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There is a strong demand for the use of virtual reality (VR) in healthcare, particularly in surgical procedures. This thesis motivates this need and presents the design and prototype implementation of Virtual Reality Remote Surgery Guidance (VRSG). This tool allows the live connection of a remote specialist surgeon to provide live guidance on surgeries at remote locations, particularly in low-and-middle-income countries (LMICs). VRSG also supports an educational experience by offering the ability for users to follow recorded surgeries for practice and review purposes. The main contributions of this work are the feasibility demonstration of the proposed VRSG system through a rigorous 3D user interface design process, the implementation of a prototype VR application that realizes the proposed design, and the usability evaluation that offers evidence towards the effectiveness of the proposed tool. VRSG's design and implementation can be summarized as follows.

The design of an interactive, immersive interface of the remote surgeon connected to the surgery room via an immersive 360º video stream mounted in a strategic location inside the surgery room. Two additional non-immersive streams were added to the interface to show a detailed view of the surgery site and monitor with patient's vital signs. The remote surgeon offers guidance to the local surgery team by performing annotations directly onto the detailed views, which are transmitted to the surgery room. To simulate the surgery room interface, we created a desktop application that displays the remote surgeon's audio, current point of view, and annotations. All the streaming videos can be saved on the local server in support of the educational element of VRSG. We performed a usability evaluation of VRSG with 6 participants to test the efficiency of the remote surgeon's user interface. Descriptive statistics show that

participants had an overall positive experience with the tool, and qualitative observations pointed to limitations that we discuss and address as recommendations for the evolution of the VRSG. Overall, this thesis achieved its goals through the design, implementation, and usability assessment of a tool to facilitate remote surgery guidance by experts.

REMOTE SURGERY GUIDANCE USING VIRTUAL REALITY

AND 360º VIDEO

by

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APPROVAL PAGE

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CHAPTER I: INTRODUCTION

Many developing countries worldwide lack access to emergency and surgical care, besides the shortage of professional doctors and surgeons. In African countries in 2007, there were approximately just 565 neurosurgeons, with an overall ratio of neurosurgeons to residents at 1:358000 (Fuller et al., 2016, p. 1). However, there are significant inequalities within Africa. For example, 485 out of the 565 neurosurgeons were concentrated in only a few countries, such as Egypt, Morocco, Algeria, Tunisia, and South Africa. In contrast, only 27 neurosurgeons were available in East Africa, across seven countries with a total population of 270 million, placing the ratio of neurosurgeons to residents at 1:10 million for neurosurgeons.

Additionally, many eastern African countries have no neurosurgeons (Fuller et al., 2016, p. 1). By contrast, the United States has a ratio of 1:65,580 neurosurgeons to residents (Rosman et al., n.d., 354). Likewise, Hsia et al. (2012) found that less than half of hospitals in sub-Saharan Africa can provide 24-hour emergency care, and fewer than 65% of the hospitals have basic infrastructure. All this makes evident an urgent need for access to emergency and surgical care in these and other low-and-middle-income countries (LMICs). We propose to offer an opportunity to increase the availability of these services by using new technologies.

One of the technologies that have shown promise in the medical domain is virtual reality (VR). Virtual reality is an immersive 3-dimensional (3D) computer-generated interactive environment. As an example of the use of VR for health care, Yang et al. (2014) proposed a tool for the real-time streaming of surgery training through an immersive 3D environment.

The major problem this thesis research proposes to address is the lack of specialized surgeons in hard-to-reach areas at an accessible cost. Specifically, this project offers a means to enable collaboration between surgeons who are geographically distributed. This collaboration

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happens through live communication via immersive, high-quality video in virtual reality. This allows remotely located surgeons to guide and give instructions to the surgery room on short notice without the need to travel or incur additional costs.

Everything in actual surgery must be accurate, rigorous, and punctilious. So, in some surgeries, more than virtual reality and 3D imaging is needed to show the necessary details. To address this challenge, this research proposes using a 360º camera inside the surgery room to offer an immersive first-person view of the surgery room in real-time, including the patient, medical staff, and equipment. To allow for more accuracy and perception of the site of the surgery and the patient's state, the proposed tool uses two additional sources of information. Involving the real-time image of a camera pointed directly at the surgery site, and the second lives feed of the patient vitals monitor, showing data such as blood pressure and heart rate.

In addition to live surgery guidance, the proposed tool provides an educational benefit. Based on the traditional way of teaching, surgery training called "See One, Do One, Teach One" expected trainees to teach another trainee after observing a procedure once and then performing that procedure (Kotsis & Chung, 2013, p. 1194). Along those lines, students observe surgeries or surgery videos as part of surgical training. To allow medical students to learn from surgeries, the proposed tool allows streams to be recorded, including the first-person immersive surgeon's view, the surgery site video, and the vitals monitor. This way, students can review a surgery, even adding annotations on any necessary parts of the stream.

In summary, the main contribution of this work is the design of Virtual Reality Remote Surgery Guidance (VRSG) a VR interface that can connect a specialist surgeon to a surgery room, allowing them to guide a team of doctors/surgeons during surgery. This research is motivated mainly by the prospect of the proposed tool to enable efficient communication

between surgical teams in LMICs and specialist doctors in developed countries that ultimately could increase the number of surgeries in the target countries and reduce the deficiency of expert surgeons as much as possible.

This project used several tools for its development. It uses the Unity game engine to provide a VR application that offers immersive telepresence to a remote user (the expert surgeon) with tools that allow the guidance of a procedure. For this application to succeed, it needs to ensure a friendly, intuitive, and usable immersive virtual environment on the surgeon's side. To that end, an annotation system with varied input options was developed to allow the remote user to visualize guidance cues during the surgery precisely. Another goal of this research was to create a live streaming link between the VR application (surgeon's side) and a web app (simulating the surgery room side) with high resolution, low-cost, and clear audio connection. The final goal was to make the web application of the surgery room side easy to use and have options to change cameras' sources, resolutions, and tools to record the call.

This thesis is organized as follows: Chapter two offers background on virtual reality (VR), Unity, and an immersive 360º video. Chapter three provides the related literature to this research and contrasts it with our proposed approach. Chapter four presents the tool design in detail. Chapter five contains details about the evaluation of the proposed tool's user interface (UI), its results, and recommendations for improvements. The thesis concludes with chapter six, where takeaways from work are discussed, and suggestions for future work are presented.

CHAPTER II: BACKGROUND

This chapter gives the reader terminology and background information required to understand our research project. It covers virtual reality (VR), Unity, and 360° videos.

II.1 Virtual Reality (VR)

II.1.1 Definition

Burdea and Coiffet (2003) have defined virtual reality (VR) in their book Virtual Reality Technology as "a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell, and taste". They also see that an application in VR should have the 3 I's: interactive, immersive, and human imagination. The researchers believe that VR applications are not only a high-end user interface but also involve solutions for real problems in engineering, medicine, and other fields.

II.1.2 VR System Components

VR means immersing subjects in a virtual environment (VE) by using sophisticated hardware and software while providing tools for user interaction in the VE. On the hardware side, there are three main subsystems: the first one is the head-mounted display (HMD) which should be light-weight, rugged, provide excellent visual display and audio, and can track the head movements and look direction (Earnshaw, 2014, p. 41). Figure 1 shows a user wearing the Meta Quest Virtual Reality HMD and controllers.

The second subsystem is the computer which provides high-detailed and updated images to display in the VR. In addition to the sounds the computer must generate for the user to be integrated with the visual scene, the computer should also accurately track the head positions and directions to make any necessary changes.

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The third subsystem is the console to accommodate all computer equipment and power supplies. Its principal function is carrying the controls, which will interact with the virtual world (Earnshaw, 2014, p. 41).

Figure 1. Person Wearing HMD and Controllers

On the software side, Earnshaw (2014) argues that the software structure of the VR system has two main areas: the central computer system is responsible for running the VR experience by using the database of the environment model. Also, it calculates the user's locations and movements, any actions from the controllers, and all interactions inside the virtual environment. Otherwise, the second one includes the programs in the graphics computer. At set up, these graphics are loaded from the disc in the computer system to display images in the visor by using data from the database and the user's position from the system computer (Earnshaw, 2014, p. 44).

II.1.3 VR Applications and Examples

Virtual reality provides applications in an extensive range of fields, such as entertainment, healthcare, manufacturing, etc. This section displays some examples of these applications in some specific fields as follows:

1. Video Games

One of the most popular uses of virtual reality is using it in video games. Examples of games in virtual reality as shown in Figure 2 (a) is Lucky's Tale for the Oculus Rift maintains a third-person perspective as the player floats above his character, and Figure 2 (b) is the Dumpy game from DePaul University (Lavalle, 2016, p. 10).

Figure 2. (a) Lucky's Tale Game (b) In Dumpy Game

(a)   (b)

2. Immersive Cinema

   This is to give a movie's watchers the feeling of being inside the movie. For example, Figure 3 shows an immersive short story about a hedgehog who wants a new friend (watcher). This short story is called Emmy-winning Henry and was produced by Oculus Story Studio in 2015 (Lavalle, 2016, p. 11).

