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Development of structural model of adaptive training complex in ergatic systems for professional use

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Abstract. The article considers the structural model of the adaptive training complex (ATC), which reflects the interrelations between the hardware, software and mathematical model of ATC and describes the processes in this subject area. The description of the main components of software and hardware complex, their interaction and functioning within the common system are given. Also the article scrutinizers a brief description of mathematical models of personnel activity, a technical system and influences, the interactions of which formalize the regularities of ATC functioning. The studies of main objects of training complexes and connections between them will make it possible to realize practical implementation of ATC in ergatic systems for professional use.

1. Introduction

Training complexes are widely applied in many industries: healthcare, engineering, transport chemical and other spheres of production [1-4]. Their undoubted advantage is the ability to model and display both regular situations of human activity, and difficult-to-implement and unlikely scenarios, which is especially valuable when training highly qualified specialists.

However, the problem of mathematical modeling of training complexes has not been studied fully, there are no universal and standardized approaches because of the wide spread of such complexes in many spheres of human activity; additional restrictions on the structure and regime parameters of simulators are necessary because of the physical and psychological characteristics of each person [5, 6].

The topical scientific and practical issue is the development of not just a virtual simulator as some software that allows personnel training, but the creation of adaptive [7] training complexes (ATC) that have greater efficiency through the combined use of software and hardware, their adaptation to physical and psychological parameters of the learner, the level of his current skills and knowledge.

The development of ATC requires careful planning at the design stage, since the errors, made in the architecture of such a complex system, will lead to significant financial and temporary losses in later development stages, and will also reduce the overall efficiency of ATC during operation. Therefore, this article considers the current task of developing ATC structural model that will permit to formalize the main elements and their interaction within the developed complex, reduce further costs for the development and introduction of ATC, and increase the efficiency of its application and the level of adaptation to human characteristics.

2. Structural model of ATC

The analysis of approaches to ATC structure development showed that they are being developed for each specific area or problem [8], but universal, general models were not presented at the moment. Having studied the subject area of simulators designing, we formulated the main regularities and components of ATC, on the basis of which a structural model was obtained (Figure 1). The structural model can be conditionally divided into software and hardware subsystems and interrelations between them, which are described by equations of mathematical models of the technical system, personnel activities and influences. Each subsystem consists of separate modules that solve specific problems.

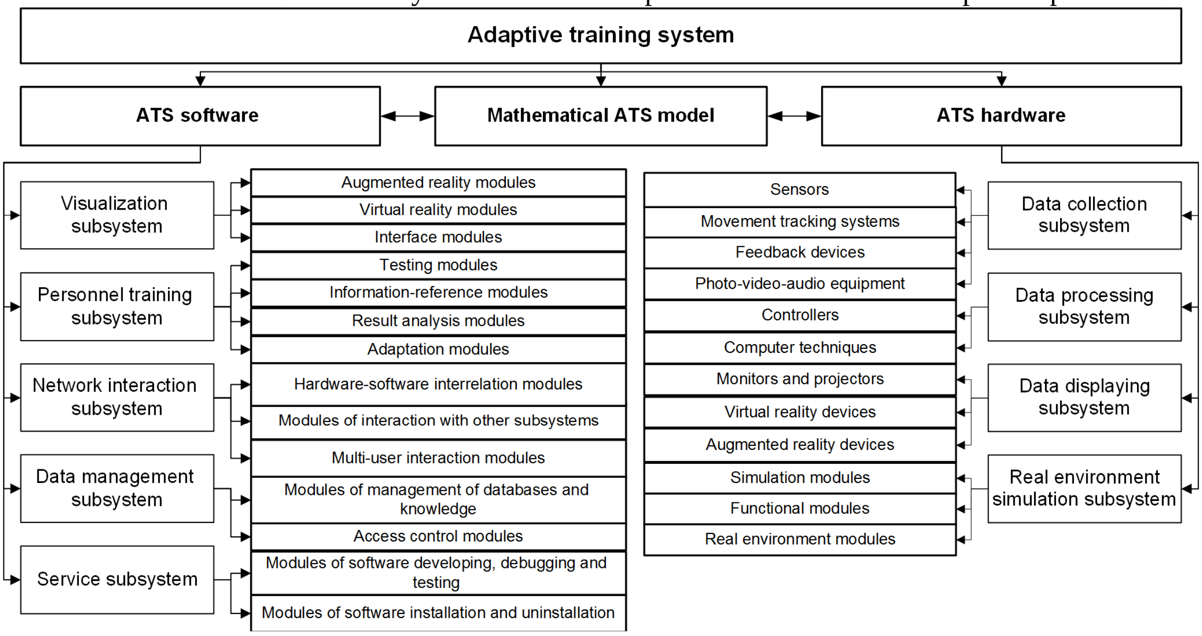

Figure 1. Structural model of adaptive training complex.

