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Information technology for assessing the operators working environment as an element of the ensuring automated systems ergonomics and reliability

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***Abstract*—The paper considers the problem of automatic assessment of working conditions at the workplaces of operators of automated complexes. We demonstrate the influence of the working environment on the reliability of the operator activity. We have developed an information technology to certify workplaces and have reasoned (from the standpoint of ergonomics, reliability, and business profitability) the choice of a set of ergonomic measures aimed at improving the working conditions of operators of complex control systems.**

Keywords—ergonomics, ergatic system, human-operator, human-machine, reliability, modeling, information technology, workplace, working conditions, workload, job certification

I. INTRODUCTION

Advances in electronics, communications, information technology and artificial intelligence, automation and cybernetization of production [1-5] have led to a fundamental change in the activities of people.

The introduction of computers in all spheres of human activity- from industry, agriculture and transport [1-5] to e-learning systems [6-9] -along with a number of advantages, brought a number of complications and problems for people working in information environments.

Together with a decrease in the loads on the muscular system and a decrease in physical loads on people [1], there was a significant increase in neuropsychological loads [2,3].

Working under stress caused by pace of tension, risks, responsibility for increasing damages and threats to people's health and life [10, 11, 12], attacks by hackers [12, 13], etc., not only complicates the activities of people, but also radically changes such concepts as “taking into account the human factor”, “designing the working environment” or “designing working conditions at the workplace of a human operator” [14,15].

II. PROBLEM STATEMENT

The catastrophic consequences [1,10,11] of ignoring the “human factor” in the design and operation of complex automated control systems actualize the task of designing an optimal set of measures to ensure ergonomic quality [16-19].

A critical element of the complex system "man-technology-environment" is the human operator, because precisely human errors or failures cause more than 80 percent of accidents in complex automated control systems [19-21]. Therefore, the reliable design of human activities is the main reserve for improving the reliability of automated control [22-24].

The main objectives of the system for ensuring reliability and ergonomic quality are [16,19,21]:

- tsk1 – choice of degree of automation (distribution of functions between automation and humans);
- tsk2 – determination of the number of personnel and their qualifications;
- tsk3 – distribution of functions between operators;
- tsk4 – design of information models and interfaces (taking into account the requirements of adaptability and usability);
- tsk5 – designing algorithms for operators;
- tsk6 – professional selection of operators (relevant for critical systems and systems for special and military purposes);
- tsk7 – examination, certification and design of working conditions at workplaces of operators (work environment).

A characteristic feature of ergonomic support tasks is the interdependence of the results of their solution [16,22–24]. Efficiency and reliability of activities are determined to a large extent by working conditions and the characteristics of the working environment, i.e. the results of solving problems tsk1, tsk2 ... tsk6 depend significantly on the results of solving problems of the type tsk7 [16,25,26].

Assessment of the factors of the working environment and the labor process is determined through the severity and intensity of labor [19].

The severity of labor [19] is a characteristic of the labor process, reflecting the predominant load on the musculoskeletal system and the functional systems of the body (cardiovascular, respiratory, etc.), ensuring its activity. The severity of labor is characterized by physical dynamic load, the mass of the load lifted and transported, the total number of stereotyped working movements, the magnitude of the static load, the nature of the working posture, the depth and frequency of the body tilt, and movements in space.

Labor intensity [19] is a characteristic of the labor process, reflecting the load mainly on the central nervous system, sensory organs, and the emotional sphere of the employee. The factors characterizing the intensity of labor include:

- Intellectual,
- Sensory,
- Emotional stress,
- Degree of the monotonic stress,
- Operating mode.

It is obvious that harmful factors affect operators at different workplaces and in different production conditions in different ways. To select appropriate measures, an operational assessment of working conditions at workplaces is necessary [9,11,26,27].

Unfortunately, despite the abundance of various local studies [2,3,15–18,22–25], which relate to the individual factors described, effective computer tools for the operational assessment of the integral characteristics of the ergonomic quality of workplaces, adapted to the tasks of their certification and a reasonable choice of ergonomic events, are missing.

