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Use Of Virtual Reality Technology In Medical Training And Patient Rehabilitation

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USE OF VIRTUAL REALITY TECHNOLOGY IN MEDICAL TRAINING AND PATIENT REHABILITATION

A Thesis submitted in partial fulfilment of the

requirements for the degree of

Master of Science in Computer Engineering

by

SANKALP MISHRA

B.E., Visvesvaraya Technological University, 2016

2019

Wright State University

WRIGHT STATE UNIVERSITY

GRADUATE SCHOOL

May 2nd, 2019

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPER-VISION BY Sankalp Mishra ENTITLED Use Of Virtual Reality Technology In Medical Training And Patient Rehabilitation BE ACCEPTED IN PARTIAL FULFILL-MENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Computer Engineering.

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Abstract

Mishra, Sankalp. M.S.C.E., Department of Computer Science and Engineering, Wright State University, 2019. Use Of Virtual Reality Technology In Medical Training And Patient Rehabilitation.

Coaching patients to follow the rehabilitation routines correctly and timely after surgery is often a challenge due to the limited medical knowledge of patients and limited availability of clinicians. Similarly, it is also a challenge to train medical professionals with both the technical and communication skills required in their practices. The recent emergence of VR technologies shines the light on improving the current training practices. In this thesis research, I will look at the development and application of VR-based immersive training games for two particular cases: 1. Post hand surgery rehab; and, 2. Training for Social determinants of health (SDOH) for medical professionals.

Particularly, I have developed two training modules. One will help patients to carry out their rehabilitation independently without having to run around to different clinics after their surgery. Assessing, coaching, progress tracking and reporting can be effectively carried out by the artificial intelligence enabled virtual coaching module based on the evidence collected and produced through its sensory system.

The progress can be observed remotely by their doctor and therapists and further treatment recommendation can be provided accordingly. Secondly, I have developed an immersive VR game module that focuses on providing training for medical professionals on social determinants of health. It provides a first-person view immersive experience for the doctors to better understand their patients with significantly different social and economic backgrounds, leading to better healthcare quality for these patients.

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1. Introduction

In today's world, communication is the key factor in every field, whether it is military, education, medical etc. For each stream, conveying your thoughts and feelings is of the utmost importance. Technology has been a great help in doing so, today we have technologies like virtual reality (VR) and augmented reality (AR) that take your expression of thought to the next level. These technologies help you visualize all the things which were once only possible to convey using words or ppt presentation. By incorporating graphic elements into our largely text-driven communications, we can communicate more effectively. Continuously, studies have discovered more about the benefits of a visual medium.

The phrase virtual reality (VR) captures what the words themselves mean. Virtual is something which is non-existent, while the reality is our real environment. Combining these two gives you a virtually created environment in which, through technology, you will experience a real-world experience. It is basically like you are living in a parallel universe which has its own existence right alongside your real world.

The primary value of virtual reality is how it brings components of your physical presence into the manipulatable digital world as a perception of the real world. Not as a simple display of data, but through the integration of immersive sensations that are perceived as natural parts of an environment.

Because of its value, it is a very hot technology in today's market along with AI (artificial intelligence). Altogether this makes it a great technology for being used in training modules.

Fig 1: 3D visualization and Virtual reality in medical training. [1]

Fig 2: 3D visualization and Virtual reality in healthcare. [2]

Fig 1 and 2 shows two examples of how virtual reality can be of great use in training and education in medicine and healthcare. In Fig 1 the medical professor is with his student inside a virtual environment where he has an enlarged view of a medical object (patient's body) and he is guiding and explaining the medical concepts. While in Fig 2, a trainee surgeon is in an operation theater in a virtual simulator where he is practicing the surgery.
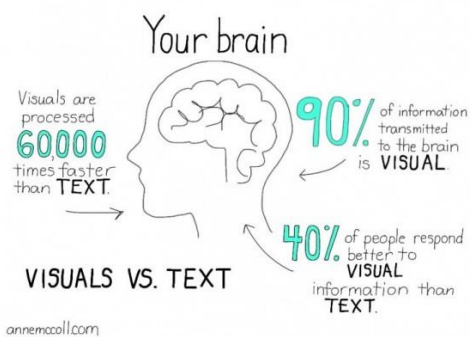
Fig 3: Text Vs Visuals.[3]

Clearly, learning from simply reading books and looking at videos can now be transformed into interactive modules where learning things comes to life and is much easier and more fun. In research studies, it has been shown that our mind reacts much better to visuals than words. Using VR technology allows us to have such a type of immersive training module that is more effective and efficient. This can apply to any kind of training like that of educational or professional, which we will talk more about in detail in the later chapter.

2. System Design

2.1 Case 1: Post Hand Surgery Patient Rehabilitation

As said before, after the surgery it becomes really difficult for the patient who has just undergone hand surgery to go out to appointments with their doctors and therapist and follow up on their rehabilitation toward recovery. Hence the idea of using virtual reality by creating an interactive and immersive medium is potentially a viable way of providing the coaching for patient's rehabilitation such that they can carry out them independently at home.

The training routine designed by Robert H. Jebsen and Neal Taylor are among the most widely used rehab exercises for the patient after hand surgeries. Small activities, such as grabbing and moving tiny objects like a cube or a sphere from a place to other are to be performed by the patient on a timely fashion. These activities are currently supervised, coached and assessed by the hand therapists. We believe these rehab activities can be created in a sensory system assisted virtual reality game for tracking, assessing, coaching and reporting.

In this research, we have used the Leap motion device for the hand and fingers tracking, which is capable of tracking patient's hand and finger movements using infrared sensors and effectively allows one to interact with virtual objects accurately.

