

Study on Information Perception and Development of Operator's Actions in Virtual Reality

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ABSTRACT

The psychophysiological influence of the virtual reality on a human has already been under discussion for a long time. There is an empirical correlation of immersion with hardware and software parameters of the virtual reality such as a frame rate, tracking a head rotation, audio, and interaction methods applied in the virtual reality. On the other side, a deep level of interaction can be explained by activation of similar cognitive structures in the brain and sensory stimuli as in same situation on practice. In this perspective, psychophysiological test is simple model of human activity and could be provided benefit to measuring of performance man-machine interaction with graphic monitor (desktop application) and head-mounted display (in virtual reality). Its key idea is to measuring of human performance in different environments (desktop and virtual reality) by the test for a reaction rate to a movable object with feedback and without. It was shown that effectiveness of man-machine interaction turns out to be higher when using head-mounted display (in virtual reality) than when using a video display (desktop application) independently on the different orders of performing the testing tasks. The data obtained could be provided benefit 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 simulation and human-computer interaction.

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I. Introduction

Deep IT penetration into controlling sophisticated processing facilities configures conceptually new working conditions for operating personnel. In this context, the status of a controlled object is rendered through a human-computer interface, and efficiency of an operator's activity in general depends on effectiveness of man-machine interaction. This means that such challenges as assurance of high efficiency of a man-machine interface, construction of new three-dimensional virtual interfaces and personalized interfaces for automatic control systems of complex processing facilities and virtual simulators for training operators of transport vehicles and processing machines are highly relevant nowadays. Deep IT penetration into controlling sophisticated processing facilities configures conceptually new working conditions for operating personnel. In this context, the status of a controlled object is rendered through a human-computer interface, and efficiency of an operator's activity in general depends on effectiveness of man-machine interaction. This means that such challenges as assurance of high efficiency of a man-machine interface, construction of new three-dimensional virtual interfaces and personalized interfaces for automatic control systems of complex processing facilities and virtual simulators for training operators of transport vehicles and processing machines are highly relevant nowadays. From this perspective, three-dimensional technologies [1] and the virtual reality giving wide opportunities for imitation of the physical environment and interaction with it [2] are of the main interest. It is proved by forecasts for market growth of this highly-demanded

innovation [3] and high potential for its application [4]. However, nowadays experiment-based data on effectiveness of man-machine interaction, on special aspects of information perception and decision-making while controlling objects in the virtual environment are missing. Therefore, this study is intended for enhancing knowledge on effectiveness of man-machine interaction in virtual reality.

II. Theoretical Analysis

Currently, virtual reality refers to a synthetic spatial (usually, three-dimensional) world which is perceived from the first person point of view in real time [5]. Consequently, man-machine interaction obtains new realias associated with deeper perception of virtual contents [6] and designing a 3D interface [7]. In a sense, a user is not any more a subject in this system as they become a part of the virtual reality which dissolves boundaries between a synthetic environment and human realias resulting in an immersion process. The sense of immersion or presence is an essential attribute of virtual reality [8]. Immersion is an internal subjective emotional experience that blocks the perception of the physical world and replaces it with the virtual environment [9]. Some researchers distinguish between presence and immersion characterizing the former as cognitive and perceptive aspects of subjective emotional experience and the latter as abilities of physical equipment to expand sensory possibilities for perception of the synthetic environment [10]. The objective evidence proving an immersion effect that impacts on human anatomic parameters is an increase in the arterial blood pressure, a change of body temperature, nervous agitation, etc. [11].

At the same time immersion might be a much more powerful means of man-machine interaction than earlier techniques [12]. There are heuristic relations between immersion and VR realism when a user turns or moves their head [13] as well as dependence of immersion between human practices in the physical environment and VR [14]. Such effect is provided by the greatest activation of cognitive and psychophysiological attributes of a user in VR in comparison with other simulated environments [15-17]. In this case, the term effectiveness of man-machine interaction refers to an inherent for systems property to achieve a set goal of system functioning with certain criteria of effectiveness. In its turn, an effectiveness criterion is a condition which makes a base for defining an index of effectiveness. The term index of effectiveness expresses a measure of correspondence between the achieved values of effectiveness criteria of system functioning and the desired values of the accepted criterion. Selection of effectiveness criteria of man-machine interaction is a rather difficult and multi-sided task that depends on the purpose of system functioning and the type of tasks being solved by an operator [18-20]. In general, the most common criteria of effectiveness of man-machine interaction are human reaction rate, accuracy of information perception, and exactness of decision-making. In addition, there are other effectiveness criteria that are also quite important, for example, visual fatigue of a human-operator during the process of information perception [21]. To investigate the process of man-machine interaction we should consider a typical structure of a man-machine control system shown in Figure 1, which presents a man-machine control system as an automated system consisting of a controlled object, an automated work place (AWP) of an operator (that is a computer system with a controlled object model executed as a mnemonic diagram, 3D model, etc.) and an operator's interface means in the form of I/O devices (a monitor, joysticks, a keyboard). Control is performed according to the purpose of system functioning that is transferring the controlled object into the certain desired state while the controlled object is functioning in the external environment, thus resulting in their interaction. In addition, under these conditions an operator is involved both in the loop of object control and in the loop of interaction with the external environment, it is represented in the diagram by the external environment - operator data connection channel.

