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Selection of visualization tools and technologies for adaptive training complexes

A.E. Arkhipov

Introduction

The need to obtain an objective assessment of visualization tools and technologies for adaptive training systems (ATC) arises in connection with their widespread use for training in various spheres of human activity: for the training of doctors, military personnel, service personnel of industrial enterprises, etc. In various fields of application, ATC has different educational tasks that are implemented both by software and hardware. Until now, no formalized methodological support for solving the problems of choosing components of the visualization system (SV) of training complexes has been proposed. The problem lies in the variety of different components of the visualization system, for which there is no classification according to certain criteria. Moreover, there is no system of compatibility of components with each other to ensure optimal performance. Also, there is no correct system of interconnection between the components of SV and the competencies that the training complex should develop in the trainee. Today, these tasks are solved exclusively by expert assessment methods, not tied to a specific methodology for the selection and classification of components.

The purpose of this work is to present an approach to the choice of visualization technologies for ATC (structure of the SV and the corresponding compatible components), which provides the required level of simulator efficiency at minimal cost. The effectiveness of the proposed technique is assessed in comparison with the generally accepted analytical approach, which provides for the phased formation of the structure of the visualization system by a group of experts based on the available experience [1, 2].

Methodology for assessing and compatibility of components of the visualization system

The main task of the visualization system is to create a learning environment that provides the necessary level of immersion of students in the work of the studied ergatic system (a system whose elements are a person and a technical device through which a person carries out his activities). The maximum approximation of the level of visualization of the object under study and interaction with the main control bodies to work on real equipment is a necessary condition for the high efficiency of the educational process and the successful application of the acquired competencies in real production activities. In addition, a well-designed visualization system will prevent learners from assimilating erroneous behavior patterns.

On the other hand, the implementation of the most realistic training environment using the training complex visualization system may require large material costs both for the purchase (or development "from scratch") of the visualization system itself, and for the development of software for training capabilities of the training complex. Situations are possible when some components of the training system are inappropriate to use for solving educational problems due to the complexity of their use or high cost (an increase in investment will not lead to a significant increase in the quality of training).

Thus, an important task is the choice of the ATC visualization technology that provides the necessary and sufficient level of imitation of the object under study with minimal material costs, i.e. maximum efficiency of the training complex.

The effect of the student's personal presence in the environment simulated by the ATC visualization system can be formulated as program-controlled influences on the main organs of perception (vision, hearing, tactile sensations), as well as providing a realistic response of the simulated environment to the student's actions. As a result of the analysis of differences in technical characteristics and a set of tasks performed, it is possible to determine many metrics for evaluating a particular component, which, in turn, can be sorted by main groups: display, interaction, movement.

1. Display - the technical capabilities of displaying various graphical information. The most important metrics of its assessment, in the context of its application in training complexes, are the accuracy of the perception of the geometric dimensions of the simulated objects and the accuracy of the perception of the distance to them. In addition, modeling large technical systems with a large number of virtual objects (3D scenes with a large number of polygons) requires a fairly high level of performance. To simulate situations associated with a high speed of movement of objects, it will not be superfluous to take into account the maximum frame rate reproduced by the display component.
2. Interaction - this group reflects metrics that make it possible to assess the possibility and reliability of interactions with objects in the virtual space of the training complex. The metric "interaction accuracy", depending on the field of application of the developed ATC, should be considered separately for small and large objects. Interaction with large objects does not require the use of fine motor skills of the fingers, for example, simple movement of objects from place to place, or control of various kinds of equipment using levers. Interaction with small objects cannot be reliably simulated without the use of fine motor skills of the fingers, for example, buttons on the control panel, assembly of a technical unit. A particularly important metric in simulators for various medical equipment is the realism of the interaction,
3. Moving - this group of metrics determines the possibilities of moving the graphical representation of the user (virtual avatar) in the open virtual space of the training complex. The important metrics in this case are the level of positioning accuracy (determination of

coordinates) and the accuracy of the movement of the virtual avatar. Realism of movement is also an important metric for training tasks related to imitation of physical activity.

