Integration of Simulation Systems into the Software and Hardware Platform of Virtual Training Complexes

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Abstract. The implementation of training complexes based on virtual reality for the training of specialists in machine-building, chemical, mining and other industries is associated with the need to solve a number of tasks. These include simulating various physical processes (temperature, humidity, and air pressure), loads (speed of movement and angle of inclination of the surface), and other external factors that cannot be reliably simulated in virtual reality. Therefore, an urgent task is to integrate various simulation systems into the software and hardware platform of virtual training complexes, which will provide a realistic immersion in the subject area due to virtual reality, as well as simulate the necessary external influences on the student. The paper considers this process by the example of integration of a simulation system of physical loads into virtual training complexes. The basis of the simulation system under consideration is a controlled treadmill. The use of treadmills allows students to develop muscle memory, perform physical training and increase the degree of immersion in virtual reality, which positively affects the effectiveness of their training. However, their integration requires the solution of a number of practical tasks for the transfer of information between the individual subsystems of the virtual training complex. The paper considers algorithms and software for solving these problems. The described approaches can be used to integrate various simulation systems into the software and hardware platform of virtual training complexes for the organization of comprehensive training of specialists.

1. Introduction

In order to become a specialist in such industries as military, mining, transport, etc. [1,2], you need not only knowledge of theoretical material, but also possession of practical skills. To achieve this goal, you need to develop a comprehensive training program that will allow you to consolidate theoretical knowledge in practice and develop muscle memory.

One of the ways to solve this problem is to use systems based on virtual reality (VR) [3-6], but in this case there is no possibility to simultaneously interact with objects and move in VR. The camera is controlled with the help of controllers; because of this the user is transported (teleported) to the selected place, which, in terms of visual and physical sensations, does not correspond to the usual movement process.

The development of new systems that will separate the movement processes and VR complexes based on treadmills [7-12] for training specialists will help prevent the problem described above (Figure 1). The advantage of this development will be to ensure realistic movement, the use of hands to interact with objects and, in general, the necessary physical training of specialists.
The laws of functioning of modern treadmills, the presence of software and hardware lags do not allow the user to comfortably move along the belt, therefore, the main task is to organize interaction with VR based on a controlled treadmill [13-16], develop new algorithms and control approaches that will increase the comfort of movement and the degree of immersion in the virtual environment.

Figure 1. An example of a controlled treadmill.

Thus, the key subsystems of the software and hardware platform are:
- a visualization subsystem that implements the user's interaction with virtual reality, tracking his actions in the virtual space;
- a logging subsystem used to collect and store information about the preparation process;
- subsystem for integration of third-party simulation systems;
- simulation systems of various types and functionality.

Within the framework of this study, the task of integrating simulation systems through the implementation of the integration subsystem in the application architecture is set. To do this, it is necessary to develop a structural model of this component of the software and hardware platform, mathematical, algorithmic and software, to conduct its approbation.

2. Structure of the simulation systems integration subsystem
The subsystem of integration of simulation systems according to the general structure of virtual training complexes should implement the following functions, distributed in three modules:

- data reception module: receives information via software interfaces (socket). The data is received in the byte array format;
- module for processing incoming information: the received byte array is processed depending on the data type or the ID of the simulation system. The array is converted to strings, numbers, or other data types, and then passed to the main Unity application of the virtual training complex;
- synchronization module for connected clients: several simulation systems of the same type can be connected to the virtual training complex at the same time. Within the framework of this module, data is synchronized between the main application and the simulation systems, as well as data is sent to the systems for the purpose of configuring them or switching modes. This allows user to keep the entire system of connected clients up to date.

Communication with simulation systems can be carried out wirelessly or wired. In the first case, user can use a local Wi-Fi network or cellular communication (3G, 4G, hereinafter - 5G). The second approach involves transferring information over a USB or LAN cable. As part of this study, we are considering a wireless connection in a local Wi-Fi network.

We get the following connection diagram for simulation systems (Figure 2).

![Simulation systems connection diagram](image)

**Figure 2.** Simulation systems connection diagram.

Next, we will consider the algorithm of functioning of the subsystem for the integration of simulation systems.

3. Algorithm formalization of the integration process of simulation systems
To implement the process of integration of simulation systems, it is necessary to carry out a number of information transformations.

Let be $S$ - a set of imitation systems. Then for some imitation system we get:

$$s_j \rightarrow \{x_{ij}\}, s_j \in S, j = 1, 2, ..., N,$$  \hspace{1cm} (1)
where $x_i$ is an information packet belonging to the system $s_i$ and $N_i$ is the number of types of data packets.

Each packet has the following characteristics: $x_i = (d_i, l_i, f_i)$, where $d_i$ is the content of the information packet, $l_i$ is the length (size) of the packet, $f_i$ is the data format.