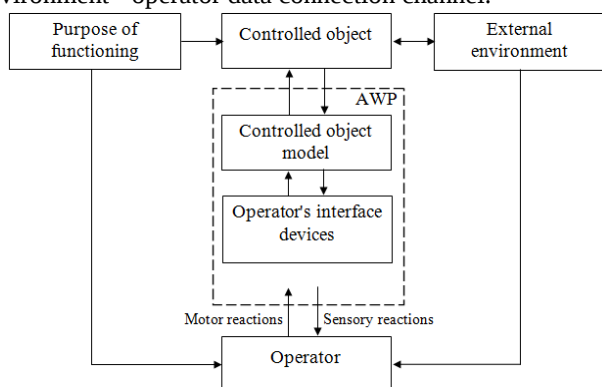


Figure 1. The typical structure of a man-machine control system.

This information channel makes it possible to visually monitor a process in the external environment as well as under condition of noise and idle information and disturbing effects arising from the external environment and affecting the operator. In this context, the information difficult for perception, informational noise and a necessity to switch their attention between heterogeneous information channels (AWP

and the external environment) result in informational overloads and quick fatigue of the operator.

The hypothesis of this study implies that the use of VR as the operator's interface means expand effectiveness of man-machine interaction. The theoretical basis for this hypothesis lies in the fact that in case of immersion into the virtual reality an operator deals with a 3D model of the controlled object only and gets isolated from the external environment. In order to ensure a desirable depth of immersion and the presence sense it is possible also to simulate elements of the external environment in a necessary degree excepting noise and disturbing effects. It should be noted that all the actions in the virtual reality might be related to actions in the real world, while the environment is safe for a human [22]. It has been demonstrated that training for actions performed in the space is more effective to drill in the virtual environment [15], both for memory development practice [16, 17] and development of spatial thinking [23]. Special attention should be given to motor skill training and memorizing [24] as well as simulation of precise operations in the conditions non-typical for a human [22].

III. Experiments

As it was stated earlier, the speed of information perception and exactness of decision-making are most commonly used as effectiveness criteria for evaluation of man-machine interaction. It is possible to evaluate these effectiveness criteria using a well-known test for a reaction rate to a movable object. The test for a reaction rate to a movable object is performed as follows. The subject is shown a video display with a circle with Marker 1 and Point Object 2 (Figure 2), the latter is moving around the circle with the set speed. The subject monitoring the movement of Point Object 2 should register the position of Point Object in the relation to Marker 1 by pressing the Record button at the moment of supposed coincidence of the Point Object 2 position with Marker 1 [25]. Upon that Point Object 2 stops moving around the circle in order the subject to evaluate their outcomes and to correct their actions (feedback) or the test continues without stops (without feedback). The response timeout is measured with a positive sign (+), and the look-ahead period is measured with a negative sign (-). After a series of measurements the T mean value (ms) is calculated, it is considered as efficiency of hand-eye tracing. The less is the T value, the higher is efficiency of hand-eye tracing. In order to compare effectiveness of man-machine interaction in the virtual reality and without it, it was suggested to make experiments with participation of 28 people having the same experience of operator work and other operating skills.

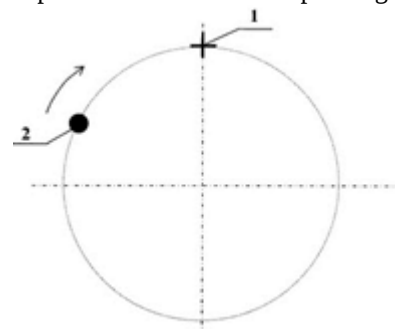


Figure 2. The diagram of the test for a reaction rate to a movable object.

It is quite obvious that multiple performance of the test for a reaction rate to a movable object helps the subject to develop a certain hand-eye skill that is test outcomes should get better over time. To assure desired confidence of testing the subjects were divided into two groups. The first group

started testing with the use of a video display and continued in the virtual reality, and the second group - just on the contrary.

