Comparative Analysis of Interaction Techniques in Virtual Reality

Rimsha Khan
Dept.of Computer Engineering,
College of EME, National University of Sciences and Technology (NUST)
Islamabad, Pakistan
rimsha.khan18@ce.ceme.edu.pk

Farooque Azam
Dept.of Computer Engineering,
College of EME, National University of Sciences and Technology (NUST)
Islamabad, Pakistan
farooq@ceme.nust.edu.pk

Sheeraz Ahmed
Dept..of Computer Science
Iqra National University (INU)
Peshawar, Pakistan
sheeraz.ahmad@inu.edu.pk

Waseem Anwar
Dept.of Computer Engineering,
College of EME, National University of Sciences and Technology (NUST)
Islamabad, Pakistan
waseemanwar@ceme.nust.edu.pk

Rudeema Chughtai
Dept.of Computer Engineering,
College of EME, National University of Sciences and Technology (NUST)
Islamabad, Pakistan
rudeema.chughtai18@ce.ceme.edu.pk

Anum Farid
Dept. of Computer Engineering
College of EME, National University of Science and Technology (NUST)
Islamabad, Pakistan
annam.farid18@ce.ceme.edu.pk

2020 IEEE 23rd International Multitopic Conference (INMIC) | 978-1-7281-9893-4/20/$31.00 ©2020 IEEE | DOI: 10.1109/INMIC50486.2020.9318194

***Abstract*— Virtual Reality is an emerging breed in technology. It is gaining an increasing amount of interest and considerable work is being done on it recently. A virtual environment without any user interaction can quickly lose users' interest. To make virtual environment more captivating, user interaction with virtual world is important. The paper reviews recent technologies and methods of human-computer interaction in the virtual environment. First a thorough examination of recent work done on different ways of interacting with virtual environment was carried out. Based on this review a variety of virtual reality interaction techniques were identified and then categorized into four major categories namely, haptic devices, gesture recognition, brain-computer interface, and gaze-based interaction. These techniques were evaluated against certain predefined parameter. An extensive analysis of the different techniques and their literature has led to a consolidated review that is presented in this paper.**

Key Words- Virtual Environment, immersive, human-computer interaction, brain-computer interface, haptic devices, gesture recognition, gaze-based.

I. Introduction

Virtual Reality has been a subject of great interest and research since quite some time. Virtual Environment (VE) offers a new paradigm of interaction in which the user not only has to observe a computer screen but can actually be a part of a 3-dimensional virtual world. Virtual reality is not only being used for entertainment [1] but is also transforming education and real estate industry [2]. It can give a simulated experience of a place where user is not or even cannot be. According to research [3], for a virtual environment to be more captivating it should allow users to interact more with the virtual world. Users can quickly become bored just by exploring around and not being able to interact with virtual objects. In an immersive virtual environment, users are immersed in the virtual world in such a way that they can not only move their heads to see around but also control the system using their bodies. Figure 1 presents an overview of VR types. Users can control the virtual objects in the virtual world around them. A better immersive environment allows user to make changes in the virtual world.

Despite the extensive amount of work being done on virtual reality technology, very few applications are coming in use outside the laboratory. This is mainly due to the challenge of creating a VE that allows more interaction with higher accuracy. Although it is well known to the scientific community that what different interaction techniques are available VR environments. Yet this paper connects the missing dots by combining the recent work in a systematic literature review.