(a) Leap Motion:

It is the Leap motion software and hardware that help brings our bare hands directly into virtual and augmented reality, thus effectively connecting between the real and virtual world. The leap controller is a small USB peripheral device which is designed as a human-computer interaction device that tracks hand and finger gestures and movements in real time.[4] From a hardware perspective, the heart of the device consists of two cameras and three infrared LEDs. They track infrared light with a wavelength of 850 nanometers, which is outside the visible light spectrum.
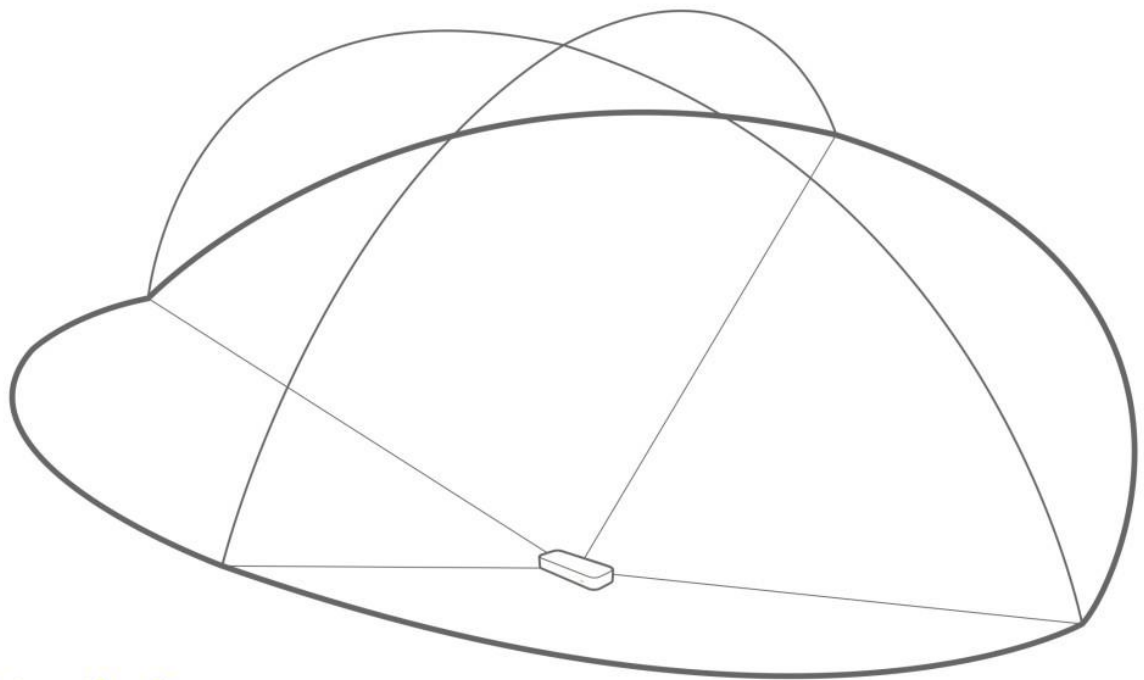
Interaction Area
2 feet above the controller, by 2 feet wide on each side
(150° angle), by 2 feet deep on each side (120° angle)

Fig 4: Shows interaction area for a Leap Motion device.[5]

It uses a wide-angle lens which lets the device interact in a space of eight cubic feet taking the space of an inverted pyramid, which is the intersection of the binocular cameras' field of view.

Software wise it uses advanced mathematical algorithms to convert the captured images into 3D representation using the ambient environment lighting and compensating background objects. Its tracking layer interprets the 3D data using filtering techniques to smoothly coherence the data. The data feeds are processed to results in frames, snapshots containing all the data. This tracking data works better when leap controller has a clear and high-contrast view of objects.[6]

Leap has a smooth hand and finger tracking which will give you a more realistic interaction than ever previously imagined. It produces an accurate and realistic experience with much needed stability and reliability, even against complex backgrounds and extreme lighting conditions. Thus, Leap motion technology is now being embedded into mobile AR/VR headsets such as Oculus Rift, HTC Vive and many cross-platform windows VR headsets. Using leap motion in these headsets gives you a 180°X180° tracking that allows you to have unprecedented freedom and range, while produces high accuracy at low latency which is critical to natural and reliable interactions. As a result, we have decided to use this off-the-shelf sensory technology for our system design, in order to make the AR experience more versatile and natural.

(b) Virtual Coaching:

The ultimate objective is to use the virtual reality technology to enable evidence-based training sessions for post hand surgery rehabilitation. Our immediate goal of this research is to showcase the true power and potential of VR-based coaching tools which can revolutionize teaching and learning and uplift the rehab process as these virtual sessions will be very immersive as if training in the real world by professional expert therapists.