Thus, in this work, we will set the task of developing information technology for the operational production of integrated (taking into account the whole complex of factors affecting the human body) estimates of working conditions at the workplaces of operators of automated systems, which are the basis for:

- Workplace certification,
- A reasonable choice of measures to improve the ergonomic quality of automated systems.

III. RESULTS

A. Statement of the problem and methodology for automatic assessment of the integral characteristics of the working environment

The task is to evaluatethe integral characteristics of the working environment, based on the available values of the local characteristics.

A comprehensive assessment of the factors of the working environment is carried out on the basis of acknowledged practice of classifying the severity of labor. The classification distinguishes six categories of labor severity. The first category is the execution of work in an optimal working environment with a favorable physical, mental and neuro-emotional stresses. The second category is the execution of work in conditions that meet the maximum permissible concentrations and levels of production factors for the current sanitary rules, norms and psychological requirements. The first and second categories correspond to a comfortable working environment. The remaining categories correspond to a relatively uncomfortable working environment, extreme and super-extreme working environment.

Based on the studies [19], we accept the following sequence of estimates:

1. Determine the value of sanitary-hygienic and psychophysiological factors of the working environment.

2. Compare the values of the sanitary-hygienic factors of the working environment obtained in item 1, with their normative values, and determine the numerical values of exceeding the norm for each factor.

3. Each of the factors of the working environment really affects the human operator: evaluate by a 6-point system.

4. Determine the integral score (varies from zero to 60) of the severity of labor:

$$U_T = \left(X_{\max} + \frac{6 - x_{\max}}{6 \cdot (n-1)} \cdot \sum_{i=1}^{n-1} x_i \right) \cdot 10$$

where

$x_{\max}$ – the highest score; x_i – the score of the considered i-th factor is taken into account;

n – number of factors taken into account.

5. Determine the category of severity corresponding to the integral score obtained in item 4 (there is a translation scale [19]).

Based on the values of the integral score:

- Calculated are indicators for [19]:
  - Fatigue,
  - Operability.
- A decision is made on the certification (non-certification) of the workplace.

- Source data generated on the reliability and execution time of individual operations of the human operator's activity algorithm (there is a system of correction factors [19]. For specific conditions and specific systems, we recommend maintaining special statistical databases to consider the impact of labor severity on the error-free performance and time of specific technological operations).

B. Information technology for assessing working conditions

The main functional elements of the technology, based on the features of the described methodology, defined are (Fig.1.):

- Reference data support (block1):
  - a directory of sanitary and hygienic factors (SHF) of working conditions,
  - a directory of psycho-physiological factors (PPF),
  - a directory of categories of severity of labor (CSF),
  - a directory of correction coefficients (CC) for indicators of the quality of operations of human activity (take into account the influence of the integrated point estimate on the probability of error-free execution, on the mathematical expectation and time of execution),
  - typical measures to improve working conditions.
- Description of the sanitary-hygienic and psycho-physiological factors of a given working environment (WE) (block 2).
- Assessment of influencing factors on a six-point scale (block 3).
- Determination of the integral score for the severity of labor, indicators of fatigue and performance (block 4).
- Determination of the category of labor severity and correction factors (block 5).
- Formation of conclusions on the possibility of certification of a workplace (block 6).
- Designing measures to improve working conditions (block 7).
- Assessment of the reliability of the operator's activity algorithm (AA) (block 8), taking into account the influence of working environment factors on the quality of the human operator's activities [26–28].
- Reporting.