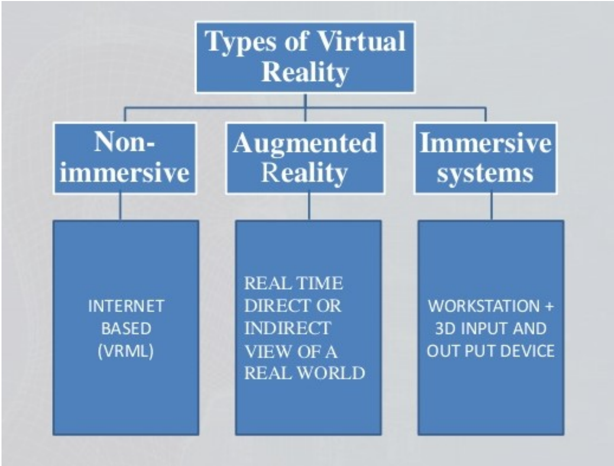

Figure 1 Types of Virtual Reality

II. Literature Review

Being able to directly and fully interact with virtual objects with hands is a challenging task in Virtual Reality. A detailed study of the recent work done on interaction techniques was carried out, which is presented in the paper. Different methods of interaction are proposed and implemented up till now. A novel system based on hand gesture is proposed with palm normal which allows user to adjust moving speed of an avatar according to hand gesture [4]. For simulation of deformed hand a penalty method is used and implemented in a proposition [5]. Head gaze interaction approach experimented on numerous volunteers which shows the effectiveness of the proposed approach [6]. Another paper proposes a gaze detection based on deep learning techniques [7]. Wolverine is a device that gives simulated feedback to user [8]. The paper compares the proposed mechanical design and its performance with other haptic devices. Two survey papers were also studied that presents the Brain-Computer Interface (BCI) applications and perspectives [9], [10]. According to the survey BCI has shown major development in virtual reality games, entertainment as well as cloud computing.

An important application of virtual reality is in games. Different interaction techniques using a diverse range of technology have been devised in various works. The trend in virtual reality technology and improvements in VR gadgets are discussed in [11] by presenting visual representation of gesture interaction feedback especially in the context of adventure games. Eye-tracking is a significant interaction technique used in head-mounted displays [12]. This paper analyzed three different techniques used for eye tracking, namely, Duo-Reticles, Radial Pursuit, and Nod and Roll. A prop that maps to multiple virtual objects including puzzle, door handle, and a switch, was proposed [13]. The mouth features recognition can be used for interaction [14]. Features were classified into seven major categories and evaluated in a virtual reality game application and produced positive results. A real-time interaction that supports a wide range of gesture interactions is proposed [15]. A user can interact non-intrusively with the virtual environment. A new approach of retargeting the position of human to an avatar with respect to some object is studied [16]. A special map was created to get location of the objects and the avatar body parts. Full-body interaction with VR demo video named TurboTuscany using Oculus Rift as head-mounted display (HMD) and Kinetic to control full body in a paper [17].

Virtual Reality is also used for trainings and educational purposes. An immersive virtual environment can more effectively lead to maintainability by training users to work in a simulated maintenance environment [18]. Interaction is achieved through data gloves and optical devices for tracking the position of the user. An interactive display service for communication through a remote virtual environment is discussed in a paper [19]. User can use the services in the physical as well as virtual world. The immersive experience can be very beneficial for learning like being in an actual classroom. A freehand manipulation system is proposed in which uses the duplicates of virtual objects to manipulate objects from a distance [20]. A one-bit mouse is proposed for disabled persons in the paper that enables users to have group interactions using single key [21]. It is also applicable in e-learning environment.

The concept of teleoperation is being used in many virtual reality applications. A desktop haptic device for teleoperation was devised which can also give feedback from the virtual environment [22]. A virtual reality application which includes operating a simulated robot in a hostile teleoperation environment is discussed in a paper [23]. A mechanism through which an operator can interact with dynamic objects with stability is an important requirement in haptic interaction [24]. The proposed mechanism is called force bounding approach (FBA) for dynamic virtual objects which overcomes the limitations that were in the FBA for static objects. A virtual reality-based setup was designed for predicting the trajectory of minimal hand jerk movement model and evaluated in a study [25].

III. Parameters for Analysis

After the literature review, for ease in study the interaction techniques were categorized into five main categories and subcategories based on the mechanism through which interaction was made with the virtual world. For analysis of virtual reality techniques the selected papers were analyzed against some predefined parameters which were extracted from the literature review. Table 1-4 present the parameters, definition and possible values of the extracted parameters.