Figure 3. Immersive Short Story

3. Telepresence

One of the most critical applications in VR is telepresence which makes the user feels like standing in another place by viewing a remote environment. This technology allows users to move around to visit faraway places virtually. A simple VR experience via Google Street View images is shown in Figure 4 (a) presents an image of the Eiffel tower, and (b) Shows left-eye and right-eye views inside the headset (Lavalle, 2016, pp. 12-14).

Figure 4. (a) Eiffel Tower (b) Inside Headset View

(a)   (b)

4.   Healthcare

These days, much research and effort are heading toward using VR in healthcare. One of these trends is using VR in distributed treatment and training; for example, doctors remotely instruct people to perform routine medical procedures in outlying areas worldwide. This means doctors guide telepresence using VR. Another use of VR is shown in Figure 5, which is a 3D heart model based on images of a real human heart. This model was generated by the Jump Trading Simulation and Education Center and the University of Illinois. Like these models are used by doctors to immerse themselves in a better study of the patient's organ before any procedures (Lavalle, 2016, pp. 19-21).

Figure 5. Heart Visualization System
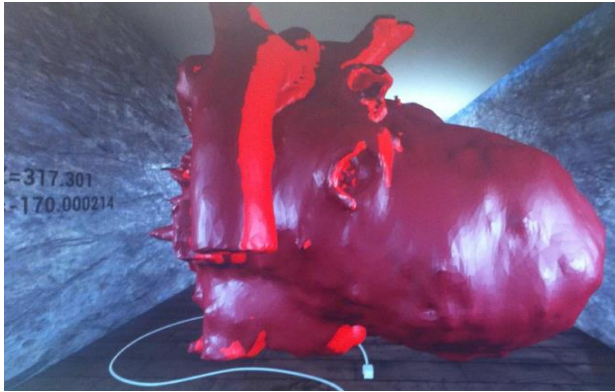
II.2 Unity

Unity (Unity3D) is a game engine developed by Unity Technologies, a 3D-based development tool, and an Integrated Development Environment (IDE) to build interactive media, especially games. Unity also can execute integrated graphics, audio, and networking (Haas, 2014).

Many reasons make Unity very popular among developers, such as its fast-prototyping capabilities. It supports independent developers who need more resources to license expensive games. Besides, its editor runs on Windows, and Mac OS X platforms, its GUI of helps new developers to approach quickly, and the produced applications are based C# (Patil & Alvares, 2015, p. 19).

Unity has a store called Unity Asset Store, which includes more than 7000 asset packages such as 3D models, textures, music, sound effects, scripting packages, projects, and online services (Patil & Alvares, 2015, p. 21).

II.3 360º Video

360º videos allow users to feel more immersion rather than stander video streaming. The immersion from the 360º video is similar to virtual reality, especially when wearing a head-mounted display (HMD) so that the user can control the angle of the view. 360º video streams

need more extensive bandwidth requirements, require a faster response to user inputs, and users may be more sensitive to lower-quality streams (Zhou et al., 2017, p. 27).

360º video is also called omnidirectional video (ODV). Figure 6 shows an image from a spherical panoramic 360º video view.

Figure 6. 360º Photo of a City

CHAPTER III: LITERATURE REVIEW

This chapter reviews work related to this project from four aspects: the history and experiences of virtual reality use in healthcare, the challenges of creating efficient 3D user interfaces in virtual reality, the meaning, and implications of interacting with 360º video, and, finally, examples of related projects that use virtual reality in remote guidance tasks.

III.1 Virtual Reality in Healthcare

Virtual reality (VR) is a way to connect humans to computers by using immersive headsets to simulate virtual and interactive environments. VR provides an immensely realistic and controllable environment for users to interact in many fields. These VR features have been used in experiences and clinical settings for over two decades (Rizzo & Koenig, 2017, p. 878). One of the first real-world applications of VR was in 1993 to treat mental health disorders, then VR applications were developed to handle specific phobias (Aziz, 2018, p. 305).

In recent years, VR has been used as a tool in healthcare to deliver exposure therapy for phobias. One of these tools is in the therapy field, which is called Virtual Reality Exposure Therapy (VRET), aimed at treating anxiety disorders and specific phobias. VRET reduces the costs of the diagnosis and increases confidence and safety compared to actual real-world exposure therapy (Aziz, 2018). VRET system is based on immersing patients suffering from anxiety, emotional, or stress/panic disorders in a simulated virtual environment to control fear stimuli. So, by using VRET, patients can practice controlling their emotions and fears in the simulation environment, and all these exercises will increase their self-control efficacy in real life (Parsons & Rizzo, 2008). Also, Parsons and Rizzo's (2008, p. 254) research brought out 52 studies (300 subjects) that could evaluate phobia before and after exposure to VRET.

Another example of using virtual reality as a therapeutic tool is Virtual Reality

Distraction Therapy (VRDT). The main aim of using a tool such as VRDT is to distract a

patient's attention from pain instead of using drugs in traditional ways. VRDT provides an

immersive and interactive environment for patients to interact using many senses, under the

hypothesis that more interaction within the virtual reality world will reduce patients' attention to

their pain (Aziz, 2018, p. 306). Sullivan et al. (2000) found that, during dental treatment, VR

does not affect the children's behavior or anxiety, but notably, VR could reduce their distress.

In an experiment by Sullivan et al. (2000), twenty-six children, ages five to seven, were

assessed for the first five minutes of two treatment visits. Half of the children wore VR headsets

during the first visit but not the second, while the other half wore VR headsets on their second

visit but not the first. Each child was asked to draw a human figure before and immediately after

each visit, which two examiners rated.

Oyama et al. (1999) found that VR could affect the mental well-being of cancer patients.

The experiment was done on twenty-two cancer patients, ages thirty-three and seventy-five. The

patients walked in an immersed virtual forest to support psycho-oncological care of the patient's

psychological and emotional states. As a result of this experiment, out of twenty-two patients,

nine were moderate to very satisfied with the experience, while only three patients rated the

experience less than satisfactory. (Oyama et al., 1999). However, using VR positively made the

treatment seem shorter, better, and more tolerable. However, VR could not decrease symptom

distress (Schneider & Hood, 2007).

VR's ability to display 3D images in a spatial setting creates a highly immersive

environment to train, test, and teach humans with complex and dynamic 3D stimulus

presentations. Using such a simulation system can make recording and tracking user actions and

behaviors easier to accurately analyze and study (Rizzo & Koenig, 2017, p. 879). Much like a 3D surgery simulator to train doctors/students under conditions like actual surgery, VR can offer similar environments where the patient and surgery equipment can take place under stimulus conditions that make learning without affecting any patients' lives possible. Other applications for mental disorder treatment are developed using immersive 3D environments to train psychologists and psychiatrists (Mantovani et al., 2003, p. 391).

There are many benefits of using virtual reality in healthcare training and education. Mantovani et al. (2003) showed the first benefit that educational healthcare VR simulations provide is operational experience and learning: using virtual environments allows students and trainees to move and engage in self-directed learning. The second advantage is that VR presents an alternate method of visualization and reification: while learning in virtual environments, the participants can see simulated real-life objects and simultaneously known graphical symbols. The third benefit is that VR allows one to try or experiment with areas unavailable in real life or when needing to use costly tools—for example, moving among molecules. The final benefit is collaboration fostering, when using VR to share experiences between groups.

Several advanced applications of VR support education and training in various domains, including healthcare. These VR applications are different in their technical and learned skills from tele-surgical applications, for example, by combining simulations with human body tracking (Mantovani et al., 2003, p. 391). One of these applications was developed by Cannon et al. (2006). Their project goal was to generate an arthroscopic virtual reality knee simulator mainly to train doctors for orthopedics in arthroscopic surgery. The simulator was connected to the Visible Human Dataset, developed by the National Library of Medicine so that the users can view the physical human knee anatomy during training. Another project where VR was explored

in surgical planning and training is called IERAPSI (Integrated Environment for Rehearsal and Planning of Surgical Interventions) (Stone, 2000). This project analyzes accurate surgical procedures, including mastoidectomy, cochlear implantation, and acoustic neuroma resection, to identify a need to rely on VR for surgery planning and training.

McCloy and Stone (2001) argue that VR simulators are suited for general surgery, while Augmented Reality (AR) is suited to guide neurosurgery. Also, the researchers point out that an integrated expert team of specialists in the ergonomics of the surgery room, software engineers, electromechanical engineers, 3D designers, and specialists in psychology needs to work together to achieve a successful VR-based surgery system.

Our research aims to employ VR technology to allow communication between remote medical specialists and non-specialist surgeons in a surgery room with the goal of providing instructions for a more successful surgical outcome. Using a VR application, we propose a prototype tool that, in the future, could work over a connection between a doctor from a developed country and a surgery room in an LMIC through a "Live connection mode." Also, we offer the ability for a remotely guided procedure to be recorded, raising the opportunity for medical students to replay the VR view of the remote surgeon to learn and review the surgery.

III.2 3D User Interfaces and Virtual Reality

Stuerzlinger and Wingrave (2011) argue that the user interface is the bridge between humans and the effective use of their tools. The user interface of 3D graphics applications such as virtual reality applications is called 3D User Interface (3D UIs) and involves 3D Interaction. 3D Interaction is defined as Human-Computer Interaction (HCI) when the user performs tasks directly in a 3D spatial context (Bowman et al., 2006, p. 3).

