Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-54575
www.engineeringscience.rs

Journal of Applied Engineering Science
Vol. 22, No. 4, 2024
Original Scientific Paper
Paper number: 22(2024)4, 1246, 828-834

THE STUDY OF ACCURACY OF AN OPERATOR'S PERCEPTION OF GEOMETRICAL OBJECT SIZES AND SHAPES IN THE VIRTUAL ENVIRONMENTS

Ilya Tanryverdiev[1]*, Igor Petukhov[2], Luydmila Steshina[3], Ilya Steshin[4], Pavel Kurasov[5], Daniil Galkin[6]

[1] Volga State Technological University, Science and technology park, Yoshkar-Ola, Russia
[2] Volga State Technological University, Department of Design and Production of Electronic Systems, Yoshkar-Ola, Russia
[3] Volga State Technological University, Department of Technologies of Mechanical Engineering and Metalworking, Yoshkar-Ola, Russia
[4] Volga State Technological University, Department of Design and Production of Electronic Computing Equipment, Yoshkar-Ola, Russia
[5] Volga State University of Technology, Department of Design and Production of Computing Systems, Yoshkar-Ola, Russia
[6] Volga State Technological University, Department of Design and Production of Electronic Computing Equipment, Yoshkar-Ola, Russia
** tanryverdievio@volgatech.net*

This paper is devoted to the experimental comparison of accuracy of an operator's perception of geometrical object sizes and shapes between the different conditions of information perception in the virtual environments and from the electronic displays. The experiments were conducted using a psychophysiological test for the accuracy of perceiving geometrical object sizes and shapes by an operator in the virtual environments and in the conditions of information perception from an electronic display. As a common metric of the accuracy of perceiving geometrical object sizes and shapes, an operator was offered to visually determine the object center of gravity. No significant differences in the measurement results of both the accuracy of perceiving geometrical object sizes and shapes and speed of this process were found based on the different methods of displaying the visual information to an operator.

Keywords: operator, perception, sizes, shapes, virtual reality

1 INTRODUCTION

Along with training simulators of technological processes based on the three-dimensional representation of objects on electronic displays, nowadays the technologies of augmented and virtual realities are actively used for generation of immersive training environments in the simulators of complex technological processes. According to the results of modern research, the use of virtual environments in the operator training and re-training processes significantly reduces the time duration of operator training, decreases a number of errors made by inexperienced operators after the training process, and reduces the costs of operator training. For example, the studies of a training process for forestry machine operators showed that additional 25 hours of practical training in the virtual reality increased the logged timber volume by 23% and reduced the expenses on repair and maintenance by 26% during the first month of work in the forest [1].

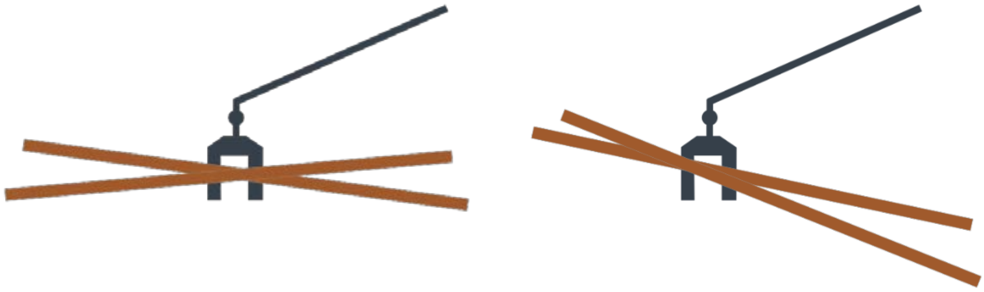
However, most of the known studies on forestry machine simulators are aimed at developing the skills of action sequences and the skills of interaction with technological equipment [2, 3].

In operator activity, the accuracy of perceiving the geometrical shapes and sizes of objects is not an endpoint task. Generally, it is a more complex sensor-motor function of an operator, which is also related to performing any kind of control, i.e. an operator is required to aim a movable operating element of the controlled object at a visually defined target.

