LEARNING IN VIRTUAL 3D ENVIRONMENTS: ALL ABOUT IMMERSIVE 3D INTERFACES

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Abstract

Human-computer interaction have entered the 3D era. The use of immersive virtual 3D environments in the area of education and learning is important field of research interest. 3D virtual worlds can be dynamically modified, updated or customized and more operators can cooperate when solving specific task regardless to their physical presence. With respect to the features of immersive human-computer interaction as well as specific cues included in virtual environments it is necessary to consider every aspect of 3D interface in the way how it influence the process of learning.

Especially, the social and communicational aspects in Collaborative Virtual Learning Environments (CVLEs) is the state of the art for the current research. Based on our research of interactive geographical 3D environments, we summarize and discuss the relevant theoretical and technological aspects entering into the issue of interaction with 3D virtual environments. The operators' manipulation and evaluation of the displayed content is discussed regarding such phenomena as fidelity, presence/immersion, informational and computational equivalence, situation awareness, cognitive workload or human error. We also describe specific interface developed for recording and measuring the participants' behavior in virtual spaces. Further we suggest the methodological background for the research of 3D virtual interfaces with respect to virtual collaboration and learning.

Keywords: 3D technology, situation awareness, user interface, human error, human-computer interaction, fidelity, presence

1 INTRODUCTION

With the rapid development of informational technologies, the communication and collaboration in virtual worlds (VWs) have entered a 3D era (Boughzala et al., 2012). 3D visualizations are a subsequent step in the efforts for creating an effective and comprehensive graphical representation of data in computer-generated virtual environments. As stated in Fabrikant et al. (2014), the use of the three-dimensional visualization widens the possibilities of representation of virtual data. By creating a three-dimensional model of an object, it is possible to incorporate more information into screen. The 3D technologies attract attention of the experts in such areas as nuclear industry, medicine, aviation, traffic, crisis management, urban planning, cartography etc. (Lin et al., 2015; Hirmas et al., 2014; Popelka & Dedkova, 2014; Rierson, 2013; Zimmerman & Koebbe, 2013; Wilkening & Fabrikant, 2013;

Popelka & Brychtova, 2013; Weber et al., 2010; Bleisch et al., 2008; Forsell, 2007). However, as suggested in a persuasive number of studies, three-dimensional virtual worlds have also potential to support effectivity of learning (Montoya et al., 2011; Lim et al., 2006; Bailenson et al., 2006; Barab et al., 2005; Hideyuki, 2004; Johnson et al., 2002). Bleisch and Dykes (2008) suggest the interactive 3D visualization as well-explaining representation of the real environment. 3D technology is for the educational purposes suggested by Weber et al. (2010) or Hirmas et al. (2014). Previsous research supported the Real 3D visualization as the promoter of map specifics recalling (Edler, Bestgen, Kuchinke & Dickmann, 2015). The 3D-visualisations tends to bring more visual fidelity into the virtual representations (Hochmitz & Yuviler-Gavish, 2011) to simulate properties of the real environment. In some studies, it was found out that stereoscopic displays compared with non-stereoscopic displays, provide greater feelings of presence (Lin, 2004; Barfield, Hendrix, & Bystrom, 1999). With the use of 3D virtual environments, it is possible to establish immersive metaverses, where more operators can collaborate on particular task regardless to their physical presence (Davis et al., 2009).