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There are many examples of using 3D Interaction by users in real applications such as games, entertainment, training, Computer-Aided Design (CAD), psychiatric treatment, and design review. The 3D interaction in most of these applications is not very complex. For example, some games need only turning the head to interact; however, more complex 3D interfaces are strenuous to design and evaluate and lead to a lack of usability, such as psychomotor training applications (LaViola Jr et al., 2017).

Creating efficacious 3D interfaces faces many challenges. The first challenge to consider is more freedom interactions in the 3D because the extra dimension increases issues not seen in 2D applications (Stuerzlinger & Wingrave, 2011, p. 204). LaViola Jr et al. (2017) sees that although people live in the 3D real world, simulating a virtual world can only have some significantly accurate cues, making user interaction with these 3D virtual worlds complex. Thus, the development of 3D UIs based on the natural world must be pursued.

Stuerzlinger and Wingrave (2011) argue that all these challenges are based on the limitations and abilities of humans and technology. That is why they divided the reasons for these issues into three categories. The first one is Input Devices. The researchers believe that applications requiring multiple input devices are more challenging for the user. Also, if the input device type is not compatible with the tasks in the application, it will be a nightmare for users to use the application. In our research, we considered these points and made sure to use only one type of input device (controllers), which is most appropriate for the annotation and zoom-in/out tasks supported by our project. The second category includes Display Devices, the most readily identifiable aspect of 3D UIs. The researchers determined two complementary characteristics of displays that should be considered when choosing the type of display device: field of view (FOV) and field of regard (FOR). Our research found that a head-mounted display (HMD) is the

best choice for our project. One of the main benefits of HMDs for our project is that they have unrestricted FOR, which means the amount of the virtual environment around the user in degrees reachable by physically looking around. We also found that the visual quality (screen size, pixel density) of the HMD suits the needs of our application. The last category of 3D UI challenges described by Stuerzlinger and Wingrave (2011) concerns human issues that simultaneously affect input and output devices. To contemplate this issue, we decided to evaluate the usability of the 3D UI of our project to identify human factory issues and propose solutions.

III.3 Interaction with Immersive 360º Videos

360º video is a new technology recorded in omnidirectional or multi-camera systems and allows the users to have a first-person perspective of the experience while watching a video. While playing the video, the users can interact with/move the video by mouse clicking or panning and tilting a mobile device to change the viewing degree of the video (Snelson & Hsu, 2020, p. 404).

The technique of 360º video is that the viewer turns in any direction while a fixed line unfolds around them. The user can see the video from different angles reachable by head movement, which is transferred to the camera perspective, effectively allowing the user to stare in any direction (Elmezeny et al., 2018, p. 2).

Comparing 360º video to VR, they are similar when using a headset to view virtual views, especially if there is a way to interact with objects inside the video. However, in 360º videos, the user cannot walk around the virtual environment and cannot change or manipulate objects as would typically be supported in a VR application. Besides, 360º video, unlike VR, does not require special equipment to watch (although the experience would not be immersive,

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equivalent to a desktop virtual environment). Also, the 360º video is generated from real-world footage, whereas VR uses digital images (Snelson & Hsu, 2020, p. 404).

For interactive applications, Argyriou et al. (2016) point out that there are two kinds of pleasure that users enjoy: immersive and engaging applications. They posit that 360-videos are highly immersive and potentially engaging environments surrounded by a total sense of existence.

There are two challenges and implications when trying to create an immersive and interactive experience using 360º video: technical implementation and design challenges. For the technical challenges, the user may face possible delays and blinking effects when changing between the 360º video sources. In our project, we attempted to use a wide bandwidth connection while using Live connection mode to avoid this as much as possible. Additionally, adding the recorded mode allowed us to maintain high playback performance that was effective in evaluating the user interface setting aside any technical problems.

Notably, there are many challenges in designing a non-intrusive, non-distracting user interface on top of a 360º video. To solve this problem, the UI should be as transparent and non-intrusive as possible, with an augmented view of the actual scene, and the interaction should not stop or block the 360º video from the user's view. In our project, there are two supporting 2D streams rendered in front of the 360º video, where all the interactive UI elements exist.

III.4 Remote Collaboration through Virtual Reality

This section reviews some research that uses VR with remote guidance.

Connecting the world and sharing real-time experiences between people who may be geographically distributed is now an urgent need. Specifically, there is a demand for remote guidance, where a remotely situated expert assists their team on the other end of some procedure,

such as a repair, maintenance, surgery, or communication task. This type of collaboration is required in many fields, such as education and healthcare.

Huang et al. (2019) developed a 3D system called HandsIn3D based on 3D virtual immersed space and 3D hand gestures. This project consists of a single computer to run the project; in the helper side/space, there is a 3D camera to capture the hand of the helper, and the helper wears an HMD to be immersed in the virtual space, which is captured by the 3D camera of the worker space. While in the worker's space, there is a 3D camera to capture the workspace, especially the worker's hands, and a 2D monitor to show the 3D view of the workspace argument by instructions from the helper. Besides, the helper space has an optical head tracker to track the helper's HMD movements.

This project works as illustrated by the following scenario. The worker sits in front of the 3D camera and calls the helper to request help. At the same time, the helper is already wearing the HMD that shows the virtual space of the worker with the objects, and the helper sits in front of the 3D camera. Then, the helper gives instructions to the worker by performing hand gestures such as pointing to the object. In this real-time communication, the worker can see the helper's virtual hands in the 2D monitor, the instructions, and the worker's space. It means that the worker sees four hands on the monitor.

Fourteen participants joined to participate in an evaluation of the project and were randomly selected as pairs (for helper and worker). And the experimental task was to assemble a set of Lego toys into a complex model under the helper's guidance. In conclusion of this experiment, the researchers observed that 3D collaboration helps the participants improve their sense of copresence. This system is functional and makes cooperation to solve complex problems more manageable.

Comparing the HandsIn3D project with our own research, both have the same working principle, and remote guidance, but the implementation and goals are entirely different. While HandsIn3D uses a 3D camera to get the other side, this project uses a 360º camera to film the surgery room entirely. Moreover, instead of creating virtual hands on the work side to help people, our work offers an annotation system to allow the worker to live draw, and take screenshots. Finally, the main goal of the HandsIn3D is to remotely help distant workers to complete manual tasks, where our project targets remote guidance from a remote surgeon to give instructions to surgery teams in LMICs.

CHAPTER IV: METHODOLOGY

This chapter details the user interface design process, the tools used on both software and hardware, and the system design and structure.

IV.1 User Interface Design

This section describes the progress of user interface design step by step to develop the proof of concept of the interface and ensure interaction efficiency under different design options. Based on the iterative design process, this project has selected the final interface design to meet the users' expectations for interaction as much as possible. This research has already tested the 3D interfaces with volunteers. The experiment and its results are shown in chapter 5.

Finding the best UI design for the project the first time is unexpected to occur. That is why the UI design needs to be intrinsically open, iterative, and incomplete throughout the project's execution to allow modification at any time in the process (Coyette et al., 2007, p. 151). This means UI design needs to consider the progress of appropriate techniques, such as prototypes and final designs, which are covered in the coming subsections.

IV.1.1 Prototyping

This project depends on the prototype fidelity concept since many rapid changes are needed for UI prototyping. Prototype fidelity means the similarity between the final coded user interface and the prototyped user interface. There are three types of fidelity prototypes: high-fidelity, when the prototype is the closest to the final design in layout and navigation. The second type is a low-fidelity prototype when the prototype represents part of the final UI, not all of its details. The third one is between low and high fidelity and is called medium fidelity (Coyette et al., 2007, p. 151).

This research uses the low-fidelity prototype to design screens on both surgeon and surgery room sides. On the surgeon side, which represents the VR project side, there is a 360º view for the user and two other regular videos to interact with. The progress of getting an exemplary user interface with efficient use takes a lot of time and steps to test and redo. One of the earlier designs is shown in Figure 7 (b) the live streaming main menu missed the screenshots list, (d) the drawing tools menu is placed over the 2D videos, now it is under the video, and the buttons were not all in the same place, some of them were in the top corners of the video.