These virtual tools allow you to do training on your own time schedule and eliminate the restrictions due to the availability of experts and locations. For a patient who has just undergone a hand surgery, going to the clinic will need assistance from others and consumes time for both, while using virtual training makes you completely independent.
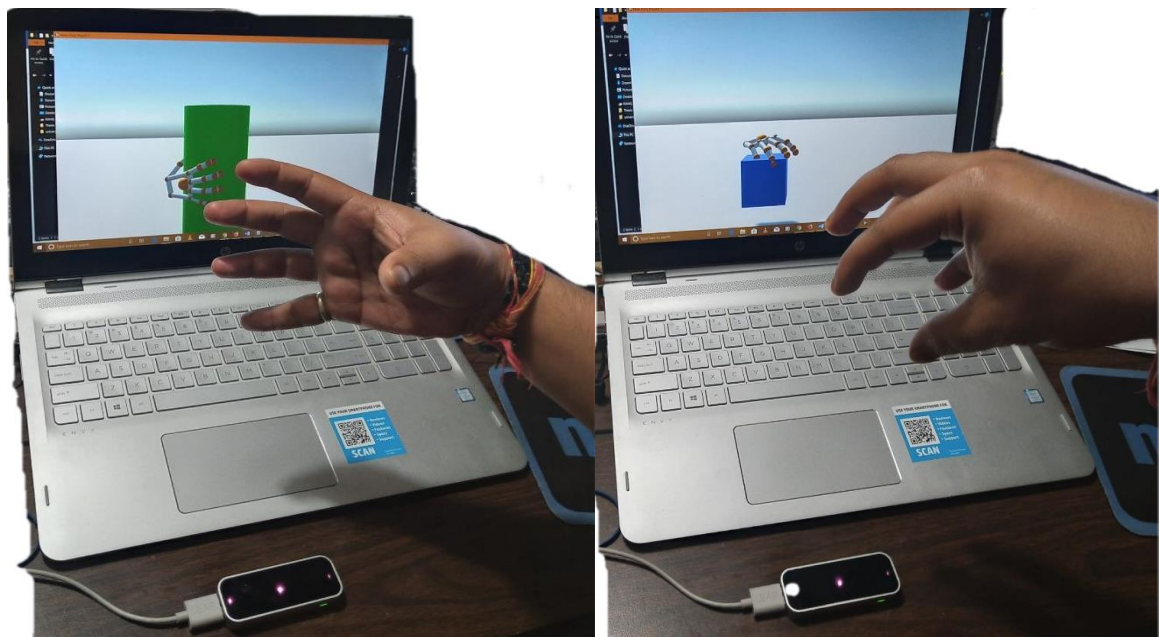

Fig 5: Shows real hand interaction with the game object in the PC using Leap Motion Device.

We have implemented virtual routines that are recommended by the hand surgeons as shown in Fig 5. The most commonly used function test done in clinics is Jebsen Taylor's hand function test. Figure 5 demonstrates selected function test that a patient can practice and perform, activities such as moving the blocks or grabbing the cylinder and performance of the patient can be noted either in terms of photos or video and forwarded to the doctor.

(c) Assessment:

For any coaching and training module to be effective, it is very important to have an accurate and continuous assessment, as these assessments provide evidence which helps continued improvement and adjustment of rehab routines. In the medical field, doctors and therapist take and use these assessments to help in making a note of the patient's progress and improving the patient's rehab treatment. For instance, as the patient conditions progress, he/she may switch to a smaller cylinder in grabbling exercise. This is usually recommended by the therapist based on timely progress assessment. In our system, this can be effectively carried out by the artificial intelligence enabled virtual coaching module based on the evidence collected and produced through the Leap sensory system. For illustration purpose, we will show the feedback on the progress of patient's hand motion capabilities using the visualization tool that comes with Leap motion in Figs. 6 and 7.
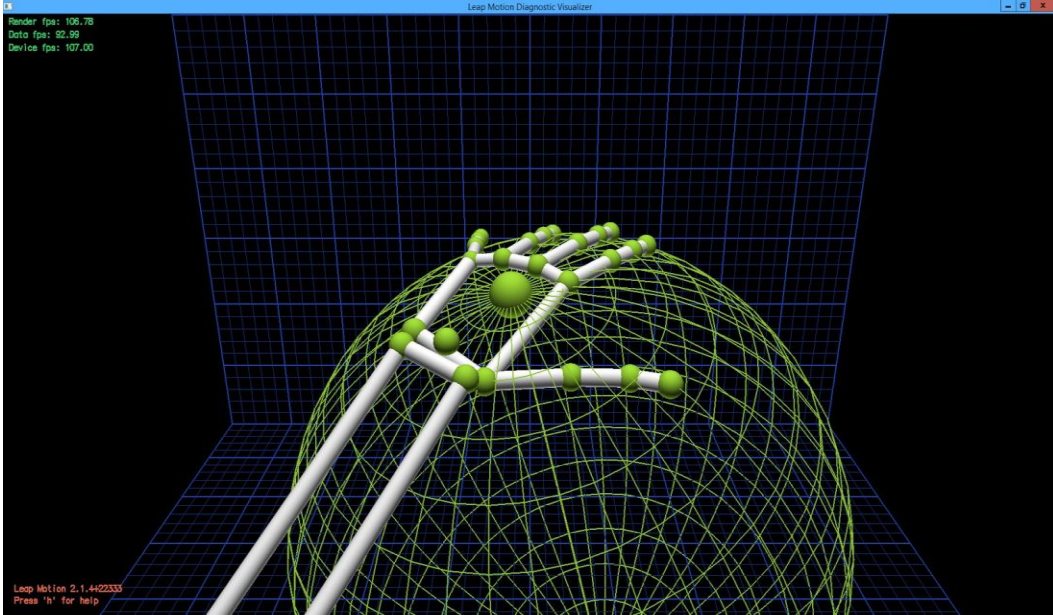
Fig 6: Shows an open hand sphere in Leap motion visualizer.[7]
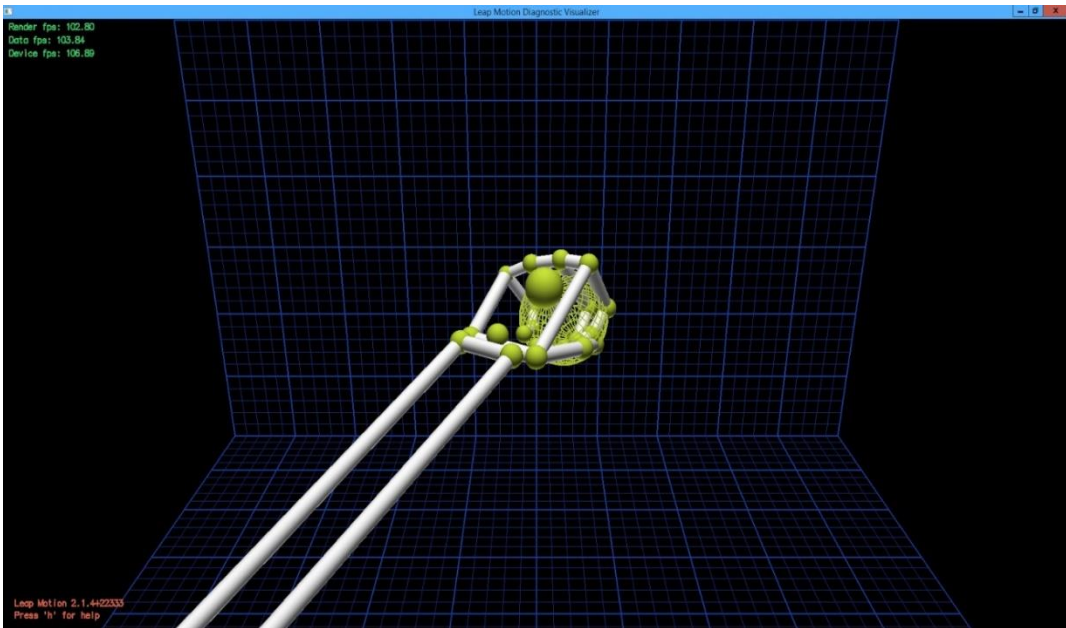