The efficiency, for example, of loading works by a forwarder depends both on the perception of geometrical sizes of assortments (logs) and on the correct aiming of a gripper device at the target visually defined by an operator. A correct grip of log bundles during their loading into the forwarder load space ensures a less rocking of the gripper and a less skew of the log bundle during a transfer with the gripper [4]. A forestry machine operator is required to grip a bundle of logs (assortments) from the ground in such a way that the center of mass of this bundle is at the point, where the bundle is hold by a gripper (Fig. 1a). A skew of the gripping point in relation to the center of mass of the log bundle (Fig. 1b) causes incorrect log loading and/or log damage during the loading process, and leads to excessive loads on the technological equipment.

It is established that particularly a high accuracy of harvester head and gripper positioning prevents timber damage during the logging process and log loading onto the transportation vehicle [5]. In this context, the positioning accuracy of these working mechanisms is determined namely by a sensorimotor reaction of geometrical shape perception, working out a solution, and implementation of this solution by an operator using an input device.

As input devices, most automated control systems of mobile objects and manipulators use joysticks and their varieties. The control process using joysticks in the virtual environments is also characterized by a number of peculiarities, which are investigated in some dedicated studies. In this study, we conducted specific experiments on perception of shapes, and standard joysticks were used as aiming devices (working out a solution). The authors believe that it is a reasonable approach, because most real technological equipment has physical joysticks but not any graphic control elements. In addition, according to the studies, the use of real joysticks instead of graphic interface elements is justified. Operators demonstrate a higher accuracy in controlling the mechanisms when they have tactile feedback, i.e. when they use physical, real joysticks [6].



a b

Fig. 1. Log gripping for loading (a – correct, b - incorrect)

Indeed, the accuracy of perception of geometrical sizes and shapes of objects in the virtual environments is influenced by the quality of visual information displaying to a person. In their study, Rebecca L. Hornsey, Paul B. Hibbard, and Peter Scarfe conducted experiments for examining the difference in perception of sizes and shapes of geometrical objects in the virtual environments using various virtual reality helmets available in the global market. The researchers did not find any significant difference in perception of object sizes and shapes using different types of VR helmets. They made a conclusion that consumer VR sets provided a sufficiently high accuracy of distance perception and perception of object sizes and shapes, so that they could be reliably used in the future experimental science of sight and for other research applications in psychology [7].

Other experiments were aimed at investigations of differences in distance perception in the physical world and in the virtual environments. It was established that the accuracy of perceiving visual information in the virtual environments was significantly influenced by a person's experience of immersion into the virtual environments. Moreover, when a person acquired work experience in the virtual environments, the human visual analyzer got "calibrated" or adapted to new conditions of information perception, and the accuracy of perception improved. In particular, it was established that movements or "walking" in the virtual environment accelerated such adaptation processes [8].

Several studies noted that an absolute error of geometry perception increased with an increase of the distance from an observer in the virtual environment [9].

The factors influencing the perception of geometry and depth when perceiving information from a display (monocular factors) and in the virtual environments (binocular factors) were studied and classified [10].

It was also established that individual parameters of VR set configurations, namely, an incorrect setting of a focus distance might significantly affect the accuracy of geometry perception in the virtual environment [11].

Beside a method of information displaying to a person, geometrical shape and size perception also depends on an operator's body position in the space. It can be explained by the fact that a person, when perceiving the sizes and shapes of geometrical objects, mostly orientates on visual information but also, to some extent, on their vestibular sense [12], [13].

This study includes experimental comparison of the accuracy of geometrical object size and shape perception by operators in the conditions of perceiving information in the virtual environments and from electronic displays. The data on differences in the accuracy of geometrical object size and shape perception in the different conditions of displaying information to an operator would constitute a base for recommendations on development of new simulators for operators of forestry and construction machines and drivers of motor transport vehicles.