Figure 7. Surgeon Side First Stage Prototypes

(a) Main Menu Prototype (b) Main Screen Prototype (c) Patient Data Zoomed Video Prototype (d) Specific Surgery Site Zoomed Video Prototype.
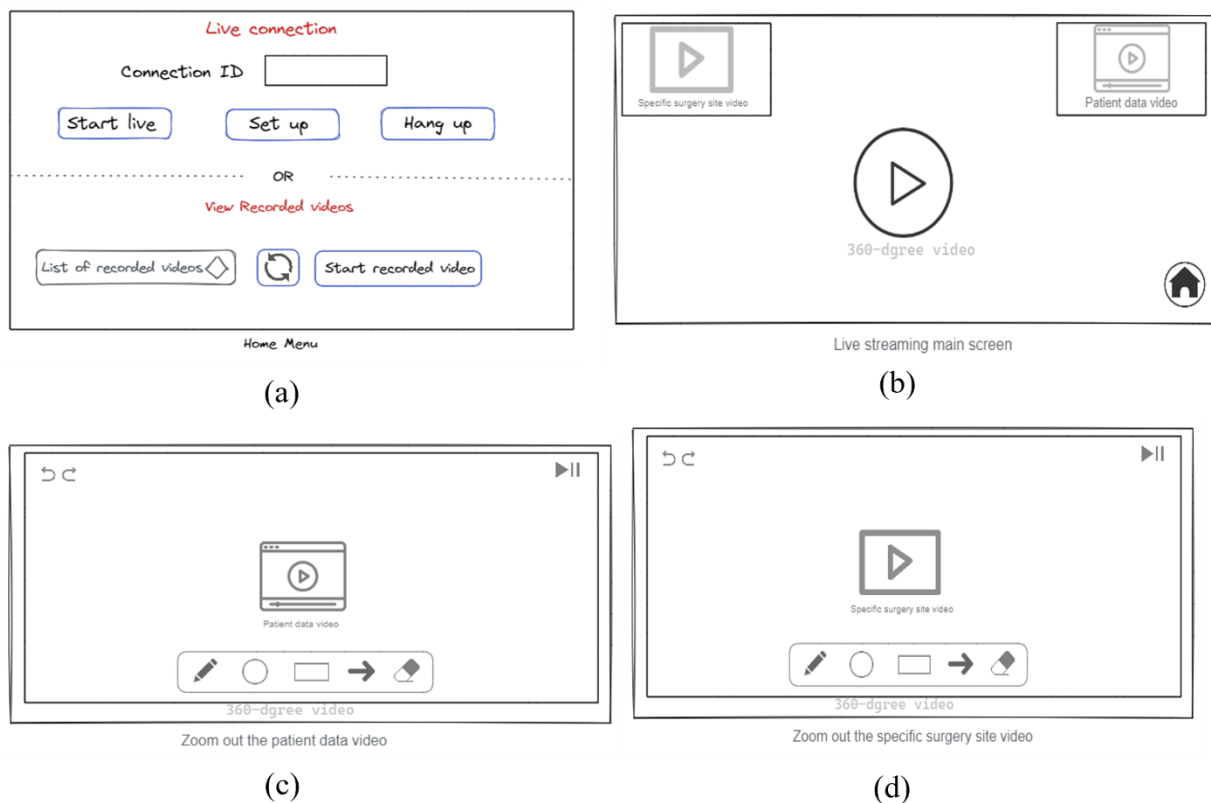
After writing code and running the VR application, design iterations that reulted in many improvements to the UI design were informed by several demos and discussions with UI experts.

Figure 8 shows design iterations of the main screens. Figure 8 (a) shows the same design as the

first prototype. Figure 8 (b) shows the main screen prototype, representing the live (or recorded)

view of the remote surgeon, with a 360º view, a specific surgery site video and a patient's vitals

monitor video. This was an iteration from the previous prototype in Figure 7 (b) by adding a list

of annotated screenshots in the lower left corner of the video. Figure 8 (c) shows a prototype of

the particular surgery site video when it is zoomed in. This was also a design iteration from the

previous prototype in Figure 7 (c) by moving the tools menu to be under the video rather than

over it. Also, all tools and buttons were placed in a single menu. Figure 8 (d) shows a prototype

of the patient's data monitor when it is zoomed in.

Figure 8. Surgeon Side Prototypes

(a) Main Menu Prototype (b) Main Screen Prototype with added screenshots in bottom-left corner (c) Specific Surgery Site Video Zoomed Prototype after moving all buttons to one menu under the video (d) Patient Data Video Zoomed Prototype after moving all buttons to one menu under the video

(a)
(b)
(c)
(d)

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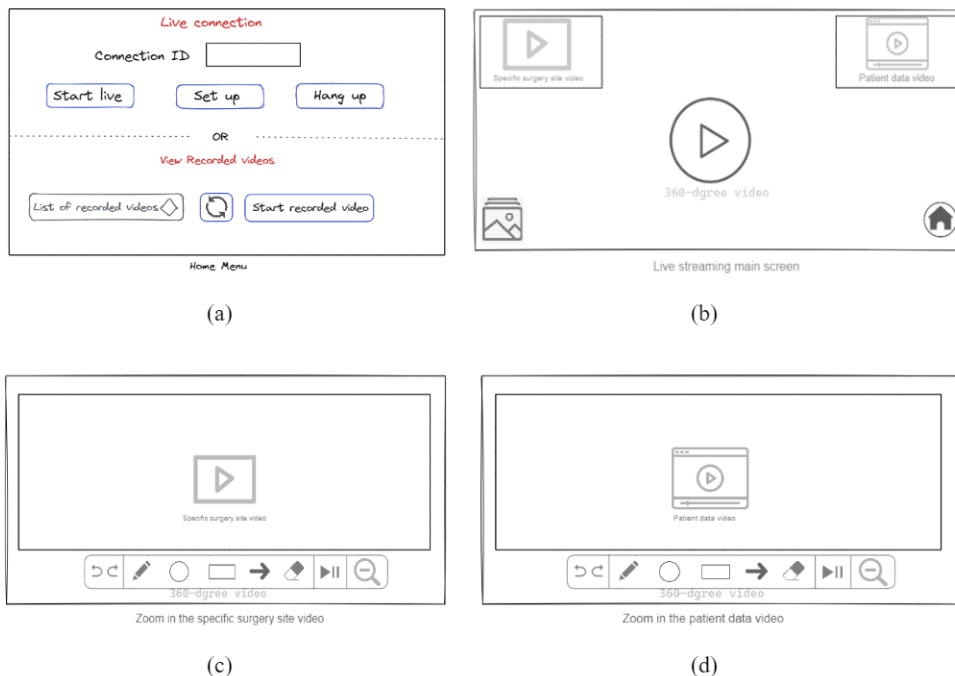
The surgery room side is simulated by a desktop web-app screen. The prototype for its main page is shown in Figure 9.

Figure 9. Web-app Prototype
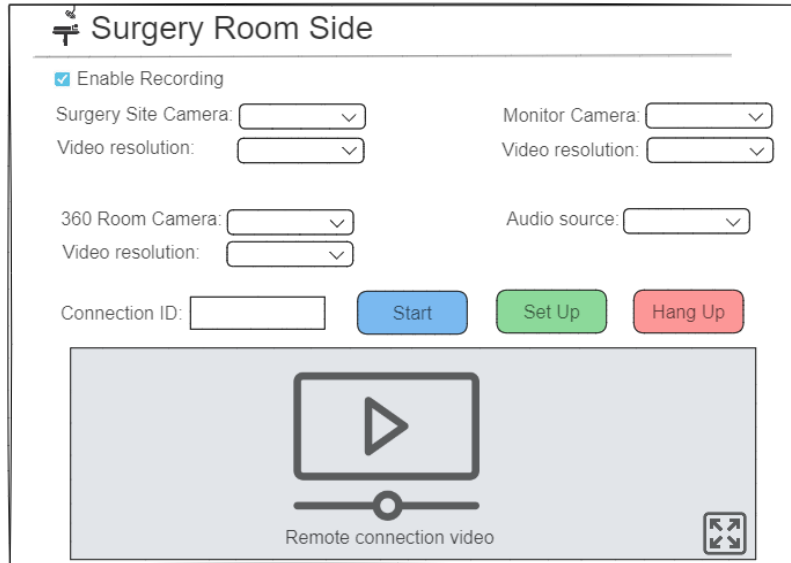
IV.1.2 Final Design

After finishing the iterative design process, we conducted several steps to ensure the final usability of the tool. Those steps involved developing the user interfaces by implementing code to the prototypes, testing the design by running and experiencing it, and finally evaluating the usability of the tool by study volunteers. Figure 10 shows screenshots of some main screens from the running project on the surgeon's side: (a) main menu screen final running design; (b) main 360° video screen; (c) the specific surgery site video screen while zooming in; and (d) the patient's data monitor screen while zooming in.

