Design Model of a Training Simulator in Virtual Reality

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Abstract— **This paper discusses problems that arise in the process of designing training simulators based on virtual reality. Virtual reality increases the performance of training due to immersion and realistic spatial objects. Unfortunately, there are problems associated with designing training simulators based on virtual reality. These problems are related to the performance of the environment in the context of effective user training. The paper presents a new approach to design a framework for a training simulator in virtual reality. Its key idea is to introduce basic principles for building of a two-level architecture using a user-centered design (on low-level) and object-closed design (on high-level). The low-level includes a modeling of the subject's orientation and the response of the environment to external influences. The high-level focuses on the specific of training scripts such as specificity of the operation or a detailed 3D model (visualization of target's operation through user interaction with the virtual environment). The data obtained can provide benefits to modeling training systems in virtual reality and for improving learning performance. The material presented can open new prospects for further research studies. It seems interesting to those who work in the field of usability engineering, training and human-computer interaction.**

Keywords- virtual reality; virtual environment; human-computer interaction; training simulator; virtual subjectivities; user-centered design; design framework component.

I. INTRODUCTION

The applications of Virtual Reality (VR) are becoming very popular in different fields of human activity. On one hand, there is a continued optimism in the growth of the immersive industry sector [1]. On the other hand, there are many opportunities in the contexts of communication and integration of human feelings and emotions in the Virtual Environments (VE) [2].

The greatest interest is simulation based training on VR (the system hardware and software are essential components of the virtual reality system), which affects the sense organs like in a realistic scenario of professional activity.

Despite the active progress of immersive and interactive technologies, some difficulties are still associated with certain restrictions. These problems include 3D interaction design in VR [3], creation of realistic 3D content such as physics and visual effects [4], unified techniques of interaction in the VE [5], the difficulties of geo-positioning and spatial relocation [6].

This paper covers actual issues linked with the analyses and description model of VR for training simulation, which takes into account the subject area and subjective user experience.

One of the most common applications of VR is simulation training in the different spheres such as medicine [7], astronautic science [8], education [9], industry [10], sports [11], military [12], games [13], building architecture [14], etc. Therefore, VR should reproduce a user's practical activity in the context of any task. At the same time, VR is safe for humans in comparison with the physical environment [15].

It was noted that the training of tasks that are performed in a three-dimensional space are better performed in VE [16], for example, memory training [17] or improving spatial thinking [18]. Moreover, perceptions of learning programs are becoming more effective in VE by increasing user motivations [19], modeling collaborative learning or other communication practices [20]. The greatest interest is training of movements and memorizing motor skills [21], such as simulations of accurate manipulations at atypical conditions for humans [8] [22].

It was shown that VE has an influence on psycho-emotional states and stress resistance [23]; thus, this one could activate the corresponding behavior like in the real world [24]. The analysis mentioned above shows the potential of VR in the context of increasing the effectiveness of learning and simulation training.

The rest of the paper is structured as follows. Section 2 describes the main problems of human-computer interaction within VR. Section 3 covers some related works in this area, summarizing the differences between characteristics and features of training simulation in VR. Section 4 mentions the mapping model, which is followed for the training simulator. Section 5 concludes this paper.

II. PROBLEMS

At the moment, the design of human-computer interaction within VR is centered on classical usability methods [25] that have been used in the Windows Icon Mouse Pointer (WIMP) - paradigm applications for a long time. At the same time, VR crucially differs from conventional desktop applications first of all by its deep psychophysiological action, a wider set of interaction techniques, and 3D contents [26].

Another key problem is related to the design of the immersion functionality. On one hand, there is an empirical correlation of immersion with hardware and software parameters of VR such as a frame rate, tracking a head rotation, audio, and interaction methods applied in the VE. On the other hand, a deep level of interaction can be explained by activation of similar structures in the brain, i.e. sensory stimuli as in the real world. Therefore, we face a problem of continuity between the subjective experience of the presence in the environment and the functional performance of the VR hardware [27].

It was noted that human performance is the basic element in VR because performance-based simulator-design guidelines include balancing perceived realism with simulator limitations, such as latency resulting from graphic and haptic renderings [28]. The problems of presence that affected humans in VR, such as user movement control, should be streamlined to enhance performance and reduce sickness [29].

