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# MATHEMATICAL MODEL OF AN ADAPTIVE SYSTEM FOR REMOTE MONITORING OF HUMAN'S PSYCHOPHYSIOLOGICAL STATE

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**Abstract:** The article discusses the remote and contactless evaluation of psychophysiological human condition in a real-time mode based on the computer-adaptive model of the evaluating system. The model takes into account that, on the one hand, the measured parameters are weakly correlated, and, on the other hand, values are multimodal and vary from individual to individual.

**Key words:** adaptive system, psychophysiological condition, "man-machine-environment, "system, biometrics parameters.

## 1. Introduction

In the modern world it becomes necessary to ensure the safe and reliable operation of various kinds of equipment in different branches of industry and in other spheres of human activity. Reliable operation means the absence of accidents, failures, and, therefore, the presservation of human life and health, the preservation of the environment, and, eventually, reduced material losses incurred as a result of accidents.

In general, all these negative manifestations of human activity can be called, using technical terms, the failure of the "Man-Machine-Environment" subsystem (MME). Considering the person as a member of society, we can speak of the failure of his/her mental functioning. Considering the person in the context of his/her interaction with machinery and equipment of modern industry, transport, etc., it seems to be more appropriate to speak of the failure of MME [1-4].

Modern society tends, by any means, to minimize the "failures" of human functioning in all situations. At the same time, considering the person as a living being with a set of physiological, psychological and other features inherent in the most highly developed mammal organism living on the Earth, in our opinion it is highly appropriate to study the failures in his/her psychophysiological state (PS).

## 2. Objective of research

The human body is an open self-organizing and self-restoring system. So, it can be assumed that the control over its PS is advisable to be carried out by means of a system which can flexibly adapt itself either to changeable internal processes in the human body, or to the variable conditions of environment.

Thus, the **purpose of this work** is elaborating the mathematical model of adaptive system for monitoring the psychophysiological state of a human.

## 3. State of the problem

There are many factors causing the disruption of normal functioning of the MME subsystem.

Provisionally, they can be divided into 3 groups:

- accident caused by a technical failure (defective or outdated equipment, operation modes with excessive loading);
- human factor (irresponsible attitude, lack of necessary skills and knowledge, intense working conditions, excessive psychological stress, disease);
- unpredictable and negatively destabilizing, rather intense influence of the environment on humans which may lead to uncontrolled and unpredictable transformation of some kinds of energy into others leading to possible catastrophic changes in the environment.

Any of these factors can lead to the failure of the entire mechanism and, therefore, to an accident.

The reliability of equipment is widely researched, but the human factor is often not taken into account. The approach to monitoring a man has always been very formal. But very often the reliability of any mechanism is provided and maintained by the human.

Nowadays various methods of PS characteristics and psycho-emotional state (PES) of a person are being actively developed [5],

Due to the urgency of this task, there is a growing need for an apparatus performing the required analysis. There are quite many systems intended for PES diagnosis or allowing it to be carried out (e.g., Mind Reader [6], The Barrier [7], Chris [8], Polarg [9] and others [10]). Regularly new PS diagnostic systems appear. However, none of them is able to perform PES monitoring in accordance with all requirements. All the complexes carry out periodic monitoring with a fairly long period (from one to several dozens of minutes), which do not allow tracking human's PES in real time. Most systems use techniques that require a person to stop working or limit his/her activity

Restrictions on the applicability of such equipment are associated with disadvantages or limitations of biometric methods implemented in them. To achieve the required level of PES monitoring, new methods of biometrics began to develop recently and, additionally, existing ones were upgraded [11]. However, the desired results in this field have not been obtained yet.

One of the main obstacles to the design of the required biometric systems is related to the peculiarities of recorded data. On the one hand, the measured parameters are weakly correlated, and, on the other hand, values are multimodal and vary from individual to individual. For this reason, there are difficulties with the mathematical processing and decision-making.

Work in this direction has been carried out for more than a decade, resulting in, for example, well-known "listening" systems installed on crowded streets, which sound the alarm in the appearance of overexcited intonations in a passersby's speech.

The method of vibraimaging proposes to register micromotions and spatial fluctuations (vibrations) of an object by the accumulation of vibration parameters (frequency and amplitude) for each element (pixel) of the object [12]. With this method, it is possible to determine the parameters of micromovements of complex objects in real time, including the determination of integral parameters characterizing human head micromovements caused by vestibular reflexes [13].

