A Review on the Development of a Virtual Reality Learning Environment for Medical Simulation and Training

Kieran Latham, Patryk Kot, Atif Wariach, Dhiya Al-Jumeily.
Faculty of Engineering and Technology
Liverpool John Moores University
Liverpool, United Kingdom
Email: {K.Latham, P.Kot, A.I.Waraich, D.Aljumeily}@ljmu.ac.uk

Mani Puthuran, Arun Chandran
Consultant Interventional Neuroradiologist
NHS The Walton Centre
Liverpool, United Kingdom
Email: {Mani.Puthuran, Arun.Chandran}@thewaltoncentre.nhs.uk

Abstract—**This paper aims to discuss specific immersive Virtual Reality Medical Training platforms developed as research projects in the use of Virtual Reality for Medical Training. It looks at the technology that is utilised by different applications and investigates the methodologies employed in the development of immersive applications. This paper identifies some critical strengths for Virtual Reality Medical Training applications, such as the reduction of risk to practitioners and patients, and the ability to simulate complex scenarios that in real-world practice would be hard to reproduce.**

Keywords- Gamification; Immersive Application; Medical Training Simulation; Virtual Reality Learning Environment.

I. INTRODUCTION

Technological advancement in the area of Virtual Reality (VR) and medical training, has seen a surge in the number of institutions investigating the development of an immersive application for the pedagogical dissemination of anatomical knowledge and the practical training of medical procedures, both at commercial and research level. Many institutions are coming up with ways to utilise VR to enhance the learning experience of medical practitioners by creating immersive simulations for users to practice. As identified by the Virtual Reality Society [1], a Virtual Reality Learning Environment (VRLE) is a platform, which allows users to engage with content actively and can improve the user's ability to develop better cognitive abilities, spatial awareness and even be used to perform hazardous tasks in a risk-free environment. Another form of immersion is the Cave Automatic Virtual Environment (CAVE) [2]. In this environment, projectors are directed to between three and six of the walls of a room-sized cube, and typical setups include either having projection screens installed to receive camera projections of the virtual world, with the user wearing 3D glasses to distinguish better what is around them. However, companies are coming up with CAVE systems that can utilise Flat Panel LCD screens and optical tracking for a much more immersive and dynamic CAVE system [3]. In the medical industry, especially, many institutions are looking for immersive solutions to disseminating medical knowledge in more interactive ways and to guiding medical professionals through complicated procedures. These procedures require repetitive and consistent training of the user in order to improve the success rates of procedural cases [4]. Section II of this paper will discuss the advantages a VRLE has on medical simulation, and the effect each one has on the quality of training provided. Section III discusses some significant works related to Immersive VR medical platforms and looks at the tools and techniques utilised within the research projects. The methods involved in assessing the effectiveness of the virtual reality simulator, in terms of heuristics and quality of training by providing users with training scenarios and ways of providing qualitative and quantitative feedback. Section IV will conclude the paper by discussing the findings of the research. How users utilised the applications and the benefits and limitations identified by the researchers. As well as potential avenues for future investigation.

II. THE PURPOSE OF A VRLE

A vital aspect of the discussed immersive VR applications are the advantages they offer to traditional non-immersive VR training platforms. While it is beneficial to the user to provide them with an immersive training experience in which to improve their technical skills and coordination, There are multiple advantages to immersive VR applications as identified below.

A. User Engagement and Immersion

The fundamental purpose of a VRLE is to provide users with a content-rich learning environment for them to train in and better engage with content related to what they are learning. As identified by Byl *et al* [5], where qualitative discussion backed by user experience questionnaires identified that the virtual simulator provided a high-quality experience which when combined with its efficient usability made for an exciting experience that maintained the user's engagement. It demonstrates that a VRLE will benefit a user's development when it provides an immersive experience and improves the quality of training.

 ISBN: 978-1-61208-724-5

B. Bespoke Training Platforms

Another benefit of a VRLE is that it can be tailored to provide users with training in a specific subject or role, allowing for training programs to be developed and utilised, evidenced by Lam *et al* [6]. They identified that the use of a training simulator developed for cataract surgery allowed trainees to learn a specific set of skills required to perform this type of procedure effectively. It is clear from this that a VRLE has the potential to enhance the quality of learning, by allowing for the creation of a simulator with specific training scenarios in mind that can allow trainees to learn skills essential to their role effectively.

C. Risk-Free Training and Assessment

A standard belief across most VR platforms is that they provide users with a risk-free environment to train in that allows them to associate themselves with hazardous situations with little to no chance of actual harm occurring. The notion of risk-free training identified by Li *et al.,* explains that an advantage of medical training within a VRLE is that the user is provided with a safe virtual environment to train inside. In this project, training Clinicians perform laparoscopic procedures in a virtual environment, allowing them to develop an understanding of the steps involved in the procedure [7]. The trainees are also able to develop a better understanding of the surgical equipment and the human body through Virtual Reality training. The user can associate themselves with the complicated procedures and associate themselves with the risks involved that are likely to cause complications for the patient. In addition to this, the ethical approval requirements for simulating training are less demanding than if a trainee was to practice on a live patient, so that is an added advantage to virtual simulation.

