Simulation of Human-Operator Behavior in Solving Intellectual Problems during Control of Technological Processes in Stresses

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Abstract

The mathematical model of the human-operator of technological process from the point of view of the mathematical systems theory is developed. The apparatus of set theory was used for modeling. The model takes into account the influence of the human factor on the quality of process control. The concept of stress-resistance of the human operator is considered. The stress resistance index is introduced and the geometric interpretation is given. The model of exit of the person-operator from a stressful condition which considers its individuality is resulted.

Keywords 1

human operator, process control, operator stress, learning curve.

1. Introduction

One of the most common human-machine interfaces of automated control systems, information retrieval systems and information processing systems is the "human-computer" linkage, which practically provides a consistent presentation of information to users. The human-machine interface is in fact fully responsible for the information provided, and therefore must be reliable, accurate and efficient. In the systemic aspect, the pair "human - computer" is a system formed by a combination of subsystems of specific psychophysical features and functional states of human associated with the processing of various information, and the subsystem of technical capabilities of modern computer technology. The role of technology is extremely high efficiency of search, special preliminary and various basic processing of the necessary information, as well as its storage, transmission, conversion and presentation in various forms.

The modern computer equipment is characterized by a high degree of reliability, has a significant speed, huge amounts of memory, which allows you to solve the problems in various domains. In practice, the failure of complex production systems due to the failure of computer equipment is becoming less common and mainly for non-technical reasons - viruses, inappropriate or poor quality software and inconsistency of computer equipment used in this class of tasks. This should also include its service by low-skilled personnel.

Therefore, the concept of reliability, efficiency, adequacy of the solution for the human-machine interface is mainly expressed by the human factor and in fact all responsibility for the decision lies with the operator, often even in situations where unforeseen reasons out of order technique.

The main adverse factors for the operator are extreme situations, stress, biorhythms, sleep and neurosis, which actually act as a consequence of the previous, and which modern science considers as a boundary between health and mental illness associated with functional disorders in the body. Different circumstances force a person to adapt quickly and fully and maintain high efficiency regardless of changes in the environment.

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One of the important tasks of the problem of restoring the functional state of the human operator, i.e. overcoming stress, is to study the processes of adaptation of this category of workers as operators. The activity of these workers in the conditions of growth of technical progress becomes more and more difficult, becomes more responsible and is accompanied by considerable nervous and mental pressure of a cognitive resource, creative forces and abilities.

The purpose of this study is to develop a mathematical model of the output of the human operator from a stressful situation, which reflects the general content of his professional activity in the human-machine interface of process control.

2. Related works

As a rule, various working situations in human activity, in particular the human operator of technological processes create preconditions for violation of modes of human-machine systems, occurrence of erroneous actions, threat of emergence of emergency situations. Research [1] is devoted to the study of such situations in order to model human behavior. The influence of stressful situations on the human body and behavior during the management of technological processes is analyzed [2]. In [3] the materials of experimental-theoretical research of information stress of the human operator as one of the types of professional stress are presented. Modern methods and tools for determining and diagnosing emotional stress are given in [4].

Modeling of human operator dynamics plays an important role in process control and is reflected in [5]. The study of the reliability of the human operator is considered in [6]. Important for the admission of a person to the management of the technological process is its preparation primarily in terms of stress resistance, and it is in this regard, of interest is the study presented in [7]. The decisive role in modeling human behavior is played by the mathematical apparatus of building a model of human-machine interface as a holistic intelligent process control system. The most common system approach for building a human-machine interface model is work [8]. Taking into account the behavior of the functional state of the operator in models of behavior is of great importance not only in the management of peaceful technological process, but also for the control of military equipment, in particular unmanned aerial vehicles [9]. The effective operation of the human-machine interface in the environment is considered in [10].

Stress-related situations play an important role in the study of operator activity. Stress in the workplace has been the subject of increased attention by researchers in various countries. The dynamics of the spread are detailed in the report of the International Labor Office [11].