Table 1. Parameters for Haptic Devices

Parameters	Definition	Possible values
Passive haptics	If physical objects are used to provide feedback to the user.	Yes, No
Extensibility	If the proposed system has the ability of future growth	Possible, not possible
Hardware	The specific haptic device used in the system.	Device name
Technique	Specific technique through which interaction is made possible using haptic input devices.	Technique name
Application	The environment where the system can be applicable	Game, teleoperation
Interaction level	The level to the virtual environment allows interaction.	High, moderate, low
Weight	Weight of the haptic device.	Heavy, Light, Value in g
Cost-effective	The degree to which the system is effective in relation to its cost.	Yes, No
Feedback mechanism	If the device produces a feedback effect when an interaction is made.	Present, Absent

Table 2. Parameters for Brain Computer Interface

Parameters	Definition	Possible values
Papers reviewed	Number of papers that were reviewed in the survey	Number
Applications	BCI application in virtual reality	Application name
Techniques Analyzed	Techniques of BCI that were focused in the survey.	EEG, ML
Field	BCI application fields.	Game, Entertainment
Analysis results	The results of survey and analysis on interaction through BCI in Virtual Reality	Positive, Negative

Table 3. Parameters for Gesture Recognition

Parameters	Definition	Possible values
Gesture Type	The part of the body which gesture is to be recognized.	Hand gesture, Face gesture, Full body
Interaction Type	The type of virtual interaction and manipulation in the virtual world	Interaction name
Hardware	Name of the specific device used in the system.	Device name
Technique	Specific technique through which interaction is made possible.	Technique name
Application	The environment where the system can be applicable	Application name
Interaction level	The level to the virtual environment allows interaction.	High, moderate, low
Efficient	Gives the required functionality using fewer resources.	Yes No
Cost-effective	The degree to which the system is effective in relation to its cost.	Yes, No

Table 4. Parameters for Gaze based Interaction

Parameters	Definition	Possible values
Extensibility	If the proposed system has the ability of future growth	Possible, not possible
Hardware	Name of the specific device used in the system.	Hardware name
Technique	Specific technique through which interaction is made possible	Technique name
Application	The environment where the system can be applicable	Select, climb, move, etc.
Interaction level	The level to the virtual environment allows interaction.	High, moderate, low
Efficient	Gives the required functionality using fewer resources.	Yes No
Cost-effective	The degree to which the system is effective in relation to its cost.	Yes, No

IV. Analysis Tables

After defining parameters a detailed analysis of the selected papers is performed against those parameters and summarized in Table 5-9

Table 5. Analysis of Hand-Held Haptic Devices

Sr. No	Author	Year	PH	Extensibility	Hardware	Technique	Application	Interaction level	Weight	Cost-effective	Feedback Mechanism
1)	S. Y. Baek *et al* [24]	2017	No	Yes	3-DOF haptic device	Force bounding approach	Dynamic virtual environment	Moderate	Heavy	No	Absent
2)	M. Folgheraiter *et al* [22]	2017	No	No	Desktop Haptic Interface	Admittance based feedback	Tele operational scenario	Moderate	200g	No	Present
3)	M. Suhail, *et al* [13]	2017	Yes	Yes	Tracked prop	Redirected reach	Game	Low	Heavy	No	Absent
4)	D. J. Zielinski *et al* [26]	2017	Yes	Yes	Specimen Box	Tangible Interaction	CAVE	Moderate	2,141 g	No	Present
5)	J. Li, I. Cho, Z. Wartell [27]	2016	No	Yes	Pair of buttonballs	3D Virtual Cursor Offset	CAVE	Moderate	Light	No	Absent
6)	M. Svinin, *et al* [25]	2016	No	No	PHANToM Premium	Minimum hand jerk model,	Dynamic Object Environment	Moderate	Heavy	Yes	Present
7)	F. Jabeen, L. Tao and Tianlinlin [21]	2016	No	Yes	One bit mouse	One Bit Interaction	Interaction for disabled persons	Low	Light	Yes	Absent