The main principles of the complex processing of input information in VR were discussed [30]. This approach considers the user through the perception of the psycho-emotional model of the environment. On one hand, it is important to find a balance between rational reasoning and emotional reasoning because these factors integrate the human psychological state with VE [31]. On the other hand, there is the virtual subjectiveness [32], which affects consistency (mapping) between the cognitive-psychological level of the user's perception and the VR system [33].

Due to the problems mentioned, various research works and studies are focusing on finding out the components of visual immersion, including field of view, field of regard, and display size. Each element of visual immersion affects measurable user performance, understanding, and preference in a wide variety of VEs [34]. In this way, it is important to define what components affect the performance of which tasks [35].

However, there is a wide set of training simulator-based VRs that gives a good account of itself. These are VR simulators in medicine [36], education [37], communication [38], military [39], etc. So, let us consider how these problems are overcome. Based on these results, it is possible to describe the attributes and architectures (approaches) for designing the training systems in VE. It should be noted that the selection of parameters for the model of training simulators will be controlled by the specifics of the user-environment relations.

III. RELATED WORK

The Structural-Functional Design (SFD) overcomes the difficulties linked with the complex structure of the VR system and defines separated components, such as visual, behavioral and interaction characteristics. Each characteristic refers to the object's state inside the VR system and includes a set of parameters. For example, the visual level includes the rendering of the 3D content after the process of a user's interaction with the environment. The behavioral characteristic defines the actions of objects in VE and the interaction between 3D objects.

In the context of training, the design model finds out the components that may have a strong impact on the modeling of a realistic training simulation. The methodology formalizes the process of VR interface into two phases, which describe levels of abstraction, and breaks down the phases into components [40]. The high-level phase defines the conceptual feature of the environment (the target of training, methods simulations); at the same time, the low-level phase guides details of human interaction, rendering of 3D objects, behavior of the environment, etc.

Consequently, SFD helps to unify around the structure of the VR system, defines the components of the systems, and finds out the target and features of components. In practice, this methodology uses the Virtual Reality Interface Design (VRID) model [40], TRES-D [41] and other examples [42-44].

Unfortunately, the mentioned model focuses to a greater extent on technical details and ignores the specifics of participants. This conceptual framework may help to plan a design process or represents the operational behavior of the system. Therefore, it is important to consider other examples of the model of VR, which takes an active part in the interaction and communication with the user.

The Communication-Information Design (CID) suggests considering a training environment like an active subject of communication with the user [45]. For that reason, the mentioned environment contains a decision support system based on Artificial Intelligence (AI) that concentrates around avatars (virtual human being) and virtual surroundings.

The typical illustration of CID is the so-called Virtual Human Project (VHP) [46]. The goal of VHP is to create realistic virtual humans to increase the effectiveness of the communication information procedure of interaction between users and avatars. In this case, the user is a concurrent part of the training environment and active object in VE.

Conceptually, the virtual humans or avatars should include three nested layers that make up the mind the agent thinks with (cognitive layer), the body the agent acts with (virtual layer), and the world of the agent (simulation layer) [46]. Each layer is the set of components that extend features of avatars and includes verbal speech, body gesture, and actions the character performs, for example, walking.

For training simulation, the approach mentioned may help to design the environment for cognition and emotion modeling of the user's condition. In practice, it is training in VR such as tactical questions in military or cultural immersive training [47], commutative capacity [48], and crowd simulation [49]. The specific feature of the communication–information approach is modeling virtual humans for interaction with the user through speech and gesture.

The Object-Closed Design (OCD) focuses on detailed implementation (visualization of granule operation's component, pressure feedback, quality of movement) of the complex manipulation in a variety of fields such as medical [50], handling operations [51], engineering [52][53], system of telepresence [54][55], etc. This approach includes monitoring the system in real time. In this case, the environment should be reacting on each event that appears after the user's manipulation, 3D object's interaction, the end of a fixed period, etc.

Therefore, VR should reproduce a user's practical activity in the context of any task. Indeed, the user is key to the system's component; at the same time, the reaction of the environment is more important. The user is defined as a secondary member and a concurrent element to perform any task. The communication between the training environment and the participant is executed through object-closed manipulation. For example, in the medical field, there is pressure on the special mannequin, imitation of elasticity and feedback of rendering a 3D view of anatomical structures [50].

