The Concept of Human Learning Professional Movements Using Exoskeleton Complex

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Abstract

Training systems are the actual direction of development of science and technology. Training systems can be built on the basis of various technical systems. This article proposes the concept of teaching a person to professional movements with the help of a training system based on the exoskeleton complex. The advantages of using the exoskeleton complex are the ability to accurately measure the angles of rotation of the human hand and introduce haptic sensations. Haptic technology allows a person to receive from the virtual environment not only visual information, but also kinesthetic, which is an important difference from other training systems based on the virtual environment. The article describes the proposed concept, describe the task for its implementation, consider requirements for the exoskeleton complex, the possibility of implementing the concept on existing exoskeleton complexes, identifies areas for further research, and considers the prospects of the proposed training system. The use of the proposed training system will improve the quality of training and the speed of human learning of professional movements.

Keywords: training system, exoskeleton, motion capture, virtual reality, professional movements.

Introduction

Education is an actively developing area. The modern education system should solve the difficult task of training new generation specialists for the conditions of professional activity in the global information society. The priority task in the preparation of a competent and competitive specialist in their field becomes the task of mastering practical skills and in particular professional movements.

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The mastering of professional movements requires numerous repetitions. In a number of areas, the mastering of professional movements on physical samples is costly or risky. For example, in the space industry, medicine, railway transport and other areas associated with increased danger. Also there are difficulties with recreating the conditions of action in extreme situations. Moreover, educational institutions often encounter a number of problems that reduce the effectiveness of the acquisition of practical skills by future specialists. The most common problem is the lack of necessary equipment or the approach to the end of its operational period, as well as materials and other means by which the specialist could consolidate the theoretical knowledge acquired in the learning process.

One of the most popular examples of solving this problem was the introduction of so-called simulator technologies. Simulator technologies are used in those areas where mistakes in learning at real objects can lead to extreme consequences, and their elimination can lead to large financial costs. Training on a simulator involves training without risk, aimed at improving the quality of services rendered (operations performed) and developing the necessary personal and professional qualities, as well as ensuring safety when performing tasks in working conditions with real objects

Among the advantages of using simulator technologies in the educational process, the following should be noted:

- indirectly helps reduce equipment wear and material consumption;
- the ability to simulate and safely study the extreme and emergency operation of equipment, and therefore increases the safety of further operation.

Examples of such simulators can be found in [Zar19, Vel14, Shu08, Tro11, Ilj11, Val14, Bat16, Ket12].

The VL10-U electric locomotive driver's training simulator was produced by the Design Bureau of the Locomotive Economy – a branch of the Russian Railways OJSC [Zar19]. The interaction of the student with the training complex passes through a specialized training environment that provides various scenarios, for example, the need for maneuvering work. This complex is made on the basis of the EP1M electric locomotive cabin, consists of a real driver's console, an instructor's workplace and has the ability to connect specialized equipment for psychophysiological research. To achieve maximum realism when performing practical tasks, the training complex is equipped with a dynamic platform that allows you to simulate the dynamic effects on the driver's seat. Video systems create the illusion of presence by displaying the driving conditions in a frontal window using a projector and in side windows on TV screens. The visualization system is based on 3D graphics. The software performs 3D-simulation of the movement of an electric locomotive taking into account its physical parameters and the dynamics of rail transport, as well as the properties of the virtual environment, allowing to simulate the electric locomotive ride in real time. To ensure tests for fatigue in the training complex, a nominal section of the track with a length of 300 km is used. It is possible to create high and low air temperatures inside the cabin [Zar19].

However, the development of simulators based on physical equipment is associated with high costs for hardware and software. The resulting simulators are highly specialized and allow you to work out only certain skills of a particular field. Information technology and computerization have become an integral part of almost all spheres of life of modern human and society. Virtual training technologies that are a software and hardware training complex, which interact through a virtual environment, are widely spread throughout the world.