III. Related Works

The purpose of this research project is to provide interventional radiologists with a VRLE in Endovascular Surgery, and as such, background research has been conducted into the area of existing medical VRLE and has identified several publications pertinent to this research project. These articles provide an insight into the methodologies they employed, how they approached their testing scenarios, and any conclusions they identified through the completion of any experiments. Identified through background research is that VR is used to identify medical simulators on a PC, regardless of whether these applications utilise immersive technology such as head-mounted displays or haptic feedback controllers. As such, this review will look at applications specifically for VR technology, looking at how researchers developed these applications, how they tested the simulators, the feedback received, and any noticeable differences using VR.

A. Tools and Techniques

The identification of what software and hardware were used to develop these immersive applications is crucial to the development of a VR training simulator. By identifying essential tools and techniques will help in creating a workflow to develop an application of similar nature and provide an understanding of what is available and commonly used in the development of medical simulations. The following is a list of such tools.

1) Süncksen et al [8]: The purpose of this research project was to identify whether a VRLE created that recreated radiographic procedures could improve the skills of practising radiologists. When developing the VRLE designed for x-ray imaging, authors opted to use Unity 3D game engine, which is a powerful engine used to create interactive visual applications [9], the completed application provides users with a visual representation of an operating theatre with c-arm interaction for radiography. Radiographic images produced are based on Computed Tomography (CT) and as such, use complex datasets commonly used in the medical industry. The DICOM Toolkit (DCMTK) is a plugin developed for Unity that allows for the importing of Digital Imaging and Communications in Medicine (DICOM) datasets, which are datasets produced by radiography [10]. The purpose of this is to convert DICOM data into readable datasheets to be visualised in-game inside Unity. For the virtual reality implementation of the application, the researchers opted for the HTC Vive [11]. The Vive utilises two stationary sensors that can track the user in an open environment and provide a full room-scaled environment, allowing users to walk around the environment and interact with objects more realistically.

2) Harrington et al [12]: Researchers developed a VRLE as a novel approach to providing Doctors with a training platform to improve their critical thinking and decision-making regarding patient care. The simulator developed by Harrington, C.M., *et al* for decision making utilised the Unity 3D game engine for the development of the simulator. Additionally, for extended functionality and platform support for Oculus VR in Unity, Oculus Utilities was installed to Unity, the toolkit provided additional features for use with the Gear VR. Furthermore, Autodesk 3DS Max 2014 was used for the 3D modelling and design of the virtual environment used in the simulator and provided the VRLE for the application. The simulator was designed to run on the Samsung Gear VR HMD, which is powered by the Oculus platform and consists of a Gear VR HMD. This setup allows the user to interact with the simulation, listen to what is said, assess the situation around them and make decisions.

3) Byl et al [5]: The simulator developed in this research project is a novel platform for the training and improvement of medical ultrasound imaging and spatial cognition for doctors. In order to develop this simulator, the researchers opted to follow a similar method to *Süncksen, M., et al* [8]. The researcher decided to use the Unity 3D game engine for the development of the immersive application, which is used to present the virtual world and training scenario that will provide users with a content-rich learning environment. Additionally, the application made use of a “visualization toolkit for artificial and medical volumetric image data”. It works like the DCMTK toolkit used in the x-ray imaging software, which allows for the realistic simulation of medical imaging in the application to improve immersion. In this instance, however, the toolkit appears to be homogenous to the Department of Applied Sciences at Flensburg University [5]. The application also utilises the HTC Vive HMD and haptic feedback controllers, which allows them to look around the virtual environment and interact with objects within, as part of the training scenarios.

TABLE I. IDENTIFIED TECHNOLOGIES FOR VR DEVELOPMENT

Project	Tools		
	Platform	***Engine***	***Plugins***
1) X-Ray Imaging [8]	HTC VIVE	Unity 3D C#	DCMTK [10]
2) Critical Decision Making [12]	Gear VR	Unity 3D C#	N/A
3) Medical Ultrasound Imaging. [5]	HTC VIVE	Unity 3D C#	Visualisation Toolkit for Artificial and Medical Volumetric Image Data [5]

Additionally, 90% of Samsung Gear apps and 53% of Oculus Rift games use Unity and C# for development. While the papers do not go into detail as to why they chose the HTC Vive, initial research suggests that the HTC Vive is capable of full room tracking using external trackers, providing enhanced motion tracking and more accurate tracking as opposed to the Oculus Rift. In terms of visual ability, the HTC Vive provides users with a complete resolution of 2,160 x 1,200 (1,080 x 1,200 per eye), and a field of view of 110 degrees, which combined with a 90Hz refresh rate allows for an improved immersive experience inside the HTC Vive [18].