Figure 10. Surgeon Side Screenshots

 (a) Main Menu Screenshot. (b) Main User Screen. (c) The specific Surgery Site Video Screen. (d) The Patient's Data Monitor Screen.
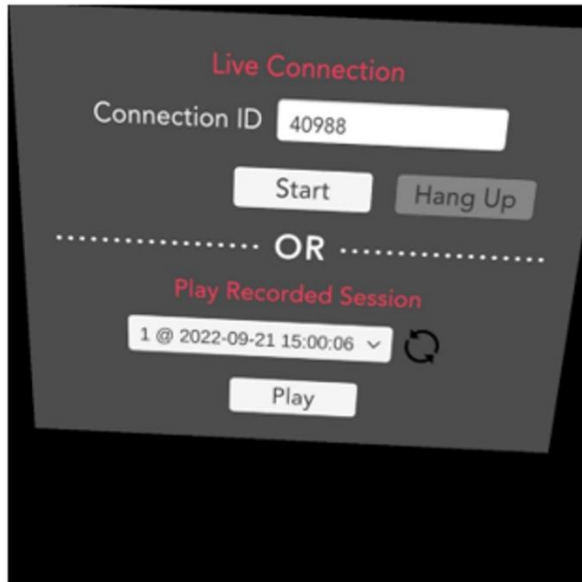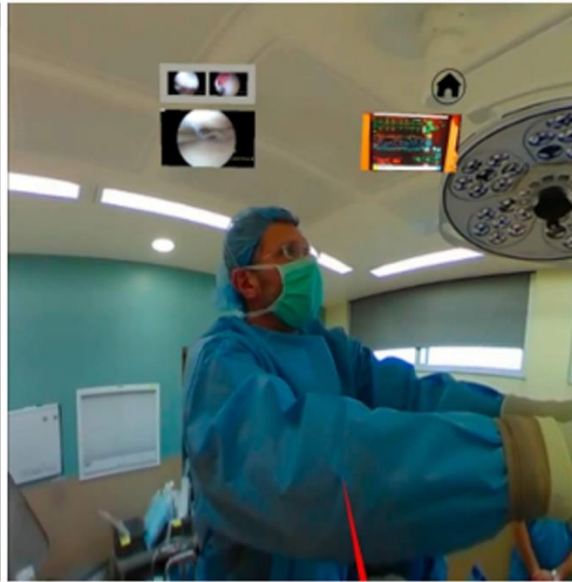
(a)　　　　　　　　　　　　　　　(b)
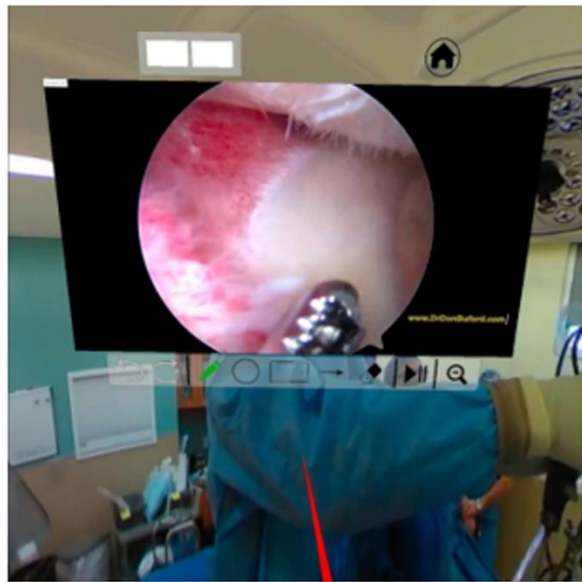
(c)　　　　　　　　　　　　　　　(d)
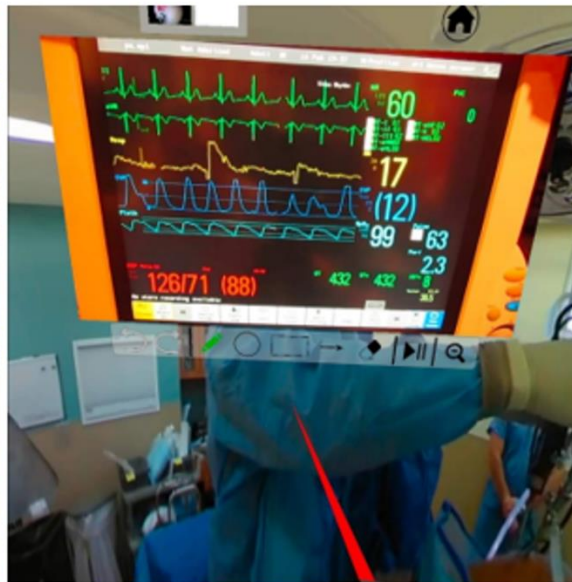
On the surgery room side, Figure 11 represents a screenshot of the web-app screen while it runs and communicates with the recorded video of a surgery room. The videos are streamed to

the surgery room web app by using virtual cameras with screen-capture software like OBS or

VLC.

Figure 11. Surgery Room Web-app Screenshot

IV.2 Tools

This section describes all software and hardware tools used to design and implement the Virtual Reality Remote Surgery Guidance (VRSG) system. The following section explains in detail how these tools are connected to make an efficient working system.

IV.2.1 Software Overview

This subsection discusses the software part and all programs that are used to build the VRSG system as follows:

IV.2.1.1 Unity Game Engine:

Unity is a real-time cross-platform tool that consists of rendering, a game engine (including physics), a user interface (Unity Editor), and an integrated development environment (IDE). Unity is known and mainly used in the 3D development, gaming, and film industries. These games and applications are developed for different Augmented Reality (AR) or Virtual Reality (VR) platforms (Juliani et al., 2018, 8).

Our project uses the Unity game engine of version 2020.3.33f1 and C# language for mainly two aspects: the first one is to build a VR application, which represents the remote surgeon side of the project. The VR application uses the Video player as a broadcaster for the 360º video to a texture called Render Texture. Then, Skybox uses this texture to display a panoramic 360º video in the application Scene. Also, this VR application uses OpenXR in Unity, an open-source plugin that helps the application seamlessly run-on VR devices such as Oculus, Vive, Index, etc.

Moreover, uploading the VR application into the VR headset (Oculus Quest 2) is done by Oculus Developer Hub (ODH). There are many advantages of ODH, such as the headset connecting to the computer via Wi-Fi without the need for wires, the ability to cast the headset to

the computer, and the apps could be directly deployed from the computer to the headset (*Oculus Developer Hub: Unity*).

The second important aspect of using Unity is using its built-in packages. One of these packages used in this project for live streaming between the VR application (surgeon side) and the web application (surgery room side) is Unity Render Streaming (URS).

URS depends on the WebRTC package (Real-time communication for the web), which adds real-time communication capabilities to any application that works on an open standard. The webRTC is available on all modern browsers and supports streaming voice, video, and generic data between peers (*Real-Time Communication for the Web*).

This means that URS has peer-to-peer (P2P) streaming using public APIs. The main goal of this package in this project is to get videos from the surgery room (360° video and two other standard videos) to render in the headset of the remote surgeon and then cast what the surgeon sees and interacts inside the headset to the monitoring view in the surgery room. See Figure 16 in the next section to see the system information flowchart.

To achieve streaming, the URS package uses a web server for signaling to create communication between two peers, then these two peers (sender and receiver) communicate via a WebSocket directly (two-way interactive communication session between two peers) as shown in Figure 12 Start the connection between two peers by signaling of the web server. Figure 13 Step by step to connect two peers starting by signaling then the WebSocket (*About Unity Render Streaming*).

Figure 12. URS Signaling Two Peers
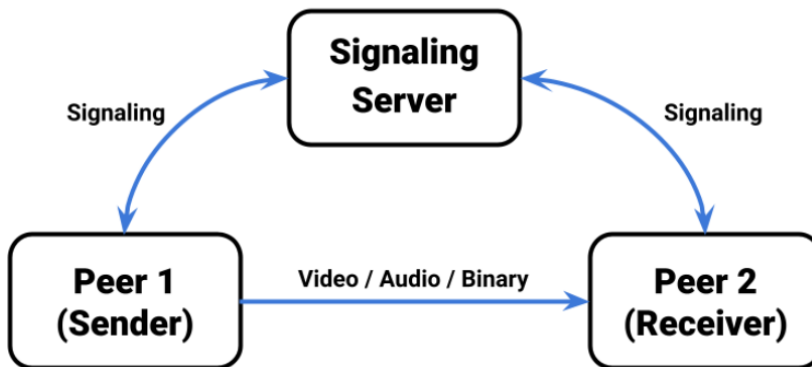
Figure 13. URS Full Two Peers Communication Steps
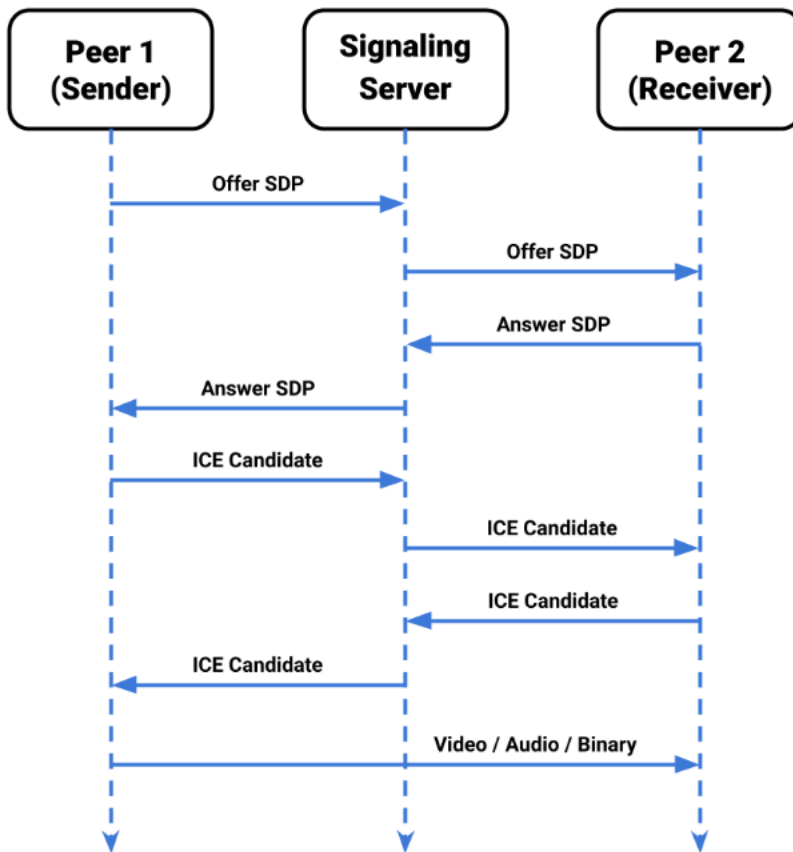
IV.2.1.2 Other Used Software Tools

- Building the web application side (surgery room side) by using Node.js, HTML, and CSS

  languages.