The influence of distracting situations, as shown in [12], leads to a decrease in the efficiency of the operator, which indicates that in the models of the operator can not be considered constant. The relationship between psychological and biological aspects is considered in [13]. Individual differences in threshold and duration of both internal and external stimuli for stress are given in [14]. The authors [15] present human-machine systems in which the human factor plays an important role, and therefore human failure can be dangerous.

Modeling a person's way out of a stressful situation is considered by many researchers. The exit curve from the stress state of the human operator is quite good, in terms of the nature of this process can be described by the learning curve given in [16]. The learning curve is an almost universal curve and is widely used in various industries [17], economic indicators and in terms of reducing production costs.

3. The materials and methods

3.1. Modeling of the process controlled by the person-operator

The subsystem of psychophysical functional features, i.e. the human operator, in most human-machine interfaces is a highly qualified specialist, well acquainted with the class of problems, methods of solving them and approaches and principles of interpretation of the results. However, a person has certain features, objective and subjective, related to the central nervous system, psyche and physiology of the whole organism, which must be taken into account when organizing its activities in the "human-computer" as part of the typical or specialized complex and multifunctional systems. Objective features include the characteristics of the psychophysiological state of man and the psychophysical parameters of the organs of interaction with the environment, which directly or indirectly participate in the work of the human operator. Subjective features, which to some extent are determined by the functional state of the organism, are manifested in the interaction with the environment, namely in relation to the work performed, in the assessment of the work situation and in the choice of decisions made by the operator.

Operator activity can be presented as follows. Suppose that over time $[0,T]$ a human operator controls some technological process $Z(t)$. Human management of such a process includes the most typical aspects and components of real operator activity. Information display systems include monitors, mnemonics, information boards. During the process of technical means of the given technological process and from the environment in regular or casual moments of time t_i such that $t_i \in T$ where $T = \{ t_i : t_i \in [0,T], \ i = \overline{1,N} \}$, some characteristic vector of the controlled indicators $Z(t)$ - this technological process, i.e. real values of the controlled parameters is fixed. The values of these parameters obtained by various measuring and controlling means must meet the specified standards of the technological process. Information about the state of the controlled technology and the environment is provided to the operator on the monitor screen, information board, etc. For changes in these parameters, i.e. their deviation, the operator analyzes the situation and makes the appropriate decision. The decision made by the operator is made by implementing the necessary commands in the field of the control panel.

Thus, the human operator and the technical means of displaying information and executing commands form the control link of virtually any technological process. They are a holistic system called a human-machine interface.

Any technological process operates within a set of predefined normative and instructional values of parameters - G^* which determine the optimal operation of the controlled technology $Z(t)$. However, in real working situations the technological process is characterized by a set - G real values of these parameters. The values of these parameters determine the current state of this technology.

In the process of work, at arbitrary moments of time t_i, the operator receives information about the progress of the technological process $Z(t)$ in the form of reflections of these parameters on the information field of the control panel.

Simultaneous display of changes in the information field can be represented by an image of the frame state of the controlled process $Z(t_i)$. Each such frame $x_i \in X$, where

$$X = \{ x_i : x_i = x(t_i), \ t_i \in T, \ i = \overline{1,N} \},$$

where N is the number of parameter changes.

A highly qualified experienced operator uses for comparison and analysis the image $x_i^* \in X^*$ formed in his memory, which meets the established standards. In other words, analyzing the image x_i and x_i^* the operator identifies the current situation, selects or constructs and makes the appropriate decision $y_j \in Y$,

$$Y = \{ y_j : y_j = y(t_j), \ j = \overline{1,N}, \ t_j = t_i + \tau, \ t_i, t_j, \tau \in [0,T] \},$$

where τ is time for decision making y_j.

