International Journal of Artificial Intelligence and Neural Networks – IJAINN

Volume 9 : Issue 1- [ISSN : 2250-3749] - Publication Date: 27 Dec, 2019

Virtual Reality in Computational Neuroscience

J.R.M. Bogahawatte, K. A. Dilini T Kulawansa
Faculty of Information Technology, University of Moratuwa, Sri Lanka
Department of Computational Mathematics, University of Moratuwa, Sri Lanka

***Abstract*— Virtual reality has been emerged into many fields of studies such as medicine, education, construction, fashion and etc. The computational neuroscience is also one of the fields that VR has been an impact. An enormous amount of data is gathered after conducting neurological and psychological experiments. Those data should be carefully analyzed and interpreted by computational neuroscientists to identify the data patterns. For the visualization of those patterns virtual reality techniques can be a massive contribution. This paper presents the technology related to Virtual Reality, how the Virtual Reality techniques are integrated with the field of computational neuroscience to identify and overcome existing barriers and to identify the future improvements to be done in order to enhance the field of computational neuroscience.**

Keywords—Virtual Reality, Computational Neuroscience, Neuroscience, Psychology, Behavioral Neuroscience

I. INTRODUCTION

Interaction of a 3D environment which is not the actual reality but a fantasy, and navigation through this environment have been enabled as a result of Virtual Reality [1]. Activities what have been experienced in reality can be brought into the lives as a near reality using this technology. Visual representation is the key component in Virtual reality. Although audio sensation is required to provide a realistic implementation through this technology. Virtual reality has been emerged to various types of research areas such as healthcare, construction, scientific visualization, fashion, entertainment, military and engineering. Even though most of the time Virtual Reality is used to simulate an environment which is similar to the real world as in military applications, it can be utilized to create environments which totally differ from reality as in gaming.

Neuroscience is a vast area of study which consists of different paths. Among those, computational neuroscience holds a major position. In Computational neuroscience the mathematical tools and functions are applied to represent the mechanisms of the brain and nervous system. Computational Neuroscience is a combination of distinct fields such as Neuroscience, Computer Science, Physics and Applied Mathematics. Based on the findings and the results which are obtained by conducting experiments, comprehensive simulation models related to neurons and the neurons as a network are developed to identify and understand the processes of nervous system [2]. When studying computational neuroscience huge amount of complex data should be analyzed and interpreted [2].

In order to conduct experiments in computational neuroscience in an effective manner, advanced visualization techniques are essential. Utilization of Virtual Reality as an advanced scientific visualization in computational neuroscience can be helpful to process the data in a realistic way. Integrating Virtual Reality in computational neuroscience can be an efficient technique to identify and understand patterns of the data that are obtained from experiments.

The organization of the paper is as follows. In the second section an overview of virtual reality and computational neuroscience is provided. Major researches in virtual reality in computational neuroscience is described under section three. The section four and section five identifies the current issues of virtual reality in computational neuroscience and the applications of virtual reality respectively. Section six is about the discussion. Finally the future directions are presented in section seven.

II. OVERVIEW OF VIRTUAL REALITY AND COMPUTATIONAL NEUROSCIENCE

Virtual Reality has become a major component in many current fields of study. VR is used for scientific visualization considering the management of huge amount of data. It is not a new trend but it is rapidly emerging into the field of science. Not in the field of science but also in the field of psychology the use of VR tools in experiments has been increased over the last twenty years of time [3]. An immersive Virtual Reality system is among the VR systems that provides a figment of imagination to the consumers giving the sense that they are inside an environment created through computer systems [4]. Computational neuroscience is a branch of neuroscience field. Computational neuroscience is emerging to the scientific experimental field. As an example “Advanced Neurologically Inspires Face recognition (ANIF) system” can be taken which uses algorithms and tools for the experiments of simulations of brain functions [5]. Combination of “Brain Computer Interface and Virtual Reality (BCI-VR)” can be improved to monitor and treat patients who have anxiety disorders [6]. Interpretation of huge amount of complex data which are generated from the stimulations of neuroscience is one of the major task of computational neuroscientists [2]. Virtual Reality enables to monitor the activities in the brain with the use of image and direct recording while enhancing the naturalistic interactive behaviors [7]. In earlier days it was extremely difficult to recognize the patterns hidden in enormous amount of data which were gathered from neuroscientific experiments. Therefore computational

neuroscientists were encouraged to use Virtual Reality in their field to analyze the data.