2 VIRTUAL COLLABORATION

Cooperation (or collaboration) is a social activity that uses the knowledge, skills and efforts of a few individuals to achieve group goals, which could not be achieved by individuals working alone (Levan, 2004). Therefore, the research is now focuesd on Multi-User Virtual Environments (MUVEs). MUVEs emphasize the importance of social, cooperative and communicational aspects of interaction (Montoya et al., 2011; Dalgarno et al., 2011; Lim et al., 2006; Barab et al., 2005, Hideyuki, 2004). MUVEs can offer users or operators more possibilities of real time interaction and can be used for sharing and elaborating of information. Via avatars (the virtual figure representing the real operator in VR) it is possible to interact each other and/or with software agents (Davis et al., 2009). The virtual platforms for learning and educational issues are the common technology helping students and university staff to maintain cooperation (Dalgarno et al., 2011; Petrakou, 2010). Design procedures for creating MUVEs, as well as for other types of 3D virtual environments, deal with the optimality of user interfaces (UIs). The work efficiency is increased with the synoptic and well configured structure of system where intuitive and user-friendly aspects of interface should be reflected. The particular features of the optimal 3D collaborative environment is an issue for ongoing research, especially regarding operators' performance efficiency and safety (Weinberg et al., 2011). In virtual collaborative environments should be discussed the specific features with respect to learning and information process enhancing. For the better insight in the VWs design it is necessary to outline the properties of the interface design. The research of human mind in the virtual environments can offer wide field of new knowledge about human as well as about the features of human-computer interaction. The human-computer interaction is a complex process, where many phenomena with should be explored, see Fig. 1. The attractiveness of VWs is emphasized also by the possibility to control and precisely measure operators' responses in terms of specific actions, strategies and complex behavior (Wilson & Soranzo, 2015). From methodological point of view the attractiveness is emphasized also with the use of dynamical and modifiable models as the stimuli, where the amount of communicated information is precisely defined.

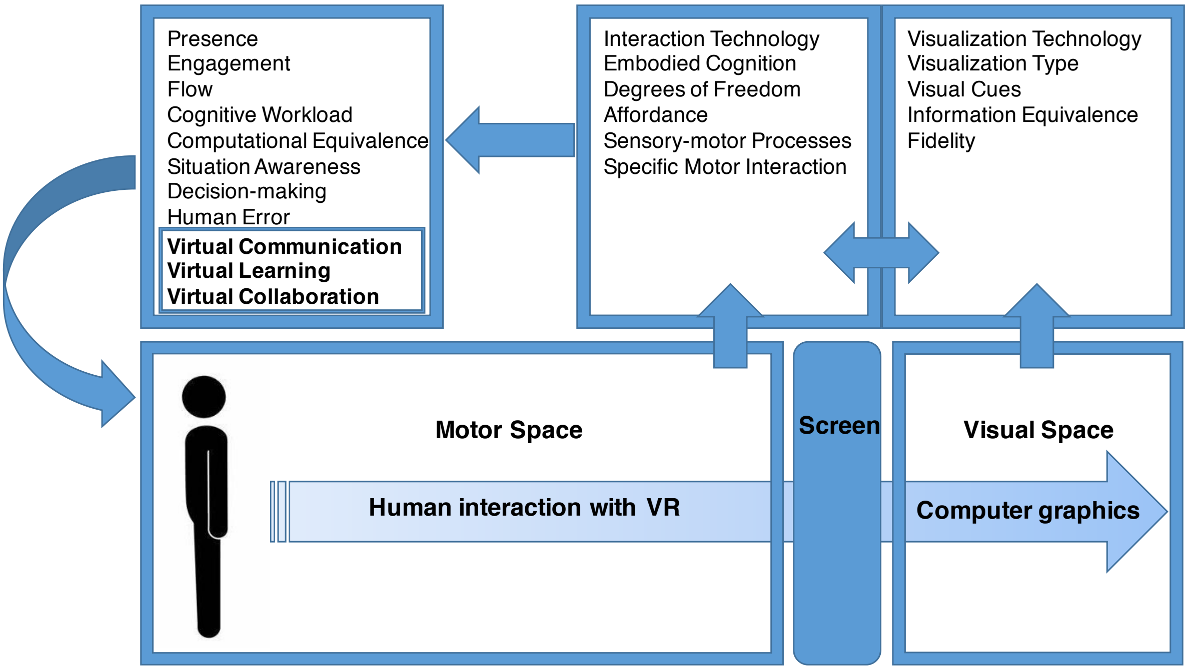

Fig. 1. The Model of Relevant HCI Issues

3 THE INTERACTION WITH VIRTUAL WORLDS

The term affordance, which was firstly described by Gibson (1986), is used in the area of human-computer interaction (HCI) and means the level of easiness which is needed to find the interaction possibilities when interacting with computer (McGrenere & Ho, 2000; Norman, 1999). The aspects of usability and presence (as seen bellow) are usually strictly evaluated due to the purpose of a specific UI, where the users' inclusion into the interface is understood as active and a holistic. Nowadays, the issue of a simulated presence in virtual environment is discussed with respect to possibilities of persuasive immersion of an operator into VWs. For the discussion about HCI design it is necessary to outline the objective framework of human-computer interface.