4. Sound - these metrics determine the quality of the soundtrack. Important criteria for choosing this visualization components are: Volumetric soundstage, the ability of the sound system to isolate the student from the external sound environment. Realism of sound implies such parameters of the system, which are responsible for the frequency, depth and purity of the sound.

Let's clarify some of the terms of CB components used to assess the quality of display, interaction and movement. Monitors, projectors, virtual reality helmets are common, widespread hardware. "" Game "controllers" are various joysticks, gamepads, game wheels, etc. "VR, AR, MR controllers" are special controllers or trackers that are compatible with virtual, augmented or mixed reality systems. A "motion tracking system" includes hardware that allows you to accurately track the movements of a virtual avatar as a whole, or its individual parts (for example, virtual reality gloves that can track the movement of each finger, or MotionCapture systems, which digitize the movement of any part of the student's body). A "special tool simulator" is a hardware and software device that simulates a working tool as accurately as possible, for example, a syringe simulator as part of a simulator for practicing intramuscular injection skills in medicine. This also includes full-scale simulators of the control panel for various equipment. "Unique system of creating physical activity" means highly specialized devices designed for physical training. Such systems are widely used in flight simulators, which allows training pilots to experience the full range of g-forces and angular accelerations. This also includes full-scale simulators of the control panel for various equipment. "Unique system of creating physical activity" means highly specialized devices designed for physical training. Such systems are widely used in flight simulators, which allows training pilots to experience the full range of g-forces and angular accelerations. This also includes full-scale simulators of the control panel for various equipment. "Unique system of creating physical activity" means highly specialized devices designed for physical training. Such systems are widely used in flight simulators, which allows training pilots to experience the full range of g-forces and angular accelerations.

Mat. model: Description of elements and criterion

Analysis of the components of the visualization system and approaches to their assessment made it possible to formulate a mathematical model for choosing the components of the visualization system, which has the form:

$$M(TS, P) = (HW, SW, R), \quad (\text{one})$$

TS - technical system;

HW - visualization system hardware

SW - visualization system software

P - the model of personnel activity when using the training complex

R - many evaluations of the components of the visualization system.

Hardware HW consists of the following subsystems:

$$HW = (COLL, PROC, DIS, SIM), \quad (2)$$

where $COLL$ - information collection subsystem;

$PROC$ - information processing subsystem;

DIS - information display subsystem;

SIM is a subsystem for simulating a real environment.

Software SW includes:

$$SW = (V, NET, DATA, TR), \quad (3)$$

where V - many rendering components, including such subsets as: many 2D and 3D rendering components, many interface components, many lighting components, many audio components, etc .;

NET - many components of network interaction (connections between elements of the visualization system)

$DATA$ - many components for storing and processing data.

TR - many scenarios for personnel training;

Personnel activity model looks like:

$$P = \{p_j\}, \quad (4)$$

where each user has the following set of parameters:

$$p_j \rightarrow (PS_j, PH_j, PM_j), \quad (5)$$

where PS_j - many psychological parameters;

PH_j - many physiological parameters;

PM_j - many ordered pairs of production rules PR_j and action PA_j carried out by the user if the rule is met:

$$PM_j = \{(pr_{jk}, pa_{jk})\}, pr_{jk} \in PR_j, pa_{jk} \in PA_j \dots \quad (6)$$

Moreover, many rules PR_j falls into two categories depending on the mode in which they are applicable:

- for normal operation: $PR_j^N \in PR_j$;

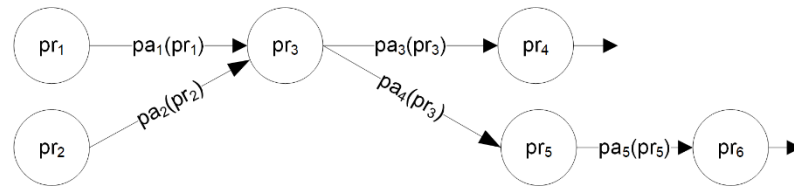
- for emergency mode: $PR_j^E \in PR_j \dots$

Each rule can be represented as: IF condition, THEN action.