The ATC structural model in formalized form is represented as follows:

$$TC = (HW, SW, TS, P, E), \qquad (1)$$

where TC – training complex;
HW – ATC hardware;
SW – ATC software;
TS – mathematical model of the technical system implemented in the ATC;
P – mathematical model of personnel activities;
E – mathematical model of influences on ATC.

Let us dwell in more detail on subsystems and their components.

ATC hardware HW consists of the following subsystems:

$$HW = (COLL\ , PROC, DI\ S, SIM), \qquad (2)$$

where $COLL$ – information collection subsystem;
$PROC$ – information-processing subsystem;
DIS – information display subsystem;
SIM – subsystem of real environment simulation.

Information collection subsystem includes sensors, various measuring instruments, materials for collecting data from the real world, for example, pulse, pressure, temperature, etc. The following devices can be an example of such modules:

- systems for tracking the movement and position of human body parts with the help of gyroscopic, infrared sensors, special suits, gloves, etc.;
- devices with feedback in the form of joysticks, wheels, seats, etc.;

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- photographic equipment, video and audio tools, allowing to fix graphic and audio information.

Information processing subsystem receives the collected data for further transformation and use them in the calculation formulas of the mathematical model. The modules of this subsystem can be implemented on the basis of both hardware and software combinations in the form of some computer technology.

Information display subsystem performs a software objects and processes mapping of ergatic systems in ATC [9]. This subsystem responds directly to the hardware used to transmit this display to the user. The main modules of the subsystem include monitors and projectors, helmets of virtual and augmented reality; each of the modules is selected depending on the tasks and objectives that are assigned to ATC, as well as the required degree of immersion

Real environment simulation subsystem allows, using additional hardware, for the realism's intensification of the processes and events displayed to the learner. An example of such equipment is:

- simulation modules that display the real world objects in ATC and take into account the key learning properties and objects characteristics (for example, form and materials), but do not have the complete internal structure and functionality of the object;
- functional modules, that represent an already complete analog of real world objects, realize all the functional capacities, design and mode parameters, that allows the object to completely replace the original;
- modules of the real environment, including various components of the technical system, real environment, equipment, etc.

The examples of these modules are also various auxiliary equipment in the form of manipulators, suits, environmental elements (treadmills, environment imitations, active floor and others). Due to the use of this subsystem, it is possible to achieve not only a greater immersion in the learning process, but also to develop additional skills, including in the muscle memory field.

Each hardware subsystem consists of a number of hardware modules hm_i:

$$\begin{aligned} &COLL \rightarrow \{hm_i\}, \\ &PROC \rightarrow \{hm_i\}, \\ &DIS \rightarrow \{hm_i\}, \\ &SIM \rightarrow \{hm_i\}, \end{aligned} \tag{3}$$

where hm_i – hardware module, which corresponds to some set of ordered combinations of hardware components, their parameters and interrelations between them, represented by the following correlations:

$$\begin{aligned} &hm_i = \{(hw_{Cj}, hw_{Sj}, hw_{Fj})\}, \\ &hw_{Cj} \in HW_C, hw_{Sj} \in HW_S, hw_{Fj} \in HW_F, \end{aligned} \tag{4}$$

where HW_C – set of the hardware complex components (sensors, additional equipment, etc.);

HW_S – set of parameters of hardware components (structural, regime);

HW_F – set of functional dependencies between hardware components, also describing the ongoing processes within the entire hardware complex.

ATC software SW includes:

$$SW = (V, TR, NET, DATA, SERV), \tag{5}$$

where V – visualization subsystem;

TR – personnel training subsystem;

NET – network interaction subsystem;

$DATA$ – data management subsystem;

$SERV$ – simulator service support subsystem.

Visualization subsystem is responsible for the process of displaying various modes of functioning and properties of professional ergatic systems in ATC in accordance with predetermined algorithms

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and models with the help of exposure to human senses using various output means: monitors and projectors, helmets of augmented and virtual reality. Various means of 2D and 3D graphics design are used to implement the software within the framework of this subsystem (for example, widespread development and graphics platforms Unity3D, DirectX, UnrealEngine, OpenGL, etc.) [10, 11].