Fig 7: Shows a close hand sphere in Leap motion visualizer.[5]

Fig 6 and 7 show examples of how we can use the virtualize tool in order to check the progress made by the patient who is undergoing virtual rehab training/coaching. The figure shows how the sphere size changes with the movement of the patient fist and hence can be used for the assessment based on how much the patient is able to grasp the virtual object in the training game.

2.2 Case 2 – Social Determinants of Health (SDOH) in Medical Training

Next, we want to showcase another application of using VR immersive experience in medical training that focuses on learning social determinants and health.

It is true that we cannot change anyone's history or the past experiences or past situations, but as medical professionals, it is really important to acknowledge the role of SDOH and how these social determinants of health affect the development of an illness or become a reason for patient's adherence towards effective treatment. For diminishing these barriers, we have developed a virtual training module for medical professionals which will help and train them to understand the patient better in order to improve the treatment outcomes.

(a) Training design:

For training for SDOH, patient's past, i.e., previous life experience, is very important. Often seen in most of such training modules, past experience of a patient is either given in a text document or a small video clip which might not generate that much empathy for the patient or may not change the medical professionals perspective as they are also facing stress at work and often have to deal with a lot of patients.

Now, by using the immersive virtual reality training module we have the power to change the perspective of the medical professionals as we can teleport them to a virtual environment where they can see and experience first-hand, in other terms, they can experience the situations or be in the situation as themselves, also known as first-person view. It changes the angle of approach for the medical professionals as they themselves will be in the environment and not just reading a story about someone. It will, for example, show them the struggle a patient goes through in order to make it to the clinic for their appointments.

This has a potentially huge impact with the patients who belong to different cultural background, e.g., refugees who are relocated to the United States from abroad.

Fig 8: Shows difference between First person view and third person view. [9] [6]

Fig 8 gives an example showing the difference between first- and third-person view. In the first image, the doctor experiences the patient's reaction first hand in a first person view rather than looking from the angle of the doctor standing behind.

In the second image, the doctor's interaction is shown with the kid from the third person view which is like looking at both doctor and kid from a distance. The selection of point of views has an essential impact on the effectiveness of the immersive virtual training module as it affects directly on the trainee on how he/she views the situation and reacts to it. It is like reacting to the situation when you yourself are in it versus the view where you get to just look at others reaction and not actually face the other individual and situation.

(b) Adaptation for device platform:

1. **Models and device utilization**

Utilizing newer technology such as Virtual Reality in creating training application is not without challenges. At one side it gives us the potential to create immersive training modules, but at the same time it comes with a con: it utilizes significantly more computing resource, such as memory and graphics processing. Moreover, if you want to reach a large population and make it more independent in terms of location and convenience, we face a major challenge as we need to make sure that your application uses less graphics and memory so that the application runs on minimal requirements and supports a larger number of devices.

To overcome the challenge faced to keep the graphics and memory utilization to a minimum while giving the same immersive experience with sufficient graphical fidelity, we will have to optimize the model graphics based on the deployed device platform. One way to do that is to reduce the detailing in the models and reduce the number of building polygons in the models and in all the virtual environment objects.