As the test for a reaction rate to a movable object is a hand-eye test in its nature, all experiments were performed according to recommendations for ophthalmological testing [26]. To assure repeatability of the experimental outcomes the speed of Point Object 2 moving around the circle was assumed as permanent and equal to 1 radian/sec, the circle diameter was 100 mm. The main background was black, the color of the movable object was red, the color of the marker was blue. The subjects of the experiments were apparently healthy people of 18-25 years old with normal or corrected sight. Measurements were performed in a binocular mode in the room equipped according to the requirements of construction standards and regulations (СНП 23-05-95) [27] during daylight from 9:00 till 14:00 with 20-30 minute breaks for the rest between measurements. All the subjects had a 20 minute light adaptation before testing. The working hypothesis assumed that in case the virtual reality did not make any impact on efficiency of hand-eye tracing within this testing, than the absolute outcomes and their changes over time would be similar enough in the both groups.

Thereafter, the first group of 14 subjects performed four measurement cycles consisting of 13 successive iterations:

- the first cycle included the test for a reaction rate to a movable object on a video display and with feedback;
- the second cycle included the test for a reaction rate to a movable object on a video display and without feedback;
- the third cycle included the test for a reaction rate to a movable object in the virtual reality and with feedback;
- the fourth cycle included the test for a reaction rate to a movable object in the virtual reality and without feedback.

The first three outcomes were excluded from analysis as warming-up outcomes. The equipment of the experiment was a 24" LCD monitor 1920x1080p used as a video display and an HTC Vive headset 2160x1200p (1080x1200p per each eye), 110° field of sight, used as a VR headset. The information input device was the same in all the tests, it was a joystick with the Record button, the subjects always had its handle in their hands.

IV. Results

Statistically analyzed average experimental values of the rate of advance or delayed subject reactions are represented by the diagrams; while Figure 3 shows the diagram of the test for a reaction rate to a movable object with feedback on a video display and in the VR conditions (Cycles 1 and 3), and Figure 4 shows the diagram of the test for a reaction rate to a movable object without feedback on a video display and in the VR conditions (cycles 2 and 4).

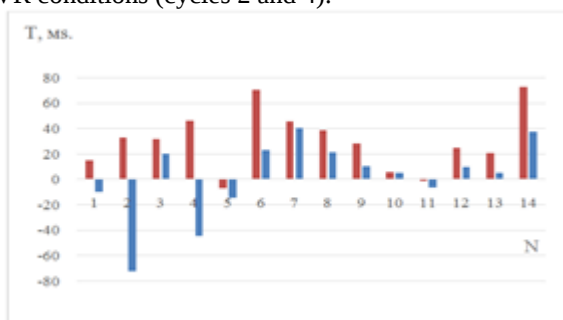


Figure 3. The diagram of outcomes of testing for a reaction rate to a movable object with feedback; T is the average time of a measurement series, ms; N is a subject number (red – results in monitor, blue – results in VR).

The evaluation of the feedback testing outcomes showed that 11 subjects had better reaction time in average by

105.4% when performing the test in a VR headset than with a video display. The evaluation of the outcomes of the test for a reaction rate to a movable object without feedback showed that 10 subjects had better reaction time by 162.13% when performing the test in a VR headset than with a video display. The second group of 14 subjects performed the similar test with the only difference that the testing began in the VR conditions.

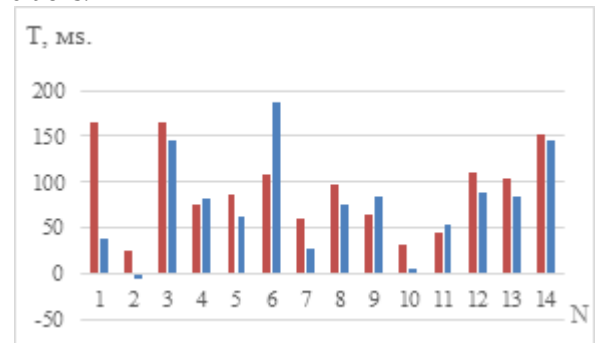


Figure 4. The diagram of outcomes of testing for a reaction rate to a movable object without feedback; T is the average time of a measurement series, ms; N is a subject number (red – results in monitor, blue – results in VR).