The rapid development of computer technology, as well as lower prices for computer equipment, opened access to the development of various types of simulators. The high quality of visualization of virtual reality glasses, as well as the rapid development of real-time visualization software, allow the future specialist to recreate a realistic picture of the workplace and related technological processes. Virtual training technologies that are a software and hardware training complex, which interact through a virtual environment, are widely spread throughout the world. Many, including Russian companies, are engaged in the development, manufacture and sale of training complexes, VR / AR-content, intended for various areas of professional activity: education, health care, industry, including space, military, transport and etc. Among them are the following Company: KS Plus LLC (also known as SIKE), Mir 3D LLC (also known as United 3D Labs), VRTech Group. As hardware for simulators based on virtual reality, standard equipment can be used. To develop a simulator, it is necessary to develop only the program part. Thus, on the same equipment, simulators can be used for various areas. The universality of the equipment used reduces its cost.

One of the developments of the company United 3D Labs is a training simulator for virtual reality glasses for working with industrial equipment. VR glasses and controllers act as the hardware of the simulator. Through the controller, the student interacts with objects of the virtual environment reproduced by VR glasses. As significant disadvantages of such training systems include:

• The need to maintain a particular position of the hands – in front of the motion capture sensor, which actually means holding hands in front of a person in a limited area and, especially with prolonged use, causes discomfort.

• The imperfection of the algorithms for determining the position of the hands, leading to the fact that at certain angles of the hand actually cease to be determined.

• Low accuracy when interacting with objects of the virtual environment.

In the field of medical education, the technology of training on the simulator is called simulation training. Today, simulation education (SE) is a mandatory step in programs of secondary, higher, and postgraduate continuing medical education. This requirement is enshrined in a number of regulatory documents [Kan14].

In the field of medical education, it is important to note the following advantages of simulation training, which are specific to this particular professional field:

• patient safety;

• increase in the time and intensity of practicing practical skills, due to the absence of refusals from real patients to be served by a young specialist.

According to research [Vit11, Mad07, Bri17], the performance of simulators based on virtual reality is close to the performance of physical simulators, and the transition from the simulator to real practice is seamless [Lam11].

Virtual reality-based simulators for laparoscopy are widely used [Waj17, Sch11, Mad03, Bri17]. There are also simulators for invasive surgery, head injury treatment, ophthalmology and robotic surgery [Nei16, Cas17, Ste05, Wil17, Luc13]. Virtual reality can be used to visualize the mechanisms of various medical phenomena [Cla18].

The technological barrier to the development of virtual reality simulators is the lack of virtualization of human haptic sensations, which reduces the depth of immersion and the quality of the accumulation of professional movements. Existing simulators do not allow to properly accumulate the muscle memory of performing professional movements. To solve this problem, the article proposed the concept of teaching a person to professional movements and proof of the possibility of its technical implementation.

1 Task

To solve this problem, it is proposed to use an exoskeleton complex with a force-moment feedback as a simulator. With this approach, in addition to the visual component, the simulator allows you to create a force-moment load on a person, which will allow you to more fully immerse yourself in the virtual environment and train your muscle memory to perform professional movements.

The general scheme of such a training system is shown in Figure 1. The overall concept is as follows. Using the virtual environment model, a virtual environment is generated, which is displayed in a human virtual reality helmet. A person performs movements, which are captured using the sensor system of the exoskeleton complex. Based on human movements, recalculation and rebuilding of the virtual environment model is performed. If a person contacts with objects of a virtual environment, for example, a bank or an instrument touches an object, the virtual environment model calculates the interaction force and affects the human hand through a drive system. The purpose of the next section is to substantiate the design and the necessary hardware composition for the implementation of the proposed concept.

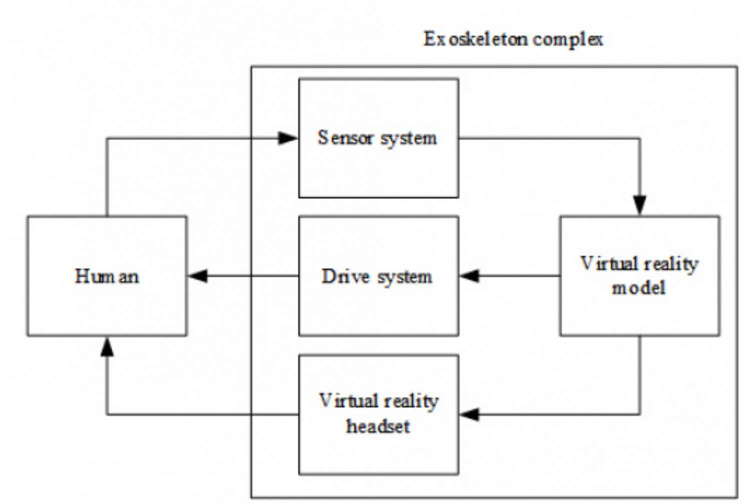

Figure 1: Exoskeleton complex

2 Development Of Methodology

To perform the task, the exoskeleton should have the following functions:

• the capture of the movements of the main degrees of freedom of the human's hand joints;

• resistance to the movement of a human's hand to simulate haptic sensations.

