The method of teaching IT students computer analysis of ergonomic reserves of the effectiveness of automated control systems

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Abstract. In the article, we consider a technique for training university students, who study IT specialties to solve problems of finding ergonomic reserves to improve the efficiency of automated systems. We describe the structure of the "Ergonomics of Automated Systems" course, software for evaluating and optimizing the activities of operators of "human-equipment-environment" systems, and methodological techniques for using ergonomic computer modeling to build effective automated control systems. Discipline is built using a man-system approach to the study and design of automated systems, when a person is considered the main element of the system, but the diverse influence of hardware, software and information support, as well as the environment, is taken into account. A significant difference between the developed method and similar existing disciplines devoted to the study of the "human factor" is that, firstly, not only the characteristics of the human operator working with technology are studied, but also the mutual influence of system elements; secondly, the course is based on a qualimetric approach to assess the reliability of the activity and the economic results of this activity; thirdly, the computer modeling used is focused on optimization with the use of economic criteria of activity, while observing the requirements of ergonomic norms and standards. Functional networks developed by the scientific school "Efficiency, Reliability, and Quality of Ergotechnical Systems" by Professor Anatoly Ilyich Gubinsky were used as a methodological basis for modeling and optimization of activities.

1 Introduction

Global challenges of the current state of ecology, politics and economics [1], an increase in the number of critical systems and industries, the growing losses from accidents and disasters, growing stress on people's activities due to increasing responsibility and the worsening mental health of the population all combine to question the prospects for sustainable development of the society [2].

The long-awaited automation of production, robotics and the introduction of artificial intelligence have greatly contributed to improving the efficiency of production systems management. However, they also brought a number of new problems [1]: social (unemployment, etc.); moral and ethical; reducing the reliability of complex systems in general; risks to the life and health of people, accidents, the growth of cybercrime, etc.

The euphoria from the ideas of unmanned production and the widespread introduction of robots begin to give a sober approach to determining the rational degree of automation, finding harmony between humans and robots and recognizing the need to pay more attention to the problems of the "human factor" [3-4]

2 Problem analysis and research objectives

The creation of irrational, difficult to operate and maintain machinery and equipment can lead to harmful social and economic consequences [4]. Today, most workers, especially young people, do not want to work in conditions that do not ensure safe and productive work.

Of course, if comfortable conditions for human interaction with technology are not provided, then it is unlikely that significant economic effect will be achieved [5].

Experience shows that ignoring the human factor in the creation of machines and automated systems leads to the loss of about 30% of their possible effectiveness [4-6].

Non-adaptive information technologies and production management systems cause accidents, huge material losses and even deaths.

It is possible to minimize the probability of erroneous actions of the personnel only based on systematic

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accounting of ergonomic requirements [7, 8].

Under these conditions, the ergonomic training of future engineers is of great importance [8, 9].

Such training can be conducted in many ways [8]:

- Training of professional ergonomists (bachelors, masters):it is carried out in many universities of the USA, Canada, Australia, Great Britain, Germany, France and other developed countries; it is implemented at several universities in Russia and Belarus; it is not available in Ukraine and in most developing countries.
- The introduction of disciplines related to the "human factor" (of ergonomic cycle) in the training programs for bachelors and masters of technical specialties (unfortunately, they often belong to optional disciplines).

A survey of graduate students (149 respondents from 5 universities of Ukraine), who study various specialties related to IT, automation of production processes and cybersecurity, has revealed [7]:

- Lack of motivation to study the discipline, lack of understanding of its role in the formation of IT-specialists ("it is more important to learn programming languages") – 89.75%
- Primitive ("common") understanding of "ergonomics" – 82.1%
- Lack of a clear understanding of the differences in subjects of the study of ergonomics and other sciences "on the human factor" – "engineering psychology", "labor protection", "scientific organization of labor", "design", "technical aesthetics", "cybernetics", etc. – 95.9%

Furthermore, the analysis of the difficulties in organizing the discipline of "ergonomics" for IT specialists is also associated with the unstable disciplinary system of science itself.

Most studies focus on local problems, such as: work environment factors[4,9]; functional state of operators[4,10]; anthropometry[9]; psychophysiological aspects of the activity[4,11]; interface design[6,17]; microergonomics [4,12];other[13-15].

If you study these particular questions in detail, you can miss the main goal - "The search for ergonomic reserves to improve the reliability and efficiency of computerized systems" [8, 16].

In addition, typical limitations for a large number of studies are [8, 18-20]:

- Purely humanitarian descriptive nature and the lack of an assessment of the quantitative characteristics of the reliability of human-computer interaction.
- Lack of an answer to a question like "what will happen if?" in relation to the impact of organizational and technical measures on the effectiveness of the system.
- Lack of focus on "organizational ergonomics" and on the formation of a program of measures to ensure an ergonomic quality system.

