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Use of Virtual Reality for Training on Procedures in an Intensive Care Unit during the COVID-19 Pandemic

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Abstract

The COVID-19 pandemic has underscored the importance of awareness and preparedness on the part of medical personnel. Virtual reality (VR) may be viewed as a useful tool in enabling knowledge and ability of medical practitioners in protecting themselves during the pandemic. This research describes the details of a VR application developed to train healthcare personnel in an intensive care unit (ICU) environment on some of the critical procedures related to COVID-19 patients. We discuss design considerations of VR for healthcare training as well as a process of selecting, based on expert opinion, key ICU training modules. The process of creating a 3D model of the ICU is outlined, and the major components and the use of the VR application are discussed. We find that a practical VR training program should apply a suitable VR platform and simulation techniques, while placing emphasis on addressing emerging problems and needs of healthcare personnel during the pandemic.

Keywords: Virtual reality; COVID-19 pandemic; preparedness; healthcare; ICU

1. Introduction

The novel Coronavirus SARS-CoV-2, first reported in China towards the end of 2019, brought about the declaration of the COVID-19 pandemic by the World Health Organization on March 11, 2020 (Spinelli and Pellino, 2020). This ongoing pandemic has caused enormous challenges for healthcare professionals and managers in hospitals and medical centers, calling for relevant and timely solutions. Simulation models are essential technologies that can serve as "virtual policy laboratories" for disaster and emergency managers (Lee et al., 2012). Simulation-based learning has proven to be an essential method in developing effective training programs (Dubé et al., 2020). Amongst various simulation techniques, VR technology is a helpful method for implementing a pandemic training program when physical interactions are deemed unsafe.

The main objective of this study is to design a learning platform using virtual reality (VR) technology for training medical personnel on critical ICU procedures involving COVID-19 positive patients. This research seeks to provide health care providers with some insights into the benefits of VR technology for training of health care professionals and inspire scientists/engineers to explore new aspects of application design for pandemic planning.

2. Background and literature review

2.1. Virtual reality and learning platforms

Cipresso et al. (2018), in a recent literature review, traced the concept of VR to the mid-1960s – "a window through which a user perceives the virtual world as if it looked, felt, sounded real and in which the user could act realistically" (Sutherland, 1965). Sherman and Craig (2019), while emphasizing the idea that VR is actually a medium, identify five key elements of a VR experience: the virtual world, immersion (physical and mental), interactivity, and the people on the creating and receiving sides of the medium. Features of a VR technology would fall into two main categories: (a) physical and (b) psychological. The physical content of a virtual environment can be viewed in terms of (i) the simulated environment; (ii) objects in the virtual environment that the user can observe and manipulate; (iii) user interface (UI) elements such as virtual buttons and menus; (iv) intermediaries such as avatars and representations of users' bodies (Mihelj et al., 2014). In terms of psychological aspects of a virtual experience, Sherman and Craig (2019) stress that the concept of presence is essential to understanding virtual reality. In this connection, creating intermediary forms such as avatars can be helpful (Aebersold et al., 2012; Steed et al., 2016; Heidicker et al., 2017).

Kurniawan et al. (2019) reported on four purposes of using VR in training programs as identified in the literature:

1. Engaging the participants by providing an interesting learning environment and materials;
2. Motivating and supporting the learners;
3. Enhancing the quality of the learning experience; and
4. Improving participants' achievement by focusing on learning outcomes.

Benefits and limitations of immersive technologies (VR and augmented reality) for education are identified by Häfner (2020). Among the benefits of immersive technologies cited are:

1. Enhancing learning outcomes;
2. Increasing motivation and concentration;
3. Fostering soft skills (e.g., problem-solving, decision making, teamwork, management, and leadership competencies);
4. Safety and health protection;
5. Saving time and costs;
6. Adapting to individual and special needs; and
7. Facilitating teaching (e.g., through elimination of preparation and follow-up activities or through automated learner evaluation).

McGrath et al. (2018) reviewed the main characteristics of a virtual training platform and identified various design elements that should be applied, including: (i) situated learning by immersing trainees in an actual work environment, (ii) debriefing and focusing on critical analysis, (iii) navigation and planning for users' movements, (iv) accurate visual representation, (v) stimulus variability and cueing items in the medical settings, (vi)prompts to progress through the learning activities, and (vii) collaborative participation of the users.