2 MATERIALS AND METHODS

The study included 105 subjects aged from 19y.o. to 23y.o., students of an educational institution engaged in professional training for forestry machine operators. All the subjects were assigned by healthcare professionals into three categories based on individual characteristics of their sight and musculoskeletal system conditions. They were also pre-tested for their occupational aptitude for operator activity before they entered the educational institution. Thus, all the subjects did not have any evident health problems that could prevent them from performing the activity as forestry machine operators. All the 105 subjects were divided into two groups. The first group of the subjects performed a test for the accuracy of perceiving the sizes and shapes of geometrical objects in the conditions of visual information perception from an electronic display. The second group of the subjects performed a similar test for the accuracy of perceiving the sizes and shapes of geometrical objects in the conditions of the virtual environment.

The technical base of the virtual environment was arranged using a HTC VIVE 2 system that included a virtual reality headset, base stations for monitoring the operator's movements in the virtual environment and a specialized software. The previous studies showed that selection of a certain VR set type does not have crucial importance from the point of view of the accuracy of perceiving the geometrical parameters of objects in the virtual environments. As a device for a control command input from a human operator, the both groups used the same equipment, i.e. joysticks with handles similar to those used in the Ponsse forestry machines. In addition, they used the same computer and software. The only difference was in the way of presenting the visual information to a human operator. It was necessary for exclusion of measurement errors due to a processing speed of different equipment of the operator interface. Such errors could have affected the reliability of the test results. The use of the same equipment (joysticks, a computer, a software) excluded additional imprecision in any of the test groups. This approach is common and recommended for testing operator reaction time when any computer equipment is used [14].

After the data were collected, the participants who had at least one outlier in any of the tests were excluded from the analysis as the analytical methods are sensitive to the presence of outliers in the data. Finally, each test group consisted of 49 persons.

Table 1. Distribution of the subjects with different occupational aptitude categories between the test groups

Test group	Category	Number of subjects
VR	I	17
	II	28
	III	4
Display	I	18
	II	27
	III	4

In this study, we used a test measuring the accuracy of perceiving geometrical object sizes and shapes by an operator, which was developed by the authors.

During the testing, an operator was offered to control movements of a pointer in the form of a green cross using a joystick in such a way that could ensure to hit the gravity center of an object as precisely as possible. In addition, a geometrical object had an irregular geometrical shape changing for each test repetition. The object position and sizes also changed at each test repetition. The object center of gravity had no marks. Thus, an operator's task was to assess the geometrical sizes and shape of the object presented, to visually determine the gravity center of this object, to aim the pointer at the gravity center of the object using a joystick, and to press a readiness button. An operator was supposed to perform 13 test repetitions, the first three repetitions for adaptation to the testing and the next 10 repetitions for control measurements of their speed of reaction to a moving object. For all the test repetitions, the same pre-set movement path of a controlled object was used, and the sizes and the targets of a controlled object were unchanged.

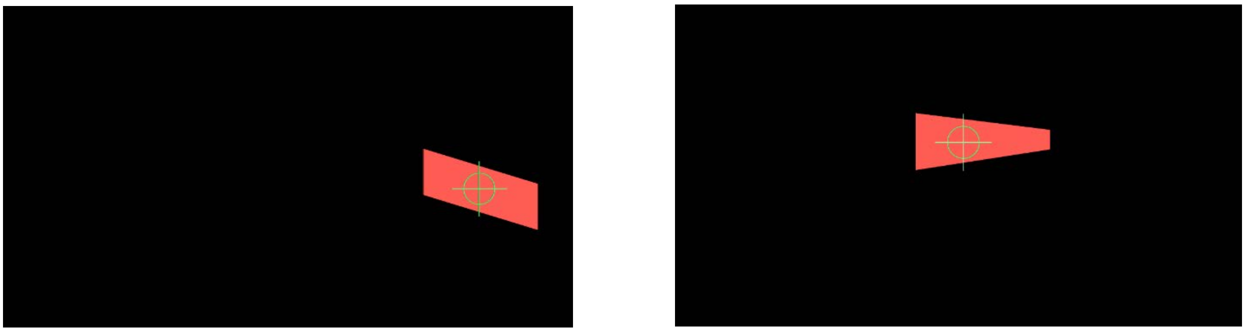


Fig. 2. Test for the accuracy of perceiving the sizes and shapes of geometrical objects