Obviously, the discipline may be useful and relevant if it answers questions such as "What measures to improve ergonomic quality should be implemented in the system in order to maximize profits (when meeting ergonomic norms and requirements)?"[21-23].

Thus, ergonomics should not be "costly" (as they say today), but "profitable" [8].

The most convenient theory that describes from the point of view of the human-system approach, methods for assessing and optimizing the functioning of "man-technology-environment" systems based on objective quantitative indicators, is the theory of functional networks of the scientific school of prof. Gubinsky A.I. [24-26]. In addition, within the framework of this scientific school, several methods have been developed for solving computer-based tasks for evaluating [27-28] and optimizing [29-30] man-machine interaction. Obviously, these developments can become the basis for this study.

Unfortunately, as a result of a review of well-known scientific research, it was not possible to find (even within the framework of the theory of functional networks) any convenient unified computer technology of "upstream (through)" modeling of the "human factor": from the model of a person performing a separate operation to assessing the reliability of the entire process of the human operator activities (taking into account all the influential factors), especially - the selection of the optimal system of ergonomic measures.

Based on the foregoing, we define the task of this work.

Formulation of the problem. Develop and describe the method of teaching the "ergonomics of automated systems" discipline for students of computer specialties based on the following principles: qualimetric modeling (on functional networks) of human-machine interaction; maximum use of computer variant modeling; the business case for the benefits of ergonomics.

3 Results

3.1 Discipline concept development

Figuratively, the goals of the discipline are defined as follows: "1. To convince future IT professionals that the application of ergonomics in IT is not only an important requirement of the international standards system, but also an important tool to reduce the risks of accidents and emergency situations and, as a result, to increase the profitability of the business; 2. To teach students computer modeling techniques for all processes of human-machine interaction occurring in automated systems in order to search for ergonomic reserves to increase the reliability and efficiency of automated control."

We define ergonomics as a science engaged in the comprehensive study and optimization of human activity in the "man-equipment-environment" system.

We offer the following level-based logic of discipline presentation, namely: "From studying specific characteristics of a person, equipment and environment to choosing organizational and technical solutions (through evaluation and optimization, using information technologies)".

Level 1: System-ergonomic analysis of "man – equipment – environment" systems:

- What you need to know about the characteristics of man; technology; environment?
- How to conduct a system ergonomic analysis?

Level 2: Modeling human-machine interaction:

- How to carry out: description of activities; performance assessment; optimization of activities?
- How to use IT to model human-machine interaction?

Level 3: Solving the basic tasks of ergonomics:

- How to solve the tasks of: ergonomic expert examination; designing working conditions; the choice of the level of automation (distribution of functions between the operator and the machine); determining the number of operators and their qualifications; distributions of functions between operators; designing information models; designing activity algorithms; professional selection?
- How to use IT to solve the main tasks of ergonomics?

Level 4: Economic justification of the ergonomic quality program.

Moreover, each subsequent level of presentation uses the knowledge and skills of all previous levels.

3.2 Development of the theoretical part of the course

The main goal of developing the theoretical part of the course was to form a new vision of the "Ergonomics of automated systems" discipline, which differs from the well-known, albeit high-quality, but usually "narrowly focused" technologies for studying the "human factor" (There are extremes: a human-centered approach (human at the forefront), a systems engineering approach (a person is an auxiliary element serving equipment), and an "equally elementary" approach (people and equipment are elements of equal importance)) focusing on a human-system approach, which considers a person to be the main element of the system, but at the same time takes into account all the features and structure of this system.

The task is to go from studying individual elements of the "man-technology-environment" system, i.e. features and characteristics of the human body, characteristics of technical means, and environmental factors, to modeling the system as a whole, and then to formalized description, assessing the reliability of activities and optimization of activities (with economic justification of the ergonomic quality assurance program).

In this regard, the following logic is proposed for lectures (sequence of topics):

1. The object, subject, goals, objectives and methods of ergonomics.
2. System-ergonomic analysis. Characteristics of the person, technology and environment.
3. Ergonomic requirements for the "man-technology-environment" system.
4. The severity of labor and the functional state of the human operator.
5. Principles of ensuring the ergonomic quality of the "man-technology-environment «system.
6. Workplace certification.
7. Ergonomic "man-technology-environment" system design support.

8. Ergonomic fundamentals of the functioning of the "man - technology-environment" system.
9. Description and evaluation of the algorithms of the human operator.
10. Optimization of human operator activity.
11. Ergonomics of information technology.
12. Ergonomic information technology expertise.
13. Usability.
14. Human-centered distributed information systems.
15. Ergonomics of critical systems.
16. Search for ergonomic reserves to increase the efficiency of automated systems.
17. Economic justification of measures to ensure the ergonomic quality of automated systems.