III. MAJOR RESEARCHES IN VIRTUAL REALITY IN COMPUTATIONAL NEUROSCIENCE

Over the past years of time researchers have been involved in finding ways of how to implement effective systems using Virtual Reality in Neuroscience field. Computational neuroscience is a combination of neuroscience, mathematics, psychology, physics, computer science and engineering. Therefore the major researches which were conducted in those diverse fields regarding VR are important.

According to M. J. Schuemie, P. v. d. Straaten, M. Krijn and C. A. v. d. Mast when using virtual reality in psychological therapy, which is based on concept of presence. This research was conducted to investigate how to utilize the knowledge of concept of presence for the understanding of psychological mechanism with related to an experience in virtual reality [8].

When considering a pilot validation study which was conducted by W. G. Wright, J. McDevitt and K. O. Appiah-Kubi, demonstrated that the "portable virtual reality balance device" is reliable and experimentally valid to examine the symptoms of mild traumatic brain injury (mTBI) [9]. In this research 27 number of healthy adults and 8 number of adults who were diagnosed with mTBI were involved as subjects to prove the validity and reliability of the device.

J. Leigh et al. presented the design of a scalable virtual reality system and heuristic based interface library for the usage of visualization of simulated data for computational neuroscientists. The software and hardware configurations of VR visualization systems were included in this research. The interface library was known as "V" [2].

According to M. K. Annett and W. F. Bischof the VR systems should be usable to all the researchers related to the fields of psychology and cognitive neuroscience regardless of their programming skills and the knowledge related to VR technology [1]. They have identified four distinct kinds of users and their relevant requirements. Different types of VR systems and platforms such as canned systems and custom VR systems which are used in psychology and cognitive neuroscience were evaluated.

Social neuroscience is another paradigm which is involved in computational neuroscience and that helps to investigate how social behaviors and interactions proceed. Enhancement of the interactions in social situations can be enabled through VR technology, by using it for experimental purposes. This research was conducted by Thomas D. Parsons, Andrea Gaggioli and Giuseppe Riva to evaluate technologies and features available for social neuroscientific experiments. Not only advantages but also some challenges when using VR in this particular field have been identified. As one of the challenges, the ethical issues that were aroused due to the involvement of social and personal information during VR experiments was presented [10].

The research which was conducted by Shyam Diwakar et al analyzed the effectiveness of utilizing virtual labs for the education purposes in the scope of neurophysiology by gathering feedbacks from students and instructors. Development of a tool which is available online to enhance academic experience was their motive [11]. Virtual neurophysiology labs were consisted of three basic components as shown in the following figure.

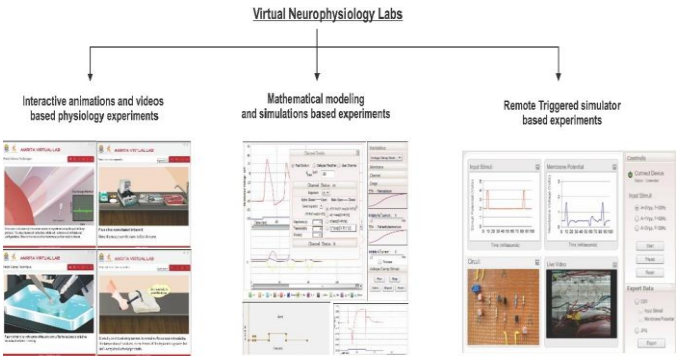

Fig. 1 Three main components of a Virtual neurophysiology lab [20]