Table 6: Analysis Table for wearable Haptic Devices

SR No	Author	Year	Extensibility	Hardware	Technique	Application	Interaction level	Weight	Cost-effective	Feedback Mechanism
1)	C. Krogmeier, *et al* [28]	2019	Yes	Haptic Vest	Galvanic Skin Response (GSR)	Bumping Into Virtual Humans	Low	Light	No	Present
1)	K. Hirota and K. Tagawa [5]	2016	Yes	Deformable hand	FEM simulation	Pinching and grasping	High	Light	Yes	Absent
2)	E. W. Hawkes, *et al* [8]	2016	Yes	Wolverine	Force controlled feedback and directional braking	Mobile VR	High	55g	Yes	Present
3)	Z. Guo, C. *et al* [18]	2016	Yes	Data Gloves	IVM simulation model	Maintenance Simulation Environment	High	Light	Yes	Present
4)	M. A. Conn and S. Sharma [23]	2016	No	Data Glove	Tele-operational sensors.	Tele operational and combat scenario	Moderate	Light	Yes	Absent

Table 7: Analysis Table for Brain-Computer Interface

SR #	Author	Year	Papers	Field	Techniques Analyzed	VR Applications	Efficiency results
1)	C. G. Coogan and B. He [29]	2018	15	Internet of Things	BCI2000	Google Cardboard	Positive
2)	S. Li, A *et al* [9]	2017	37	Entertainment, Cloud computing	EEG based BCI models, machine learning, and current active platforms	Mind-Mirror, Brain AR/VR	Positive
3)	B. Kerous and F. Liarokapis [10]	2016	53	Gaming	Electroencephalography (EEG)	SSVEP Head mounted Displays, mouse cursor, file management and speller application, etc.	Positive

Table 8: Analysis Table for Gesture Recognition

SR #	Author	Year	Gesture Type	Interaction Type	Hardware	Technique	Application	Interaction level	Efficient	Cost effective
1)	D. Zhao, Y. Liu, Y. Wang and T. Liu [30]	2019	Hand gesture	Answer/decline call, turn up/ down volume	Leap Motion	Usability study	Infotainment	Low	Yes	Yes
2)	W. Jung, W. T. Woo [20]	2017	Hand gesture	Remote selection, grabbing, rotation, etc.	Leap Motion, Ovr-vision RGB Camera	Duplication Based remote manipulation	GoGo, HOMER	High	Yes	No
3)	U. Ciftci, X. Zhang and L. Tin [14]	2017	Face gesture	Eat cake, change location of cake, jump etc.	Kinect SDK	3D edge map approach	Cake eating game	Moderate	Yes	No
4)	Y. Kim *et al* [16]	2016	Hand gesture	Pulling a bow, casting spells, flourishing sword etc.	Gesture Recognition Engine	Neural networks	Raw Data, The Unspoken, Waltz of the Wizard	High	Yes	Yes

5)	L. Guan *et al* [31]	2016	Full body	27 operations	Kinect V2 sensor	Bag of Angles (BoA)	CAVE	High	Yes	Yes
6)	B. Wilson *et al* [15]	2016	Hand gesture	Open, close, grasp, v shape gestures.	Leap Motion, Inverse Kinematics	Hand Motion Calibration and Retargeting	Epic Game's Unreal Engine 4	Moderate	No	No
7)	C. Khundam, Songkhla [4]	2015	Hand gesture	Move forward, backward, left, right and hold	Leap Motion	First person movement control	3D object handling, 3D walk-through in large immersive display system	High	Yes	Yes
8)	T. M. Takala and M. Matveinen [17]	2014	Full body	Climb ladder, play soccer etc.	Kinect, Razer Hydra, PlayStation Move controllers	Combination of commercial input devices	TurboTuscany	High	Yes	Yes