2.2. COVID-19 training for healthcare personnel

Because of the fast spread of COVID-19, hospitals have been rapidly becoming hot zones for treatment, and health care workers have been at increased risk (Brindle & Gawande, 2020). During a pandemic, implementing training courses and emergency drills and exercises would be beneficial in raising nurses' and other healthcare workers' awareness about disaster readiness and post-disaster response measures (Al Khalaileh et al., 2012; Rega and Fink, 2014).

Hsu et al. (2013) point out that an effective training program is a cornerstone for improving disaster preparedness and response of healthcare personnel. For example, medical staff must be trained on proper donning and doffing of personal protective equipment (PPE) in order to stay safe against COVID-19 (Wong et al., 2020). Due to the high mental pressure caused by the COVID-19 pandemic, Heath et al. (2020) note that implementing training programs and education sessions among healthcare workers is truly important not only for protecting against infection but also for mitigating the risk of psychological distress and building resilience amongst medical responders. Lessons learned from the COVID-19 pandemic have revealed that significant attention needs to be given to the preparedness of the healthcare system by investing in proper training and practice programs (Oraebosi et al., 2020).

2.3. Virtual reality and COVID-19

VR is a beneficial technology for pandemic training. VR provides an alternative affordable, low cost, low risk and low anxiety learning environment (Kardong-Edgren et al., 2019; Plotzky et al., 2020). It provides contactless training using virtual guidance and feedback which makes it an ideal method for education and interaction during a pandemic (Plotzky et al., 2021; Meng et al., 2020; Hussein and Nätterdal, 2015; Hsu et al., 2013; Willaert et al., 2012). In addition, VR adds convenience by increasing the ability to distribute simulations widely with lower costs (McGrath et al., 2018). Moreover, VR can be used for learning complex medical and health care procedures by allowing health care professional to improve their skills by unrestricted repetition (Marescaux et al., 1998). As Dunne & McDonald (2010) explained, while such training platforms increase timeliness and efficiency, they also facilitate high-quality and updated experience-based learning programs.

In terms of COVID-19, VR applications can play significant roles given that close physical interactions are risky and not recommended. As Remtulla (2020) noted, the challenges posed by COVID-19 is a turning point for VR technology, and it can help digitally reconstruct and simulate clinical environments. VR simplifies remote work (Wang et al., 2020), facilitates cognitive rehabilitation (Mantovani et al., 2020), and helps in complex operations and physical recovery (Singh et al., 2020). It also offers a suitable environment for communicating between patients and medical professionals to reduce the psychological effects of isolation (Manto et al., 2020). As noted by De Ponti et al. (2020), VR helps develop simulation-based training platforms for medical personnel in COVID-19 when in-hospital training is not possible.

The content of a training program, of course, should respond to trainees' expectations. With COVID-19 and the unique challenges of social distancing rules, developing a proper educational program cannot be achieved without understanding learners' needs, expectations, and emotional challenges during the pandemic (Baran and AlZoubi, 2020; Darling-Hammond and Hyler, 2020).

3. Conceptual model of design elements

In this section we develop a conceptual framework to present primary considerations and design elements of creating a VR application for pandemic training. Such framework helps to have an overall picture of the concepts relevant to the study and their relationships (Leshem & Trafford, 2007). We outlined critical points from the literature review and identified relevant key notions to develop the conceptual design framework (Figure 1). As the model presents, there are two primary considerations for developing a VR application, including physical and psychological elements. While various studies about the attributes and contents of a practical VR platform present different descriptions, they all indicate that VR applications consist of physical and psychological aspects.

In this work, we focus on physical characteristics provided by Mihelj et al. (2014), such as virtual environment, object, UI elements, and intermediaries. For the psychological aspect, we emphasized the virtual experience elements presented by Li et al. (2001), such as active process, presence, involvement, affordance, and enjoyment. In addition, there are critical design elements for developing a usable VR training platform in time of a pandemic following the main goals and objectives of the public health measures. In this regard, we should address specific considerations to create a VR-ICU application for healthcare personnel during the COVID-19, emphasizing healthcare personnel's need (Baran & AlZoubi, 2020; Darling-Hammond & Hyler, 2020), responding to emerging situations, navigation, debriefing and delivering feedback to users, situated learning, and accurate visual representations (McGrath et al., 2018).