The space connecting the real and virtual worlds can be divided into a *motor space* and the *visual space (*Argelaguet & Andujar, 2013). A physical space in front of a screen, which is available for a user to operate, is called the *motor space (*also the working space). The motor space is constrained by available *degrees of freedom* (DoF) and virtual reality technology features, including peripheral devices. On the other hand, the *visual space* is situated behind a screen, in an exposition. It is the visually perceived representation of the environment and in general it is secured with the use of computer graphics. Visual space is framed or defined by the accessible visual field. The issue of designing user interfaces (UIs) is one of the most accented topics is human-machines interaction paradigm.

3.1 Visual Space – The Issue of Visualization

The visual space is in general secured by the use of graphical design - via visualizations. Visualization is a graphical representation of specific issue. The adequate design for graphical displays which is consistent with information-processing principles was already discussed in some older studies (Goettl, Wickens & Kramer 1991). Visualization can be classified as an external graphical representation and it should be designed to represent abstract data in possibly most suitable way (Card, Mackinlay & Shneiderman, 1999). Bauer and Johnson-Laird (1993) claim that the type of graphical representation being used can facilitate (or inhibit) the problem-solving. A particular design of visualization, with respect to the purpose of such a design, can facilitate the cognitive processing of a particular kind of depicted information (Ware, 2012).

Computer generated visualizations are usually performed through 2D planar display (computer screen) and not all visual aspects (e. g. visual depth cues) are therefore involved. The visualizations contain the specific number of visual cues and the realistic UI should simulate the maximum number of them to reach real properties. Visual cues are almost always elaborated conjointly rather than separately (Goldstein, 2009; Yantis, 2001). The spatial perception is secured via depth cues and can be considered as automatic and embedded mechanism of seeing (Goldstein, 2009). The human ability to detect spatial context is ensured by monocular and binocular cues (Smyth et al., 1994). Monocular depth cues, also *pictorial cues*, represent the features of environment providing the spatial perception and secure the 3D vision even when the binocular vision is weakened (McCoun & Reeves, 2010). The binocular depth cues combine the percepts from both eyes simultaneously. Monocular depth cues can be further divided into the static and dynamic cues. Within static monocular depth cues are included *linear perspective, aerial perspective, relative size, interposition, texture gradient, shading and lightening and elevation* (O'Shea et al., 1994; Goldstein, 2009; Prinzmetal et al., 2001; Granrud & Yonas, 1984; Wilcox & Lakra, 2008; Granrud & Yonas, 1984; Ramachandran, 1988). Dynamic monocular depth cues are represented by *motion parallax* (Nawrot et al., 2009; Ono et al., 1986; Nawrot & Joyce (2006) and *kinetic depth effect* (Wallach and O'Connell, 1953). Binocular depth cues are based on merging the different perception of left and right eye, where pupillary distance is approximately 6 centimeters (Dodgson, 2006). Each eye, therefore, captures slightly different image of surroundings and provide *stereopsis* (Rowe, 2012; Howard, 1995). Binocular depth cues include *binocular convergence* (Brenner & Van Damme, 1998), which is effective to detect distances especially for the close objects, then *shadow stereopsis* (Puerta, 1989) and *binocular disparity* (Landy et al., 1995). Based on the number of secured visual depth cues, three main types of 3D visualization can be established - two-dimensional visualization slanted into 3D space to accomplish some 3D effect (considered as a 3D visualization), Weak 3D visualization and Strong 3D (Seipel, 2012). For the last two visualizations is also used the term Pseudo 3D and Real 3D visualization (Sprinarova et al., 2015).