Another way to deal with the challenge is to use a feature called Occlusion Culling provided by the Unity game engine. It basically uses your viewing angle of the camera in the game to render the objects in the training application. This feature allows you to reduce the utilization of the graphics by rendering the objects when you see them or are in the camera's viewing space.
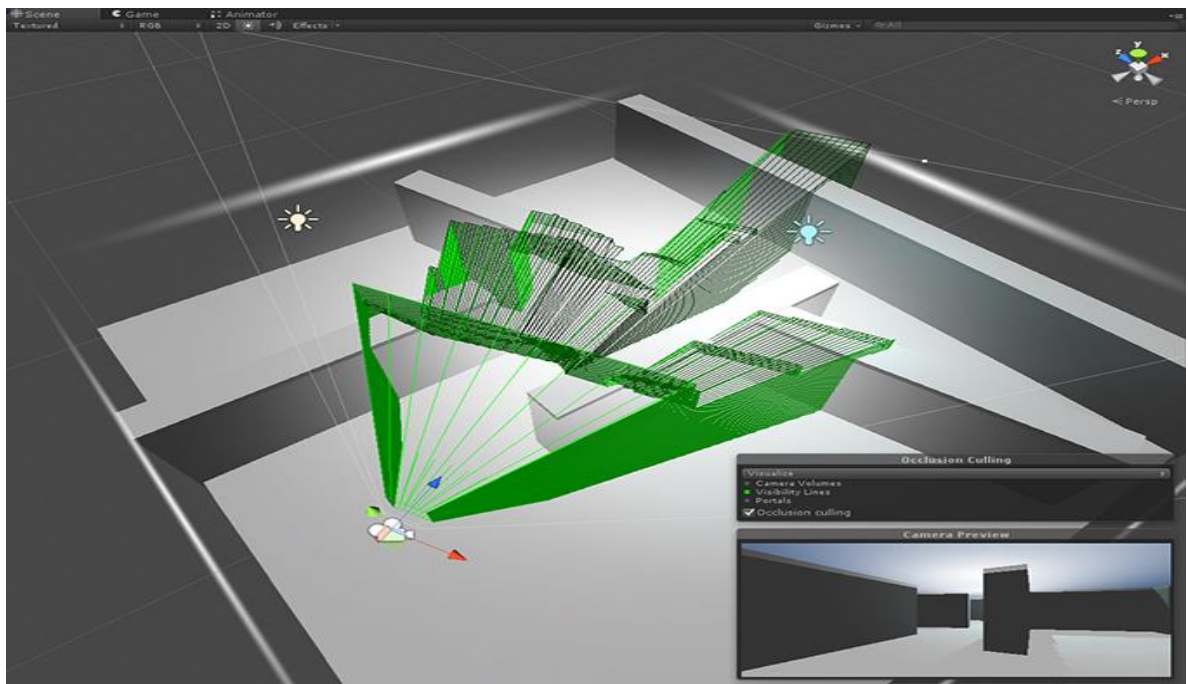

Fig 9: Showing rendering of objects using Occlusion Culling.[10]

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Fig 10: Reduction of polygons in the model and all its components.[11]

The above figure shows examples of reducing the graphics using the feature of Occlusion Culling and by reducing the polygons in a model. Fig 9 shows the rendering of objects within the range of the camera in the application while the other objects are hidden hence using the less graphics memory. Fig 10 shows the reduction of number of polygons while still maintaining the detailing in the model. This is also a great way of reducing the graphics memory utilization.

2. Emulated attention tracking

In any simulation is it really important to keep the trainee focused. It is similar to what a teacher needs to do while students are in class, the teacher needs to have the attention of the students while teaching any concept.

Thus, another challenge we faced in the system design while creating such immersive training application was to have the attention of the trainee and make them focus on the details that the virtual training aims for. Since there is no physical trainer present to make the trainee focus on the necessary details that the trainee should notice as the application has a virtual environment. In this research, we explore the use of the blur effects to get the attention of the player/trainee which help provide clear visual cue to the user about where he/she need to focus on.
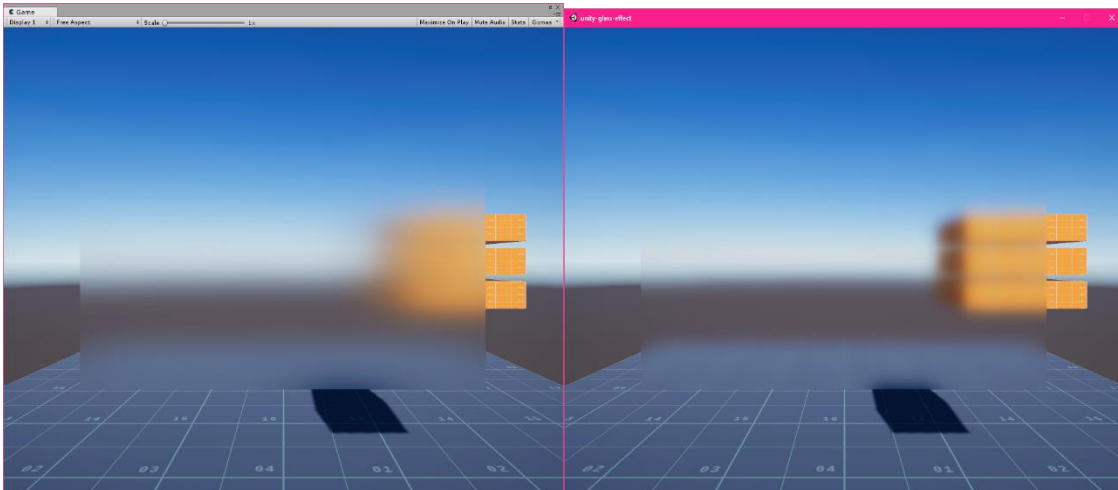

Fig 11: Shows the blur effect in an application. [12]

Fig 12: Shows the blur effect in an application emphasizing on where to pay attention. [13]

Fig 11 and 12 provide illustrations on how we can use the blur effects to get the attention of the player/trainee. Figure 2.8 shows the blur effect in a scene blurring the middle sight of the application screen, while Figure 2.9 blurs the background and makes the model in the application clear in order for the player to pay more attention to the model than the background activities.