Every action $pa_{jk} \in PA_j$ transitions to the next state:

$$\begin{aligned} pa_{jk}(pr_{jl}) &= pr_{jm}; \\ pa_{jk} &\in PA_j; \\ pr_{jl}, pr_{jm} &\in PR_j. \end{aligned} \quad (7)$$

To describe the presented model of personnel activities, the columns are used $GP_j(PR_j, PA_j)$. The graph allows you to illustrate the sequence of personnel actions, while production rules will correspond to the vertices PR_j , and for arcs the set of actions PA_j to move from one rule to another. An example of such a graph is shown in Figure 1.



Picture 1. User activity model graph.

The next component of the mathematical models - a set of evaluations of the components of the visualization system R looks like:

$$R = (R_S, R_T, R_C, R_{TT}, R_{QT}), \quad (\text{eight})$$

R_S - Cost of software development for a component of the visualization system;

R_T - Software development time for a component of the visualization system;

R_C - The cost of operating a component of the visualization system;

R_{TT} - Training time using a component of the visualization system;

R_{QT} - The quality of teaching using a component of the visualization system.

The cost of software development is calculated using the formula:

$$R_{S_i} = (sd_i + sa_i)k_{dev}, \quad (9)$$

where:

sd_i - the cost of developing the system;

sa_i - the cost of developing additional software to ensure the interconnected performance of other elements of the visualization system. Calculated by the same methods as sd_i ;

k_{dev} - coefficient of complexity of software development for the i -th component based on the expert assessment of the developers.

The software development time is calculated using the formula:

$$R_{T_i} = (td_i + ta_i) \cdot k_{dev}, \quad (10)$$

where:

where td_i - system development time;

ta_i - time of development of additional software to ensure the interconnected performance of other elements of the visualization system;

k_{dev} - coefficient of complexity of software development based on the expert assessment of developers.

The operating cost of the i -th component of the visualization system can be found by the formula:

$$R_{C_i} = S_f + S_p + S_a + S_e + S_r + S_{em} + S_{oh}, \quad (\text{eleven})$$

where:

S_f - costs for the purchase and delivery of the component;

S_p - salary of service personnel;

S_a - depreciation deductions;

S_e - energy consumption costs;

S_r - costs of repair or restoration;

S_{em} - the cost of purchasing consumables;

S_{oh} - overhead costs.

Studying time TT_i using the i-th component of the ATK visualization system, based on extrapolation of empirical estimates of previous tests on training complexes:

$$R_{TT_i} = \frac{\sum_{j=1}^{nP} tt_j(v_i)}{nP}, \quad (12)$$

where tt_j is the total training time for the user of the j-th student.

Quality of teaching QT_i using the i-th component of the ATC visualization system, depending on the success of the training tasks:

$$R_{QT_i} = \frac{\sum_{j=1}^{nP} \sum_{k=1}^{nK} vp_{jk}(v_i)}{nP \cdot nK}, \quad (\text{thirteen})$$

where vp_{jk} - the number of completed tasks when using the i-th component;

v_{jk} - the full scope of tasks within the k-th competence;

nK - the number of analyzed competencies.

The proposed estimates are based on the results of a system analysis of the visualization components used in training complexes and training systems used in various fields of human activity, and are distinguished by their originality and scientific novelty, since these criteria were not previously considered in aggregate.

1.3 Formulation of the problem

Thus, to find the optimal solution from various points of view, we formulate the problem statement in the following form:

$$\begin{cases} R_S \rightarrow \min, \\ R_T \rightarrow \min, \\ R_C \rightarrow \min, \\ R_{TT} \rightarrow \max, \\ R_{QT} \rightarrow \max, \end{cases} \quad (14)$$

when fulfilling the relations of the mathematical model (1-14) and restrictions on:

- correspondence of mastered competencies PK required PK^* :

$$PK \subset PK^*, \quad (15)$$

- total training time:

$$\sum_{j=1}^{nP} tTR_j \leq t_{TR}^*, \quad (\text{sixteen})$$

- economic resources:

$$R_E + R_{ET} \leq E^*, \quad (17)$$

- correspondence between the selected software and hardware modules (for each module m_k belonging to the hardware and software of the ATK, there is a correspondence cm_k modules included in the total set $SW \cup HW$):

$$(\forall m_k \in SW \cup HW) \exists cm_k, cm_k(m_k) \subseteq SW \cup HW, \quad (\text{eighteen})$$

where PK^* - a set of required competencies;

t_{TR}^* - the maximum possible training time.