Let’s denote the virtual training complex as $T = \{t_i\}$, where $\{t_i\}$ is the set of modules of the complex.

Then it is necessary to implement the following mappings:

- the procedure for converting the original data into a byte format, which will change the format $f_i$ to $byte$, as well as convert the length and content of the information packet:

  $$f_b : f_i \rightarrow byte, x_i \rightarrow x_i^b, l_i \rightarrow l_i^b.$$  (2)

- the procedure for transferring encoded data from the client socket of the simulation system to the server socket of the virtual training complex:

  $$f_i : (x_i^* \in s_i) \rightarrow (x_i^* \in T).$$  (3)

- the procedure for converting the encoded data into the desired format $f_{ij}^*$ for further use in the virtual training complex:

  $$f_p : byte \rightarrow f_{ij}^*, x_i^* \rightarrow x_i^{**}, l_i^* \rightarrow l_i^{**}.$$  (4)

On the basis of the developed software, it is necessary to implement an integration algorithm for each simulation system and a specific application of the virtual training complex. It is also recommended to create a database of systems with their types and identifiers of specific simulation systems, which will ensure the correct operation of the client synchronization module and identification of the connected systems.

4. **Approbation of the subsystem for the integration of simulation systems**

This architecture of integration of simulation systems is reasonable when there is a large amount of complex data and high accuracy of results is required. Because their use allows users to visually simulate all the factors of the workflow in various scenarios.

An important part of training systems for personnel in the chemical and mining industries is the simulation of loads on the respiratory system, for which real or simulating devices are suitable [10,11]:

- ergospirometers, which allow cardiopulmonary exercise testing (ergospirometry) and are useful in obtaining indicators of the respiratory and cardiovascular systems during stress tests;

- specialized self-contained breathing apparatus (eg self-rescuers).

Connecting systems for changing the microclimate in a room is also necessary to study the problems of changing the physical parameters of a person in conditions of high humidity, intense heat radiation, low air exchange.

Third-party devices within the hardware and software platform may also include other simulation and auxiliary software used in the training process, for example, additional sets of sensors from third-party developers, systems for monitoring vital signs, nervous activity, and so on.

Modern devices that simulate pressure and impacts on the body are quite rare developments of their kind [11]. This firmware is a suit that simulates pressure, vibration, force, touch, etc. thanks to a set of force sensors and pneumatic airbags [13-18].

A unique component of the personnel training system is a controlled treadmill with the ability to adjust the angle of inclination of the belt and organize movement along two axes [19-20]. This allows the user to freely and naturally move within the platform, as well as dynamically change the intensity of loads on the musculoskeletal system. The possibility of automatic regulation of the platform speed
allows user to fix the user in its central zone at different speeds of his movement and will not allow him to independently leave the work area before the end of the workout. The treadmill includes the treadmill hardware itself, which includes a frame and power elements, a module for determining the position of a person in the area of the working area of the platform, based on the use of position trackers. The data transfer module integrates the track with other systems to synchronize the user’s movement speed with the movement of the camera in virtual space.

To implement a connection on the client side, a socket must be created with an indication of the host and port of the virtual training complex server. On the server side, the following components must be implemented (Figure 3) [21-22]:

![Figure 3. Algorithm for the integration of simulation systems into a virtual training complex.](image-url)
- Socket listener that will listen on the port throughout the entire execution time. Conceptually, it will not perform read / write functions, since its only responsibility is to receive connection requests to the port to which it is associated;
- Socket handler that is created when an incoming connection is received. It is his responsibility to receive and distribute input data in a virtual reality movement system.

The C# language features contain high-level classes that work with additional threads, so the implementation of the architecture of the server application is based on the use of asynchronous methods and interfaces [23].

The developed algorithm and software for the treadmill integration subsystem into the training complex made it possible to organize the interaction of the treadmill and virtual reality (Figure 4). This made it possible to realize comfortable movement of a person in the virtual space.

![Figure 4](image.png)

**Figure 4.** An example of data transfer between treadmill modules (left) and Unity (right).

5. Conclusion
The paper considers the process of integrating simulation systems into virtual training complexes to improve their functionality in training specialists. The use of systems for simulating physical activity, breathing apparatus, various physical processes is associated with the need to integrate software interfaces and hardware equipment that has different standards and formats for information transfer.
To solve this problem, the concept of a software and hardware platform for virtual training complexes is considered and a subsystem for the integration of simulation systems is implemented. The structure of the integration subsystem, the algorithm of its functioning, the hardware and software used for its implementation within the framework of the software and hardware platform are presented. Approximation of the proposed approach is considered on the example of integration into a virtual training complex of a system for simulating physical loads (controlled treadmill).

The approaches considered can be used to integrate various simulation systems into the software and hardware platform of virtual training complexes, which will increase the efficiency of training specialists.

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