3. Interactivity

Another key factor in creating an immersive virtual training application is that the experience for the trainee should be as close to real situations as possible. Thus, in a virtual environment, it's important that we make it more interactive and realistic through multiple modalities: expressions, voices, visuals, gestures, movements and etc.

Having the virtual models produce the voices and the animated movement close to real life surroundings can help create a realistic response from the trainee.

Fig 13: Shows different facial expression close to a real person's expressions.[14]

Fig 13 gives us a better understanding on how a virtual model can help in creating a generic simulated response from the trainee as the expressions produced by the virtual model are as realistic as done by any real human being. It shows a mapping of expressions of the real human being with that of the virtual model, which helps in maintaining the virtual environment to be as realistic as possible.

3. Prototype Development and Validation

In this chapter, we first describe the process to develop the prototype systems for the two cases of thesis research. Then, we will describe the Beta test carried out to validate the usability of our training/coaching tools.

For the post-surgery rehab case of this thesis, we are using Leap motion as the sensory technology and Unity as a platform to create the application. We have implemented selected common function test and practices done in clinics as recommended as Jebsen Taylor's hand function test. In these function tests and practices, patients perform activities such as moving the blocks or flipping the cards and the time is noted and performance of the patient is also noted. The activity will be performed by the patient using the VR application created using Unity in front of any PC with leap motion device attached and can send the progress of his activities to the doctor.

For the second case of this thesis we are using Reallusion developing tools, such as IClone, to create realistic characters with similar facial expressions to normal human beings in order to maximize the immersive experience, and then Unity is the platform to use such plugins and prefabs for creating the game.

3.1 Unity-3D:

For developing the interactive training/coaching game, we are using a very strong gaming platform, which is UNITY-3D.

This platform is very much capable of developing such interactive applications. Unity has the capabilities that helps one to create games and interactive experiences in both 2D and 3D by scripting your logic and algorithm in C#. There are a bunch of unity plugins which you can directly use by just dragging and dropping. Also, it allows you to export and create such a good immersive experience on any platform, e.g., Android, iOS or PC Linux standalone.
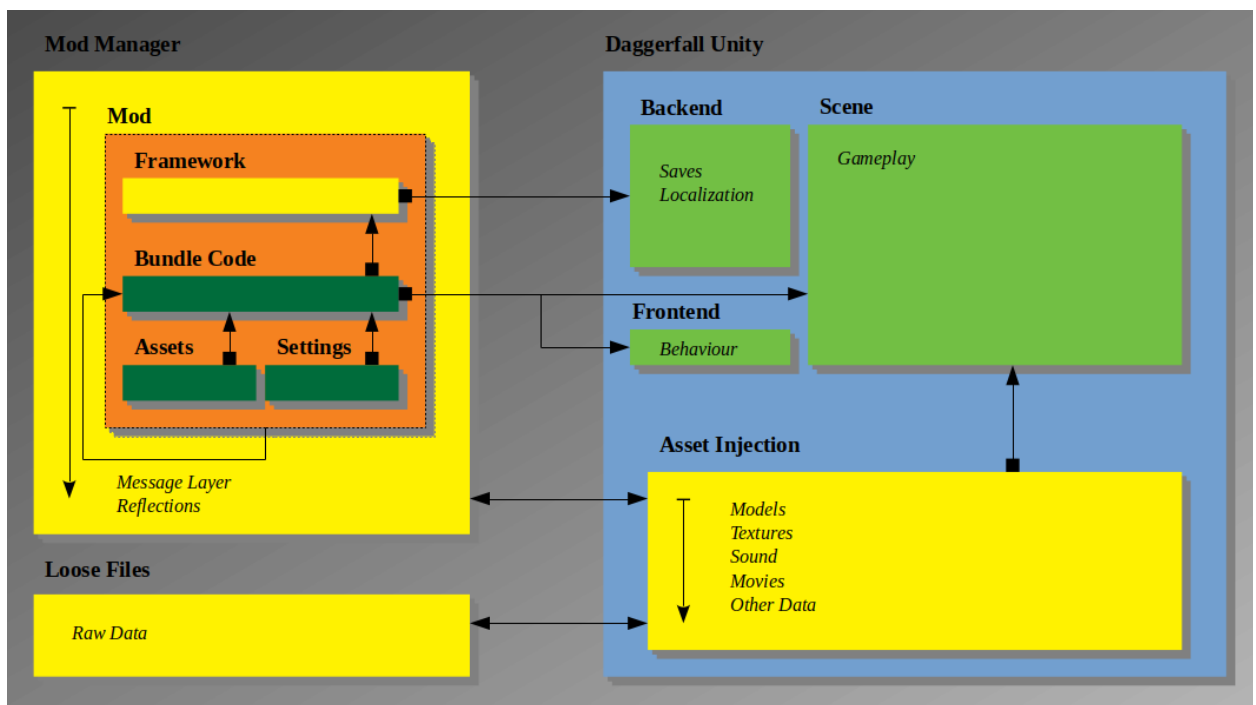

Fig 14: Insight of unity game engine.[15]

Fig 14 provides you with the insight of the unity game engine by giving the high-level structure of each building blocks that are used in the engine to create an application. It has different bundles of code and assets and the backend framework of the engine which are used to create different logics and algorithm required by an application. The scene is the

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gameplay of the application where you can see the working of the application and can control the frontend behavior of the application using all the assets which can be models, textures/materials, audio-video clips or any other data.