The object-closed approach may help with detailed modeling of task execution. Unfortunately, this model disregards the significance of user's attribute such as motility, psychophysiological specificity, subjectivity, and experiences.

The User-Centered Design (UCD) models a training environment that consists of users (humans) as the most important items in interaction with virtual content through equipment. For that reason, the user is no longer "a black box" because this one may *be considered* like an object with previous experience or psychophysiological specificity. It was noted that human performance is related to the quality of the VE (level of immersion, self-explanatory navigation, ease of interaction with 3D object, etc.). At the same time, it has shown the positive and negative impact of VR on the health of humans [56]. Therefore, it is important to extract a human feature, which affects the performance of the environment. For example, in the Conceptual VR Model (CVRM), the user handles effectors (shell, fixture, appliance) from VR, which reduce feedback in the form of sensory stimuli. Consequently, for correct modeling, UCD finds out the mapping of the virtual effectors and the perceptual system of the participant. So, the visual perceptual system is linked with visual display such as orientation in time and space [57].

Conceptually, there are three independent main parts of the system, such as the environment, a user and a mediator. The mediator integrates the user with VE through Virtual Subjectivities (VS) [53]. The VS includes reminiscence about the surrounding medium and subjective experiences in the context of the psychophysiological-cognitive patterns that become active in the same situations as in physical reality. The mediator appears in the form of scale perception, orientation, action, etc. The UCD does user an active actor in the scheme of training systems because the virtual model combines human perception and dynamic spatial content. Unfortunately, the border between the user and the VE remains diffuse in this model. The mediator is a key component needed in defining the factors that support the performance of the training simulation in VR.

Table 1 summarizes the differences between the characteristics and features of different model designs. As the table indicates, each approach brings significant challenges in modeling the training environment. For example, CID fits collaborative training or face-to-face communication, but it is unlikely to be used in an illustration of surgical operation. UCD, for example, does not completely reflect the specific quality of the operation, but it probably allows to include the virtual subjunctives in the process of simulation.

TABLE I. PREVIOUS RESEARCH AND DEFINITIONS OF THE DESIGN MODEL OF TRAINING SIMULATION IN VR

Name	***Framework and design model***	***Type of training***	***Central elements***	***Key features***
SFD	Tanriverdi V., Jacob R. J. K. VRID 2001 [40], Molina J. P. et al. TRES-D 2006 [41], Cochrane T. et al. DBR 2017 [43].	none	The visual, behavioral and interaction characteristics	Defines components of the systems; finds out target and features of components
CID	Kenny P. et al. VHP 2007 [46], Prange A. et al. MDS 2017 [48], Ulicny B., Thalmann D. Crowd simulation 2001 [49]	Collaborative training, communication, crowd training, cultural interchange.	The cognitive level and AI, model of avatar (verbal speech, body gesture, and actions the character performs)	Creates a realistically virtual human to increase the effectiveness of communication–information procedure of interaction between users and avatars
OCD	Çakmak H. K., Kühnapfel U. KisMo 2000 [50], Pürzel F. et al. 2013 [51], Stoll	Modeling of granule operation's component, pressure feedback, quality of movement	The reaction of VR on actions of user (pressure, feedback, imitation of elasticity and	The special mannequin or a detailed 3D model. Visualization of target's operation through user

Name	*Framework and design model*	*Type of training*	*Central elements*	*Key features*
	E., Wilde M., Pong C. 2009 [54]	and etc.	etc.)	interaction with VR.
UCD	Stanney K. M., Mourant R. R., Kennedy R. S. 1998 [56], Latta J. N., Oberg D. J. et al. CVRM 1994 [57], Parés N., Parés R. 2006 [32]	Modeling of training simulator includes user experiences, characteristics, and psychophysiological-cognitive patterns.	The user handles effectors (shell, fixture, appliance) from VR and reproduces feedback in the form of sensory stimuli	Model of mapping virtual element's and correct user's perception.

It is necessary to emphasize that current models are linked with targets of training simulation and use different architectural components. The most interest brings UCD and OCD approaches' focus on the subjective perception of the environment and VE's reflection on input user's action. In the next section, the extended model of training systems based on UCD and OCD will be discussed.