The testing was performed on the same weekday (Monday) at the same time, in the afternoon from 13:00 to 16:00. Taking into account a rather large volume of testing (a sampling size) it was impossible to test all the subjects on the same day and approximately at the same time. If to conduct testing of all the subjects on the same day, it would have required a greater time interval (from the early morning to the late evening), and it was unacceptable from the point of view of result reliability and exclusion of any fatigue factor. Further under that logic, operators performing the tests in the evening would have had a significantly higher level of fatigue as compared to those performing the tests in the morning or in the afternoon. Therefore, the tests were conducted for four consecutive weeks, on the same weekday approximately at the same time for all the operators.

Before the testing, all the operators were informed about the test procedure and the function principles of the devices, i.e. joysticks and a virtual reality headset.

To estimate a significant difference between the groups, we applied a Bootstrapping approach [15] with a sampling size of 20 persons. To determine that the distributions in the groups were different in some indicators, we used a significance level of 5%.

To identify possible clusters in the measurement results, we used clustering methods, in particular: a PCA [16] and a UMAP [17] dimension reduction methods and a k-means unsupervised machine-learning method [18]. To find an optimal number of k-means clusters, we used an elbow method [19] and the Euclidean representation [20] as a distance metric. The elbow method was used to estimate the sum of the squares of the distances of each data point to their centroid (WCSS). All the calculations for data analysis were performed using Python 3 and the NumPy [21], Pandas [22], SciPy [23], Umap [24], Scikit-learn [25] libraries. Before the algorithms were applied, the data were standardized. The dimension reduction was performed to two variables.

3 RESULTS AND DISCUSSION

As metrics, in the test results for the both groups (the VR group and the electronic display group) we used the following:

- The mean deviation along the horizontal axis, expressed in conventional units of distance;
- The mean deviation along the vertical axis, expressed in conventional units of distance;
- The summary error of positioning expressed as the L1 distance;
- The mean time of test performing, expressed in seconds.

According to the Bootstrapping results, the p-value exceeded the significance level everywhere. Therefore, no difference in passing the tests for the VR group and the group with the perception of information from the electronic display was noted.

Table 2. Bootstrapping analysis of the data on passing the tests for the VR group and the electronic display group

Metrics	P-value (Bootstrap)
Mean deviation along the horizontal axis	0.64
Mean deviation along the vertical axis	0.51
Summary error of positioning	0.53
Mean time of test performing	0.49

The analysis of the VR and electronic display groups using the PCA method showed no cluster formation, while the k-mean elbow method and the UMAP representation gave optimal division of the electronic display group into two clusters (Table 3). The coordinates of the cluster centers are provided in Table 4.

The division into two clusters for the electronic display group is based on the performance in the tests. At the same time, the gathering of all the Category III subjects in the same cluster with the worst test performance is probably an accident, not a pattern. Firstly, Occupational Aptitude Category III included a small number of the subjects; secondly, disposition of the subjects in the UMAP representation is boundary between the clusters; thirdly, Occupational Aptitude Category III shows no trend to agglomeration in the VR group.