3.3 Development of the practical part of the course

The main goal of the formation of the practical (laboratory) part of the discipline was to develop 100% of the course topics by means of computer modeling using the technology of "what will happen if?" with the implementation of the principles of the training sequence (the gradual complication of the material and an increase in the number of factors taken into account - from the workplace to assessing the reliability of the activity) so that teaching students how to optimize the activities of operators taking into account ergonomic norms and requirements and the need to ensure the economic efficiency of the automated system became the logical conclusion to the course.

In this regard, we offer the following structure of the sections of the practical part:

- Certification of the workplace.
- Description and evaluation of the algorithms of the human operator.
- Ergonomic expert examination of information projects.
- Designing a system of measures to ensure ergonomic quality.

Each of these sections provides for laboratory work.

The first section includes three laboratory works.

1-st lab:

- Analysis of factors affecting the working environment.
- Definition of point estimates of working environment factors.

2-nd lab:

- Determination of the category of labor severity.
- Determination of performance indicators.
- Determination of correction factors for indicators of the quality of the human operator's activity.

3-rd lab:

- Development of measures aimed at improving the working environment.
- Business case for certification of workplaces.

The second section of the practical part of the course consists of five laboratory works that ultimately Describe, Evaluate, and Optimize algorithms of the human operator.

The third topic involves two laboratory works:

- Justification of the selection of characteristics that affect the ergonomic quality of information technology.
- Method of conducting expert examination and processing the results of expert work.

The fourth topic provides two final laboratory work topics:

- Economic justification of ergonomic measures (taking into account the whole complex of influencing factors: technology, environment, characteristics of operators, activity algorithms, motivation) for monoergatic systems (one operator)
- Economic justification of ergonomic measures for polyergatic systems (many operators).

3.4 The use of computer technology ergonomic research

3.4.1 Defining a development goal

As the experience of teaching future IT specialists disciplines focused on the "study of the human factor" has shown, students are extremely negative about declarative reasoning about the importance of applying ergonomic methods and even the need to use a system of international ergonomic standards if they cannot get specific values of indicators characterizing the benefits of systemic application of ergonomic methods.

In this regard, we set the task of developing and systematic application of computer technology that ensures the assessment and optimization of activities from assessing working conditions and the workplace of a human operator certification to evaluating indicators, such as: the probability of an error-free task (function), mathematical expectation and variance of the execution time of the task (function), probability of timely completion of a task (function), profit from the use of ergonomic measures, and further, to the solution of the corresponding optimization problems.

Based on this, we have developed a unified technology for end-to-end computer simulation of human-machine interaction, consisting of two interconnected subsystems, which will be briefly described below.

3.4.2 Computer technology for assessing working conditions at the workplace of a human operator

General characteristics of the program.

It implements the methodology [24] for assessing working conditions.

The software package consists of modules embracing:

- Support of reference data (a directory of sanitary and hygienic factors of working conditions, a directory of psychophysiological factors, a directory of categories of labor severity, a directory of correction factors for indicators of the quality of a human operator, measures to improve working conditions);
- Description of the sanitary-hygienic and psychophysiological factors of the working environment;

- Assessment of influencing factors according to a 6-point scale;
- Determination of the integral point assessment of the severity of labor, indicators of fatigue and performance;
- Determination of the category of labor severity and correction factors;
- Assessment of the impact of working environment factors on the quality of the human operator's activity;
- Reporting.

Features of using the program in the educational process.

The laboratory work to certify the workplace is carried out in two stages. At the first stage, a description of the working environment is introduced and initial values of the influencing factors are set. In this case, it is possible to select data from the directory. Data entry forms for filling out directories and an input form for describing factors of the working environment that represent the interface. For each given factor, a point score and an integral score are determined. Next, the category of labor severity is determined, which corresponds to the integral score obtained and the correction factor for assessing the influence of working environment factors on the quality of the human operator.

3.4.3 Computer technology for modeling the activities of a human operator

General characteristics of the software package.

The software package works in 2 modes.

In mode 1 (estimation), the probability of error-free execution and the characteristics of a random value of the execution time of the functioning algorithm (FA), as well as the probability of timely execution of the FA, are evaluated. The initial data that the user enters or selects from the database is the FA structure, as well as the reliability and lead time of individual FA operations. For given alternatives of the FA structure and (or) methods for performing individual operations - the choice of the optimal option (24 problem statements) including:

In mode 2 (optimization), with given alternative variants of the FA structure and (or) methods for performing individual operations, the best option is selected (24 problem statements), including single-criterion and multi-criterion ones.

The main modules of the software package: support for reference data; dialog entry of the description of the FA; automatic evaluation of the FA; variant analysis of the FA; FA optimization.