The decision y_j is realized by operator using set of commands $\mathbf{u}_h$, with control vector $\mathbf{u}_j = \langle u_1, \dots, u_h \rangle$, $\mathbf{u}_j \in U$, where U – set of control command, $h = 1, 2, \dots$ – number of commands in situation j.

Constant nervous and mental stress, a sense of responsibility and duty, long-term work naturally create a significant psychophysical load on the operator. At the same time, cognitive and motor functions are slowed down, visual search deteriorates, efficiency and infallibility of actions decrease, and significant nervous and mental overstrain occurs. Despite the large reserve and adaptive capabilities of man, this condition has a negative impact on the quality of his work.

Therefore, the efficiency of the operator must be linked to specific operating conditions c_k. The set of these states can be represented as follows:

$$C=\left\{ c_k : c_k = c\left(\delta t_k\right),\ \delta t_k = t_{k+1} - t_k;\ \ t_k, t_{k+1} \in [0,T] \right\}.$$

General model requirements for the operator and in fact its activities in the control technology system $Z(t)$ can be formulated as follows: detect on the information field of the control panel of the technological process $Z(t)$, represented at the time t_i of the image-frames $x_i \in X$ and compensate for existing deviations of the values of current parameters $\mathbf{g}_i$ from the mode $\mathbf{g}_i^*$, by selecting the appropriate vector of commands $\mathbf{u}_h$, the implementation of which will return the technology $Z(t)$ for the mode. Moreover, the choice, adoption and implementation of the decision in this situation must have the maximum probability $p \to 1$ with minimal time $\tau \to 0$, ie

$$X\left(\mathbf{g}_i - \mathbf{g}_i^*\right) \xrightarrow[\substack{p\to 1\\ \tau\to 0}]{} optU\left(x(t_i),\ c\left(t_j - t_i\right),\ y\left(t_j\right) \right),$$

where x_i - the running frame of the information field, $c\left(t_j - t_i\right) = c(\tau)$ - the time of choice of solutions and commands, $y\left(t_j\right)$ - the decision.

This expression reflects the main requirement for the intellectual activity of the operator, namely, the optimization of the modes of the process controlled by him.

Thus, the human-machine interface as a system S can be represented by a relation $S = X \times Y$, and given its existence at many points in time *T*, which are observed, and changes in the functional state *C* of the human operator, we can represent it as a tuple:

$$S = \left\langle X, Y, C, \bar{\rho}, \bar{\phi}, T \right\rangle.$$

Its elements reflect all the main components of the technological process:

$$X = \left\{ x_i : x_i = x\left(t_i\right),\ i = 1, 2, \ldots,\ t_i \in T \right\}$$

is a set of input frames that reflect the actual state of the technological process, provided on the monitor for processing;

$$Y = \left\{ y_j : y_j = y\left(t_j\right),\ j = 1, 2, \ldots,\ t_j \in T \right\},$$

a set of decisions made by the human operator, which compensate for changes in parameter values and ensure the normal course of the technological process;

$$C = \left\{ c_k : c_k = c\left(t_k\right),\ k = 1, 2, \ldots,\ t_k \in T \right\}$$

the set of functional states of the human operator during the control of this process.

The behavior of such a system is significantly determined by the change in functional state under the influence of input information, ie

$$\bar{\varphi} = \left\{ C_t \times X_t \to C_{t'},\ t, t' \in T,\ t' > t,\ t' - t = \Delta t' \to 0 \right\},$$

if at the time the operator was in a state C_t and at that moment the image of a frame $x_i(t) \equiv X_t$ with change of parameters for which the corresponding decision does not exist in memory of the operator is given. In this situation, the person begins to quickly look for a way out of the situation, resulting in a nervous breakdown and at the moment t' it is already in a state $C_{t'}$. The transition time from state to state is very short.