This study compared the accuracy of perceiving the sizes and shapes of geometrical objects by operators in the conditions of information perception in the virtual environments and from the electronic displays. The main hypothesis proposed by the authors was the one that the accuracy of perceiving the sizes and shapes of geometrical objects in the virtual environments would differ from the accuracy of perceiving the parameters of the same objects when visual information is perceived from electronic displays. Theoretically, it could be explained by different mechanisms of binocular sight in the virtual environment and perception of actually flat two-dimensional objects on the electronic display. However, we did not detect any significant differences in the measurement results of both the accuracy of perceiving the sizes and shapes of geometrical objects and the speed of this process for different methods of presenting visual information to an operator. Thus, the P-value in the result Bootstrap processing is more than 0.05 both for the different metrics of object and joystick positioning errors and the time required for task performing. It indicates a deep correlation between the measurement results of the time required for task performing and the positioning errors in the both groups. It may imply that immersion into the virtual environments does not make any significant negative or positive effect on the accuracy of perceiving the geometrical sizes and shapes of objects by an operator. Nevertheless, it should be noted that in this test all the objects were presented to the operators both in the VR group and in the electronic display group at the same (close) distance in the three-dimensional plane of an operator's field of vision. Any variations of object remotion from an operator were not included in the test as the study was conducted, first of all, in the context of forestry machine operators. While gripping objects, forestry machine operators are always located at a relatively close and constant distance to the targets.

The previous studies on distance perception in the virtual environments established that "farther" distances are perceived significantly worse in the virtual environments than in the physical environments. Based on the results of those studies, it is possible to suppose that there is a difference also in the perception of the geometrical sizes and shapes of objects located at the farther distances in an operator's field of vision. In addition, it should be noted that in this study an operator was proposed to find the gravity center of an object visually, and it was used as a common metric of the accuracy of perceiving the geometrical sizes and shapes of objects. This approach is conditioned by the specificity of forestry machine operator activity as a task of determining the gravity center of objects is typical for a loading operation. However, this process might be difficult for inexperienced operators as it is a complex cognitive process developed mostly in experienced operators and athletes. The authors admit that difficulties in determining the gravity center of objects might also affect the test results. It explains the revealed clusterization into two evident clusters in the electronic display group.