E^* - the maximum possible costs for the implementation and maintenance of ATK.

So, a multicriteria optimization problem has been formulated, therefore, as a result of its solution, a certain Pareto-set of feasible solutions will be obtained that satisfy the stated conditions, but differ in the values of the criteria. Our task will be to choose the only solution based on the conditions of the subject area, technical task or other analytical considerations. Moreover, not always the correct solution is optimal according to all criteria, sometimes the solution that is in the second or third places in terms of optimality shows the greatest complex efficiency.

The use of expert judgment with the use of the listed metrics in conjunction with the test results, data from the statistics of experimental and industrial operation, made it possible to develop a system for assessing the components of the ATC visualization. This system allows you to form the structure of the training system, which is optimal for the educational problem to be solved, and to determine the appropriateness of using one or another component for a specific range of training problems. The proposed assessments of the components of the visualization system of training complexes are summarized in Table. 1-4, where the assessment of metrics is carried out on a ten-point scale.

Table 1. Estimates of display metrics

	Accuracy of perception of dimensions of 3D objects	Distance perception accuracy	Immersion level, visualization volume	Working with highly ligonal scenes	High frequency rendering capability	TOTAL
Monitor	5	2	eight	10	9	6.8
Projector	6	3	7	10	5	6.2
Smartphone	3	one	5	3	7	3.8

VR helmet	eight	9	10	eight	10	9
AR glasses	one	0	2	2	7	2.4
MR glasses	10	10	eight	3	6	7.4

Table 2. Estimates of interaction metrics

	Interaction accuracy		Realistic interaction	TOTAL
	with "large" objects	with "small" objects		
Keyboard and Mouse	4	2	2	2.67
"Game" controllers	5	3	5	4.33
VR, AR, MR controllers	6	4	6	5.33
Motion Tracking System	9	eight	eight	8.33
Special simulator instrument	eight	10	10	9.33

Table 3. Estimates of movement metrics

	Accuracy of movement	Realistic movement	Positioning Accuracy	TOTAL
Keyboard and Mouse	2	one	3	2
"Game" controllers	3	2	5	3.3
VR, AR, MR controllers	4	3	eight	5
Motion Tracking System	9	10	10	9.67
VR platforms	eight	eight	9	8.34
Unique system of creating physical activity	10	10	10	10

Table 4. Estimates of soundtrack metrics

	Insulating properties	Sound volume	Realistic sound	TOTAL
Single channel system	2	one	3	2
Surround sound systems	9	10	9	3.3
Headphones	10	10	eight	5
Special systems signals (sirens)	10	10	10	9.67

Thus, the developed system of evaluating the components of the training complex allows automating the structural synthesis of ATC due to the analysis of data on the influence of the elements of the simulator on individual components of the training process.

Below is a fragment of the production model of the compatibility of the components of the visualization system, see table. 4. General formula of the rule: IF "component is used:", THEN "components are compatible".

Table 5. Compatibility of visualization system components

IF component is used	TO compatible components
VR helmet	Keyboard and mouse; "Game" controllers; VR, AR, MR controllers; Motion tracking system; Special tool simulator; VR platforms
Projector	Keyboard and mouse; "Game" controllers; Special tool simulator
MR glasses	VR, AR, MR controllers; Motion tracking system; Special tool simulator
Monitor	Keyboard and mouse; "Game" controllers; Special tool simulator

An example of the application of the technique

As an example, consider the problem: it is necessary to develop a visualization system for a training complex for training the personnel of an industrial enterprise in the rules of working with a fire extinguisher when localizing a small area fire. Basic requirements for the developed visualization system:

- The need to ensure the accuracy of 3D models of objects
- Various types of interaction with virtual objects and the fire extinguisher itself.
- Providing the possibility of free movement in the virtual space of the training complex.