Pseudo 3D visualization or also 2,5D is displayed perspective-monoscopically on planar media (Buchroithner & Kunst 2013). The three-dimensionality of models presented on the screen are in this case based entirely on the monocular depth cues. There is also no need of peripheral 3D device to read the presented content. *Real 3D visualization* is based on the principle of stereopsis provided by binocular disparity and uses both binocular and monocular depth cues (Buchroithner & Kunst 2013). Real 3D visualization offers more visual cues (more information) about the spatial distribution of the scene, compared to Pseudo 3D. To reach stereopsis in the interaction with the planar media, the peripheral stereoscopic technology is usually needed. We can use a wide platform of peripheral 3D devices, which is described below in more details. The information and computational equivalence of these forms of 3D visualization is on the spot. To emulate Real 3D visualization, the peripheral 3D device providing the binocular disparity is usually needed. Most of the 3D systems are based on the principle of glasses and a large format planar media (a monitor or a projection screen) where the specific filter splits the observed exposition into two slightly different images for each eye separately and produces stereopsis. 3D glasses secure the distribution of the left-intended image for the left eye and the right intended image for the right eye. In general we can find active and passive 3D technologies.

3.1.1 Passive 3D technologies

Passive 3D technology does not have electronic components embedded in the peripheral device. It is based on restriction of the light that reaches each eye by filtering the light-signal of different length-waves or by polarization. To induce 3D sensation, two images are simultaneously projected or depicted on the same projection screen (usually through different filters or via two projectors). All aspects of the exposition for the left and the right eye are actually superimposed on the projection screen, so if we look at the screen without the glasses, the picture seems fuzzy. Due to filters in the glasses, only a matching signal passes through to the corresponding eye. The stereopsis is therefore secured and then 3D sensation occurs. The specific types of passive 3D peripheral device is anaglyph, which is the elementary device for 3D stereoscopic vision. Filters of a different color for each eye let only a specific wavelength pass through them and so each eye can see a different image (Howard & Rogers, 2012). The technology labeled as Dolby 3D system might be considered as more sophisticated anaglyph and is based on wavelengths filtering. A better quality of vision which is not color-biased is provided by the filter for more than one color placed in each eye-glass (red, blue and green). To distinguish these three colors for each eye, slightly different wavelengths of the colors are used (Roebuck, 2011). Polarization offers another way to reach 3D visualization. The principle is based on the polarization of the light and because light is an electromagnetic wave, it can be polarized to reach a specific vector. Two projectors broadcast two overlapping pictures on a screen through two perpendicular polarization filters giving the light to the vectors and also the eyeglasses have differently polarized filters to let the light pass to each eye. In this case, sometimes two projectors instead of one are needed. The signal goes only through coherently polarized glass, so that only matching (similarly polarized) light goes into each eye (Roebuck, 2011).

3.1.2 Active 3D technologies

The active 3D technologies usually include active electronic component to provide alternation of the image for each eye. Active shutter 3D system has embedded electronic component, which is able to conceal alternately right or left eyeglass in a very high speed. It presents the image for the left eye while blocking the view of the right eye and vice versa. This alternation enables a user to read synchronized information for a corresponding eye on a projection screen. The synchronicity between glasses and the refresh rate of the screen (the projection screen) is secured with a timing signal, via Bluetooth or another wireless technology, but it is also possible to use a wired signal. The speed of the alternation of the pictures for the left and right eye is upon human perception limits and therefore, final picture is synthesized as a 3D sensation. The frequency of the broadcasted content should be on the level of 120 Hz (60 images per second for each eye), so a specific kind of projection screen/monitor is needed - at least 120 Hz display (Roebuck, 2011). The next step in 3D visualization represents head-mounted display which is placed on a user's face and expose binocularly images separately for the left and right eye. The value added to this technology is a detector of movement. Due to the movement detector, an user is able to look around in a virtual environment and so the level of fidelity and immersion is very high. As the level of computer graphics and technology grows, the possibilities of such a device for virtual simulations are almost unlimited. Unfortunately, frequent feelings of sickness while using this device are reported by users.

3.2 Motor Space – The Issue of Interaction

Next to specific type of visualization of VR it is the interactive level, which is creating the background of psychological phenomena influencing the human behavior. The concept of *embodied cognition* (EC) (Anderson, 2003), where cognition is always considered as a situated activity, emphasizes the inclusion of body schema and human motor activity into process of cognition and human-computer interaction. Within EC concept, the cognition is considered as always situated, time-pressured (real time) and more active rather than passive (Wilson, 2002). The wider context of body and environment (e.g. the user interface) is a part of the cognitive system (Dijkstra et al., 2007; Niedenthal, 2007; Dijkstra & Misirlisoy, 2006; Varela at al., 1991). The human lifetime experience is encoded in his nervous system (Barsalou et al., 2003; Damasio, 1999; Glenberg, 1997). The bodily elaborated information should acquire different quality than solely visually communicated information (Meteyard et al., 2012). The evaluation of interactive nature of immersive 3D visualization is therefore actual issue.

