



Expandable Digital Functional State Model of Operator for Intelligent Human Factor Reliability Management Systems.

Lyubov V. Kolobashkina¹, Mikhail V. Alyushin² (MVAlyushin@mephi.ru), Kirill S. Nikishov³.

^{1,2} National Research Nuclear University MPEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, Moscow, 115409, Russia .
³ PJSC «Mosenergo» Vernadskogo prospect, 101 bld. 3, Moscow, Russian Federation, 119526



ABSTRACT

The relevance of the human factor (HF) reliability management is substantiated due to the reliable prediction of a possible change in the functional and psycho-emotional state (PES) of operators for controlling potentially hazardous objects (PHO). It is shown that PES modeling based on digital behavioral models (DBM) is a modern tool for such forecasting. Personalization of the DBM is carried out by taking into account individual bioparameters, which are registered, as a rule, using remote non-contact biometric technologies. The low reliability of the forecast in the event of emergency situations is highlighted as the main drawback of the existing DBMs. The main reason is the lack of reliability of the registration of bioparameters when using one or a limited number of biometric technologies. The relevance of the development of an expandable DBM, which allows to eliminate the indicated drawback, has been substantiated. The study proposes an expandable DBM that allows you to expand the range of processed biometric data. At the same time, it becomes possible to integrate biometric data obtained using remote non-contact technologies with data obtained using wearable biometric devices, such as, for example, bracelets. The developed DBM makes it possible, simultaneously with the implementation of the forecast, to monitor the health status of PHO personnel.

INTRODUCTION

The reliability of the HF is an integral part of the problem of ensuring the safe and trouble-free operation of PHO. One of the aspects of ensuring the reliability of the HF is the timely identification of PHO management operators who are in an inadequate, stressful or very tired state. In this regard, the task of making a reliable forecast of a possible change in the PHO management operator PES in the short and long term becomes especially relevant.

The short-term forecast assumes an assessment of the possible change in the PES over the next hours and, as a rule, does not go beyond the current work shift. The reliability of this type of forecast is especially important in the event of abnormal and emergency modes of PHO operation, as a rule, accompanied by a high level of psychological and physical stress on the operators of object control.

A long-term forecast of a possible change in the PHO management operators PES is carried out on the basis of an analysis of the changes dynamics in biometric indicators over fairly long time intervals, usually constituting units and tens of months. The results of this type of forecast make it possible to reasonably plan the production load. At the same time, they should be considered as a tool for identifying hidden disorders in health.

The basis for the implementation of short-term and long-term forecasts is the DBM. These models, as a rule, involve the analysis of the available biometric data characterizing the operator's current PES, with their subsequent extrapolation. Most of the models used in practice are based on the analysis of a limited range of bioparameters, for example, characterizing the work of the operator's cardiovascular system [1-4]. At the same time, to measure these bioparameters, as a rule, a limited number of biometric technologies are also used [5-7]. Typical examples are biometric bracelets that use optical technology to record heart rate. The reliability of measurements of such wearable biometric devices largely depends on the level of human motor activity.

These circumstances reduce the reliability of the forecast based on the DBM in complex and changing conditions of production activities, caused, for example, by emergency and abnormal modes of PHO operation. For these situations, characterized by increased levels of physical and mental stress, obtaining a reliable forecast is most important. To increase the reliability of the recorded bioparameters in such situations, it is desirable to simultaneously use several different biometric technologies based on different physical measurement principles [8]. For example, they measure bioparameters simultaneously in the visible and infrared ranges of optical radiation, as well as in the acoustic range [9]. This makes it possible to maintain the required reliability of the bioparameters measurement while reducing the validity of the data obtained by one or several of the applied biometric technologies.

The creation of new high-tech sensors makes it possible to receive and process additional biometric information, which makes it important to develop behavioral models with the possibility of expanding the composition of analyzed bioparameters. For example, the use of tera-hertz biometric sensors [10-12], as well as optical sensors for analyzing the face image [13] and measuring the oxygen concentration in the blood, makes it possible to take into account the parameters characterizing the state of metabolism in forecasting, as well as to timely detect health disorders.