Table 9: Analysis Table for Gaze Based Interaction

SR #	**Author**	**Year**	**Extensible**	**Hardware**	**Technique**	**Application**	**Interaction level**	**Interaction type**	**Efficient**	**Cost-effective**
1)	Tantisatirapo *et al* [32]	2018	No	Tobii Eye Tracker 4C model	Natural Language Processing	Virtual Keyboard	Moderate	Typing and menu selection	Yes	Yes
2)	P. R. Krishnappa Babu, *et al* [33]	2018	Yes	ViewPointEyeTracker-2.9.2.5	Pupil Diameter, Blink Rate and Fixation Duration	Social Communication platform for autism patients	Moderate	Emotional expressions	Yes	Yes
3)	G. Lee *et al* [12]	2017	Yes	HMD with Pupil Labs eye tracker	Duo-Reticles, Radial Pursuit, Nod and Roll	Game	Moderate	Match objects, select object etc.	Yes	No
4)	M. Soccini [7]	2017	Yes	HMD	Deep CNN	Menu	Low	Menu selection	Yes	Yes
5)	R. Atienza *et al* [6]	2016	No	HMD	Head gaze marker focusing	Slash the Fruit, The VREx,	Moderate	Selection panels, walk, climb	Yes	Yes

V. ANALYSIS RESULTS

The result of analysis for each of the five main categories and subcategories are explained in this section.

A. *Haptic Input Devices Based Interaction*

1) Handheld

Table 6 shows the analysis of handheld haptic input devices used for interaction in a virtual environment against the parameters defined in Table 1. A 3-DOF haptic device is discussed in the paper which is based on the relative motion between dynamic virtual objects and user [24]. Another work proposes a haptic device designed with sewed in motors [22]. Vibration can be spread in different direction hence giving a 2-dimensional haptic feedback effect.

Figure 2 Hand Held VR Haptic Device

A redirection approach is used to move the virtual hand according to the relative position of physical and virtual objects [13]. A passive haptic technique is discussed in which the location of the virtual content can be calculated based on the actual location of the real-world specimen box [26]. Four different techniques were evaluated including no offset, fixed-length, nonlinear and linear offset for navigation [27]. Modeling human-like reaching based on predicting the trajectory of minimal hand jerk movement model is implemented [25]. Interaction using a one-bit mouse which worked on a single key was designed for disabled persons [21].

2) Wearable

Referenced paper [28] describes effects like emotional arousal by bumping into virtual humans in a VR Environment using a haptic vest, head mount, and galvanic skin response (GSR) sensors. The paper claims no significant difference was found in haptic and non-haptic feedback due to the small sample size.

Figure 3 Wearable VR Haptic Device

A hand model implementation and contact simulation are discussed in the paper [5]. A light-weight haptic device is designed for simulating the sensation of grasping a virtual rigid object [8]. Interaction can also be achieved by adapting the data driver class of data gloves, optical devices for tracking and other peripherals [18]. IVM simulation model is used to study how maintenance can be conducted in virtual environment using 5DT Data Glove and Oculus Rift. [23]

B. Brain-Computer Interface (BCI) Based Interaction

Brain bases computer interface has important application in virtual reality gadgets Brain-computer interaction is the interaction with digital content through controlling content with the brain alone without any action. An analysis of the work done BCI is shown in Table 8. A survey paper provides a description of Electroencephalogram (EEG) based BCI models and machine learning techniques used for the analysis of BCI readings [9]. Another survey paper analysis of publications and applications of brain-computer interfaces in virtual environment using electroencephalography (EEG) technique, is done [10]. Direct Neural Interfacing processed using BC1200 is used to control VR and IoT devices [29].