In a formalized form, the visualization subsystem is represented as follows:

$$V = (V_{2D}, V_{3D}, V_{AR}, V_{VR}, V_{INT}, V_{LIGHT}, V_{AUDIO}, V_{ANIM}), \quad (6)$$

where V_{2D} – set of 2D visualization components;
V_{3D} – set of 3D visualization components;
V_{AR} – set of augmented reality components;
V_{VR} – set of virtual reality components;
V_{INT} – set of interface components;
V_{LIGHT} – set of lighting components;
V_{AUDIO} – set of audio components;
V_{ANIM} – set of animation components.

Then modules sm_i of visualization subsystem V correspond to some subsets of the above-mentioned elements:

$$V \to \{sm_i\}, sm_i \to V_{2D} \cup V_{3D} \cup V_{AR} \cup \\ \cup V_{VR} \cup V_{INT} \cup V_{LIGHT} \cup V_{AUDIO} \cup V_{ANIM}. \quad (7)$$

Personnel training subsystem implements the procedures for preparing, verifying and evaluating the performance of ATC users. One should note that the training module in ATC is significantly influenced by the adaptation module, which analyzes the mental and physiological characteristics of each learner, which ultimately makes it possible to increase the effectiveness of training by flexibly adjusting of the training course, developing a set of recommendations for the activities carried out by a person. Moreover, the analysis carried out within this subsystem makes it possible to disclose the availability of abilities for new forms of work activity of the learner. The important parts of this subsystem are test modules (realization of set of tasks and simulation of the necessary virtual reality for the learning process implementation) and analysis of results (assessment and correction of the training course, identification of complex aspects for the learner).

The formalized representation of learning subsystem in the framework of structural model has the following form:

$$TR = (TR_C, TR_{INF}, TR_{RES}, TR_{AD}, TR_M), \quad (8)$$

where TR_C – set of training courses;
TR_{INF} – set of information data;
TR_{RES} – set of learning outcomes;
TR_{AD} – set of adaptation factors;
TR_M – set of teaching methods.

Similarly (7) the modules sm_i of training subsystem TR are formed by combining the elements of the above-mentioned sets.

Network interaction subsystem allows one to transfer and process data between individual hardware and software components of ATC. A hardware and software communication module is used for the interaction between sensors, measuring devices and control of software and hardware (for example, training and visualization subsystem). It includes analog-to-digital conversion of signals from multiple measuring systems and sensors and the return transfer of control actions via various communication channels (wireless and wired). A module of interaction with other subsystems is used for data transfer between individual modules and components of ATC, which allows converting the information into a format understood by all software components, decoding it and sending it to storage or processing

It is necessary to implement a multi-user mode and provide the possibility of combining several simulators into a single connected one for realization of collective training. A multi-user interaction

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module is used for this, simultaneously processing information from multiple users and allowing collective training.

Thus, the network interaction subsystem can be represented as follows:

$$NET = (NET_{HS}, NET_M, NET_P), \quad (9)$$

where NET_{HS} – set of hardware and software interactions;

NET_M – set of interactions of subsystems and modules with each other;

NET_P – set of rules of multi-user interaction.

Formation of modules of a subsystem is carried out similarly (7).

Data management subsystem is responsible for the transfer, processing and storage of information within the software. The database and knowledge management module can be implemented as a DBMS and carry out all the necessary work on entering, processing and outputting information in databases. Data integrity is guaranteed by the access control module, which permits to organize a hierarchy of user categories, assign appropriate access levels and allowable privileges for changing information.

Data management subsystem *DATA* is formed on the basis of a set of rules of databases management $DATA_{DB}$ and a set of rules for the distinction of access to information $DATA_{AC}$:

$$DATA = (DATA_{DB}, DATA_{AC}). \quad (10)$$

Service support subsystem SERV allows for development $SERV_{DEV}$, testing and adjustment $SERV_{TEST}$, the software itself, the initial setting $SERV_{SETTING}$, installation $SERV_{INST}$ and uninstallation $SERV_{UNIST}$ of the ATC software in the corresponding modules:

$$SERV = (SERV_{DEV}, SERV_{TEST}, SERV_{SETTING}, SERV_{INST}, SERV_{UNIST}). \quad (11)$$

This subsystem includes modules that are not directly involved in the learning process, but used in the design, debugging and installation phases of the software, checking its operability and compatibility with the selected hardware.

The remaining elements of ATC structural model (model of technical system, user activities and impacts) will relate directly to ATC mathematical model, which will be briefly discussed in this article.