The aim of the study is to develop an expandable DBM that allows for a reliable forecast of a possible change in the PHO management operators PES, focused on the use in intelligent systems for managing the reliability of the HF at these facilities.

STATE OF RESEARCH IN THIS AREA

A typical form of a behavioral model used to predict a possible change in PES without taking into account the effect of accumulation of fatigue is presented in [9]. The model is designed to implement an iterative modeling process:

$$G_{M+1} = G_M + \Delta(G_{M-1}, G_{M-2}, G_{M-3}, \dots, G_{M-N})$$

where M – the number of the iteration step of the modeling process;
 $\Delta(G_{M-1}, G_{M-2}, G_{M-3}, \dots, G_{M-N})$ – the expected change in the value of the value G_M , characterizing the operator's PES, at the iteration step $M+1$;
 N – the order of the extrapolating function.

The dimensionless value G_M considered in the study [9] is determined based on the integral processing of bioparameters recorded by three different remote non-contact technologies:

$$G_M = \sum_{k=1}^K B_k G_{Mk}, k=1,2,3. \quad (1)$$

where B_k ($0 \leq B_k \leq 1$) – the coefficients of the significance of the particular characteristics G_{Mk} for determining the characteristic G ;
 G_{Mk} – partial PES estimates using visible optical technology ($k=1$), infrared optical technology ($k=2$), and acoustic technology ($k=3$).

The limitation of this approach is due to the fixed number ($k=1, 2, 3$) of the analyzed technologies for recording bioparameters, as well as the lack of taking into account the possible change in the values of the B_k parameters when the conditions of production activity change. For example, an increase in the level of acoustic noise in the event of abnormal conditions of PHO operation, as a rule, leads to a decrease in the significance of the PES estimates when using acoustic technologies for recording personnel bioparameters.

In the study [14], to take into account the effect of fatigue accumulation, it is proposed to use a special function $R(M)$, which takes into account in modeling the total level of increased production load that causes fatigue:

$$\hat{R}(M) = (1/T_0) \sum_{i=1}^M (G_i - G_0) dt_i$$

where dt – the time interval corresponding to the simulation step;
 G_0 – the individual value of the G function for normal operating conditions corresponding to normal production load;
 T_0 – the individual value of the maximum working time for G_0 (for a healthy worker, the value of T_0 significantly exceeds the duration of the work shift).

A behavioral model that takes into account the effect of accumulation of fatigue is as follows:

$$G_{M+1} = G_M + \Delta(G_{M-1}, G_{M-2}, G_{M-3}, \dots, G_{M-N}) \cdot (1 + \alpha \cdot R(M) / G_M), \quad (2)$$

where α – the individual degree of influence of fatigue taking into account the body's resources on physiological parameters.

In the model under consideration, individual parameters (G_0, T_0, α) ensure its adaptability. These parameters are determined on special tests during periodic examinations, or in the process of training on simulators. The disadvantage of this model is also a rigidly fixed set of biometric technologies used.

THE ESSENCE OF THE PROPOSED APPROACH

To reliably predict a possible change in PES, the study proposes the use of an expandable digital behavioral model focused on the use in intelligent control systems for the reliability of the HF in PHO. The proposed model makes it possible to make a reliable prediction using an extended set of biometric technologies, for example, based on the registration of terahertz radiation, as well as on the measurement of the oxygen concentration in the blood (blood oxygen saturation SpO2). For this, when determining the value of G_M in the behavioral model (2), instead of expression (1), a dynamically changing function G_M^* is used, defined by expression (3):

$$G_M^* = \sum_{k=1}^K B_{kM} G_{Mk}, k=1,2,3,4,5,\dots,K, \quad (3)$$

where K – the total number of biometric technologies used (in particular, $K=4$ for terahertz technology, $k=5$ for the technology for determining blood oxygen saturation SpO2);
 B_{kM} – current values of the significance coefficients for these technologies.