For a movement in a three-dimensional space, different principles must be applied. Controlling options must allow user to move in all directions and the number of degrees of freedom (DoF) is discussed. Common computer interface is usually controlled by a regular computer mouse, which offers two degrees of freedom. Bowman et al. (2004) suggested that the device with more than two degrees of freedom should be used to comfort the need of the user-friendly 3D UI. As Rolland summarizes (2001), tracking devices are able to capture x, y, z positions of specific points in real time and so the controlling aspects as well as measuring could be performed with well-conditioned technology. Some of them were developed precisely with the focus on human-computer interaction issue.

3D mouse is frequently used for controlling of three-dimensional virtual spaces, especially used by 3D visualization developers (for CAD applications or a 3D modeling and animation etc.). The 3D mouse allows the movement in all six DOFs. A user can pan, zoom and rotate in all three axis (x, y, z) and this can be performed simultaneously. The 3D mouse controller consists of a pressure-sensitive handle to move through 3D environments or interact with 3D models. The next technology, *Leap motion,* is represented by a small, flat hardware USB device designed to control a computer by free moves of a human hand or fingers. The Leap motion controller requires no hand contact. Using gestures the technology control virtual environment. It works on the principle of monochromatic IR cameras and three infrared LEDs. The technology was developed in 2008 and seemed to be very promising because of its open possibilities of gesture-based movements and a possible connection to VR head-mounted displays. *Kinect technology*, as well as the Leap motion, senses a movement of a user, but compared to a smaller observation area and a higher resolution of Leap motion, the Kinect is used more for whole-body tracking and requires a bigger space. Via gestures and spoken commands, a user can modify an interface or carry out specific performance on a distant screen, e. g. gaming. *Data gloves* can be classified as input tracking devices that provide detailed information about a movement of hands. The Pinch Glove is a subtype of the data gloves device and is designed to record user's fingertips. Bend-sensing data gloves can recognize variety of gestures (e. g. pointing with one finger). *Wii Remote Controller* was originally developed for the Nintendo's Wii console. This device disposes with motion sensing capability, which ensures user's ability to manipulate with exposition presented on a screen via gestures and pointing. In combination with the Kinect or the Motion Capture, it can be used to control remote Planar media expositions such as e. g. the visualizations on 3D projections screens or monitors. As the state of the art of the tracking and controlling devices could be considered *Motion capture system.* MoCap or motion tracking system is an example of a tracking device working on mechanism of recording movements of reflective points in its visual space. MoCap can be used as a control device for interaction with an virtual environment. In MoCap the optical system triangulates data captured from image sensors to compute a 3D position of a subject between two or more cameras calibrated to provide overlapping projections. Usually, the movement data are collected by recording the position of the markers attached to the actor's body. The markers can be passive (retroreflective) or active (LEDs) and they are clipped on the human actor to provide the actual position in the space. The system of the surrounding cameras produces movement information of 3 degrees of freedom for each marker. The information about rotation is derived from the positions of three or more markers. The human-computer interaction during controlling an with respect to embodied cognition concept can be simultaneously effectively measured and he user's spatial activity is not limited by the MoCap design.

4 PSYCHOLOGICAL PHENOMENA

The above mentioned ways of virtual 3D environments design should reflect the specific features of human cognition within human-computer interaction. With the number of different possible ways of how to create virtual environment there is also the issue of psychological phenomena entering into the process of HCI, which should be studied with respect to e. g. efficiency of learning processes. The different features of the visualization types (Real 3D versus Pseudo 3D) and different ways of interaction with it is expected to influence the human cognition.