The kinematic structure of a human's hand has seven main rotational degrees of freedom [Pet18]. The kinematic structure of the human's hand is shown in Figure 2.

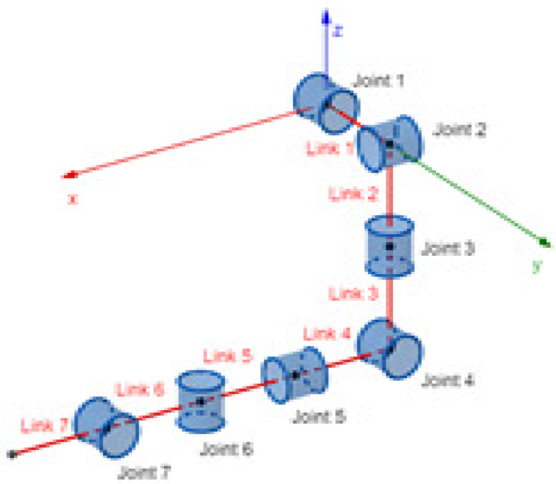

Figure 2: Kinematic structure of the human's handa

To accomplish the task, it is proposed to use exoskeletons, like the one described in [Pet18]. This exoskeleton is a lever system, the links of which are parallel to the human hand (Fig. 3). In spite of the fact that the exoskeleton is intended for the copying control of the manipulators of an anthropomorphic robot, its features allow it to be adapted for use in teaching a person to professional movements.

Figure 3: Exoskeleton [Npo18]

Figure 4 shows the kinematic diagram of the interconnected exoskeleton and operator hands [Pet18]. In the diagram, the letters A,B,C,D and A_0, B_0, C_0, D_0 designate the shoulder, elbow, wrist and hand center of the exoskeleton and the shoulder, elbow and wrist joints, and the center of the human's hand, respectively. The points D and D_0 have a rigid coupling between each other and are the center of capture of the driver and operator's palm, respectively. The humeral, elbow, and wrist links are designated for the setting device as AB,BC,CD links, respectively, and for the operator's hand, A_0B_0, B_0C_0, C_0D_0, respectively. Hard links in the distance between the shoulder and wrist joints of both kinematic chains are designated as $AA_0 \quad CC_0$. A,B,C - exoskeleton articulations, which correspond to the shoulder, elbow and wrist joints of the operator's hand A_0, B_0, C_0.