Figure 4 BCI based Interaction

C. Gesture Recognition based Interaction

Gesture recognition is done through various devices which are presented in some of the recent work on virtual environment interaction. In Table 9 a detailed analysis is shown. Referenced paper [30] describes how effective gesture interaction can be in virtual driving. A User can select the object using a ray casting technique by pointing at the object with the index finger and clicking. The duplicate of a remote object comes within reach of the user who can easily grab it from the distance [20]. A major limitation in face gesture recognition is that the user's whole face is not visible for expression recognition because of the head-mounted display (HMD). It is addressed by proposing a system that makes virtual interaction based on mouth gesture recognition [14].

Figure 5 Gesture based Interaction

Large scale skeletal movements are usually registered by virtual sensors for interaction if combined with small movements like finger movements using Calibration mechanism can result in more advanced VR [15]. A technique of human gesture recognition by skeleton joint representation called Bag of Angles [31]. The hardware used is Kinetic V2 sensors alone, hence it is cost-effective. A special relation technique using Neural Networks is proposed [16]. This technique can save vital motion of the user. The proposed system was tested with various experiments including Raw Data, The Unspoken, Waltz of the Wizard, with positive results. Another work presents how new technologies for VR like the Oculus Rift and Leap motion can be used together to control the movement of an avatar in any direction through hand gestures [4]. Activities like ladder climbing, playing soccer and interacting with virtual objects are made possible using the Kinetic and PS Move which controls the avatar by tracking its position [17].

D. Gaze Based Interaction

In many virtual reality applications, coordinates of sight are used as input for interacting with the virtual environment. Mostly gaze is tracked using eye-tracking devices. Gaze based interaction technique is evaluated against parameters defined in Table 5 and the analysis is represented in Table 10. Gaze based HCI mostly comes in handy for people with disabilities. Research has been done on a gaze controlled virtual Thai Keyboard for Thai people with disabilities [32]. An eye tracker based on Tobii Eye Tracker 4C model is experimented on 10 adults with the result that automatic typing is more effective than freeform typing. In another work Autism patients are addressed by creating a VR platform for social communication [33]. Anxiety of such patients can be bio-marked using gaze related indices. Feature of images and the movement of the head can be combined as input and inferred using Deep convolution neural network [7]. The system works with a simple HMD alone (see figure 6). Hence it is cost-effective.

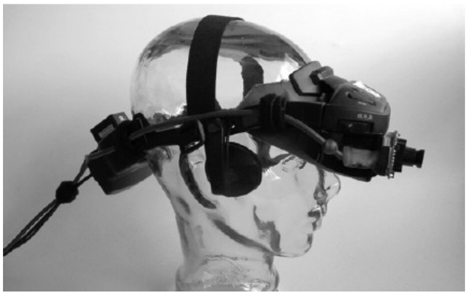

Figure 6 Head Mounted Display (HMD)

Three techniques were analyzed and evaluated against the baseline condition while identifying their weaknesses and strengths in the paper [12]. It was concluded that the three approaches along with Gaze-Dwell had positive results, while the latter showed better user experience. A more reliable approach towards interaction is proposed using gaze as input [6]. Head gaze marker focusing technique is used for interaction. Gaze gestures are mapped to elicit virtual objects. Interactions like selecting panels, walking, and climbing are allowed by the system.

VI. Conclusion

Virtual reality is gaining an increasing amount of importance by researchers. The idealistic goal of virtual reality interaction is to directly interact with virtual objects using our hands and receive feedback from the objects too. Different approaches have been devised in different works to achieve an efficient way of interacting with the virtual environment. A detailed analysis of these works is presented in this paper. Based on the analysis the interaction techniques were divided into four main categories and sub-categories which include wearable haptic devices, gesture recognition, brain-computer interaction, and gaze-based interaction. A lot of work is done on handheld as well as wearable haptic devices with the goal of making them light-weight and accurate. Gaze based interaction does not allow greater interaction compared with the interaction through haptic devices. Gesture recognition is also effective. Work needs to be done on interaction through BCI.

REFERENCES

[1] S. Rothe, P. Pothmann, H. Drewe and H. Hussmann, "Interaction Techniques for Cinematic Virtual Reality," *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Osaka, Japan, 2019, pp. 1733-1737.