4.1.1 Usability

User interfaces should be designed to consider operator's perception abilities and limits. As mentioned above, every visualization should be usable for its purpose. Usability focuses on manufacturing systems or also products which are easy to use and customize them according to user's needs and requirements. In the area of human-computer interaction, it is necessary to ensure the effective interaction between a user and virtual environment. Any inconvenience in human-machine interaction can lead to the decreased level of performance, errors or misjudgments. The usability features discusses Quesenbery (2001). The term intuitive is often mentioned in the UI design and is connected to words such as "learnable" or "familiar". Intuitive environment should increase the ability of an operator to control environment in an automatic and unstudied way.

4.1.2 Fidelity

A level of fidelity constitutes quality of virtual simulation. A good level of fidelity enables a VR operator to interact with the UI in effective way (Hochmitz & Yuviler-Gavish, 2011; Gopher, Weil & Bareket, 1994). Basically). *Cognitive fidelity* represents the type of the simulated cognitive activity which has the same functional features as the simulated reality, but its form (e. g. visual) is different. Good level of cognitive fidelity does not necessary represent the real world in all visual aspects, but keeps the basic features of the interface on the functional level (Kaiser & Schroeder, 2003). Contrary, the *physical fidelity* simulates all aspects of the reality on the most possible level. Physical fidelity in virtual environments is very often provided with the use of Head-mounted displays or CAVEs (Cave Automatic Virtual Environments). Sometimes we can find another terminology as *physical fidelity* for a level of environmental resemblance, *functional fidelity* for a functional performance resemblance in virtual reality) and *psychological fidelity* (a subjective feeling of operator's immersion into virtual environment).

4.1.3 Presence

Immersion into the virtual environment is labeled as the *presence* (Mania et al., 2006; Björk and Holopainen, 2004; Mania and Chalmers, 2001; Slater and Wilbur, 1997). Presence deals with the subjective feeling of being in the virtual world, with user’s feeling of “being there” (Slater & Usoh, 1993). Slater and Wilbur (1997) understand presence as the condition of consciousness and relate it to the sense of being in a place, being (1) inclusive, (2) vast, (3) surrounding and (4) vivid. In the game design field, Björk and Holopainen (2004) determine sensory-motor immersion, cognitive immersion, emotional immersion and spatial immersion to evaluate the flow, involvement and actual state of PC game players. In the field o psychology research, it is known as *presence* or *spatial presence*. With the operator' sense of presence in the particular environment, the effectiveness of performance (e. g. learning) is expected to improve (Bailenson et al., 2006). On the other hand, the immersion can lead just right to the opposite and decrease the level of e. g. situation awareness about a scene and promote error-making as suggested by Sprinarova et al. (2015).

4.1.4 Media Synchronicity

Presence could be explored with respect to *media synchronicity* theory (Dennis et al., 2008). Effective collaboration technology should improve the process by which people work together at the same time with a common focus. Media synchronicity theory speaks about improving users' collaboration when the synchronicity capacity of technology matches the needs of collaborators. Hassell and Limayem (2010) found presence playing important role in the motivation of VR users, which is further affecting positive relationship between media synchronicity and job satisfaction. The presence or “the feeling of being there”, was found important for the effectivity of learning in VR also by Bailenson et al. (2006).

4.1.5 Engagement

Engagement (Bakker et al., 2011), which is closely related to the feeling of presence, means the involvement of user into VR. Within the field of education in the VR the engagement is the connected to the the state flow (Bakker et al., 2011; Hossain and Wigand, 2004), which was earlier defined by Csikszentmihalyi (1990). Flow should be considered as a huge effector of how the users interact with the VR. With respect to another studies (Goel & Prokopec, 2009), on the level of communication the social aspects of the virtual simulations are discussed with respect to the engagement.

4.1.6 Information and Computational Equivalence

Information and computational equivalence were developed (Larkin and Simon, 1987) speaks about the objective forms of visualizations and their understanding by human. Visualizations are informationally equivalent when the amount of information in both of them is on the same level. Computational equivalence constitutes the amount of assumed mental processes needed to reach the information from representations. Representations are computationally equivalent when the deduced number of cognitive processes needed for information reading is the same for both conditions.