For normal operating situations, the function of obtaining the result of the operator's actions, depending on the input information X_t and the state C_t in which the operator is, has the following form:

$$\bar{\rho} = \{ \rho_t : \rho_t = \rho(t''),\ C_t \times X_t \to Y_{t''},\ t, t', t'' \in T,\ t'' > t' > t,\ t'' - t = \tau \to 0 \}.$$

Important in this model is the set of time points at which the beginnings and endings of all changes in the system:

$$T = \{ t_i : t_{i+1} > t_i,\ t_{i+1} - t_i \neq 0,\ i = 1, 2, \ldots \}.$$

The moment of time means the moment of acceptance, but rather its implementation by a set of commands.

Time moment t'' means moment of decision making.

The concept of the state of the human-machine interface can be formally presented as follows:

$$C = \left\{ C_k : \bigcup_{k=1}^{K} C_k = C,\ \ C_k \cap C_l = \varnothing,\ \ k = \overline{1, K} \right\},$$

where $k = 1$ – for working environment parameters, $k = 2$ – for algorithms and software parameters, $k = 3$ – for psyho-physical state of human-operator. So, the attention is to state $k = 3$.

3.2. The concept of stress resistance of the human operator

Stress is any external influence on the body that requires an adequate response by mobilizing certain protective forces. There are three phases of stress (Figure 1).

The first phase is that the body mobilizes the defenses and supplies enough energy at the right time for an adequate response.

In the second phase, the body realizes its potential. However, this condition can not be long because it quickly depletes the body's reserves, disarms it, and this leads to the breakdown of adaptation mechanisms.

The third phase is post-stress, which is characterized by a certain type of relief and mostly short duration, although in many cases this phase is quite long - days, weeks and even months.

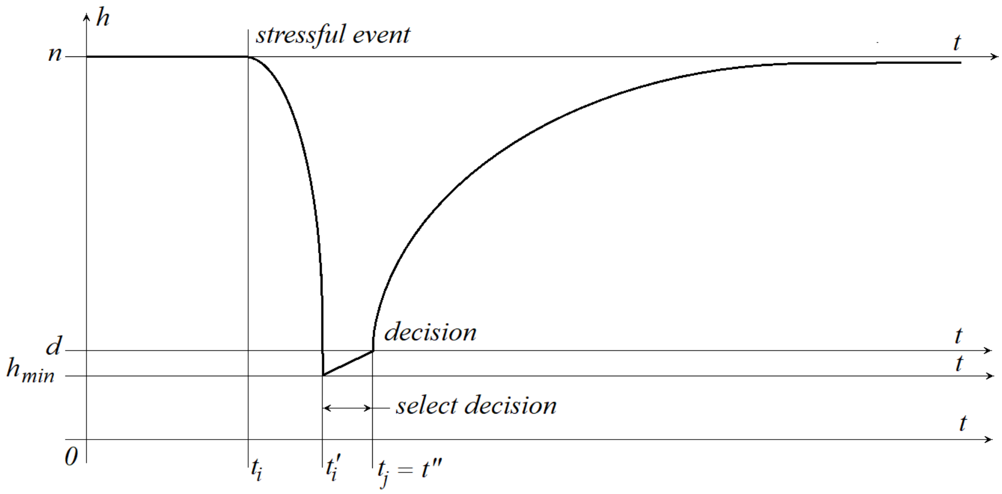

Figure 1: General view of the dynamics of the reaction to stress and recovery from stress

The authors of this study proposed an approach to establish the value of the stress indicator of staff h. The basis of this indicator are the following four general characteristics, namely: the human operator (two), the working environment and the amount of information about changes in the parameters controlled by the operator, the technological process. Such characteristics are:

Q - level of qualification of the human operator,

D - experience in managing similar technological processes,

E - discomfort of the working environment,

W - the amount of information with changed parameters.

The relationship between these characteristics is as follows:

$$h = \frac{Q \cdot D}{E \cdot W}.$$

The content of this indicator is that a well-trained, ie highly qualified operator (Q) with extensive practical experience (D) is quite difficult to "surprise". Such an operator is very quick to navigate in possible work situations, even when there is significant discomfort in the work environment (E), and the amount of information about changing parameters (W) is quite large.