Using the software package in the educational process.

The software package is the basis of the laboratory work, the purpose of which is to acquire skills for the description, evaluation and optimization of the FA.

Such assessment is used in solving problems relating to: determination of the degree of automation; distribution of functions between operators; designing information models; designing activity algorithms, selection of measures of the system for ensuring ergonomic quality).

Consider, for example, the principle of solving the problem of choosing the optimal set of measures for an

ergonomic quality system (due to measures to improve working conditions in the workplace) – a monoergic system.

Formulation of the problem.

- The structure of the FA, a set of options for improving working conditions with known costs and the calculated error-response characteristics of the individual FA operations (through a system of correction factors that take into account the influence of the integral point estimate of the severity of labor)
- You must choose the option that provides the maximum profit from ergonomic activities.

Decision fundamental.

Reduce the functional network corresponding to the FA and "substitute" the values obtained taking into account the influence of the environment (working conditions), operator's qualifications, technical parameters as input data and thus determine the values of indicators for each variant of the system of measures: the probability of error-free execution of $B(k)$; mathematical expectation $M(k)$ and variance of runtime $D(k)$; probability of timely execution of $P_{rt}(k)$ (we accept the normal distribution law).

For each option $k=1$, n of the system of measures, determine the value of the profit indicator from the N-fold implementation of the algorithm according to the formula

$$C(k) = [P_1 B(k) P_{rt}(k)]N - [U_1(1 - B(k)P_{rt}(k))]N,$$

where

- P_1 is the amount of profit from a single timely and error-free performance of activities
- U_1 is the amount of damage from a single performance of an activity with an error or (and) untimely performance
- N is estimated number of planned executions of the algorithm
- k is option number of a system of measures to improve working conditions
- $C(k)$ is the amount of profit from the N-fold implementation of the algorithm.

For each version of the system of measures to determine the value of profit:

$$E(k) = C(k) - Z(k),$$

where $Z(k)$ is the amount of costs for events.

Such modeling allows convincing business managers and owners that ergonomic improvements are not only necessary to meet the standards and requirements, but are beneficial for the business.

3.5 Approbation

The developed course has been tested:

- In full at the universities: Sumy State University (Sumy, Ukraine); Sumy National Agrarian University (Sumy, Ukraine); Higher School of Technology and Energetics (St. Petersburg, Russia);
- Partially at the universities: National University of Life and Environmental Sciences (Kyiv, Ukraine, Kiev); Ukrainian Engineering-Pedagogical Academy

(Kharkiv, Ukraine); St. Petersburg Electrotechnical University (St. Petersburg, Russia); Belgorod Agrarian Academy (Belgorod, Russia).

Moreover, the developed technology was used in the writing theses of bachelors and specialists and dissertations of masters and candidates of sciences. Among them, there are the works of graduates of Sumy State University devoted to the ergonomic support of machine-building production (Nikolai Bakhmach), chemical production (Alexander Skidanenko, Anastasia Fedorova and others), main gas pipeline management systems (Victor Koshara), outsourcing companies (Andrey Rokityansky, Alexander Barchenko, Dmitry Semenov, Eugene Plekhanov, Tatyana Shcherban, Julia Mikhailenko and others), information systems for various purposes (Julia Shapochka, Liliana Danilova, Andrey Kurochkin and others), e-learning systems (Evgeny Nikolin, Evgeniya Kaba, Nataliya Rudakova, Svetlana Vakal, Vitaliy Chernets, Anna Lebedka and others).

4 Conclusion

The aggravating problems of finding ergonomic reserves of the effectiveness of automated systems necessitate an increased attention to teaching at universities the methods that consider the "human factor".

Ergonomic training of a modern specialist in the field of information systems should include computer simulation of "man-technology-environment" systems.

It is convenient to evaluate the reliability of the human operator's activity using models and software tools that have been developed in the framework of the theory of functional networks of a scientific school of prof. A. I. Gubinsky.

The proposed training method based on information technology for modeling human-machine interaction allows you to teach students: methods for evaluating alternative options for organizing a human operator in information systems; techniques for solving the basic problems of ergonomics of automated systems; technologies for choosing a system of measures to ensure the ergonomic quality of information systems.

The scientific novelty lies in the fact that, firstly, in contrast to the well-known (usually purely descriptive) approaches to the study of human activity, for example, engineering-psychological or cybernetic, the proposed models take into account the interaction of all elements of an automated system (hardware and software, human and the environment) as well as form (taking into account all the influencing factors) the initial data on the quality of the individual operator's performance and alternative activity models in the form of functional networks and provide automatic assessment and optimization of activities.

Secondly, the developed teaching method is focused on qualimetric models, which makes it possible to search for reserves to increase the efficiency of automated systems.

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