Some research experiments [14] showed that vestibular reflexes and parameters of human head micromotions reflect his/her emotional state. Thus, it is possible to speak of a human vestibular-emotional reflex that characterizes the emotional state of a human by parameters of his head micromovements. It allows us to solve the practical problem of determining PES of a person in the course of remote contactless television scanning of the person in a quasi-stationary state during no more than 10 seconds. Testing the system in Domodedovo and Pulkovo airports in 2007 showed that the system could detect an aggressive or stressed passenger and could be used as a technical means of passengers' profiling.

However, in general, the problem of remote monitoring of human PS in a given situation is still far from being solved.

#### 4. Solution to the problem

It is appropriate to develop and implement (wherever it is technically possible) the system of continuous on-the-job monitoring of mental and physical health of employees in real time.

It is necessary:

1. To place high-resolution cameras at the workplace. The cameras need to capture and transfer to a computer the condition of worker's eye. Eye condition is not chosen arbitrarily. During manufacturing a sensor can not be attached directly to the employee. In some cases, employees may be required to wear a pulsometer and be given a diagnosis according to the data obtained, but it is not always convenient and accurate. Diagnostic by eyes has been known since ancient times. Further, technical means already exist for eye monitoring (a camera).

2. To develop the software for processing the information received from the cameras. In our opinion, the following parameters must be monitored and analyzed:

a) $R$ – eye opening width. During a specified time period readouts for a particular employee are taken. A maximum width $R_{max}$ is reduced by some error $\Delta_r$, and the resulting value is temporarily stored as a template or norm $R_{nor}$.

$$R_{nor} = R_{max} - \Delta_r \quad (1)$$

If during further monitoring $R < R_{nor}$ for longer than the allowed time period $t$, it indicates that the employee is getting tired and, therefore, distracted and possibly needs to be replaced.

b) $M$ - frequency of eye blinking. For a given time interval readouts are taken for a particular employee. A maximum frequency $M_{max}$ has some error $\Delta_m$, and the resulting value is temporarily stored as a template or norm $M_{nor}$.

$$M_{nor} = M_{max} - \Delta_m \quad (2)$$

If during further monitoring $M > M_{nor}$ for longer than the allowed time period $t$, it indicates that the employee is getting tired and, therefore, distracted and possibly needs to be replaced.

c) $Z$ - pupillary reflex (contraction and dilation). Here the illumination of employee's eyes should be considered, since insufficient or excessive illumination affects the size of pupils. During the specified time interval readouts are taken for a particular employee. Furthermore, the obtained average value $Z_{sr}$ is compared with predetermined reference values (at conventional room illumination a pupil diameter can vary within certain limits). If $Z_{sr}$ fits within the boundaries of reference values, the value is temporarily stored as a template or norm $Z_{nor}$.

If further monitoring shows that $Z > Z_{nor}$ for longer than the allowed time period $t$, this may indicate the presence of narcotic or psychotropic substances in the body of the monitored employee.

If further monitoring shows that $Z < Z_{nor}$ for longer than the allowed time period $t$, this may indicate the stress state of the given employee.

In both cases, it is necessary to replace the employee to give him the opportunity to come to normal condition.

d) $D$ – speed of pupil movements. For a given time interval readouts are taken for a particular employee. We get an average value $D_{sr}$. This value is then temporarily stored as a template or norm $D_{nor}$.

If further monitoring shows that $D > D_{nor}$ for longer than the allowed time period $t$, it indicates that the employee is stressed or mentally unstable.

If further monitoring shows that $D < D_{nor}$ for longer than the allowed time period $t$, it may indicate that the employee is getting tired and, therefore, distracted and possibly needs to be replaced.

3. To develop and implement an alarming system for signalizing the emergency situation caused by the physical or mental indisposition of the employee. The sound indicator should be placed in the workers' recreation room, and the light indicators should be placed both in the recreation room and at the workplace near to the employees who need to be changed.

4. All the data on the extraordinary replacements of employees has to be recorded in a common database, access to which should be restricted to medical staff (additional non-editable field in the electronic medical record) and the Department of Professional Suitability.

An adaptive electronic system for monitoring the psychophysiological human state can cope with the task. The output of such system has to be some integral parameter that can change its values in certain (predetermined) range. When its value goes beyond tolerance limits, it means that a complex of alarming signals and recommendations for eliminating the problem should be produced by the system. This complex can be named a measure of disorder (or chaos) *S* of the MME system. This denotation is not chosen arbitrarily. In thermodynamics of irreversible processes and mathematical statistics this letter usually denotes entropy. In this case, the above mentioned integral parameter can be called the entropy of the MME system. With regard to the analysis of this system, the permissible value of entropy must be given in advance on the basis of summarizing the basic requirements for the safety level in this particular situation.

