based on thermally reduced graphene oxide (RGO). This sensor was placed on the skin of the face near the eye.
- **Legs and the whole body**. The Authors of [16] analyzed the pressure of the feet on the ground. On this basis, they also analyzed the shift of the body's center of gravity. The result of the research is the assessment of muscle fatigue in the upper and lower body parts. Such an assessment can be especially important for people who work in a standing position for a long time.

Application aspects of selected methods

An application analysis of selected methods was carried out using a common set of criteria. The results of the analysis are presented in Tables 1 and 2. In the analysis, we took into account the following factors and criteria:

- Parameter (feature, property) that is analyzed to determine the level of fatigue. The non-conventionality of the method may lie in the use of a new indirect way of evaluation - finally it may lead to a well-known method. For example, PERCLOS determines the level of fatigue based on the timing of opening and closing the eyes. But the identification of the opening and closing of the eyes can be made in several different ways: eye image analysis, EOG - Electrooculography.
- Hardware and software requirements as well as a set of sensors those are necessary for the implementation of the method. For all analyzed methods, apart from the hardware listed in the table, a computer system is required.
- Analysis and evaluation of the accuracy of the method. Of course, the sense of practical application has the methods of the highest correctness (over 95%); however, in several articles [14-16] the authors do not specify the correctness of the fatigue assessment. The aim of this works was to isolate the method or check its compliance with another recognized analysis. However, the described works are so advanced that we decided that we could considered their applicability.
- Factors influencing and disturbing the measurement. All methods that use the camera are sensitive to imaging properties, including e.g. glasses covering, face rotation, and lighting.
- Difficulties in implementation in a specific environment - determination based on the data presented in the article on the necessary hardware and software. Low means basic sensors and easy-to-implement software.
- Total cost – based on factors that significantly increase the cost of implantation. Low means the purchase of basic equipment (computer and e.g. a camera).

Table 1. Methods – properties

Document	Parameters/Features	Hardware and software requirements	Evaluation of correctness
[6]	PERCLOS	camera	error % 0.75%
[7]	PERCLOS + yawning frequency	camera, convolutional neural network	95.10%
[8]	PERCLOS + yawning frequency	camera, convolutional neural network	98.81%
[9]	PERCLOS + yawning frequency.	camera, multi block local binary patterns analysis and Adaboost classifier	normal conditions 96,5% under mild fatigue 94,7%
[10]	PERCLOS + mouth opening size + eyebrow position	camera	92%
[11]	surface electromyography (sEMG) signal,	sEMG recording system, computer system, novel model of neuromuscular system	error level around 2.0%
[12]	yawning frequency + position of hand	camera, binary classifier using linear SVMs	95%
[13]	respiration and heartbeat signals	Doppler radar, the smart bracelet, extreme learning machine (ELM), diferential evolution ELM (DE-ELM)	ELM (92,59%) DE-ELM (94,44%)
[14]	forehead skin temperature (FHT),	thermography device, wireless biological measuring equipment	high statistical compliance of FHT changes with changes in induced drowsiness
[15]	tension of skin, finally PERCLOS	rectangular grid-patterned sensor based on thermally reduced graphene oxide	tension sensor signal, fully compatible with eye blink
[16]	the pressure of the feet on the ground and the shift of the body's center of gravity	piezoelectric Kistler force plates	statistically confirmed the impact of fatigue upper body musculature to maintain a balance

Table 2. Methods – basic application aspects

Document	Difficulties in implementation	Total cost	Factors influencing and disturbing the measurement
[6]	High	High (high computational cost needed)	high processing speed, imaging properties, lighting
[7]	Medium	Low	imaging properties, lighting
[8]	Low*	Low	imaging properties, lighting
[9]	Low	Medium*	imaging properties, lighting
[10]	Low	Low*	noise from image
[11]	High	High*	complex and different fatigue development under dynamic task
[12]	Low	Low	imaging properties, lighting
[13]	High	Medium	noise
[14]	Medium*	Medium*	measurement itself could impose a physical and mental load
[15]	Low	Low	influence of the sensor and its contact with the skin**
[16]	High* (need to do exactly exercises)	High* (prices of one of force plate)	influence of the participant's behavior

* parameters not defined directly by the Authors. We assumed these parameters on the basis of a comparative assessment.
** putting the sensor on the skin around the eye can hardly be considered as non-invasive.

Applications of methods in different occupational groups

We conducted an analysis of the possibilities of using the discussed unconventional methods in various professional groups. Four groups were taken into account: drivers, office workers, manual workers, doctors / surgeons. The results of the analysis are presented in Table 3. When assessing the possibilities, the difficulty of implementation in selected workplaces was taken into account. Low means little interference in the workplace, medium and high – requiring modification from small to major changes of the workplace.

Table 3. The possibility of using methods in selected occupational groups.

Document	Drivers	Office workers	Manual workers	Doctors/ surgeons
[6]	Low	Low	Low	Low
[7]	Low	Low	Medium	Medium
[8]	Low	Low	Medium	Medium
[9]	Low	Medium	High	High
[10]	Low	Medium	High	High
[11]	Medium	Low	High	High
[12]	Low	Low	Medium	Medium
[13]	High	High	High	High
[14]	Low	Low	High	High
[15]	Low	Low	Low	Low
[16]	Low	Low	Low	High

Conclusions

An analysis of nonconventional methods of human fatigue assessment was carried out, taking into account various practical aspects. We took into account 11 methods presented in recent years and we tried to answer the question about the possibility of practical use of such methods at selected workplaces. The result of our analysis is quite surprising. The most universal method turned out to be the method that uses PERCLOS in a classic way. This method is universal and requires the least interference for all of the workplaces considered. If it is based only on the image from the camera, it can practically be used in almost all conditions. The only problem is the quality of algorithm for the facial image analysis. However, this task has been known and developed for many years, and it has resulted in many effective solutions. The second similar result was obtained by a method based also on PERCLOS, but using a skin tension sensor. However, in this case, it can hardly be considered as non-invasive. It is difficult to use this type of sensor, for example, in industrial conditions. In both cases, PERCLOS was a method of recognizing fatigue. This confirms the very important role of facial image analysis methods in this problem. On the other hand, there are still published new ideas for very interesting sensors and unconventional ways to recognize fatigue. These are scientifically attractive ideas that give the chance for interesting publications. However, it is always worth considering the application side of such solutions.

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