According to S.V. Adamovich et al a system with VR simulation environment was proposed to understand the behaviors and interactions of the brain through functional MRI and validity of that approach was evaluated using a sample of 13 healthy right handed people including 9 males [12]. At the time of execution of movements in VR, those were analyzed and compared with the real experiences. As the results had been proved a VR environment with the compatibility to function with fMRI can be used to study neural networks and derive computational representations. Although this system was limited to simple movements it could be further developed to cure the patients with neurological disorders by integrating hand function rehabilitation.

IV. CURRENT ISSUES OF VIRTUAL REALITY IN COMPUTATIONAL NEUROSCIENCE

Even though there are improvements in the field of computational neuroscience where virtual reality is used, some limitations still can be identified that need to be overcome.

A. *VR and neuroscience*

The users of the VR system in the field of neuroscience can be different according to their skill set and knowledge level. Therefore at the time of the creation of a VR system this condition should be taken into account. Although the permission is granted for the researchers and scientists who have a sufficient knowledge about VR technology to access all the components in the virtual surrounding the installation and continuous maintenance is complex and difficult [1].

B. *Computational Neuroscience*

In computational neuroscience analyzing and interpreting a numerous data which were gathered during neuroscientific experiments is essential. To perform that task there should be an efficient pattern searching technique. The human visual system is the most advanced technique that is in the use [2]. The implementation of a VR visualization system that can be used to detect patterns as human visual system is difficult.

C. *VR applications*

Advanced virtual reality systems are highly expensive and require the expertise support for programming, texturing and character modelling and animation [7]. As an examples "wide-field-of-view head-mounted display (HMD)", a tracking system which covers a large area and exploratory new systems can be costly. The VR systems required a higher computation speed and graphics processing power [13].

Although there are inexpensive small installations of virtual reality such as "desktop virtual reality" as in computer games like Doom, there is a limited permission for the user to keep a relationship with the virtually created world [14]. As the user is controlling the system with the use of a mouse or a joystick the experience is not immersive.

D. *VR and behavioral neuroscience*

The utilization of resources related to VR technology in the field of behavioral neuroscience and psychotherapy has been limited as there are few standardized protocols available, and because of that adjusting the tools according to experimental requirements is difficult [15].

V. APPLICATIONS OF VIRTUAL REALITY IN COMPUTATIONAL NEUROSCIENCE

Virtual reality techniques and systems have been applied in computational neuroscience by approaching with diverse fields such as neuroscience and psychology.

Virtual reality based system which is known as Rehabilitation Gaming Station (RGS) for neurorehabilitation and brain repair was developed [16]. The recovery time of stroke in the stages of acute and chronic is reduced. This system is based on a framework which is related to mind, brain and behavior that is known as Distributed Adaptive Control architecture (DAS). The motions of arms are plotted into the virtual character and allows for exercising from the elbow and shoulder. This speedup the recovery of stroke patients who are in those two stages. This system has currently been developed only up to at home treatment range.

Although virtual reality is emerging into the field of psychology the researchers do not have sufficient knowledge regarding VR. Therefore a virtual toolbox for experimental psychology was implemented [17]. Various types of data about the objects in the virtual environment can be stored in this toolbox. This toolbox provided an interface which varied from an empty room to big cities. This could be used to understand how the brain processes and analyze those data which is the field of computational neuroscience.

Virtual reality game was designed to provide motivation for memory skills. Not only that people who have difficulties of learning because of disorders such as Asperger and Dyslexia can use this game to reduce their difficulty. Analyzing of the responses of the brain during the VR game was performed using Quantitative electroencephalogram (QEEG). This game was developed using unity programming and JavaScript [18]. During the test three subjects were involved in the game and memory skill was evaluated using auditory and visual stimulations.