- The server reserved to host the web application is awsEC2 server with a size of T2.micro 1vCPU, 1GB ram. This Linux server also hosts the database of recorded videos' URLs. Also, a space in this server is used as a hard disk to save the application's recorded videos.

- Database: this project uses an SQLite database to store the recorded surgeries videos' URLs.

- Insta360 pro application to cast the insta360 camera's videos of the surgery room to the web application before sending it to the remote surgeon.

- OBS Studio application is used to create a virtual camera of the insta360 pro application to send it to the web application to start the live streaming with the remote surgeon.

IV.2.2 Hardware Configuration

This subsection describes the hardware tools used to build the Remote Surgeon Guidance project. These tools are listed as follows:

- Virtual reality headset and controllers: this project finds that Oculus Meta Quest 2 is the most appropriate for the requirements. The remote surgeon wears the headset to communicate with the surgery room via the VR application. As well as using a VR controller to zoom in/out the two videos and draw annotations inside the VR application. Figure 15 (a) shows a surgeon wearing the Oculus Meta Quest 2.

- 360º camera: this project uses an insta360 pro camera to capture a video of the whole surgery room and send it to the insta360 pro application. The 360 camera is shown in Figure 14.

Figure 14. Insta360 Pro Camera

- Two 2D cameras: these two cameras are used in the surgery room where the first one is used to spot a specific surgery site of the patient, and the second camera is to show the patient data monitor. See Figure 15 (b) of the surgeon's view to note that the top-left video is from camera 1 and shows the specific surgery site, and the top-right video is from camera 2 for the patient data monitor.

- Screen (monitor) in the surgery room to see the remote surgeon's view to be able to see the annotations which are made by the surgeon. Figure 15 shows the surgery room with the screen displaying the specific surgery site video zoomed out and annotated by the remote surgeon.

- The surgery room's PC (computer/server) is connected to the WiFi to communicate with the VR application (remote doctor). And all three cameras and the screen (monitor) are connected to this PC.

IV.3 System Design

This section views the project's idea and system structure in detail. Also, it describes how we put together all software and hardware equipment from the previous section to shape the final implementation. Finally, this section highlights the project's modes of live connection mode, view recorded video mode, and view the Annotation system.

The primary purpose of this project is to offer the first step towards enabling a remote surgeon to guide a surgeons' team in a distributed area such as sub-Saharan Africa. This project consists of two spaces: the first space is an immersive VR application for the remote surgeon, as shown in Figure 15 (a), which shows an imaginary image of a doctor wearing the VR head-mounted (HMD) and controllers while using the application. This VR application streams three videos in the same interface: a 360° video to provide an immersive view of the surgery room, and two other videos are arranged on the 360° video: the top-left video for a specific surgery site video and the top-right video for the patient data monitor as in Figure 14 (b). The surgeon can turn in any direction to see everything in the surgery room. As the user changes their view direction, the UI follows their head movement in all directions after a 0.5-sec delay through a smooth animation.

Figure 15. VR Application on The Surgeon Side

(a) The Idealized Image of a Doctor Using the VR Application (b) VR Application Interface on the Remote Surgeon Side.

(a)   (b)

The second user interface, shown in Figure 16, represents the surgery room in a simplification that allows the emulation of the idealized complete project while maintaining the scope of the work focused on the remote surgeon user interface. There are several tools in the surgery room application: a 360 camera to record the whole room, two 2D cameras: one directly over the patient to record the specific site of the surgery, another showing the patient's data monitor with data such as pulse and blood pressure, a computer/PC to connect all these cameras to it, and a screen/monitor to display the connection with the remote surgeon for the surgeon team.

Figure 16. Mock-up Surgery Room Side

Mock-up Image to Show the Idealized Use of Surgeon's Team Looks at an Annotated Video from the Remote Surgeon.

Figure 17 shows the information flowchart of the entire communication between these two spaces. The flow starts from any side by the connection ID to start streaming videos over a WebSocket after finishing the signaling between them. The surgery room side app streams 360º

video, specific surgery site video, and patient data monitor video to the VR application on the remote surgeon side. On the VR application side, the specialist can interact with these videos by annotating them in the live stream. All these annotations as well as the three streams, are shown on the surgery room screen to be viewed by all surgeons (Figure 11–screenshot of the surgery room app). Indeed, there is live audio in this video call between the two sides. After closing the streaming, a copy of this video call is saved on the server to be used in the view-recorded video mode in the VR application by medical students or other doctors in our idealized scenario.

Figure 17. Information Flowchart
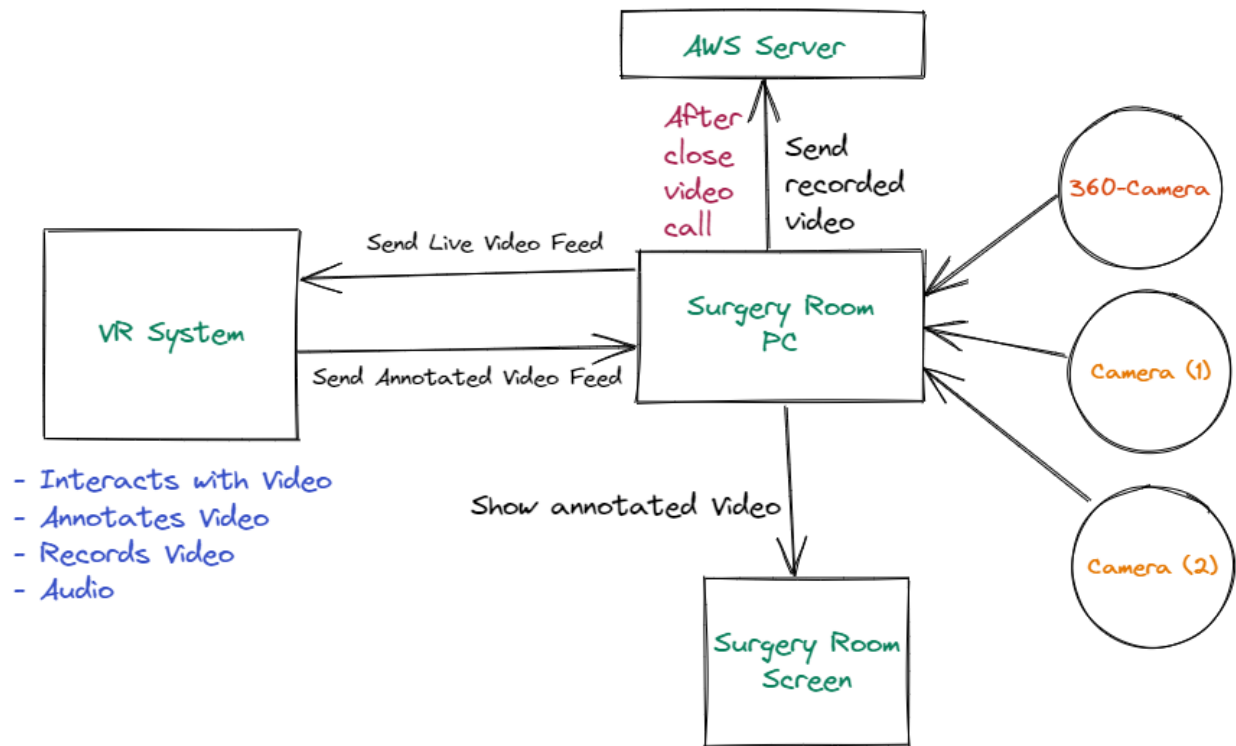
IV.3.1 Live Connection Mode

There are two modes to run the VR application: The live connection mode, which is discussed in this subsection, and the recorded video mode, presented in the following subsection. The Live Connection Mode represents the main mode and idea of the application and creates communication between the remote specialist and the surgery room. We also explain the

sequential interaction of the user while using this mode in the application via a sequence diagram.

The main goal of this application is achieved by using the live connection mode, which establishes a live interactive communication channel between the remote specialist and the surgery room, as shown in the connection map in Figure 18.

To start the connection, both sides start signaling by talking to the web server (this project uses the AWS server) to ask to connect it with the other side. Then, by switching the connection ID, the server provides each side's information to the other side. That means the server gives VR application information to the PC (of the surgery room) and vice versa. Then the server opens a WebSocket for a direct connection between them. In this way, the live connection is done, but as the connection is recorded, the server needs to save the recording when either side hangs up. So, when the communication ends, the server saves the recorded video to local storage and its URLs in the database.

Figure 18. Connection Map Diagram

LIVE SESSION

Local Storage

sqlite db

Signaling Server

Surgery Room
+ 3 cameras

1. I want to create & connect to session X

2. Here are info about the other entity (if available yet)

3. Both entities start communicating directly Peer-to-peer (not through the server)

4. When either party hangs-up a recording for each of the 3 cameras is sent to the server

5. The server stores the recording on local storage

6. The server inserts a row into the sessions table with a timestamp and local paths to the three videos

To understand the sequential actions the user needs to do when using the live connection mode, see the sequence diagram in Figure 19. According to the diagram, when the user opens the VR application, a main menu of the two modes will be shown (see Figure 10 (a)). In this case, the user must enter the connection ID provided by the surgery room web app and click start to connect with the web app side. Once the connection begins, the user will have access to the main interface, as shown in figure 15 (b), which displays 360º of the whole surgery room in addition to two videos in the top corners: a specific surgery site video and a patient data monitor video.