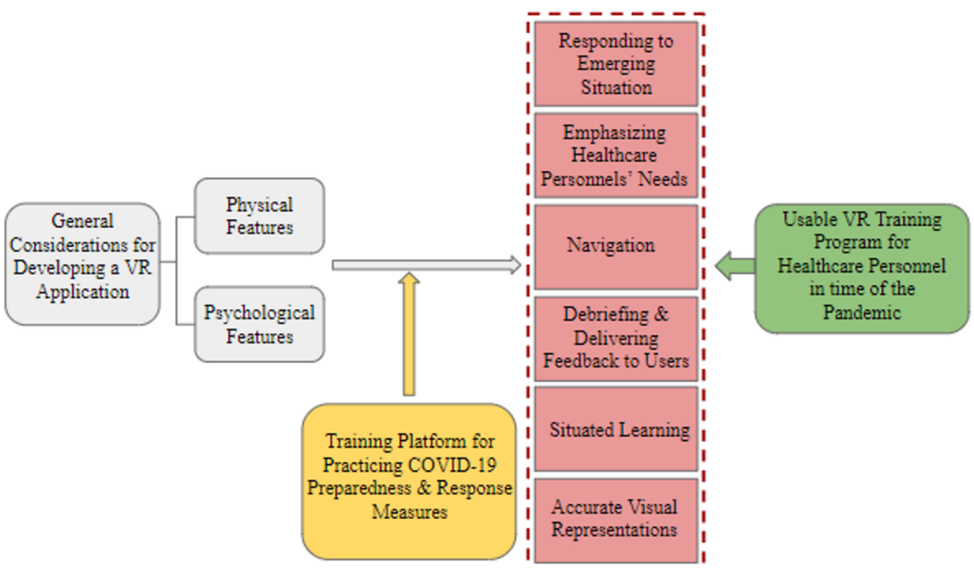

Figure 1. Conceptual framework: main considerations for designing a VR training application for medical responders in time of COVID-19

4. Methodology

4.1. System Architecture

Creating a system for supporting a virtual environment in VR applications is a multidimensional challenge and requires diverse areas of expertise (Gutierrez et al., 2008). Given the interactive nature of VR systems and the primary purpose of the current study, we developed a system architecture (Figure 2) to describe the main components of our system. As the model shows, the VR-ICU application has three main layers. The data layer presents the basic information needed for developing the training topics, learning contents, and simulation process. VR framework indicates how 3D models and medical activity simulations are performed based on the findings from the data layer and specific design considerations. In addition, it shows the 3D software and tools used in the design process. Lastly, as the output layer shows, a VR device is applied to deploy the VR-ICU application and make it available for health care providers. [Note that this model is inspired by Architecture of the Flood Action VR framework proposed by Sermet & Demir (2019).]

4.2. Data collection for modeling and simulation

One of the critical steps to develop the VR-ICU training application was to gather information and data related to COVID-19 preventive and response measures. This information was used for designing the training program and helped to simulate medical activities accurately based on real-time environment. The initial step of the application development process was to identify critical ICU procedures related to COVID-19. Accordingly, an internal expert opinion survey questionnaire was conducted among nine medical experts of the Toronto General Hospital (TGH) to seek their opinion on which medical procedures are the most important for COVID-19 training. In this regard, the research team produced a list of ICU procedures related to COVID-19 and six criteria to assess them. The survey aimed to rank these procedures based on the criteria to prioritize the medical procedures for this study based on expert knowledge.

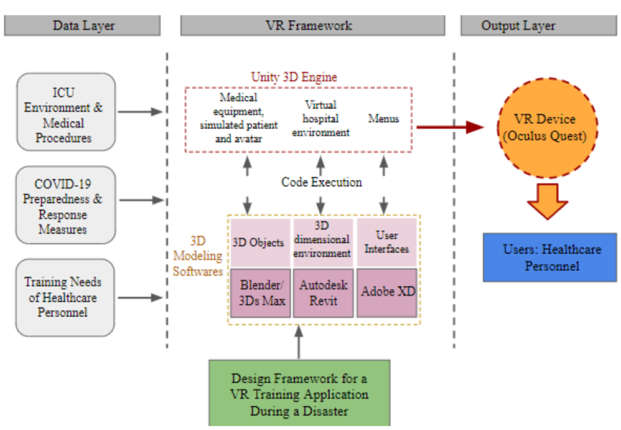

Figure 2. System architecture

There were two steps for evaluating medical experts' opinions: (1) they were asked to compare items of the criteria list; and (2) they were asked to value the importance of each criterion for each ICU activity. In order to analyze the data gathered by questionnaire, a fuzzy analytical hierarchy process (AHP) approach was applied (Vahidnia et al., 2008). Results showed that procedures related to (i) donning and doffing PPE and (ii) respiratory supports are the most critical measures in the time of COVID-19 (Asgary and Tofighi, 2021). Accordingly, this information was used as a basic scenario for the VR-ICU training application. We decided to simulate a process in which healthcare personnel could learn and practice the proper use of protective equipment and the intubation of COVID-19 patients as the respiratory support.