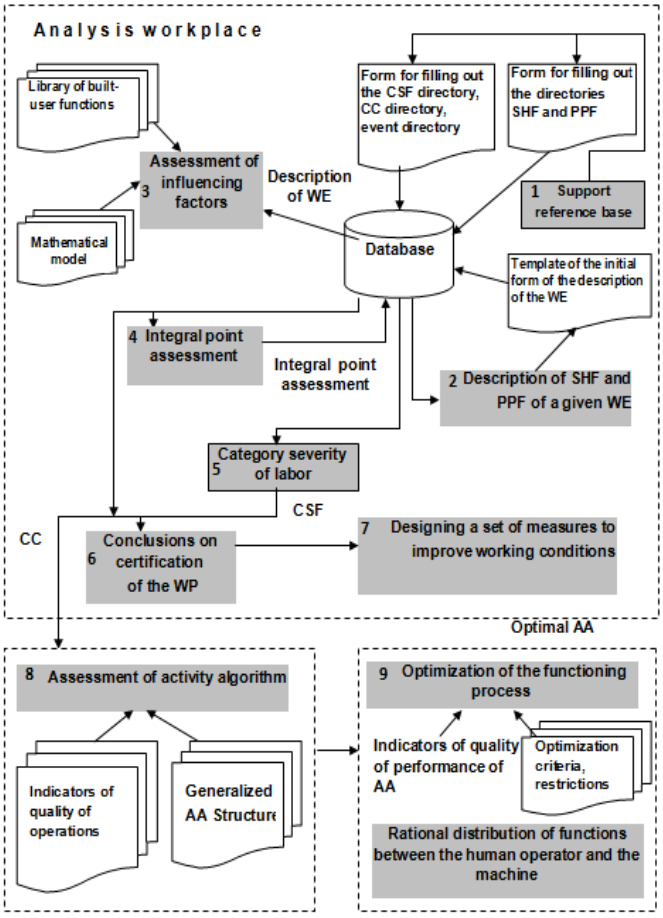

Fig. 1. Information technology for assessing working conditions

To implement information technology, we developed a special software package, using Visual Basic for Application (VBA) tools. All data required to automate the analysis and evaluation of the workplace are presented in the form of a MS Excel spreadsheet (database). Fig. 2 shows the data structure and their placement on the worksheets of the book.

The use of information technology is carried out in two stages. At the first stage, the ergonomist introduces a description of the working environment and sets the initial values of the influencing factors. In this case, it is possible to select data from the directory. If the normative value and the method of comparison with the existing one are known for the factor, the deviation of the set value from the normative value is determined (block 2 in Fig. 1). For each given influencing factor, a point estimate of the standard value is determined (block 2 in Fig. 1). In addition, for each given influencing factor, a point score is determined (block 3 in Fig. 1).

First, the integral score, indicators of fatigue and performance (block 4 in Fig. 1) are calculated. Next, the category of labor severity is determined, which corresponds to the obtained integral score, and correction factors for assessing the influence of working environment factors on the quality of the operator's activity (block 5 in Fig. 1). The performance indicators of operations can be refined by the correction factors obtained.