While the user is inside the VR application, they can interact with all interface elements. For example, the user can zoom in on any one of the 2D videos, then the user will be able to select any tool from a full menu of different drawing tools, as shown in Figure 10 (c) (d) and

Figure 22. Clicking on the home button will return the user to the main menu, then clicking on the hang-up button will end the connection. After that, the user can start a new connection, move to the "view recorded videos" mode, or quit the application.

Figure 19. Live connection Mode Sequence Diagram
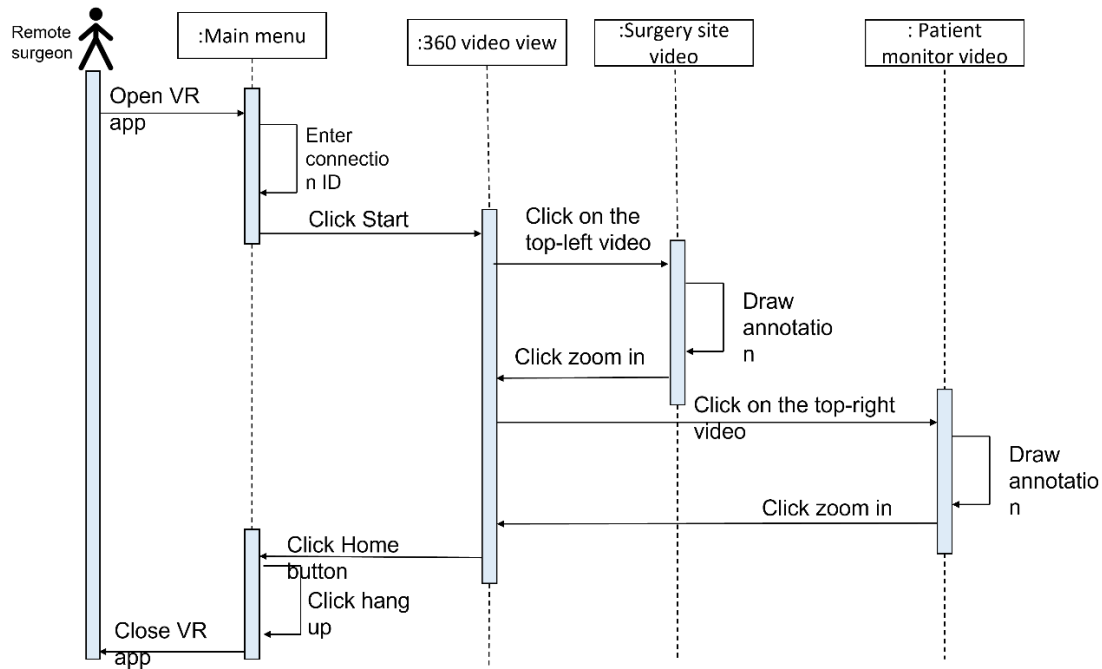
IV.3.2 Recorded Video Mode

The second mode of this application is to use it by using recorded videos instead of live communication. This mode is found to record surgeries by the web-app in the surgery room side and give the ability to the doctors to review these records by the VR application. Also, give the new surgeon or medical students a chance to look and learn from the actual surgery, especially the critical ones, which they are not allowed to enter. Finally, it allows us to evaluate the user interface without technical network impairments.

This subsection shows the structures of using a recorded video mode and the sequential interaction of the user inside the VR application while using this mode.

As shown in Figure 20, the recorded video mode requires the VR application only, as there is no live communication with the surgery room. It starts when the VR application connects to the web server (AWS server) to request recorded videos to use. Then the web server connects to the database to get the URLs of all recorded videos. The server quickly finds the videos in the local storage using these URLs and gets all of them. After that, the server returns a list of recorded videos for as many surgeries as possible. Notice that for each surgery, there are three stored videos: the 360º stream and two 2D streams, such that the VR application receives three videos and puts each of them in its place as the original communication video (Figure 15 (b)). In this way, the user can interact with all these videos and use the annotation system over them.

Figure 20. Recorded Video Structure
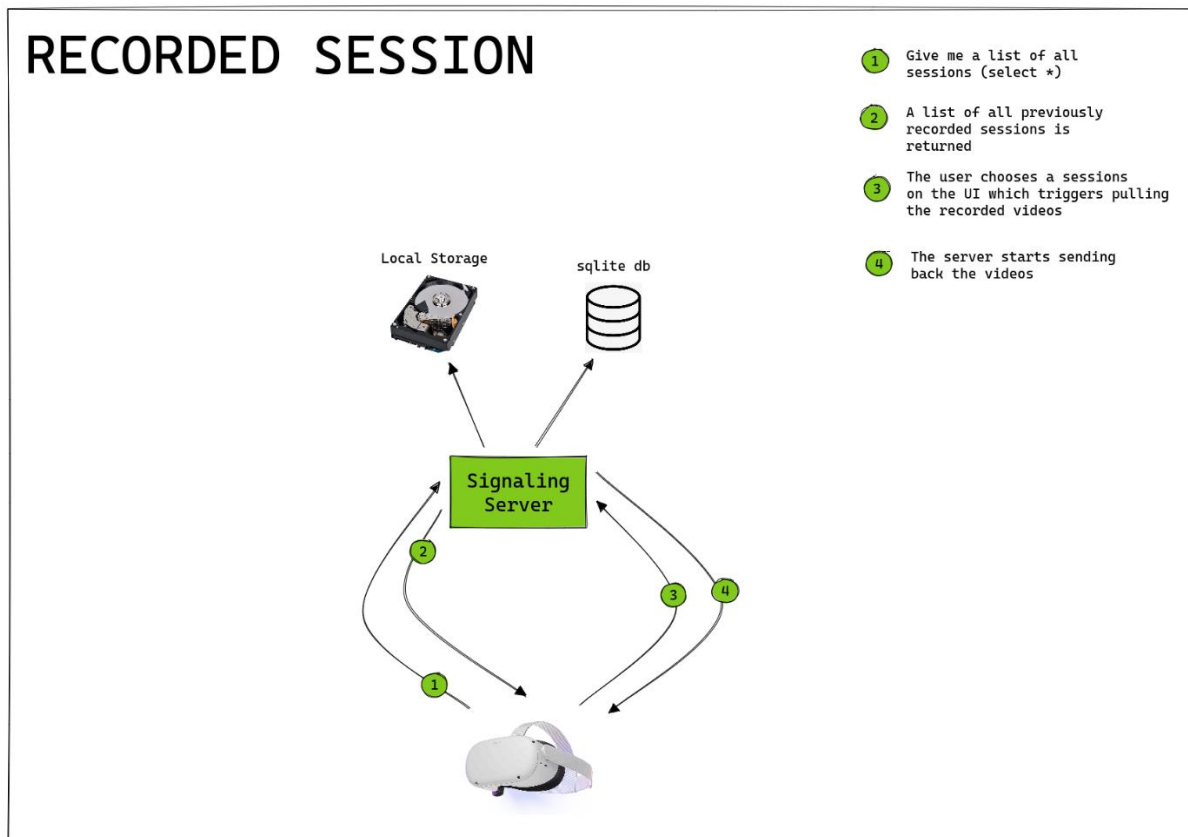
To use the recorded video mode, there are sequential interactions/steps that the user can

do, as shown in the sequence diagram in Figure 21. Once the user opens the VR application, the

main menu with two modes is shown in Figure 10 (a). The user clicks on the Refresh button to

allow the VR application to connect to the server to get the list of the recorded videos. From the

list, the user can select the desired video of the saved surgeries videos to open by clicking the

start button. The moment that the video starts, the user will be able to see the exact interface that

the surgeon sees in the live connection mode, which is shown in Figure 14 (b). The user has the

same features to interact and annotate the videos precisely as the remote surgeon. Clicking on the

Home button will return the user to the main menu to have a chance to select another video and

start again, move to the Live connection mode, or just quit the application.