The significance coefficients are not static. Their values may change with changes in the conditions of production activities of personnel, including changes in: the level of illumination in working rooms; climatic conditions of work (air temperature, humidity, oxygen concentration in the air, concentration of CO₂ and other gases and aerosols); the level of acoustic and vibration noise and interference; motor activity of personnel; work clothing (for example, use of personal respiratory protection).

The above factors determine the possibility of using biometric technology and the reliability of the obtained biometric results. So, for example, in the presence of stable lighting and a high level of acoustic noise $G_1, G_2 > G_3$. In the absence of stable lighting $G_2 > G_1$. With a high level of high-frequency electromagnetic interference $G_1, G_2, G_3 > G_4$.

To determine the values of B_{kM} , it is proposed to use the majority principle. Its essence is as follows.

- Distances are determined $P_{ij} = \sqrt{(G_i^* - G_j^*)^2 + \dots + (G_{iM-Q} - G_{jM-Q})^2}$ between functions $G_i^* = \{G_{M1}, G_{M2}, G_{M3}, \dots, G_{M-Q}\}, i=1, \dots, K;$
 $G_j^* = \{G_{M1}, G_{M2}, G_{M3}, \dots, G_{M-Q}\}, j=1, \dots, K; i \neq j, i, j \in K;$

- where Q – the number of analyzed steps of the iterative process (the value corresponds to the analyzed time interval).
 For a quiet working environment, the value of Q can correspond to fairly long time intervals, measured by hours. For a rapidly changing production environment, the value of Q should correspond to the rate of change of the factors listed in $\bar{p}$ ve.
- The average distances are determined: $\bar{P} = (2 / (K \cdot (K-1))) \cdot \sum_{i=1}^K \sum_{j=1}^{K-1} P_{ij}$.
- With G_i^* , help of three $|p_i - \bar{P}| < \beta \cdot \bar{P}$ ination, F of the most similar functions, for which $|p_i - \bar{P}| < \beta \cdot \bar{P}$, where β determines the value of the discrimination threshold, are distinguished. For most PHO, $\beta=0.1-0.2$.
- The average normalized values of $\bar{G}^* = (1/F) \cdot \sum_{i=1}^F G_i^*$; to determine the $B_{kM+1} = A \cdot C / (A + G_k^* - \bar{G}^*)$,

where the parameter $A=1-0.1$ specifies the slope of differentiation of the parameters B_{kM+1} , and the $\sum_{k=1}^K B_{kM+1} = 1$ is determined from the normalization condition

$$C = 1 / (A \cdot (K \cdot A + \sum_{k=1}^K (G_k^* - \bar{G}^*)))$$

RESULTS OF EXPERIMENTAL TESTING

The proposed approach was tested when monitoring the PES of tested employees when the conditions of production activity changed. Fig. 1 shows the results of dynamic adaptation of the model to changing conditions of production activity.

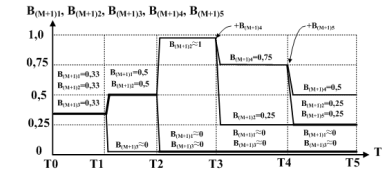


Fig. 1 – An example of dynamic model adaptation

Experimental studies have shown that the use of the developed model makes it possible to preserve the reliability of the recorded bioparameters and predict a possible change in PES in the event of the previously considered destabilizing factors.

CONCLUSIONS

The approach makes it possible to naturally integrate bioparameters registered using both remote non-contact technologies and wearable contact biometric devices, which, first of all, include modern biometric bracelets. This permits to increase the accuracy of predicting a possible change in the PES of operators, which is of fundamental importance for ensuring the reliable and safe operation of PHO. Long-term forecasting should be seen as a tool for protecting the health of PHO staff.

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