Immersion or presence is a critical attribute of VR [58]. Immersion is the state of mind of an individual where he or she excludes the outside world and is totally focused on experiencing another world [59]. It was shown that the immersion appears in the form of cognitive and perception components of user's subjectivities [60]. On the one hand, immersion influences the performance and quality of an executed task [61][62] through correct selection and specification of spatial elements. In this context, the 3D content and property elements of VR are important attributes of the presence. Especially, the important role of physical laws [63], velocity [59][64], collision and occlusion [65] were shown.

There is a set of properties of VR devices that affect presence, for example head rotation [66], tracking system [67], screen resolution [68], and rendering [69]. Moreover, the empirical result found in [70] confirms the requirement for the presence of the following parameters: frame rate, tracking head rotation, sound, and technique of interaction.

The relation between the correct properties of spatial objects and any parameters of devices remains an open discussion. This problem has been considered through different schemes, for example, human reaction and subjectivities mapping.

Subjectivities mapping attracts the most interest because this approach defines two additional and important cues for the understanding of the psychological impact of VR. These two cues are the physical interface (any manipulation of devices based on the movement of the user) and the logical interface (any rendering or view's feedback after the movement of the user). Then, the virtual subjectivities impact on the environment itself seem to be a mapping or correct association between the user movement and the view rendering. Unfortunately, the approach mentioned is needed in the definition of mapping elements. At the same time, the elements are key to understanding the principles of modeling the training environment in VR. In the next section, we will discuss the mapping elements based on the training requirements and the framework for designing a training environment in VR.

IV. The Mapping Elements of Training Simulation

The sequence of human actions in a VE was shown [71]. Firstly, the person orients himself/herself in the VE and, after that, he/she interacts with the VE. We believe mapping elements might include a set of grouped human actions based on the priority for human perception inside the VE.

For this reason, the Queuing Network-Model Human Processor (QN-MHP) may help to describe the process of human perception through the functioning of the sensory-motor system based on three layers (sensory, cognitive and motor) [72]. Therefore, human actions are associated with ordered sensory-motor reactions. Indeed, the person perceives visual information through the sensory layer (sensory analysis). The visual information activates previous experiences from the human knowledge (the database of knowledge). Finally, the motor program is reproduced in the form of actions and manipulation (motor program).

These assumptions about the process of human perception and mapping elements may have a strong impact on modeling training systems. On one hand, the mapping in the VR system in context of human knowledge (the database of knowledge) from QN-MHP may include human perception of VE in form (distance = scaled, rotation = viewing angle, lighting = visual effects, sound = audio effects) and the simulation of behavior for the environment based on previous user experiences from real situations such as (physics laws = correct rendering 3D-content, tracing = moving reaction, fitting = distance reacting).

On the other hand, for modeling of the specific process in form of focused actions should be included components from human perception of VE and the simulation of behavior for VE. We believe this combination is a high-level model for object-closed design. It is focused on specific training simulation. The relation between mapping and design levels for the training simulation is shown table 2.

The sensory-motor activation in training simulation with mapping model may help to understand the relation between VE and the functioning of the human perception. For this reason, each perception layer may be linked to virtual subjectivities, which include logical interfaces, physical interfaces and mapping.

The logical interface is responsible for visual effects in context of virtual subjectivities. In this way, human perception in the form of sensory analysis is related to the logical interface through visual feedback. The visual feedback perceives from the database of knowledge «Conceptual model» inside the cognitive layer. The extracted situational model may be corrected according to the current situation. Accordingly, the synchronization of previous user experiences is triggered.

TABLE II. THE CONCEPTUAL SCHEME OF MAPPING ELEMENTS OF TRAINING SIMULATION

High-level (OCD)	**Object-closed modeling**			
	Execution a task: The logic of application with modeling of different scripts and important of components (the imitation of workflow, operation's quality, precedence, and time delay).			
Output:	Logic interface (correct rendering of VE as feedback from physics interface)			
Low-level (UCD)	**User-centered modeling**			
	Orientation		Imitation	
	The mapping elements			
	Distance	Scaled	Moving	Time correlation
	Rotation	Viewing angle	Tracking	Moving reaction
	Lighting	Visual effect	Fitting	Changed distance
	Sound	Audio effect	Physics laws	Correct rendering
Input:	Physics interface (manipulation with virtual devices: Head-mounted display, virtual glove, tracking, joysticks and etc.)			