Not only virtual environments but also another person's body can be sensed through virtual reality. The bodies can be swapped using VR. The head movements of a different person can be viewed through head mounted display (HMD) and those can be controlled [19]. The experiment was conducted between two participants at a time considering four main conditions namely exploration where they could see the other person's movements instead of their own movements, explore touch, narrative with objects, shaking hands and face to face communication. The following figure

shows the system namely "Machine To Be Another (TMBA)" which was used to carry out this research.

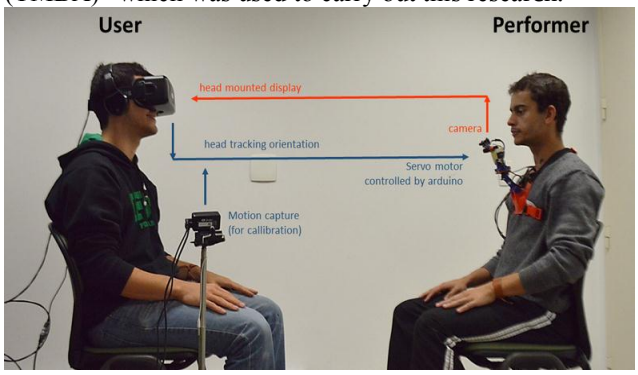

Fig. 2 "The Machine to Be Another(TMBA) system", by "BeAnotherLab" [5]

In addition to that another set of experiments have been conducted based of this virtual interchanging process of bodies. According to that although the interchange is virtual it is affected to the attitudes and behaviors. As an example the researchers have shown that an adult who occupied in a virtual body of a child overestimated the objects since the mindset is changed based on the virtual body swapping [20].

A web based neuron and network simulator using virtual reality was developed with the technologies such as JavaScript, python and HTML5. That was utilized for modeling of spatio-temporal computations in nervous system of animals [21]. This tool was used for teaching purposes in neuronal biophysics and circuit dynamics.

When there are many experiments done in neuroscientific field the growth rate of data of different types will have an exponential growth. As discussed, it is difficult to analyze and interpret the data that were utilized in "non-linear discriminant neural networks". Therefore as a solution for this problem VR spaces with a better quality were introduced with the use of "multi objective optimization based on genetic algorithms (MOGA)" [22].

Neuro-Imaging gave the opportunity to get the images of functioning brains for the experiments which are used by neuroscientists. However information which is available in 3D environment is getting limited when those are captured with the use of 2D images. Therefore "Neuro Imaging in VR (NIVR)" technique was proposed with the engagement of immersive visualization [23]. This application was developed using unity platform. In this tool the MRI files of the user are included and represented in a "Data Cube" that can be positioned into a socket and a particular neuro visualization mode gets activated depending on the socket. This is able to provide a natural and real environment which opens doors for fine volumetric details. Not only that, users have the ability to interact with any of the visualized region by moving that region.

VI. CONCLUSION

With the vast development of technology all the scientific field are becoming more advanced. The utilization of virtual reality in the branches of computational neuroscience such as psychology, cognitive neuroscience and behavioral neuroscience is visible through applications and researches which have been conducted. Therefore the challenges in this area of study are also identified. Because of those challenges more future directions are revealed for the continuous improvement of this particular field.

VII. FUTURE DIRECTIONS OF VIRTUAL REALITY IN COMPUTATIONAL NEUROSCIENCE

As the technology become advanced the improvements in the field of computational neuroscience with the use of virtual reality is visible.

A. *VR technology*

The automation of VR based experiments will cause the trials to be shortened and many trials can be taken place within a short time period [24]. VR technologies can be integrated with gaming applications when using them for basic neuroscientific experiments as this leads to many benefits such as reduced cost [25]. At the present time, from the implementation of virtual environments it has been developed to virtually swapping body movements of two people. Step by step it is being further developed to full body swapping and invisible body [19].