Table 3. Data clusterization by the PCA, k-means, and UMAP methods

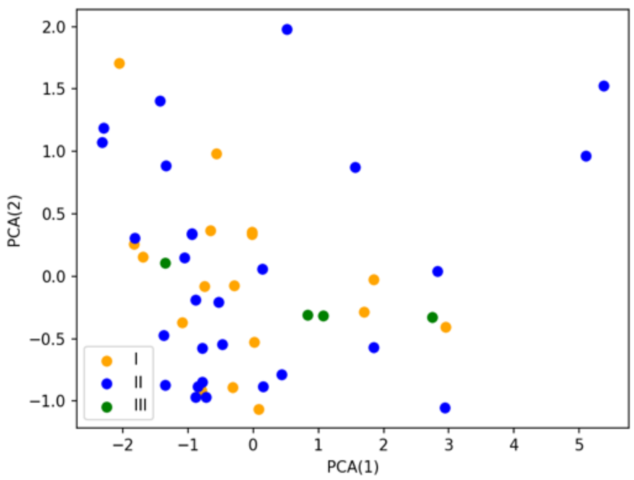
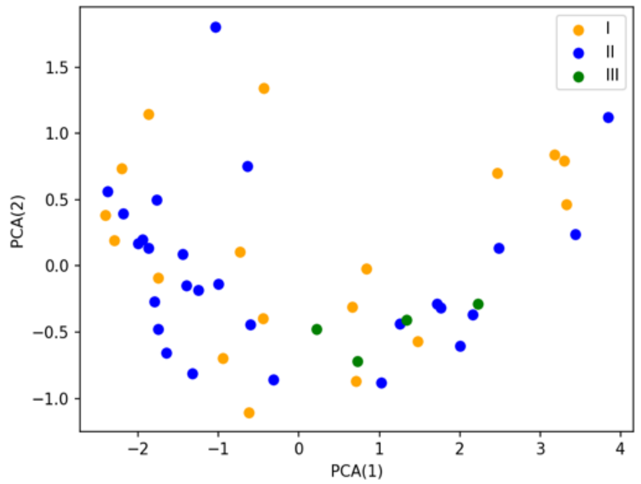
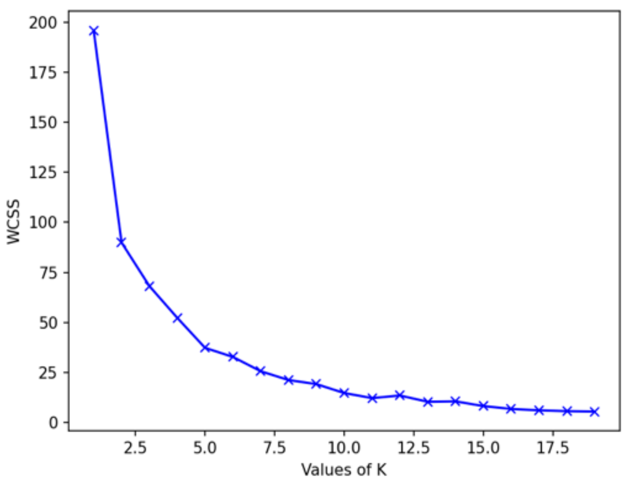
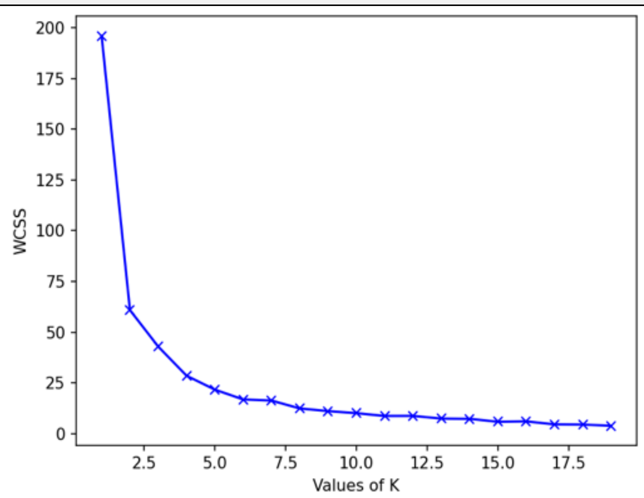
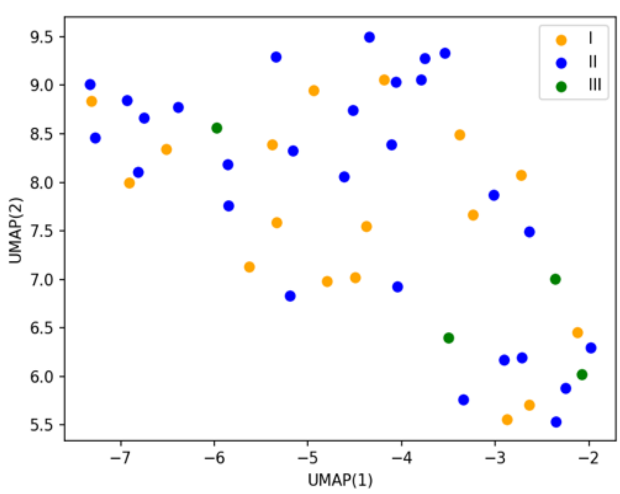
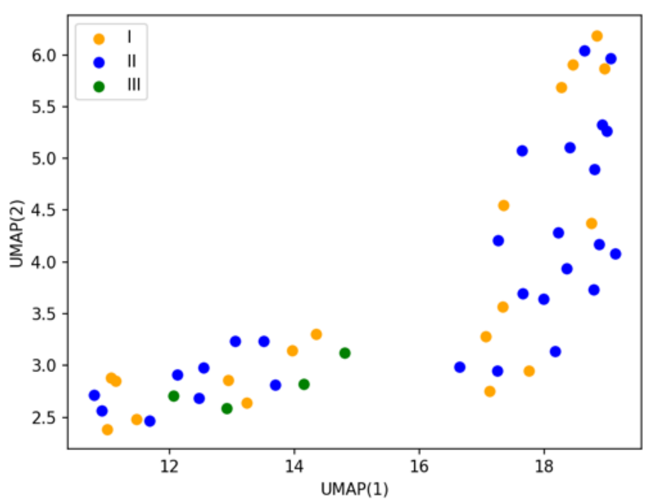
<table>
<tr><th>VR group</th><th>Display group</th></tr>
<tr><td colspan="2">PCA</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">K-means, elbow method</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">UMAP</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Table 4. Cluster center coordinates after the UMAP clusterization of the electronic display group