4.1.7 Situation Awareness

According to Endsley (1995), situation awareness (SA) is *“the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”* (Endsley, 1999, p. 258). Nunez (2005) discusses SA as an organizing feature standing behind all individual’s decision-making processes on several processing-levels. It includes cognitive processing of mental models, working memory and situated cognition. Parasuraman et al. (2008) understand it as a dynamical diagnosis the real world features. Concept of situation awareness speaks also about prediction of ongoing features of a specificsituation. Snidar, Visentini and Bryan (2013) suggests that for useful SA it is needed to design the systems which are able to integrate both low and high level of information processing. The low level should ensure the perception of the specific separate information, and the high level should integrate those separate information into comprehensive, complex awareness. Wickens (2008) distinguishes the SA compared to cognitive processes and also emphasizes the role of the different information processing levels in SA; a) SA speaks about understanding of the situation more than about an action itself, b) SA is not considered only as a long-term memory — schemas or scripts are being used within the SA concept as well as in a long-term memory, but SA is a dynamic process, a memory is of the static nature, and c) a process of SA is not a product – the SA processing leads to various outcomes. SA is closely related to the human error phenomenon (Gartenberg et al. 2013).

4.1.8 Human Error

When the cognitive workload of operator working with the exposition is too high (e.g. too high level of situation awareness), human error may occur (Forsell, 2007; Tavanti et al., 2003; Lange, 2003). This phenomenon is known as information overload (Keim et al., 2008). Further, Hammond and Stewart (2001) suggest the proximal cues included in the system (UI) as possible effectors of decision-making. In user interfaces, which are considered as informationally equivalent, but they consist of different technological background, there can be some proximal cues prioritized to others and affect the judgement of operator. In coherence with Neisser's (1976) perception cycle, the anticipatory schemata as the two-ways modifiable structures affecting the process of searching for information should be considered. Cyclically, with respect to the incoming information, the behavioral processes are further focused on the particular objects in the visual field. Plant and Stanton (2012) discuss the Niesser’s Perceptual Model as the possible theoretical framework for the human error analysis.

5 THE ISSUE OF UI AND VIRTUAL COLLABORATION

As suggested above, aspects of presence based on the Real 3D visualization types can offer value added to the issue of virtual learning and collaboration. On the other hand, limits of 3D visualization such as increased time for solving tasks or visual discomfort were evidenced (Livatino et al., 2015; Seipel, 2012; Pascher & Philip, 2001). This issue, however, still remains ambiguous and when creating virtual space, the purpose of the interface should be considered. Every feature of virtual environment may play an important role in HCI. Although persuasive number of previous empirical speaks for minimal differences between Real and Pseudo 3D visualizations (Fabrikant et al., 2014; Schobesberger & Patterson, 2007; Wood et al., 2005), the properties of these visualization in combination with the sensory-motor tendencies of users may influence the process of cognition. In our previous study (Sprinarova et al., 2015) was explored the strategy of how participants in different 3D conditions evaluated the altitude data in virtual geographical environment(VGE). The results shown different tendencies in interaction with VGE and suggested that specific interface hugely influence the HCI.

Collaborative Virtual Learning Environment (CVLE) is the specific version of MUVEs. CVLE is the space, where operators are allowed to communicate and cooperate via text, pictures and videos or directly by virtual 3D avatars representing them in the VR with the learning purposes (Biocca et al., 2003). CVLEs are expected to support and enhance the process of learning (Montoya et al., 2011; Lim et al., 2006; Barab, et al., 2005; Hideyuki, 2004; Johnson et al., 2002), or group communication effectivity and workflow (Ibáñez et al., 2013). Collaboration in VR represents the new quality of interaction and should be compared to real-world collaboration (Greiner et al., 2014; Riedl et al., 2014). For such a purposes the optimal interface should be design to capture not only the precise types of participants action, but also to provide intuitive and natural possibilities of interaction with Virtual environment. Bellow we suggest the UI design we developed within our research of VGEs with respect to the above mentioned concepts.