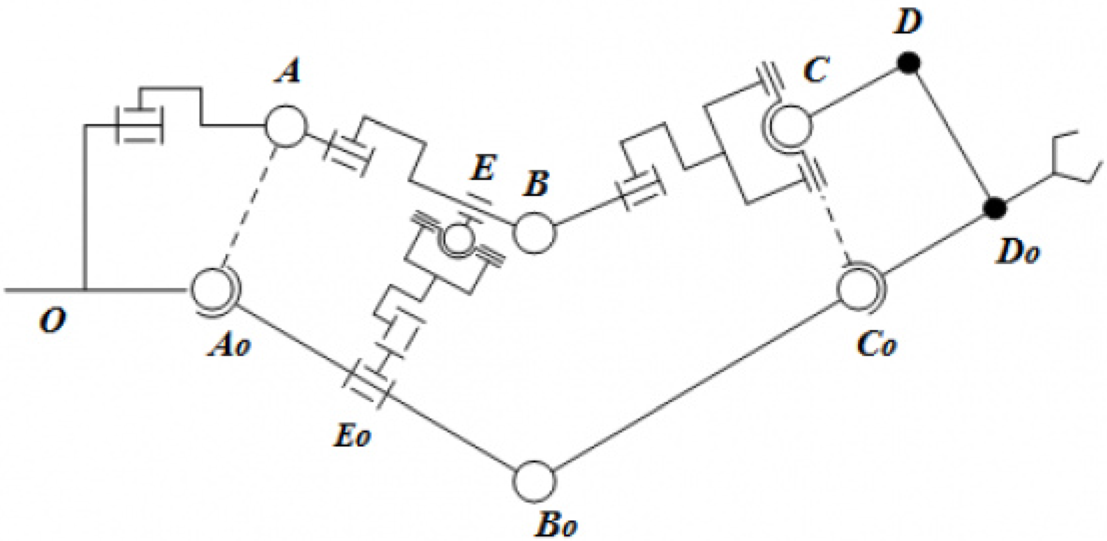

Figure 4: The ratio of the rotational pairs of the driver with the joints of the operator's hand

The exoskeleton has a kinematic scheme, a similar scheme of the human hand. This constructive solution is introduced for ease of interpretation of the rotation angles of the rotational kinematic pairs. Sensors are installed in the exoskeleton articulations, which allow measuring the angles of rotation in all basic degrees of freedom of the operator's arm. A feature of this exoskeleton is the correlation, but the mismatch of the angles of rotation, in the joints of the human hand and the exoskeleton. However, on the basis of known data, rotation angles can be recalculated using the methodology developed in [Pet18].

In the considered system of teaching professional movements, an exoskeleton with 7 degrees of freedom was chosen as the hardware component. There are 7 sensors that transmit at each time the value of the angle of change of the position of a human's hand in a particular exoskeleton node. Under the movement of a person in the training system, we will assume the gesture performed by students. In this gesture is considered as an ordered set of certain poses. To recognize a gesture, you must repeat each of its postures in the specified sequence. We assume that a pair of values "moment of time - the value of the angle of rotation" will describe the specific position of the human hand, and the set of such points will describe its gesture. In addition to sensors, the exoskeleton can also be equipped with drives that allow the exoskeleton to resist the movement of the human hand [Bat16].

The sensor system allows you to get a time series of the operator's hand movement, which will allow the simulation model of the virtual environment to perform visualization in the virtual environment of the operator's hand and calculate the interaction between the operator's hand and the virtual environment objects.

Each person has his own particular hand structure, which is somewhat different from the model embedded in the virtual model. However, as evidenced by the results of experimental studies, thanks to proprioception, a person does not experience any difficulties in interacting with the virtual environment.

3 Results

Consider the prospects for the use of this training system. This system opens up the following perspectives.

Machine control the correctness of human movements. The most valuable in the consultation of experts is the ability to analyze the movement and identify errors. Existing systems are able to capture and analyze only the movements of the final effector. The proposed system allows you to measure the angles of rotation of the entire hand of the operator, which allows you to perform analysis and so on.

The presence of digitization of the operator's hand movement allows the system to operate in several modes:

1 In free training mode. In this mode, the desired trajectory is displayed in the virtual environment, and the person repeats the desired movement. An improvement over peers is the granularity of the virtual environment. In the helmet of the virtual environment, you can not only look at the environment, but also feel it "at a touch."

2 In auxiliary mode. The presence of auxiliary drives allows you to direct the movement of the human hand. At the same time, a person works in a passive mode, muscular memory is accumulated for performing professional movements.

3 control mode. In this mode, the exoskeleton does not support the person, but only assesses his movements. This mode can be used to determine a person's readiness to perform actions by profession, or to move to more costly training on full-scale samples.

The approach to learning is as follows. With the help of a sensory system, the movement of a person is captured. With the help of a computer system, the construction of human movements and their visualization in a virtual reality helmet are performed. In the event of deviation from the desired movement, the operator's movements are adjusted.

To determine the proximity of the analyzed movement to the model, mathematical methods used in motion recognition technologies can be used. The essence of the task of motion recognition is to assign a recognizable motion to one of the predefined classes. Classification is performed on the basis of any metrics of the proximity of the object being analyzed to the objects of the training sample. The task of pattern recognition is to relate the object to be recognized to any previously described class of objects, the standards. The classification of recognizable objects is based on precedents - images, the classification of which is known.