In this series of measurements the subjects performed four cycles of the test for a reaction rate to a movable object, each cycle consisted of 13 successive iterations:

- the first cycle included the test for a reaction rate to a movable object in the virtual reality and with feedback;
- the second cycle included the test for a reaction rate to a movable object in the virtual reality and without feedback;
- the third cycle included the test for a reaction rate to a movable object on a video display and with feedback;
- the fourth cycle included the test for a reaction rate to a movable object on a video display and without feedback.

The methods and equipment of this experimental step were the same as in the previous one. The evaluation of the outcomes of the test for a reaction rate to a movable object with feedback showed that 10 subjects had better reaction time by 290.93% when performing the test in a VR headset than with a video display. The evaluation of the outcomes of the test for a reaction rate to a movable object without feedback showed that seven subjects had better reaction time by 125.84% when performing the test in a VR headset than with a video display. Consequently, the outcomes of the experiments evidence that efficiency of hand-eye tracing while testing for a reaction rate to a movable object in the VR conditions is higher than when using a standard video display.

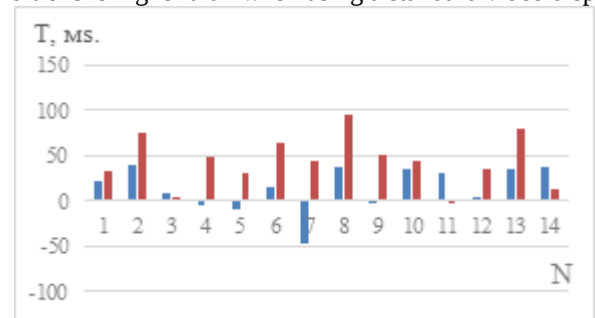


Figure 5. The diagram of outcomes of testing for a reaction rate to a movable object with feedback; T is the average time of a measurement series, ms; N is a subject number (red – results in monitor, blue – results in VR).

This effect was observed in the both subject groups. It means that the development of the hand-eye tracing skill from a series to a series did not affect the confidence of the results.

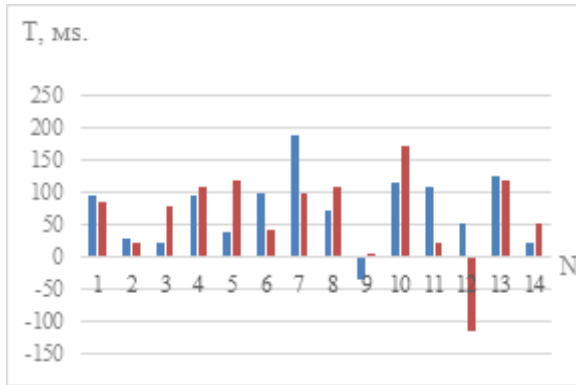


Figure 6. The diagram of outcomes of testing for a reaction rate to a movable object without feedback; T is the average time of a measurement series, ms; N is a subject number (red – results in monitor, blue – results in VR).

V. Discussions

The impact of the virtual reality on a human has already been under discussion for a long time. On the one side, the deep level of interaction can be explained by activation of the similar brain structures by means of activation of the sensory stimuli and the corresponding reaction as in the physical reality [28]. On the other side, there is a minimum set of immersion parameters: a frame rate, tracing a head turning, sound and methods of interaction in the virtual environment [29]. This study shows that effectiveness of man-machine interaction turns out to be higher when using a VR headset than when using a video display independently on the different orders of performing the testing tasks. In addition, this study assumes only accuracy of an operator's reaction to a movable object as an effectiveness criterion. This study shows that effectiveness of man-machine interaction turns out to be higher when using a VR headset than when using a video display independently on the different orders of performing the testing tasks. In addition, this study assumes only accuracy of an operator's reaction to a movable object as an effectiveness criterion. Probably, it is conditioned by deeper immersion into the testing procedure and a decrease in the impact of external distracting factors. The previous studies from the analyzed literature showed an affective impact of the virtual environment on a human, which influences a human psycho-emotional state [30] that was not measured within this study as well as an operator's fatigue.

VI. Conclusions

In any case, the level of the virtual environment impact on a human can hardly be overestimated that is proved by many studies [31-34]. A number of studies demonstrate that virtual reality causes an additional motivational impact within the learning process [32], an increase in social activity [33] and helps simulate team work and communicative practices [34]. All this indicates an attempt of this technology to replace the physical environment of a human, through establishing cognitive semantic connections, by a synthetic settings in the typical for a human 3D environment, that makes the deepest and most effective impact. Nevertheless, this study does not give an idea of accuracy of human perception of the external environment in the VR conditions as the external environment is intentionally excluded from the experiments. For example, precision of human perception of geometric dimensions and distances in the VR conditions is unknown. The authors are planning to consider these issues within further research into this field.

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