Furthermore, we needed to study the hospital environment, medical procedures, and equipment for visualization and 3D modeling. Respectively, we asked several medical personnel of the TGH to join the design team. ICU ward floor plan, video footages and pictures were used to create the 3D model of the ICU. The ICU floor plan presented the overall structure of the building, ICU rooms' placements. Pictures and videos also displayed interior space of the ICU rooms, various medical equipment, donning and doffing PPEs, and the intubation process of COVID-19 patients. It is also worth mentioning that we conducted several virtual group discussions with the medical team to explore their feedback and validate our design product and 3D models during the design process. At these online meetings, we ran and presented the VR-ICU application to the medical team, and they could share their thoughts and ideas about the model, simulated medical activities, and UI elements.

4.3. 3D modeling and programming

As Figure 2 presented, to create the 3D model of the hospital environment and medical equipment, we used 3D modeling software, including Autodesk Revit, Autodesk 3Ds Max, and Blender. Autodesk Revit was used for creating the initial 3D model of the hospital building, and it contributed to creating the model in an efficient and accurate manner. The model was developed based on the ICU section of the TGH. We used Autodesk 3Ds Max and Blender 3D modeling software to create objects such as the virtual patient, hospital furniture and protective equipment for our training application. Besides, some of these models were purchased from 3D model databases such as TurboSquid and were modified according to our learning scenarios and objectives.

According to the system architecture (Figure 2), after the 3D modeling process, the 3D objects and models were imported to the Unity 3D software for further development. For example, the hospital building was imported to Unity with a .fbx file extension, and more details and materials were added to simulate a proper ICU room (Figure 3). Unity is a powerful and convenient platform for making games and simulation purposes and consists of notation and logical reasoning for programming (Barros et al., 1994). As discussed by Jerald et al. (2014), it is a full-featured platform and provides a high-quality environment for creating interactive 3D content and can be combined with VR hardware to generate a VR application for consumers.

To simulate medical procedures, we needed to define and execute codes to assign tasks to each object. Microsoft C# language was used for programming. To assign code to objects, we added script components to the relevant objects (Figure 4).

4.4. Oculus Quest platform and user interface menus

After programming in the Unity engine, we used the Oculus Quest device to implement the virtual ICU and the interactive learning environment. Users can enter and connect with the virtual world by wearing the headset and using the hand controllers. Each item has several features and command buttons to help users run the device and interact with the environment. We used the Oculus Quest device because it is a convenient and efficient platform. Oculus Quest device is a wireless, fully stand-alone VR system that does not need to be connected to a high-graphic computer; therefore, it is accessible for all users (Wohlgenannt et al., 2020). It is also a scalable, portable, and easy-to-use platform for the VR experience. It also includes strong data center security and powerful account management to safeguard the device and software (Barnard, 2020).

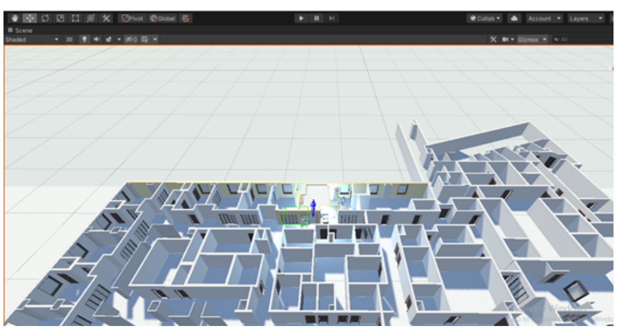

Figure 3. Toronto General Hospital ICU department 3D model in Unity

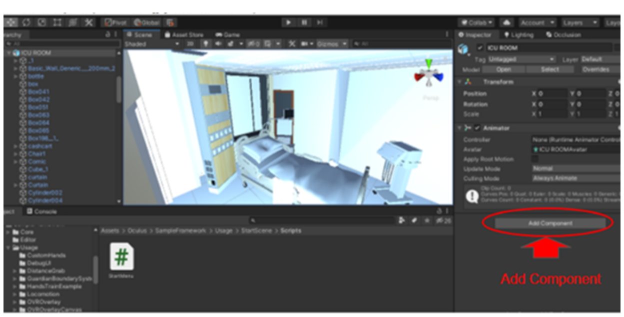

Figure 4. Assigning components to 3D medical models

One of the significant aspects of the ICU-VR training application is the design of menus and icons to facilitate user interaction in the environment and help trainees follow the learning process. In order to develop the menus in Unity, we first designed a prototype using the Adobe XD tool, and then implemented the model in Unity to launch it onto our project. Adobe XD helped us to design different wireframes of the training application menus. To implement the menus wireframes in Unity, we used the UI canvas. Buttons, images, icons, texts, and other components could be added to develop the menus based on the templates.