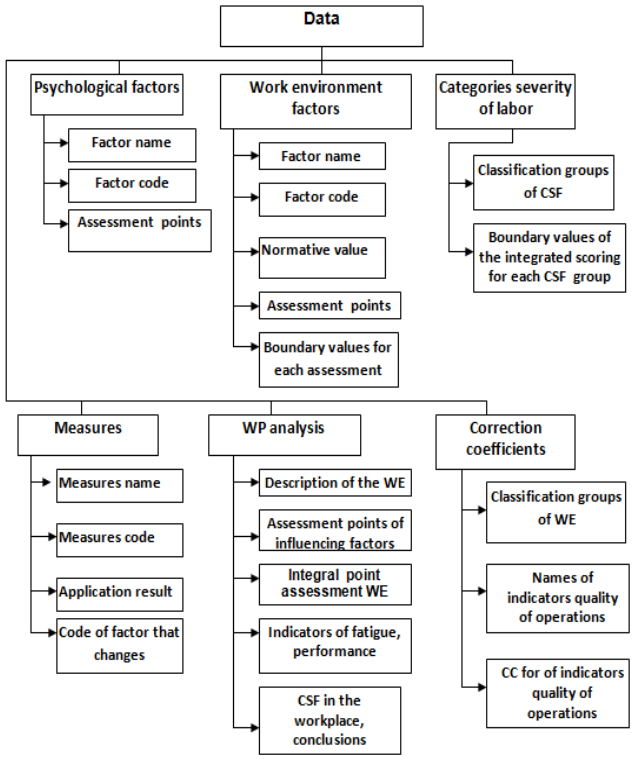

Fig. 2. Data organization

If a category of labor severity is above the second and (or) there is at least one factor with an assessment above three, the transition to the second stage is carried out. At the same time, a set of measures is being designed to improve working conditions at the workplace. After the proposed measures, the introduction of new values of the influencing factors is carried out (block 2 in Fig. 1) and the execution of blocks 3, 4 and 5 is repeated. The expected indicator of the prospective increase in labor productivity is determined, and conclusions are made regarding the certification of the workplace.

To reduce the pace of work, a rational distribution of functions between the human operator and the machine may be one of the proposed measures. Reducing the neuro-emotional load is achieved by choosing the optimal algorithm for the functioning of the "man-machine" system (block 7 in Fig. 1). The modules «Support for the help database» (block 1 in Fig. 1) and "Description of (SHF) and (PPF)" of a given working environment" (block 2 in Fig. 1) provide support for the MS Excel database in the software package. In this case, data entry forms for filling out directories and input forms for describing the influencing factors of the working environment represent the user interface.

The assessment of working conditions is associated with the input of a large number of source data placed in special forms. Due to the limited volume of the article, it is not possible to provide a complete calculation technology; we will demonstrate here only examples of some output video charts (Fig. 3-5)

	A	B	C	D	E	F	G	H
1	Values	Maximum score (x_{max})	Number of factors considered,n	Total points without maximum	Integral point assessment, (U_T)	CSF in the workplace	Fatigue indicator, Y	Workability indicator, P
2	Initial values	4	11	28,25	49,417	4	52,839	47,161
3	Final values	2,625	11	15,625	35,039	3	30,374	69,626
4								
5	Values	Working environment	Conclusions regarding the certification of WP	Labor productivity growth, %				
6	Initial values	Extremal	Not certified. The value of scores of some factors exceeds 3. Category severity of labor on WP is extremal					
7	Final values	Relatively uncomfortable	Attested	9,5				

Fig. 3. Graph display: "Results and conclusions on certification of the workplace" (example calculation results)

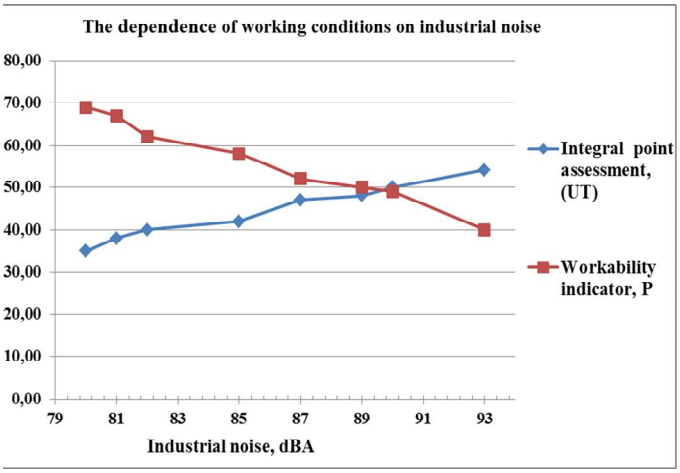

Fig. 4. Graph display: " The impact of industrial noise on the severity of labor" (example calculation results)