3.2 Iclone:

Reallusion softwares provides the features to create different sets of animations and models required by the training modules. It helps us in creating realistic expression of models close to real human beings. It allows us to create such game objects and export or import to the game engines such as Unity-3D. This software is so powerful that it can produce different animated characters, can help doing any prop conversion if required while creating the training module, also can produce realistic motions for the models along with the facial setup.
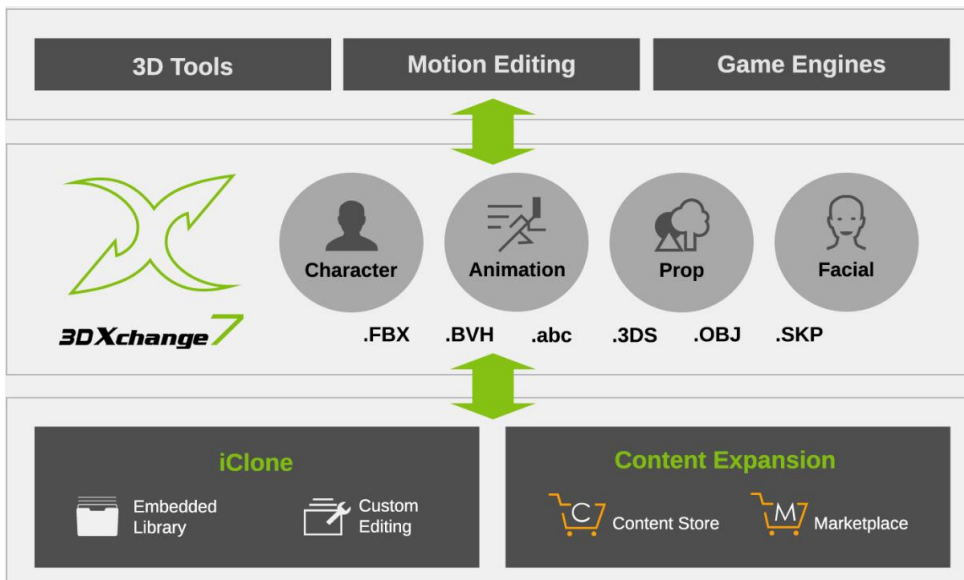

Fig 15: It shows the features of IClone software and its supported plugins.[8]

3.3 Validation

It's really important for any application developer to test out the design and make corrections to them before it goes out into the market. Since this virtual training module was for medical professionals, we did 3 beta testing with a group of medical students and improvised our training application based on the feedbacks and problems faced by the medical students.

During our beta testing, we got numerous valuable feedbacks stating certain problems in the training applications. Since it's a virtual training module some students got confused as there was no proper instruction page to help them navigate through the application and on how to use all the features provided in the application for training to make it an immersive experience.
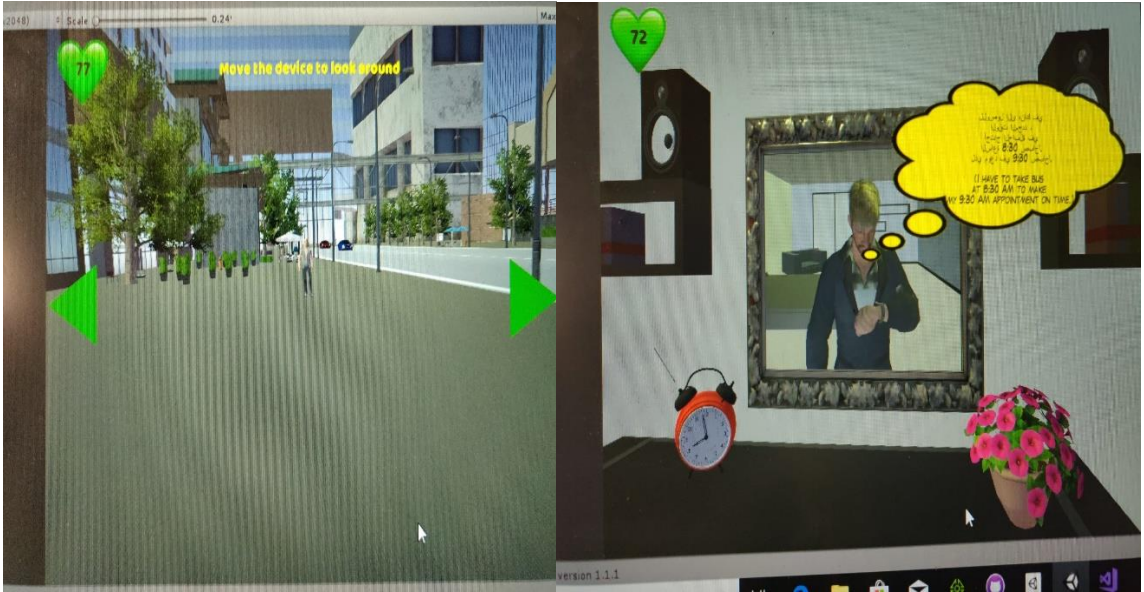
Fig 16: Instructions and proper interaction to understand the story of the patient.