At the same time, the corrected model influences to choose motor action in the form of "motor reaction". Finally, this motor reaction converts to muscle efforts through the physical interface. The mentioned steps are summarized in Figure 1.

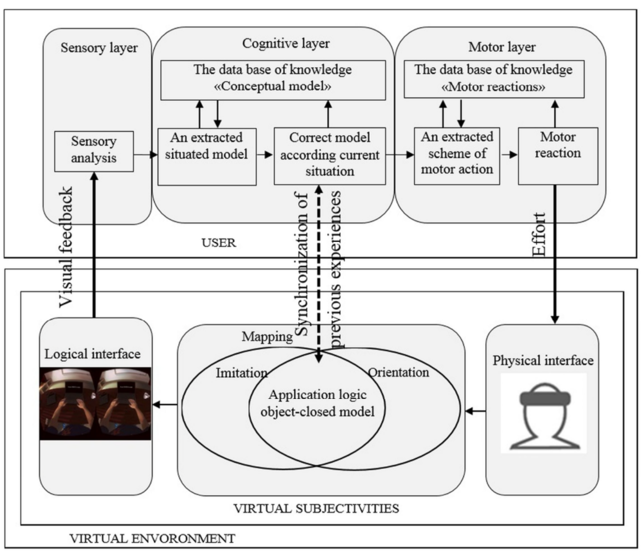

Figure 1. The user's role in training simulator based on mapping model

The mentioned model is focused on human reactions, which are related to virtual subjectivities through synchronization of previous user experiences. Therefore, the abstract database of knowledge «Conceptual model» needs great numbers of training situations for effective training. It reminds us of training a set of examples for Artificial Neural Networks (ANN).

We do not know the deep principles of brain learning. At the same time, there are different primitive models of the human brain such as ANN. This models show better results than human beings in some tasks such as classification or image recognitions. For that reason, we should make an analogy about ANN and «Conceptual model» from the mapping model. The ANN gets many various pieces of data for training, and then a training simulator based on «Conceptual model» may be considered as the generator of nonrecurring learning situations. Those situations may help to overcome the problems that are linked with the satiation of the database of knowledge «Conceptual model».

V. RESULTS AND CONCLUSION

In this paper, we identified the contemporary approaches to the design model for the training simulator in VR. It was noted that there is a relationship between the type of training and the design model of training simulator in VR. The greatest interest is in a design model based on OCD and UCD. Both approaches are perspective in different fields of training process. These approaches offer to focus on a detailed process of task execution is the same as integrating the user into the workflow. We believe in a central role of human reactions in the training process based on the mapping model.

The mentioned approach for training simulator based on VE allows us to define a design framework, including two design levels. The low-level UCD paradigm focuses on the human reaction, simple actions and perception. This level includes mapping logical and physical interfaces.

On one hand, the main target is a correct adjustment of mapping using scaled setting, viewing angle, visual and audio for correct orientation inside the VE. For example, scaled and viewing angle may be selected by empirical value based on experimental results (regression model and least square method - LSM). The other attributes (lighting and sound) are selected with expert's requirements and normative standards.

On the other hand, the environment should reproduce the imitation of basic tasks through reacting to the user's actions (movement, changed distance, time and physics laws). In this case, simple tasks (tracking and fitting) may be reduced in simple special tests (reaction on moving an object or changed object's distance).

The other things such as the physics laws or the movement may be corrected by developing tools (example Unity3D: colliders or rigid body). The main purpose is to create the immersion of a recipient in VE.

Then, after the process of immersion, there is a need to fill the environment with dynamic content. The high-level consists of building correct low-level and application logic based on the OCD. Therefore, the main target of this layer is to collect an unbound data in the complex training context based on a specific training simulator. There are many templates of OCD such as a complex 3D object or a mannequin.

Further research work should be focused on the low level of the design model. Especially, we will focus on scale and viewing angle based on experiments. A person will evaluate the distance between two points in the VE and real-world such as viewing angle. The results will be shown in the form of recommendation for the design of the training system, for example, simulator of harvesting machine.

 ISBN: 978-1-61208-750-4

ACKNOWLEDGMENTS

The results of this study were obtained with the support of Grant No. 25.1095.2017/4.6.

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