The present level of development of computer technology, as well as devices for obtaining current information and its registration allows us to choose a set of monitored parameters and requirements for accuracy and reliability of received information without any restrictions. However, the functioning algorithm of such system must be defined correctly by its mathematical modeling.

As a mathematical model of adaptive system of remote monitoring of the PS of a human the following expression may be proposed:

$$S = F[a, b, g, t], \quad (3)$$

where $a = \{a_1, a_2, ..., a_n\}$ is a group of constant parameters of a particular person, which do not change throughout human's life (see Table 1); $b = \{b_1, b_2, ..., b_m\}$ are quasi-constant biometric parameters characterizing the human PS, that is, those parameters that change occasionally (see Table 2); $g = \{g_1, g_2, ..., g_k\}$ are varying biometric parameters that characterize the PS of a human (see Table 3); $t$ stands for time.

*Table 1*

**Constant human biometric PS parameters**

| № | Name | Index | Notes |
|---|---|---|---|
| 1 | Gender | Women/ Men $a_1$ | |
| 2 | Hereditary characteristics | $a_2$ | The presence of hereditary diseases, characteristic of the place of residence from an environmental point of view, etc. |
| 3 | Nationality | $a_3$ | |
| 4 | Type of nervous system | normotonic sympathic otonicvago tonic $a_4$ | Optimization of physical working capacity of individuals with different types of autonomic nervous system |
| 5 | Color of irises | $a_5$ | |

*Table 2*

**Quasi-constant human biometric PS parameters**

| № | Name | Index | Notes |
|---|---|---|---|
| 1 | Location | $b_1$ | |
| 2 | Type of activity | $b_2$ | |
| 3 | Financial state | $b_3$ | |
| 4 | Marital status | $b_4$ | |
| 5 | Children | $b_5$ | |
| 6 | Standard eye size | $b_6$ | |
| 7 | Standard pupil size | $b_7$ | |
| 8 | Comfortable work conditions | $b_8$ | |

*Table 3*

**Varying human biometric PS parameters**

| № | Name | Index | Notes |
|---|---|---|---|
| 1 | Age | $g_1$ | |
| 2 | Presence of disease | $g_2$ | Acute, chronic, hereditary, acquired as a result of accident or environmental situation, bad habits. |
| 3 | Type of work activity | $g_3$ | |
| 4 | Presence of harmful habits | $g_4$ | |
| 5 | Complexity of particular task | $g_5$ | |

The proposed mathematical model is only the "first step", an attempt to approach analytically the solution to the problem, as it is a long way to solving it definitely. There are still many questions to which more or less acceptable answers should be found beforehand.

For example, it should be determined to what extent the parameters of the three groups can vary, how these values can be set, and most importantly, what form of the functional in the equation (3) is to be used.

Regarding the range of parameters' values we can say the following. For each case (production situation, the level of social organization, climate, year season, etc.) the range of acceptable deviations for certain parameters is different. To say this is in fact to say nothing. It is therefore advisable to carry out preliminary performance tests of the entire system and enter obtained MME biometric information into the memory of the system. Thus, the system has to be adaptive, i.e. able to adapt to the situation, flexibly recalculating the level of entropy to reflect changes in the internal and external environments of MME by adjusting the ranges of acceptable deviations of the informative parameters.

### 5. Conclusions

1. The mathematical model of adaptive system of remote monitoring of human PS is presented.

2. A set of informative parameters of the adaptive system of remote monitoring of human PS is proposed.

3. The recommendations on the collection and adaptation of ranges of their acceptable deviations for the adaptive system of remote monitoring of human PS for specific conditions are given.

4. The recommendations for improving the system of continuous monitoring of workers' mental and physical health during a work shift are proposed.

5. Future research concerns elaboration of ideas about the set of informative parameters for the proposed adaptive system, formulation of analytical instruments for maximum correlation of the MME entropy with the level of its operation reliability, and development of application software for its implementation.

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## МАТЕМАТИЧНА МОДЕЛЬ АДАПТИВНОЇ СИСТЕМИ ДИСТАНЦІЙНОГО КОНТРОЛЮ ПСИХОФІЗІОЛОГІЧНОГО СТАНУ ЛЮДИНИ

Сергій Мещанінов, Олександра Льдовска

У статті розглянуто питання дистанційної та безконтактної оцінки психофізіологічного стану людини в режимі реального часу на основі адаптивної комп'ютерної моделі системи оцінки. Модель враховує, що вимірювані параметри є, з одного боку, слабо корельованими, а з іншого – їхні значення є мультимодальними і змінюються від індивідуума до індивідуума.

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