For example. Fig 16 was the correction done to make the trainee get a good hold of the application. Also, there were certain gaps in terms of proper communication through the application which was slightly confusing. To eliminate we provided thinking dialogue boxes which made the scenario much clear.
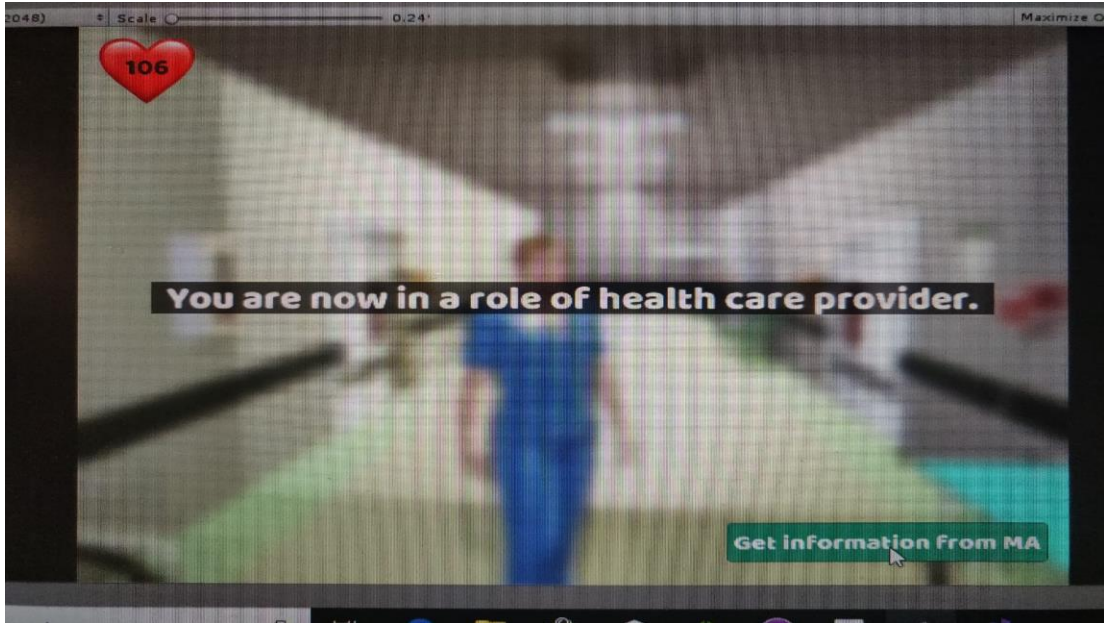
Fig 17: Making the transition clear when switching between the different character.

Another problem that the medical student indicated was in the training application there were places where the transition between the point of views was not very clear. Hence, as shown in Fig 17, we added more details at all the scenario within the application which would let trainee know how and what role the trainee is currently in.
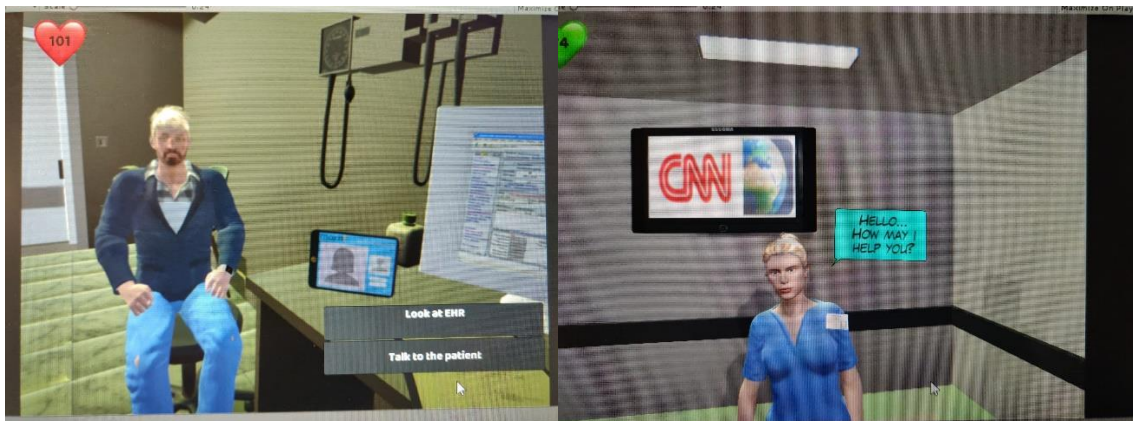

Fig 18: Shows the interaction of patient, receptionist and doctor.

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In the final beta testing, we were able to successfully test out the interaction between the patient and the doctor. Also, we made sure that the interaction of patients before reaching the clinic and the troubles faced by patient are noticed by the trainee. We were able to notice the changes in the feedback from the beta testing about the virtual training application were improving. Also, many students felt that playing through the game really help improve their understanding about the effects of SDOH for their future encounter with such patients.

4. Conclusion and Future Works

In this thesis, I have explored the use of VR-based immersive training/coaching games in medical practices. Particularly, I have developed two training modules for: 1.) Coaching for post hand surgery rehab; and, 2.) Training for Social determinants of health (SDOH) for medical professionals.

Through system design and prototype development and validation, I have shown that VR-based technology can:

1. Help patients to carry out their rehabilitation independently. Assessing, coaching, progress tracking and reporting can be effectively carried out by the artificial intelligence enabled virtual coaching module based on the evidence collected and produced using Leap sensory system.

2. Provide effective training for medical professionals on social determinants of health. Through the first-person view immersive experience, doctors can better understand their patients with significantly different social and economic backgrounds, potentially leading to better healthcare quality for these patients.

Future development and validation in these applications could help make them ready for real-world deployment and distribution in the healthcare market.

1. For the post-surgery rehab coaching case, it will be beneficial to the patients to have an immersive communication and distributed collaboration platform integrated inside the application so that the patient can work with therapist and doctors or other patients to stay engaged as a team in distance in a supportive environment.

2. For the SDOH case, we can harness the latest advances in machine learning, such as speech recognition, natural language processing, image processing, to support more natural interactions between trainees and patient in an augmented reality environment, through voice, expression, gesture and movement, which potentially make the interaction experience more immersive.

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