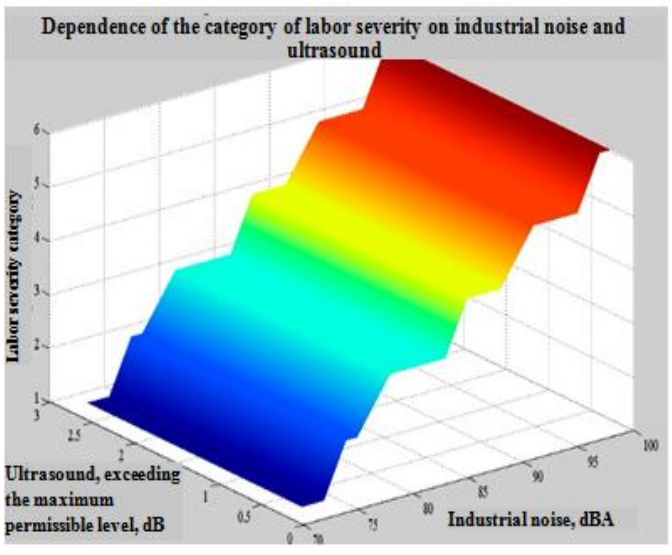

Fig. 5. Graph display: "The effect of industrial noise and ultrasound on the category of labor severity" (example of calculation results)

C. *Analysis of the merits and limitations of the method. Recommendations for use*

Based on information technology, development allows to:

- Ensure optimal working conditions for people, taking into account the whole complex of influencing factors,
- Conduct regular certification (using objective assessments) of all workplaces of the enterprise,
- Minimize the complexity and increase the transparency of the examination of working conditions,
- Timely identify a set of measures for certification of jobs with minimal cost,
- Calculate possible damage from operator unreliability,
- Calculate possible profits from improvements in working conditions,
- Carry out a variant analysis of income and damage according to the type of "What will happen if".

Possible concerns of managers and supervisors may be related to the restructuring of the enterprise information system, as operational actions required:

- Fixing values,
- Maintaining a database of parameters of all production factors for each workplace.

However, our calculations, commissioned by a number of enterprises, indicate that such expenses pay off, as a rule, in 2.5–6 months.

Possible difficulties can be associated with the assessment of intellectual and emotional stress, degree of responsibility, work and rest modes, work in a queue, etc., since the devices cannot measure these indicators directly at the workplace.

To fix these values, we have developed the procedures:

- Expert assessment using the fuzzy logic apparatus (for assessing intellectual and emotional stress and degree of responsibility) [29,30],
- Simulation of the processes of activity in the conditions of the flow of tasks (for indicators that evaluate the queue coefficients, average queue length, workload, etc.) [31].

Thus, the integrated use of measurement results and model data (expert and simulation) as source data allows us to solve the problem of forming an information base for calculations and to ensure the reliability of estimates, and therefore, the effectiveness of the proposed method.

IV. APPROBATION

The developed technology is a functional subsystem of the software package "Computer technology for modeling discrete man-machine interaction" [11,26], which was tested in the simulation man-machine systems for various purposes [9,11,26–28,30,31]. At the same time, the assessment is carried out automatically and reasoned recommendations are formed on the selection of measures of the ergonomic quality system. The technology is embedded in the decision support system, with each decision being justified not only from the standpoint of ergonomics, but also from the standpoint of the economic efficiency of management processes.

Currently, the development is used in the educational process of the magistracy of Sumy State University (Department of Computer Science) and Sumy National Agrarian University (Department of Cybernetics and Informatics). Students perform three labson the subject.

- Work place certification,
- Justification of the system of ergonomic measures aimed at certification of workplaces,
- Optimization of economic investments in the ergonomic support of the management system, taking into account the structures of actions of operators.

V. CONCLUSION

The effectiveness of the human operator in automated systems substantially depends on the characteristics of the workplace and the work environment. A comprehensive assessment of the influence of the factors of the production process on the human operator is conveniently carried out using the technology of forming an integrated point estimate of the severity of labor, which determines the category of severity of labor. Information technology, which provides quick estimates, allows certification of workplaces, recommends measures to improve working conditions and substantiates decisions not only in terms of ergonomic indicators, but also in terms of business profitability. We used a computer program in the design and operation of systems for various purposes and confirmed the constructive approach. We can recommend the technology for implementation in a wide class of information management and processing systems.

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