Based on the table. 1-3 and the production model (Table 4), we determine the levels of compatibility of the components with each other, and calculate the final result in the form of the sum of the scores of the assessments of the SV components, depending on the requirements for the visualization system, see Table. 5.

Next, we will present a set of CB structures that fully satisfy the training requirements. The number at the end indicates the sum of points, according to the totality of the assessments of the SV components that are included in this structure:

1. VR helmet - a simulator of a special tool (fire extinguisher) - a system for creating physical activity - 28.7.
2. VR helmet - simulator of a special tool (fire extinguisher) - VR platform - 27.05.

3. VR Helmet - Motion Tracking System - 25.6.
4. Helmet VR – VR, AR, MR – VR-platform controllers - 23.05.
5. VR helmet - VR, AR, MR controllers - 19.6.
6. Monitor - "Game" controllers - "Game" controllers - 15.4.
7. Monitor – Keyboard and Mouse – Keyboard and Mouse - 12.

Table 6. Compatibility of visualization system components

	Metrics	Result for a set of metrics
Display virtual model of a technical object	Distance perception accuracy	VR-9 helmet
	Accuracy of perception of dimensions of 3D objects	MR glasses - 7.4
	Immersion level (visualization volume)	Monitor -6.8
	Working with high poly scenes	Projector - 6.2
	High-frame display capabilities	Smartphone - 3.8
Interaction with fire extinguisher Interaction with objects of the environment	Interaction with virtual objects	Special tool simulator - 9.3
	Accuracy of interaction with large objects	Motion Tracking System - 8.3
	Realistic interaction	VR, AR, MR controllers - 5.3
		"Game" controllers - 4.3
		Keyboard and Mouse - 2.6
Moving	Free movement	Personal system for creating physical activity - 10
	Accuracy of movement	Motion Tracking System - 9.75
	Realistic movement	VR platforms - 8.75
	Positioning Accuracy	VR, AR, MR controllers - 6.25
		"Game" controllers - 4.3

Estimation of the cost of the selected SV structures without taking into account the cost of software development (the cost of a personal computer - the main control system of the ATC, we will assume ≈ 100 thousand rubles):

1. VR helmet Simulator of a special tool (fire extinguisher) - system for creating physical activity = 28.7

$$120000 + 200000 + 1500000 + (200000) = 1.920.000$$

2. VR helmet - Simulator of a special tool (fire extinguisher) - VR platforms = 27.05 |

$$120000 + 200000 + 800000 + (200000) = 1.320.000$$

3. VR helmet - VR, AR, MR controllers - VR platforms = 23.05

$$120000 + 800000 + (150000) = 1.070.000$$

4. VR helmet - VR, AR, MR controllers = 19.6

$$120000 + (150000) = 270.000$$

5. Monitor - "Game" controllers = 15.4

$$20000 + 5000 + (100000) = 125.000$$

6. Monitor - Keyboard & Mouse = 12

$$20,000 + 2,000 + (100000) = 122.000$$

The optimal in terms of price / estimate ratio is the layout of SV No. 5: VR Helmet-VR, AR, MR controllers-PCs, with an average cost of 220,000 rubles. This structure is only 3.45points xalready a complex system with a rather expensive VR platform worth more than 1 million rubles. and by 4.2points better than a structure with a monitor and "Game" controllers, which will not allow you to achieve a sufficiently high level of visualization and immersion.

conclusions

To solve the problem of increasing the efficiency of the formation of the ATC visualization system, an original method of choosing visualization tools and technologies is proposed, which is qualitatively superior to the subjective assessment, since allows you to formalize the process of selecting components of the visualization system, evaluate them according to a number of criteria, and take into account the possible incompatibility of individual components of the resulting structure.

The given example of the application of the methodology illustrates a reduction in the time for making decisions on the choice of the structure of the visualization system and an increase in the objectivity of the obtained assessment by reducing the influence of the human factor. Thus, the relevance and superiority of the proposed method for choosing visualization tools and technologies over the classical expert method is confirmed.

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