5. ICU VR application components

We defined our target audiences, learning objectives, training techniques and materials, and an evaluation process to determine if participants have successfully completed the program. We considered that the primary users of our ICU-VR training application are healthcare personnel who were dealing with COVID-19 patients in the ICU environment. Figure 5 shows a simulated COVID-19 patient in an ICU room in the ICU-VR application.

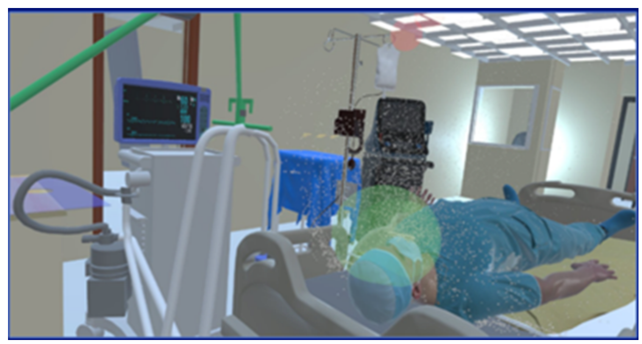

Figure 5. ICU Room and Simulated Patient in the VR Training Application

The purpose of our project was to prepare a safe platform for healthcare personnel to learn and practice critical ICU measures related to the COVID-19 patients, particularly:

1. Donning and doffing of PPEs; and
2. Intubation.

Participants could use the program by wearing the VR headsets and running the application. Additionally, a grading system was assigned to the training platform, and users can evaluate their performance by taking a quiz and checking their scores.

Because there is a very high risk of contamination during the doffing process, it is vital that medical personnel be aware of the safe way for removing PPEs to mitigate the exposure risk, as follows: (1) cleaning and sanitizing the gloves, and removing and discarding them into the medical waste bin; (2) sanitizing hands; (3) removing the gown; (4) washing and sanitizing hands; (5) removing face shield; (6) sanitizing hands; (7) removing the respirator mask; and (8) sanitizing hands.

For the intubation of COVID-19 patients, Orser (2020) suggested a process as follows: (1) donning PPE; (2) pre-checking the required items such as drugs, ventilator, and standard monitoring; (3) preparing necessary items for the intubation process; (4) confirming the correct position of the tracheal tube; (5) installing the ventilator and stabilizing the patient; (6) decontaminating all airway equipment; (7) doffing PPE; and (8) washing hands.

6. Discussion and conclusion

The main goal of this research was to examine how the VR simulation technique could be applied to develop a training program for pandemic preparedness and response in healthcare settings. To achieve this goal, we developed an ICU-VR training application for practicing COVID-19 protective measures, focusing specifically on two critical ICU procedures: (i) donning and doffing of PPEs and (ii) intubation of COVID-19 patients. To create an effective pandemic awareness platform for healthcare personnel, we needed to address various considerations during the design process. In particular, we needed to develop the application following the complex and unexpected situation of the COVID-19 pandemic, and to place emphasis on healthcare personnel needs and expectations. We have considered general features of a VR training platform to facilitate user interaction and increase user experience. These considerations could improve the quality of the training program leading to the enhancement of healthcare personnel's preparedness against the COVID-19 pandemic.

There were various challenges in conducting this study due to the COVID-19 pandemic and associated public health restrictions. These limitations included difficulty in obtaining healthcare personnel and professionals' feedback. As mentioned before, we tried to include medical experts' opinions in our work. However, because of social distancing rules and the busy schedule of healthcare workers during the pandemic, accessing nurses and medical experts was difficult. Therefore, we were unable to conduct more comprehensive and structured interviews of healthcare personnel, which could have helped to enhance the quality of our training application. As a result, our training sessions and learning content might need improvement in the future. Moreover, providing a high-quality VR environment highly depends upon the technical aspects, such as the resolution of the display device. There might be more advanced 3D modeling software and VR devices for producing a more realistic 3D environment.

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