Cluster number	Cluster center coordinates			
	Mean deviation along the horizontal axis (conv. unit)	Mean deviation along the vertical axis (conv. unit)	Mean deviation (conv. unit)	Mean time of test performing (ms)
1	0.12	0.08	0.21	1682.12
2	0.04	0.02	0.06	5005.12

The clustering results show that the operators in the one cluster performed the task less accurately but with a greater speed, and the operators in the other cluster, on the contrary, performed the task with a greater accuracy but they needed more time. In addition, some operators noted that it was difficult for them to determine gravity centers visually, and they had never solved such tasks before. Probably, the operators included in the cluster with a less accuracy and a greater speed of performing the test simply used the center of objects, i.e. the intersection of diagonals, as the gravity center of these objects. It is easier from the point of view of a cognitive load, such task is more understandable for an operator, but it is incorrect to find the gravity center in such a way in the real-world tasks of assortment (log) loading.

Moreover, the gathering of all the subjects of Occupation Aptitude Category III in the same cluster with the worst test performance is most likely an accident, not a pattern. It may be explained by a small number of subjects included in this group but should be investigated additionally.

A new and especially interesting result is that immersion into the virtual environment and isolation of an operator from the ambient environment (i.e. actual depriving an operator of the possibility to visually observe physical joysticks) also makes neither negative nor positive effect on the accuracy of a pointer positioning with joysticks and on the speed of this positioning.

4 CONCLUSIONS

In this paper, we compared the accuracy of perceiving the sizes and shapes of geometrical objects by operators in the conditions of information perception in the virtual environments and from the electronic displays.

No significant differences in the measurement results of both the accuracy of perceiving the sizes and shapes of geometrical objects and the speed of this process for different methods of presenting visual information to an operator were found. The P-value in the result Bootstrap processing is always more than 0.05 both for the different metrics of object and joystick positioning errors and the time required for task performing. The immersion into the virtual environment does not make any significant negative or positive effect on the accuracy of perceiving the geometrical sizes and shapes of objects by an operator. This gives reason to believe that virtual environments can be used to train operators of mobile objects and manipulators, and namely, to practice the tasks of aiming operating elements at targets and objects. Considering other advantages of virtual environments such as an effect of deep immersion and realistic simulation of technological processes and the results obtained by this study, it is possible to suppose that training of manipulator operators in aiming tasks in the virtual environments will have advantages over training them in the simulators based on electronic displays.

In addition, no relation was found between an operator's work experience in the virtual environments or any other factors and the accuracy of their perceiving information. These data make it possible to use virtual learning environments in the process of operator training without any prior measures for operator adaptation to virtual environments.

5 ACKNOWLEDGEMENT

These results were obtained with the support of the Russian Science Foundation Grant No. 23-19-00568 "Methods and intelligent system for supporting dynamic stability of operators of ergatic systems", https://rscf.ru/project/23-19-00568/.

6 REFERENCES

[1] Lapointe, J. F., Jean-Marc, R. (2000). Using VR for efficient training of forestry machine operators. Education and Information Technologies, no. 5, p. 237-250.

[2] Zheng, Yili. (2018). Research on virtual driving system of a forestry logging harvester. Wireless Personal Communications, no. 102, p. 667-682.

[3] Pereira, J. J. (2019). Development of a Harvester Machine Simulator in Virtual Reality. MS thesis, from https://trepo.tuni.fi/bitstream/handle/10024/115646/Pereira.pdf?sequence=2, accessed on 01.11.2024.

[4] Hartsch, F. (2022). Influence of Loading Distance, Loading Angle and Log Orientation on Time Consumption of Forwarder Loading Cycles: A Pilot Case Study. Forests, no. 13(3), p. 384.