B. Methods and Approaches

A crucial part of the research is how the users interacted with the system. Providing users with a series of objectives that enable researchers to assess the users level of ability and user experience of the application. The following is a list of conventional methods used for this purpose.

1) Süncksen et al [8]: In the x-ray imaging application, the aim is for the user to correctly reproduce radiographic images, with the constraints of the game being that users complete the challenge in an efficient amount of time, with a minimal amount of patient radiation dosage. The user is provided with text-based instructions and imagery to show the expected output and what the users must do to achieve this. Additionally, the user is scored based on three variables: accuracy of the radiographic image, amount of time taken, and patient dosage, with points being provided based on the user's score, while also comparing the users score to an expert’s score. Furthermore, to improve the development of spatial awareness, a non-medical mode exists in which users must identify objects hidden in a box, correctly, to improve their skills in c-arm navigation.

2) Harrington et al [12]: For this project, researchers developed an application that places the user at the centre of a traumatic situation in which they need to make critical decisions and diagnoses pivotal to the patient's survival, RSCI Medical [19]. The application has the user following a patient through the early stages of hospital arrival, listening to the doctors and nurses provide information about the situation. Users then choose an option regarding patient care, which contributes to a score at the end, based on whether the patient survived. It requires the user to critically think and lets them experience the quick paced and stressful environment where it is imperative to take on multiple sources of information at once in order to succeed in making the right decisions.

3) Byl et al [5]: This paper on ultrasound imaging takes an unconventional approach to gamifying the training of ultrasound imagery by taking users out of a medical environment and into an industrial setting, with the objective being to conduct ultrasound scans on packages containing objects to determine that the contents were packaged in the correct box in the correct way. This scenario allows the user to gain experience conducting ultrasounds and analysing what is seen on screen, allowing them to determine whether what they are seeing is correct. The simulation uses a point system that increments as the player makes correct guesses, as well as how long it took for users to make decisions, and the total number of correct answers. Additionally, a leader board is provided to compare high scores to other users as an incentive to perform better and obtain a higher score.

C. Evaluation and User Experience

As a part of the user experience, researchers can record qualitative and quantitative feedback from users regarding the user’s experience of an application, the functionality, and determine the applications overall effectiveness.

1) Süncksen et al [8]: While utilising the application, users had several tasks to accomplish; this exposed the user to multiple aspects of the system, which would allow for a variety of responses from the users. Users provided feedback in the form of a user experience questionnaire (UEQ) [14]. Users were asked to provide quantitative feedback regarding the usability and effectiveness of the x-ray imaging application. 65.85% (27) of users agreed wholeheartedly that the system is adequate for medical training, 29.27% (12) of users agreed and provided additional feedback on potential improvements, 2.44% (1) of users mostly agreed that the application was useful, lastly, 2.44% (1) of users disagreed with the notion of using this application for medical training.

 ISBN: 978-1-61208-724-5

2) Harrington et al [12]: The application evaluated the use of VR technology for the training of Doctor's critical thinking and ability to diagnose patients in a stressful environment. The user experience questionnaire used a Likert scale between 0 and 7; scores were considered negative if they were below 3, with scores above five classed as positive. User feedback identified that the RCSI Training Simulator received positive results with an average score of 5.09 out of 7 regarding Immersion and Realism of the VR simulation, 5. Regarding the method of learning, it was rated 5.7 out of 7 as a useful teaching tool, with 58% of candidates claiming their belief that there currently are not enough patient management simulators available.

3) Byl et al [5]: Evaluation of the novel application for medical ultrasound imaging was conducted using User Experience Questionnaires which provided quantitative responses regarding aspects of the system using a Likert scale between -3 and 3, with results between -0.8 and 0.8 being neutral. Nine users tested the application: 6 male and three male participants, with five already possessing experience with VR technology. Quantitative responses from the UEQ looked at six factors: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. Results showed that the Attractiveness, Efficiency, Stimulation, and Novelty categories all scored good results over 0.8. Regarding Perspicuity and Dependability, users believed improvements could be made to improve information dissemination, a modification of object transforms to accommodate changes in users height, and audio cues to support their stimulation.

IV. CONCLUSION

The literature review conducted in this paper indicates that the use of VR technology is indeed beneficial to the learning experience of medical professionals. The feedback from users regarding the projects revealed that most users believe VR to be a useful tool for medical training and assessment. The training applications reviewed benefitted from a content-rich and realistic working environment for the user's training. The applications developed also utilised a point system, which would keep score of the user's progress throughout the tasks and be indicative of their performance, which provides accurate measurement for supervisors to refer to when reviewing the user's progression when training. Furthermore, a common occurrence in these projects was users initially struggling to understand how to accomplish tasks within the simulation, this combined with the low number of users that have experienced VR, indicates a lack of familiarity with VR technology and immersive applications.