B. *Computational neuroscience*

The process of analyzing and interpretation of multidimensional data obtained by neuroscientific experiments including neuroimaging and fMRI scans can be done using a "data driven approach" which enables more advanced tools. There is a future trend, to directly apply highly detailed computational neuroscientific models to understand the activities of brain.

C. *VR technology and computational neuroscience*

The laboratories which were installed for visualization of simulated data from the neuroscientific experiments to use in computational neuroscience analysis should be continuously improved. When considering the implementations in current time a virtual reality system for

psychology and cognitive neuroscience research known as SNaP framework was developed [1]. It can be further improved to create a system to allow the users who are not familiar with VR technology to get the full control over VR environments and become more user friendly.

ACKNOWLEDGEMENT

Firstly, I would like to express my gratitude to Dr. L. Ranathunga Department Head at Department of Information Technology for the great guidance and supervision provided during this course of this research. I am grateful for the people who have dedicated their lives to research on these areas and who have published their papers. Not only that my sincere thanks goes to my parents for supporting throughout writing this paper and life in general.

REFERENCES

[1] M. K. Annett and W. F. Bischof, "Investigating the Application of Virtual Reality Systems to Psychology and Cognitive Neuroscience Research," *MIT press Journals,* vol. 19, no. 2, pp. 131-141, 2010.

[2] J. Leigh, C. A. Vasilakis, T. A. DeFanti, R. Grossman, C. Assad, B. Rasnow, A. Protopappas, E. D. Schutter and J. M. Bower, "Virtual Reality in Computational Neuroscience," *Virtual Reality in Computational Neuroscience,* pp. 1-17, 1994.

[3] A. Soranzo and C. J. Wilson, "The Use of Virtual Reality in Psychology:A Case Study in Visual Perception," *Computational and Mathematical Methods in Medicine,* vol. 2015, p. 7, 2015.

[4] H. G. Hoffman, T. Richards, B. Coda, A. Richards and S. R. Sharar, "The Illusion of Presence in Immersive Virtual Reality during an fMRI Brain Scan," *CyberPsychology & Behavior,* vol. 06, no. 02, 2004.

[5] S. Karimimehr and M. R. Yazdchi, "How Computational Neuroscience Could Help Improving Face Recognition Systems?," in *4th International Conference onComputer and Knowledge Engineering (ICCKE) IEEE conference*, Ferdowsi University of Mashhad, 2014.

[6] X. Tan, Y. Li and Y. Gao, "Combining Brain-Computer Interface with Virtual Reality: Review and Prospect," in *IEEE International Conference on Computer and Communications*, Chengdu, China, 2017.

[7] C. J. Bohil, B. Alicea and F. A. Biocca, "Virtual Reality in neuroscience research and therapy," *Natural Reviews Neuroscience,* vol. 12, pp. 752-762, 2011.

[8] M. J. Schuemie, P. v. d. Straaten, M. Krijn and C. A. v. d. Mast, " Research on Presence in Virtual Reality: A Survey," *CyberPsychology & Behavior*, vol. 04, no. 02, 05 July 2004.

[9] M. K. Annett and W. F. Bischof, "Investigating the Application of Virtual Reality Systems to Psychology and Cognitive Neuroscience Research," *MIT press Journals,* vol. 19, no. 2, pp. 131-141, 2010.

[10] T. D. Parsons, A. Gaggioli and G. Riva, "Neuroscience, Virtual Reality for Research in Social," *Brain Sciences,* vol. 7, no. 4, 2017.

[11] S. Diwakar, H. Parasuram, C. Medini, R. Raman, P. Nedungadi, E. Wiertelak, . S. Srivastava, K. Achuthan and B. Nair, "Complementing Neurophysiology Education for Developing Countries via CostEffective Virtual Labs: Case Studies and Classroom Scenarios," *The Journal of Undergraduate Neuroscience Education (JUNE),* vol. 12, no. 2, pp. 130-139, 2014.