In this case, the reference movements of a professional, previously known and described in the system, will be taken as a precedent. As a recognizable object, there is a movement digitized using an exoskeleton. Therefore, to solve the problem of determining the degree of conformity of a student's movements to professional movements, mathematical methods used for pattern recognition can be used.

Classification of recognizable objects will be carried out on the basis of comparison with the reference image. The task of this classification is to find out, on the basis of some measure of proximity, or similarity, which reference is closer to the object to be recognized. The measure of proximity is defined as the distance between objects. The basis for the experimental calculations is a method describing a measure of proximity based on the spectra of movements obtained using the direct Fourier transform.

Insert a description of the proposed method.

For the experimental studies were used various performances of the same movement, obtained from the source [Tec07]. As input data, the angles for each of the seven exoskeleton sensors describing some professional movement were considered. One of the performances was used as a model movement. Also, for the purpose of testing, the analyzed movements were artificially modified to test the operation of the method in slow motion and others.

In fig. 1 shows the graphs of human movement when performing exemplary movement. Artificial changes made to test the method are shown in Figure 2. At the same time, scaling along such axes and some other distortions are performed.

Insert pictures, graphics and results at least on the page.

We offer a new approach to the system of training professional movements. The hardware part of the training system is an exoskeleton. The system can operate in several modes - training, testing. This article will be considered testing mode.

The results of the experiment confirm the efficiency of the proposed method. In conjunction with the method for the recognition of movements on the basis of these methods, an educational system of professional human movements can be built. Also, the proposed method can be used for the operation of the training system in the mode of practicing movements. This system allows you to find the deviation in which you want to intervene. It is assumed that, thanks to the support of feedback between the exoskeleton and the student, such a system, being in the training mode, will be able to form the correctness and accuracy of the movements, developing muscular memory.

The proposed method can be improved due to the fact that the cross effect of the degrees of human mobility is taken into account. These results are planned to be obtained in subsequent articles. Also, the movements of a person from a physiological point of view and the individual characteristics of the movement of people are considered little.

4 Discussion

The article proposed the concept of training professional human movements using the exoskeleton complex and considered the prerequisites for the possibility of its implementation. To put the proposed concept into practice, a number of activities are required. It is necessary to perform a technical implementation of the training system. To do this, it is necessary to develop a virtual training environment and organize the exchange of information between the virtual environment and the exoskeleton. The exchange of information includes the transfer from the exoskeleton to the virtual environment of the rotation angles in the joints of the operator's hand, and the transfer from the virtual environment to the exoskeleton of the video stream and the magnitude of the force effects exerted by the exoskeleton on the operator to simulate haptic sensations. The formation of the visual component does not contain elements of novelty. However, the implementation of force on the operator to simulate haptic sensations is a relatively new area. In order to realize haptic sensation, the development of a methodology that takes into account the capabilities of the exoskeleton, the accuracy of the transmission of sensations and safety requirements is also needed. After the technical implementation of the concept, it is possible to conduct a study of the effectiveness of its use for training professional human movements.

5 Conclusion

The article considers the general trends in the process of teaching a person professional skills and, in particular, professional movements. A significant direction in the development of learning technologies is the virtualization of learning environments due to the universality and relatively low cost of the necessary equipment, and the simplicity of developing learning environments. The main disadvantage of virtual learning environments is the ability to virtualize only audiovisual human sensations. The proposed concept of teaching a person to professional movements using an exoskeleton complex allows one to overcome this barrier and improve the quality of teaching.

The advantages of using the exoskeleton complex lies in the exact capture of human movements and the possibility of virtualizing haptic sensations. Accurate capture of human movements makes it possible to implement systems for evaluate the professionalism of his movements based on mathematical methods. Virtualization of haptic sensations due to drives installed in the degrees of freedom of the exoskeleton allows to increase the depth of human immersion in a virtual environment, increase the realism of the movements being worked out and develop the necessary psychomotor skills.

For the technical implementation of the proposed concept, an exoskeleton with all the necessary functionality was selected and considered. The analysis showed that there are all the necessary prerequisites for the technical implementation of the concept.

In addition, the article described the prospects for the implementation of this concept in practice and outlined areas for future research.

6 Acknowledgment

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