[5] Steshina, L., Petukhov, I., Tanryerdiev, I., Kurasov, P., Glazyrin, A. (2019). Training of high-skilled workers using exercisers and simulators. 2019 3rd European Conference on Electrical Engineering and Computer Science (EECS), IEEE, p. 134-139.

[6] Bachman, P., Milecki, A. (2019). Safety improvement of industrial drives manual control by application of haptic joystick. Intelligent Systems in Production Engineering and Maintenance, Springer International Publishing, p. 563-573.

[7] Hornsey, R. L., Hibbard, P. B., Scarfe, P. (2020). Size and shape constancy in consumer virtual reality. Behavior research methods, no. 52, p. 1587-1598.

[8] Creem-Regehr, S. H., Stefanucci, J. K., Bodenheimer, B. (2023). Perceiving distance in virtual reality: theoretical insights from contemporary technologies. Philosophical Transactions of the Royal Society B, no. 378(1869), 20210456.

[9] Ping, J., Weng, D., Liu, Y., Wang, Y. (2020). Depth perception in shuffleboard: Depth cues effect on depth perception in virtual and augmented reality system. Journal of the Society for Information Display, no. 28(2), p. 164-176.

[10] Lebreton, P., Raake, A., Barkowsky, M., Le Callet, P. (2014). Measuring perceived depth in natural images and study of its relation with monocular and binocular depth cues. In Stereoscopic Displays and Applications XXV, SPIE, no. 9011, p. 82-92.

[11] Watt, S. J., Akeley, K., Ernst, M. O., Banks, M. S. (2005). Focus cues affect perceived depth. Journal of vision, no. 5(10), p. 7-7.

[12] Kim, J. J. J., McManus, M. E., Harris, L. R. (2022). Body orientation affects the perceived size of objects. Perception, no. 51(1), p. 25-36.

[13] Harris, L. R., Mander, C. (2014). Perceived distance depends on the orientation of both the body and the visual environment. Journal of vision, no. 14(12), p. 17-17.

[14] Holden, J., Francisco, E., Lensch, R., Tommerdahl, A., Kirsch, B., Zai, L., Tommerdahl, M. (2019). Accuracy of different modalities of reaction time testing: Implications for online cognitive assessment tools. BioRXIV, 726364.

[15] Efron, B. (2003). Second thoughts on the bootstrap. Statistical science, no. 18(2), p. 135-140.

[16] Jolliffe, I. T., Cadima, J. (2016). Principal component analysis: a review and recent developments. Philosophical transactions of the royal society A: Mathematical, Physical and Engineering Sciences, no. 374(2065), 20150202.

[17] McInnes, L., Healy, J., Melville, J. (2018). Umap: Uniform manifold approximation and projection for dimension reduction. arXiv preprint arXiv:1802.03426.

[18] MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. In Proceedings of 5-th Berkeley Symposium on Mathematical Statistics and Probability/University of California Press.

[19] Thorndike, R. L. (1953). Who belongs in the family? Psychometrika, no. 18(4), p. 267-276.

[20] Deza, E., Deza, M. M. (2009). Encyclopedia of distances. Springer Berlin Heidelberg.

[21] Harris, C. R., Millman, K. J., Van Der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., Oliphant, T. E. (2020). Array programming with NumPy. Nature, no. 585(7825), p. 357-362.

[22] McKinney, W. (2010). Data structures for statistical computing in Python. SciPy, vol. 445, no. 1, p. 51-56.

[23] Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Van Mulbregt, P. (2020). SciPy 1.0: fundamental algorithms for scientific computing in Python. Nature methods, no. 17(3), p. 261-272.

[24] McInnes, L., Healy, J., Melville, J. (2018). Umap: Uniform manifold approximation and projection for dimension reduction. arXiv preprint arXiv:1802.03426.

[25] Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Duchesnay, É. (2011). Scikit-learn: Machine learning in Python. the Journal of machine Learning research, no. 12, p. 2825-2830.

Paper submitted: 05.09.2024.

Paper accepted: 13.12.2024.