The lack of familiarity about VR in the medical community could be worth investigating, potentially identifying methods in which VR could further enhance the quality of quality as identified by the reviewed projects. Furthermore, the use of gamification in medical training as a metric for progress review could be reviewed further to develop a greater understanding of the impact this could have on monitoring progression within medical training platforms.

REFERENCES

[1] Virtual Reality Society (2011) *Virtual Reality Learning Environments* [online] Available at: https://www.vrs.org.uk/virtual-reality-education/learning-environments.html [Accessed: 18th February 2019]

[2] C. Cruz-Neira, D. J. Sandin, T. A. DeFanti, R. V. Kenyon, and J. C. Hart, "The CAVE: audio visual experience automatic virtual environment," Communications of the ACM, [online] vol 356, pp.64–72. Available at: http://portal.acm.org/citation.cfm?doid=129888.129892, 1992. [Accessed 18th Feb. 2019].

[3] A. Febretti, "CAVE2: A Hybrid Reality Environment for Immersive Simulation and Information Analysis," Proceedings of SPIE - The International Society for Optical Engineering, vol 8649, pp.01-13. [Accessed 30th May. 2019].

[4] M. Maytin, T. P. Daily, and R. G. Carillo, "Virtual reality lead extraction as a method for training new physicians: A pilot study," PACE - Pacing and Clinical Electrophysiology, vol 383, pp.319–325, 2015. [Accessed 25th Feb. 2019].

[5] B. Byl, M. Süncksen, and M. Teistler, "A serious virtual reality game to train spatial cognition for medical ultrasound imaging," 2018 IEEE 6th International Conference on Serious Games and Applications for Health, SeGAH 2018, pp.1–4, 2018. [Accessed 19th Feb. 2019]

[6] C. K. Lam, K. Sundaraj, and M. N. Sulaiman, "Computer-based virtual reality simulator for phacoemulsification cataract surgery training," Virtual Reality, vol 184, pp.281–293, 2014. [Accessed 18th Feb. 2019].

[7] L. Li, et al, "Application of virtual reality technology in clinical medicine," American journal of translational research, [online] vol 99, pp.3867–3880. Available at: http://www.ncbi.nlm.nih.gov/pubmed/28979666, 2017. [Accessed 19th Feb. 2019].

[8] M. Süncksen, et al, "Gamification and virtual reality for teaching mobile x-ray imaging," 2018 IEEE 6th International Conference on Serious Games and Applications for Health, SeGAH 2018, pp.1–7, 2018. [Accessed 19th Feb. 2019].

[9] K. Yang and J. Jie, J, "The Designing of Training Simulation System Based on Unity 3D," In: 2011 Fourth International Conference on Intelligent Computation Technology and Automation. [online] IEEE, pp.976–978. Available at: http://ieeexplore.ieee.org/document/5750762/, 2011. [Accessed 30 May 2019].

[10] M. Eichelberg, et al, "Ten years of medical imaging standardization and prototypical implementation: the DICOM standard and the OFFIS DICOM toolkit (DCMTK)," Proc.SPIE, 5371. Retrieved from https://doi.org/10.1117/12.534853 [Accessed: 29 May. 2019]

[11] J. Egger, et al, "HTC Vive MeVisLab integration via OpenVR for medical applications," PLOS ONE, [online] 123, p.e0173972. Available at: https://dx.plos.org/10.1371/journal.pone.0173972 [Accessed 30 May 2019].

[12] C. M. Harrington, et al, "Development and evaluation of a trauma decision-making simulator in Oculus virtual reality," American Journal of Surgery, [online] vol 2151, pp.42–47. Available at: https://doi.org/10.1016/j.amjsurg.2017.02.011. [Accessed 18th Feb. 2019].

[13] J. Kim, C. Y. L. Chung, S. Nakamura, S. Palmisano, and S. K. Khuu, "The Oculus Rift: a cost-effective tool for studying visual-vestibular interactions in self-motion perception," Frontiers in Psychology, [online] vol 6, p.248. Available at:

http://journal.frontiersin.org/Article/10.3389/fpsyg.2015.00248/abstract [Accessed 30 May 2019].

[14] M. Schrepp, et al, “Design and evaluation of a short version of the user experience questionnaire (UEQ-S),” IJIMAI - International Journal of Interactive Multimedia and Artificial Intelligence, vol 3, pp.103-108, 2017. [Accessed 29th May. 2019].

 ISBN: 978-1-61208-724-5