For the implementation of an adequate and realistic simulation of *TS* technical system within ATC, it is necessary to adequately reflect in it the objects of the real world and the processes taking place in them. For this, it is necessary to systematize the main objects of the real world with a view to their further formalization and software and hardware implementation. Then let us get that the **mathematical model of the technical system,** implemented in ATC, is formed from a set of objects, their states, operations and restrictions on their realization, as well as the life cycles of each object and can be represented by a tuple:

$$TS = (U, C, O, L, GU), \quad (12)$$

where *U* – set of objects of technical system, including control equipment, environment, tools and devices;

C – set of objects states of a technical system at moments of time *t*; i.e. each object corresponds to a certain subset of states:

$$(u_i, t) \rightarrow C_i, C_i \in C \quad (13)$$

At the same time, within the framework of ATC, each object can be associated with its hardware, software or hardware-software analog:

$$u_i \xrightarrow{TC} HW \times SW, \quad (14)$$

and the situation is possible where

$$u_i \xrightarrow{TC} \varnothing, \quad (15)$$

i.e. the object is not involved in the ATC and is not required for training.

Next, let us consider the **mathematical model of personnel activities**, which allows us to formalize the information about each user of the virtual simulator and to evaluate his psychological and physiological characteristics, as well as the activities he performs in normal and emergency modes. So, let a set of all users *P* be given:

$$P = \{p_j\} \tag{16}$$

each user has the following set of parameters:

$$p_j \rightarrow (PC_j, PM_j, PK_j) \tag{17}$$

where PC_j – set of individual parameters of a person (psychological and physiological);

PM_j – model of a user's activity that can be represented by a set of ordered pairs of product rules PR_j and actions PA_j, carried out by the user in the case of rule implementation:

$$PM_j = \{(pr_{jk}, pa_{jk})\},$$
$$pr_{jk} \in PR_j, pa_{jk} \in PA_j, \tag{18}$$

$PK_j = \{pk_{jk}\}$ – set of mastered competences by user p_j.

Let us use graphs to describe the model of the activities of personnel $GP_j(PR_j, PA_j)$. They allow illustrating the sequence of activities of personnel; at the same time, the production rules will correspond to vertices PR_j, and arcs - set of actions PA_j to move from one rule to another. An example of such graph is shown in figure 2.

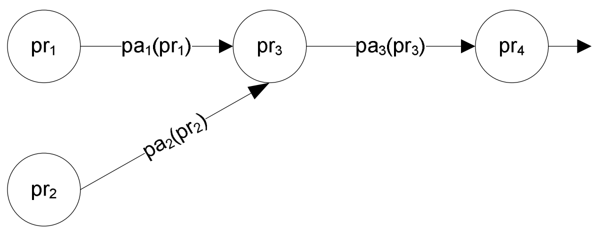

Figure 2. An example of a figure graph of the user activity model.

The influence model allows formalizing the interrelations between technical system *TS*, personnel *P* and their interactions within the framework of ATC. Set of influences *E* implements in the virtual and augmented reality processes such as emergencies, transitions from working in the normal mode to emergency, changing the visualization elements in accordance with specified scenarios**.**

A set of influences *E* includes the impacts of the following categories:

$$E = E_{HW} \cup E_{SW} \cup E_P \cup E_{TS} \tag{19}$$

where E_{HW} – subset of the influences on the hardware, for example, on the means of simulating the real environment, manipulators, means of displaying information, etc.;

E_{SW} – subset of the influences on the software aimed at obtaining some result in the form of visualization of determined scene, process, teaching method, etc.;

E_P – subset of the influences on personnel in order to improve its psychophysical characteristics, change the operating mode;

E_{TS} – subset of the influences on the technical system, leading to a change in the state of the objects of system under the impact of a set of operations for a given time.

Thus, using the impact model, we manage ATC both at the design and operation stage to achieve the necessary results. Feedback in the form of a variety of effects allows maintaining the current and correct state of all components of ATC, and can be used during structural and parametric synthesis in the formation of the structure and determination of optimal parameters of ATC.

3. Conclusion

In this article, the authors examined the structural model of ATC, its subsystems and modules, as well as the mechanism of interaction of individual components of the software and hardware complex. The conducted scientific researches allowed formalizing the main objects of ATC, presenting in the form of a clear structure the software and hardware of training complexes for professional ergatic systems. The detailed descriptions of subsystems and modules in the publication can be used to design ATC with the use of various layout methods and structural-parametric synthesis.

Also in this paper, the authors briefly examined the mathematical models of the technical system, personnel activities and effects. These models allow linking the components and subsystems of ATC into a single whole, organizing their interaction and functioning through feedback in the form of a set of control effects.

The obtained structural model of ATC, as well as the presented mathematical models of personnel, technical system, effects, will be used in further studies in the development of the complete mathematical model of ATC and formulation of the problem of its structural-parametric synthesis, which will increase the efficiency and speed of training, hardware support of ATC and educational-methodical material.

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