[12] S. V. Adamovich, K. August, A. Merians and E. Tunik, "A virtual reality-based system integrated with fMRI to study neural mechanisms of action observation-execution: A proof of concept study," *Restorative Neurology and Neuroscience,* vol. 27, no. 3, pp. 209-223, 2009.

[13] L. R. Valmaggia, L. Latif, M. J. Kemptom and R.-C. Maria, "Virtual reality in the psychological treatment for mental health problems: an systematic review of recent evidence," *Psychiatry Research*, 2016.

[14] M. J. Tarr and W. H. Warren, "Virtual reality in behavioral neuroscience and beyond," *Nature Neuroscience,* vol. 5, p. 1089–1092, 2002.

[15] G. Riva, A. Gaggioli, D. Villani, A. Preziosa, F. Morganti, R. Corsi, G. Faletti and L. Vezzadini, "NeuroVR: an open source virtual reality platform for clinical psychology and behavioral neurosciences," *Studies in health technology and informatics*, vol. 125, 2017.

[16] P. F. M. J. Verschure, "Neuroscience, Virtual Reality and Neurorehabilitation: Brain repair as a validation of brain theory," in *IEEE Conferences*, Boston, MA, USA, 2011.

[17] M. Vasser, M. Kängsepp, K. Kilvits, T. Kivisik and J. Aru, "Virtual Reality toolbox for experimental psychology – Research Demo," in *IEEE Conferences*, Arles, France, 2015.

[18] D. Anopas and Y. Wongsawat , "Virtual Reality Game for Memory Skills Enhancement based on QEEG," in *Biomedical Engineering International Conference* , 2014.

[19] E. C. d. Oliveira, P. Bertrand, M. E. R. Lesur, P. Palomo, M. Demarzo, A. Cebolla, R. Ba˜ nos and R. Tori, "Virtual Body Swap: A New Feasible Tool to be Explored in Health and Education," in *IEEE Conference*, Gramado, Brazil, 2016.

[20] M. Slater and M. V. Sanchez-Vives, "Transcending the Self in Immersive Virtual Reality," *Computer,* vol. 47, no. 7, pp. 24-30, 2014.

[21] J. Alphonse, C. Medini, B. Nair and S. Diwakar, "An Open-Source Computational Neuroscience Virtual Laboratory Tool for Simulating Spiking Neurons and Circuits," in *IEEE Conferences*, Udupi, India, 2017.

[22] J. J. Valdes and A. J. Barton, "Virtual Reality Visual Data Mining via Neural Networks obtained from Multi-objective Evolutionary Optimization: Application to Geophysical Prospecting," in *International Joint Conference on Neural Networks*, Vancouver, BC, Canada, 2006.

[23] T. Ard, . D. M. Krum, T. Phan, D. Duncan, R. Essex, M. Bolas and A. Toga, "NIVR: Neuro Imaging in Virtual Reality," in *IEEE Conference*, Los Angeles, CA, USA, 2017.

[24] A. Lehmann, M. Vidal and H. H. Bulthoff, "A High-End Virtual Reality Setup for the Study of Mental Rotations," *MIT Press Journals,* vol. 17, no. 4, pp. 365-375, 2008.

[25] D. Sternad, "From theoretical analysis to clinical assessment and intervention: Three interactive motor skills in a virtual environment," in *International Conference on Virtual Rehabilitation (ICVR)*, Valencia, Spain, 2015.

About Author(s):

I am J.R.M. Bogahawatte who is an undergraduate in Faculty of Information Technology, University of Moratuwa, Sri Lanka reading for Honors Degree of Bachelor of Science in Information Technology.

K. A. Dilini T. Kulawansa
Senior Lecturer
Department of Computational Mathematics, Faculty of Information Technology,
University of Moratuwa., Sri Lanka.