In other words, the value of the stress-resistance h indicator of the human operator significantly depends on the state of the working environment and the value of the given volume of the changed parameters that characterize the technological process managed by him.

An important point regarding the use of this indicator is that the values of all four values can be determined on a scale of, for example, expert assessments. Obviously, they can also be measured as expert scores on a scale. Although such assessments are very general, in the systems of professional selection, training and certification of operator personnel, they are quite sufficient to identify operators and cluster them by level of training.

3.3. Model of operator exit from stress

The model of the operator's exit from the stress state is easily represented by a differential equation

$$\frac{dh}{dt} = k\left(h_{max} - h \right),$$

where k is the coefficient of proportionality.

This equation characterizes the growth rate of stress resistance h from the time t_j when the operator made a decision.

The following differential equation is an equation with separable variables, so its solution can be easily found in general:

$$h_{\max} - h = Ce^{-kt}$$

The constant C can be found from the initial condition: $h\left(t_j = 0\right) = V$. Therefore, $C = h_{max} - V$. Here the moment $t_j = 0$ means that the counting of the argument of the curve of the operator's exit from the stress state refers to this moment.

The operator's exit curve from the stress state is called the "learning curve", but its application is much wider. Thus, this curve in our case is described by the following formula:

$$h(t) = h_{max} - \left(h_{max} - V\right) \cdot e^{-kt}.$$

The parameter V means the minimum level of stress resistance, at which the operator is still able to make and implement an adequate decision (save the process). The difference $\left(h_{max} - V \right)$ characterizes the stress potential of the human operator.

If $V = 0$ the operator needs to stop controlling the process.

4. Conclusions

The presented models of human-machine interface, indicator of human operator stress and operator exit from stress can be interpreted as an attempt to formalize operator activity in human-machine control systems of many types of technological processes. From a practical point of view, these three models are focused on the use of quantitative indicators and characteristics, not only of the human operator, but also to some extent relate to both the technological process and the environment.

The model of human-machine interface, implemented by the apparatus of set theory, gives an idea of the technological process in this way.

First, the input information is clearly defined by a set of frame images, namely: possible number of adverse events (changes in process parameters). And these events, although they can be dangerous in different ways, but in fact their danger unites them in a set. In addition, they can be very different, but they all characterize this process, although at different times in its operation.

Secondly, the initial result of such a human-machine interface is a set of commands that implement the decisions made by the operator. The analysis of such sets of teams as well as the decisions implemented by them gives grounds to assess the professional level and efficiency of this operator in relation to the process managed by him.

Third, an extremely important point of such a model is the formal consideration of the state of the system - the human-machine interface. Such a system mapping draws attention to the human operator, indicating that he is a weak link in the whole system. In other words, the "human operator" component of the process control system requires appropriate attention from the organization of its operation. This in turn stimulates the selection, training and certification of operator personnel.

The proposed indicator of stress resistance of the human operator, already under the condition of using the appropriate scale of expert evaluation of its four elements, provides an opportunity to select the best from the group of candidates for the position of operator. This indicator, given the quantitative values of its elements, the relationship between the professional level of the operator, the external environment and the amount of information provided.

The model of the dynamics of the operator's exit from the stress state follows from the results of the analysis of the stress resistance indicator. Analysis of numerous data on human stress shows that the way out of stress is not instantaneous, but lasts for some time. In addition, the dynamics of the restoration of a person's functional state to normal is usually nonlinear and monotonous, and there may be a final nervous and mental stress, which accelerates his fatigue.

These results can be used in various laboratories and institutions for the organization of professional selection of applicants for the staff of operator personnel, their training and retraining, as well as for the certification of the qualification level. It is obvious that in such cases an expert commission should be formed and the characteristics of a specific technological process and requirements to it should be taken into account.

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