[2] A. Raikwar *et al*., "CubeVR: Digital Affordances for Architecture Undergraduate Education using Virtual Reality," *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Osaka, Japan, 2019, pp. 1623-1626.

[3] T. Williams, D. Szafir, T. Chakraborti and E. Phillips, "Virtual, Augmented, and Mixed Reality for Human-Robot Interaction (VAM-HRI)," *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, Daegu, Korea (South), 2019, pp. 671-672.

[4] C. Khundam, "First person movement control with palm normal and hand gesture interaction in virtual reality," *12th International Joint Conference on Computer Science and Software Engineering (JCSSE)*, Songkhla, 2015, pp. 325-330.

[5] K. Hirota and K. Tagawa, "Interaction with virtual object using deformable hand," *IEEE Virtual Reality (VR)*, Greenville, SC, 2016, pp. 49-56.

[6] R. Atienza, R. Blonna, M. I. Saludares, J. Casimiro and V. Fuentes, "Interaction techniques using head gaze for virtual reality," *IEEE Region 10 Symposium (TENSYMP)*, Bali, 2016, pp. 110-114.

[7] M. Soccini, "Gaze estimation based on head movements in virtual reality applications using deep learning," *IEEE Virtual Reality (VR)*, Los Angeles, CA, 2017, pp. 413-414.

[8] Choi, E. W. Hawkes, D. L. Christensen, C. J. Ploch and S. Follmer, "Wolverine: A wearable haptic interface for grasping in virtual reality," *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Daejeon, 2016, pp. 986-993.

[9] S. Li, A. Leider, M. Qiu, K. Gai and M. Liu, "Brain-Based Computer Interfaces in Virtual Reality," *IEEE 4th International Conference on Cyber Security and Cloud Computing (CSCloud)*, New York, NY, 2017, pp. 300-305.

[10] B. Kerous and F. Liarokapis, "Brain-Computer Interfaces - A Survey on Interactive Virtual Environments," *8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES)*, Barcelona, 2016, pp. 1-4.

[11] H. Park, S. Jeong, T. Kim, D. Youn, and K. Kim, "Visual Representation of Gesture Interaction Feedback in Virtual Reality Games," *International Symposium on Ubiquitous Virtual Reality (ISUVR)*, Nara, 2017, pp. 20-23.4

[12] T. Piumsomboon, G. Lee, R. W. Lindeman and M. Billinghurst, "Exploring Natural Eye-Gaze-Based Interaction for Immersive Virtual Reality," *IEEE Symposium on 3D User Interfaces (3DUI)*, Los Angeles, CA, 2017, pp. 36-39.

[13] M. Suhail, S. P. Sargunam, D. T. Han and E. D. Ragan, "Redirected reach in virtual reality: Enabling natural hand interaction at multiple virtual locations with passive haptics," *IEEE Symposium on 3D User Interfaces (3DUI)*, Los Angeles, CA, 2017, pp. 245-246.

[14] U. Ciftci, X. Zhang and L. Tin, "Partially occluded facial action recognition and interaction in virtual reality applications," *IEEE International Conference on Multimedia and Expo (ICME)*, Hong Kong, 2017, pp. 715-720.

[15] B. Wilson, M. Bounds and A. Tavakkoli, "Hand motion calibration and retargeting for intuitive object manipulation in immersive virtual environments," *IEEE Virtual Reality (VR)*, Greenville, SC, 2016, pp. 313-314.

[16] Y. Kim, H. Park, S. Bang and S. H. Lee, "Retargeting Human-Object Interaction to Virtual Avatars," in *IEEE Transactions on Visualization and Computer Graphics*, 2016 pp. 2405-2412.