5.1 How to Measure Virtual Collaboration

The collaboration as well as learning in the virtual space lags especially in real-time real-place situated issues. The possible way is to create virtual collaborative space. Such environments are already studied within the fields of psychology or education. The most promising option of suggested technologies is that we can combine them and set the adequate interface for measuring and controlling the human-computer interaction. As the optimal device for securing stereoscopy in VR is suggested using 3D glasses (Torres et al., 2013) due to providing *presence* and also because of practical use. 3D glasses could be enriched with the mobile eye-tracking device to record spot of interests in the visual field of participant. Compare to glasses, the Head-mounted display technology still remains the issue for future development. Regarding the different types of visualization, identifying the spots of interests in the user's visual field is necessary for the research. VWs contains specific number of proximal cues (Hammond & Stewart, 2001) which are used for the users orientation in the system. The relevance of the cues can be affected by the type of UI. To record users' spots of interest in the visual field the eye-tracking technology can be used. Eye-tracking system captures the participant's eyes movement and links it with the objects in the visual field (Brychtova et al., 2012). We can use eye-tracker combined also with head-mounted display, which can be attractive for the comparative research of 3D technologies.

For the precise measurement and simultaneous controlling of the virtual exposition the combination of tracking system and the active-button device is needed (Sprinarova et al., 2015). For the purpose of the human behavior research, the necessary freedom of movement for better analysis of human sensory-motor strategies is provided by motion capture system, which is suggested as the most promising device in the field of HCI. MoCap is precise and offers wide range of motor freedom. It may be combined with the Wii RC as a active-button. With respect to our previous research (Sprinarova et al., 2015) we assume this combination as the user-friendly device for the natural HCI, where both, technological and embodied aspects remain minor limits. We assume that the motor inclusion when interacting with the VR leads to more inclusion and activation of perceptual and motor body traces, which can affect subsequent cognitive processes (Damasio, 1999). Social aspects of virtual interaction such as Proteus Effect (Yee & Bailenson, 2007) should be further studied. The relevance of MoCap in the virtual collaboration issue grows also with the option to generate a virtual avatar in MUVEs, which can represent the user in VR. Also, the matter of neuroimage and biofeedback technologies as EEG (Electroencephalography) or fNIRS (Functional Near-Infrared Spectroscopy) is the question for further research. Such technologies also in available mobile versions can be included in UI and bring the dynamic information about neural activity of user.

5.1.1 Software Platforms

To create virtual environments there are more than one software available. For the purpose of our experimental design we used software platform Hypothesis, which is designed for the research of virtual collaboration based on 2D visualizations (graphs or interactive maps). Hypothesis is a web based software for experimental testing. More details about this software are stated in Sterba et al. (2015). Hypothesis provide the options to perform quantitative and qualitative methods. For interactive

3D visualizations we use VRECKO and Unity 3D softwares. VRECKO is an open-source modular software, which has been since 2003 continuously developed by the Human-Computer Interaction (HCI) Laboratory at the Faculty of Informatics, Masaryk University. HCI laboratory and Department of Psychology at the Faculty of Arts are in long-term cooperation. VRECKO is programmed in C++ using the OpenSceneGraph library. A set of modules for visualization of geographical data was created specifically for these studies (Kovalcik et al., 2012; Sprinarova et al., 2015). VRECKO supports most of above mentioned devices (3D mouse, Wii RC), and can provide Pseudo 3D and Real 3D projection (for more details see http://vrecko.cz). For this purpose of further virtual collaboration the Unity 3D engine can be used. Unity supports also visualization through Head-mounted displays.

6 FUTURE RESEARCH AND OUTLOOK

Within this paper we outlined the possibilities of establishing the platform for the research of human-machine interaction and virtual collaboration. The influence of mentioned technologies on the human cognition still remains to be explored. The interest of applied areas, however, enhances the research efforts with focus on the capturing the relationship between specific technology and human cognition. The ongoing research of virtual worlds as well as virtual collaboration in computer-generated interactive 3D environments generates a broad filed of new questions and issues to be discussed. The technological features define the research paradigm which should be explored with respect to human cognitive processes and human tendencies to interact with UIs. From the fundamental issues of visualization type through the controlling devices we should focus on the phenomena as situation awareness and human error.

Hand in hand with psychological research it is necessary to secure the technological background with all its aspects and set the adequate properties research design. Within our research it is important to customize the software platforms for communication and collaboration in cooperation with IT experts. For the better analysis of the data it is also necessary to create platform for synchronized data recording from multiple devices (Eye-tracker, MoCap, fNIRS etc.) to bring complex, more holistic view on the human behavior in virtual environments.

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