[17] T. M. Takala and M. Matveinen, "Full body interaction in virtual reality with affordable hardware," *IEEE Virtual Reality (VR)*, Minneapolis, MN, 2014, pp. 157

[18] Z. Guo, C. Lv, D. Zhou and Z. Wang, "Human-computer interaction in immersive virtual maintenance," *2016 12th World Congress on Intelligent Control and Automation (WCICA)*, Guilin, 2016, pp. 2567-2573.

[19] J. Naber, C. Krupitzer and C. Becker, "Transferring an Interactive Display Service to the Virtual Reality," *IEEE International Conference on Smart Computing (SMARTCOMP)*, Hong Kong, 2017, pp. 1-8.

[20] W. Jung and W. T. Woo, "Duplication Based Distance-Free Freehand Virtual Object Manipulation," *2017 International Symposium on Ubiquitous Virtual Reality (ISUVR)*, Nara, 2017, pp. 10-13.

[21] F. Jabeen, L. Tao and Tianlinlin, "One Bit Mouse for Virtual Reality," *International Conference on Virtual Reality and Visualization (ICVRV)*, Hangzhou, 2016, pp. 442-446.

[22] M. Folgheraiter, A. Oleinikov, A. Galiyev, Y. Kassenov and D. Abdygali, "Development of a desktop haptic interface for teleoperation and virtual environments interaction," *IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, Munich, 2017, pp. 478-483.

[23] M. A. Conn and S. Sharma, "Immersive Telerobotics Using the Oculus Rift and the 5DT Ultra Data Glove," *International Conference on Collaboration Technologies and Systems (CTS)*, Orlando, FL, 2016, pp. 387-391.

[24] S. Y. Baek, Sungjun Park, and J. Ryu, "Force Bounding Approach for Stable Haptic Interaction with Dynamic Virtual Environments," *IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, Munich, 2017, pp. 34-39.

[25] M. Svinin, I. Goncharenko, H. Lee and M. Yamamoto, "Modeling of human-like reaching movements in the manipulation of parallel flexible objects," *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Daejeon, 2016, pp. 4830-4835.

[26] D. J. Zielinski, D. Nankivil and R. Kopper, "Specimen Box: A tangible interaction technique for world-fixed virtual reality displays," *IEEE Symposium on 3D User Interfaces (3DUI)*, Los Angeles, CA, 2017, pp. 50-58.

[27] J. Li, I. Cho and Z. Wartell, "Evaluation of 3D virtual cursor offset techniques for navigation tasks in a multi-display virtual environment," *IEEE Symposium on 3D User Interfaces (3DUI)*, Arles, 2015, pp. 59-66.

[28] C. Krogmeier, C. Mousas and D. Whittinghill, "Human, Virtual Human, Bump! A Preliminary Study on Haptic Feedback," *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Osaka, Japan, 2019, pp. 1032-1033.

[29] C. G. Coogan and B. He, "Brain-Computer Interface Control in a Virtual Reality Environment and Applications for the Internet of Things," in *IEEE Access*, vol. 6, pp. 10840-10849, 2018.

[30] D. Zhao, Y. Liu, Y. Wang and T. Liu, "Analyzing the Usability of Gesture Interaction in Virtual Driving System," *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, Osaka, Japan, 2019, pp. 1277-1278.

[31] N. El Din Elmadany, Y. He and L. Guan, "Human gesture recognition via bag of angles for 3D virtual city planning in CAVE environment," *IEEE 18th International Workshop on Multimedia Signal Processing (MMSP)*, Montreal, QC, 2016, pp. 1-5.

[32] S. Tantisatirapong and M. Phothisonothai, "Design of User-Friendly Virtual Thai Keyboard Based on Eye-Tracking Controlled System," *2018 18th International Symposium on Communications and Information Technologies (ISCIT)*, Bangkok, 2018, pp. 359-362.

[33] P. R. Krishnappa Babu, P. Oza and U. Lahiri, "Gaze-Sensitive Virtual Reality Based Social Communication Platform for Individuals with Autism," in *IEEE Transactions on Affective Computing*, vol. 9, no. 4, pp. 450-462, 1 Oct.-Dec. 2018