Figure 21. Recorded Video Mode Sequence Diagram
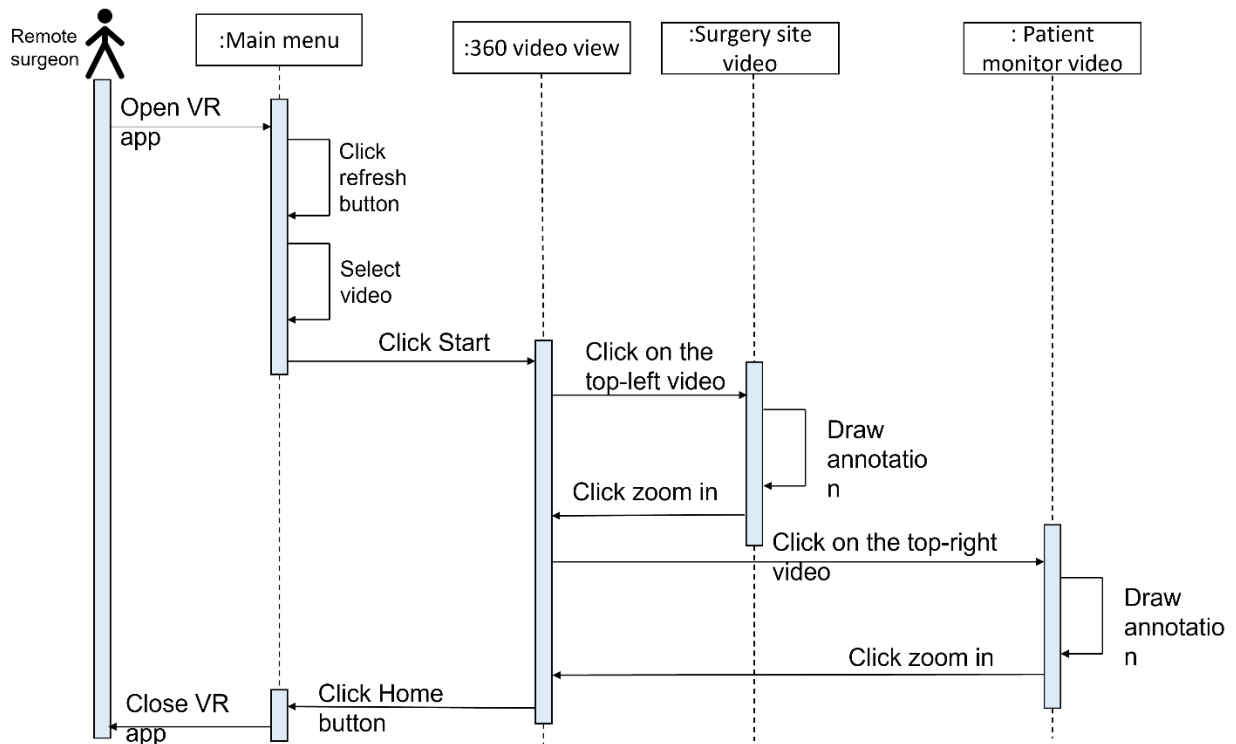
IV.3.3 Annotation System

One of the most essential features of this project is giving the surgeon the ability to annotate surgery details for the surgery room with the Annotation system. This system appears on the 2D streams when the surgeon points the controller to one of the 2D videos in the main interface to zoom it in. After the video becomes larger, a menu of the drawing tools will be seen in front of the surgeon in the VR application, as shown in Figure 22, and on the surgery room's screen in front of the surgeon's team, as in Figure 16. The menu has four tools to help the surgeon in the annotation: The first tool consists of "undo" the last line you drew on the video and "redo" buttons. The second tool is the central part of the menu with shapes of pencil (free drawing), oval, rectangle, arrow, and eraser, respectively. This gives the user many options to use different shapes to point out exact areas over the 2D video, besides an eraser to erase the drawing. The third tool has a play/pause button which, in addition to playing and pausing the video, also takes a screenshot of the annotated 2D video. Looking at Figure 22 in the left-bottom corner, there are two most recently taken screenshots. The scenario is as follows: once the user starts annotating the 2D video automatically paused to be able to mark desired points in the detailed stream. After finishing, the user should click on the play button to play the video, then the play button plays the video and implicitly take a screenshot and save the two most recent in the left-bottom in the VR application only, so that they are viewable by pointing controllers. The last part of the list is a zoom-out button to return the 2D video to its original size and location.

Figure 22. Annotation System
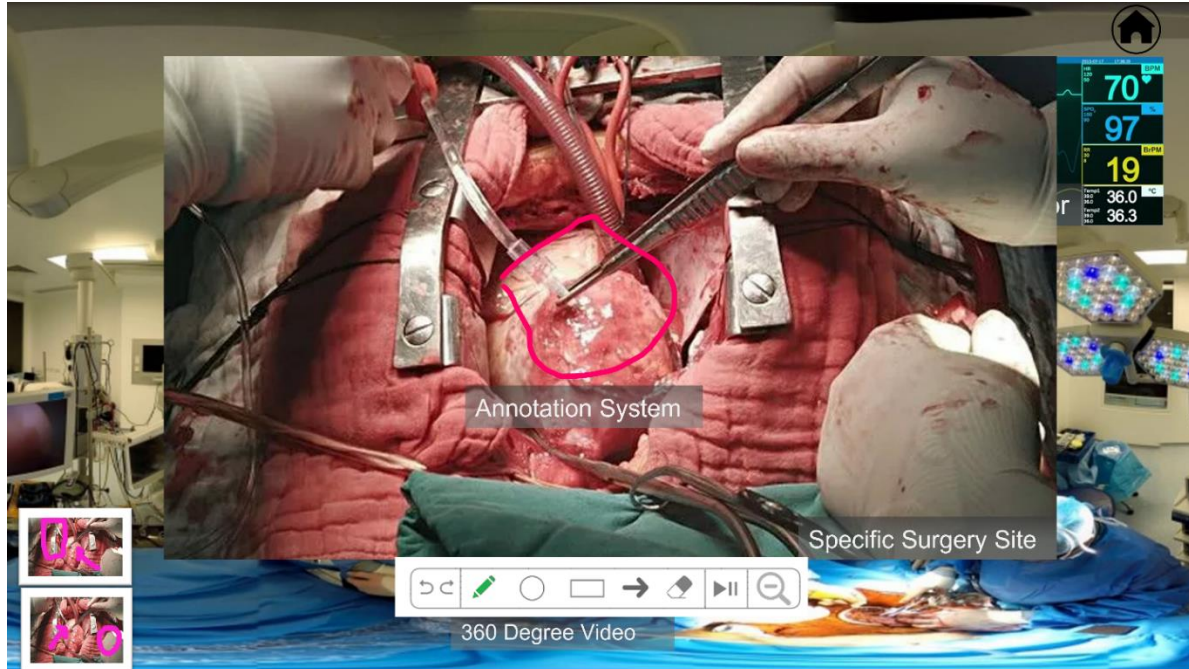
Technically, for free drawing in Unity, this project uses the Line Renderer component. This component takes points drawn by pointing the VR controller and drawing a straight line over each one. When adding this component to the project, the developer can modify the line color and width (*Manual: Line Renderer Component*).

CHAPTER V: VR REMOTE SURGERY GUIDANCE SYSTEM EVALUATION

This chapter presents the process, goals, and participants of this project's UI evaluation and its results. The chapter concludes with a discussion of the results, including strengths, challenges, and limitations.

V.1 Evaluation

The main goal of doing experiments is to test the efficiency and usability of the 3D user interface in the VR application (surgeon side) by using "View recorded videos" mode. This section describes the design and conduct of this project's evaluation.

All researchers took Institutional Review Board (IRB) training in human resources in the Collaborative Institutional Training Initiative (CITI Program) at UNCG. Then applied to the Cayuse Human Ethics IRB Application and got the approval to experiment with the Interactive Realities Lab (IRLab) at UNCG (IRB-FY23-128).

V.1.1 Experiment Design

The Virtual Reality Remote Surgery Guidance project aims to offer an immersive and compelling user interface to a remotely located surgeon to connect the team of surgeons who are virtually present in surgery rooms in countries/areas that are geographically distant. The motivation of this project is to allow remote experts to assist regions that lack certain kinds of medical experts, such as Sub-Saharan countries. In this experiment, the participants wear the virtual reality headset to put themselves in the place of the remote surgeon. The goal of this study is to evaluate the user interface of the remote surgeon's virtual reality tools with members of the general population and ensure it is rated as high in usability and related metrics. Establishing a high usability standard is essential for the project to move forward to include medical doctors and remote connections, as those are costly and less available. Ultimately, ensuring that non-

medical-related issues are addressed before the system is tested with experts ensures that the experts will concentrate on design aspects that are particular to their expertise, making their time and contribution more efficient.

This experiment addresses three research questions, for which we also formulate hypotheses.

RQ1. What is the overall usability of the VR software?

H1. The interface will be regarded as having a high degree of usability.

RQ2. Are the VR user interface tools perceived as sufficient and helpful for the users to offer remote guidance to a surgery team?

H2. Users will perceive the VR user interface tools as sufficient and helpful

RQ3. Does the experience induce a sense of presence?

H3. Users will feel a high degree of presence during the VR experience.

The experiment had two objective and three subjective outcome measures:

- Objective metrics:
  - Task completion time: the time a participant spends to finish each task.
  - Success rate: whether the user could successfully complete the task.
- Subjective metrics:

    Slater-Usoh-Steed presence questionnaire: this questionnaire has many
    questions which belong to one of three themes: the sense of being inside
    virtual environment, the extent to which virtual environment becomes
    real, and the extent to which the virtual environment being able to be
    remembered as place not images (Usoh et al., 2000, p. 500). So, the

standard questionnaire has six questions to score the level of sense of

presence in virtual environment. The questionnaire is shown in Table 1.

Table 1. Slater-Usoh-Steed (SUS) Questionnaire

Question No.	Question Text
1	Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.
2	To what extent were there times during the experience when the virtual environment was the reality for you?
3	When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited?
4	During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or of being elsewhere?
5	Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.
6	During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

- o System Usability Scale questionnaire: this questionnaire was originally

  created by John Brooke in 1986, and it provides quick and reliable tool to

  measure the usability. It consists of ten questions with five response

  options; from strongly agree to strongly disagree. The benefit of using

  this scale is its results is valid and return if the system is useable or not,

besides, it can be used with small sample size such as ours (Brooke, 1996). The list of its questions is viewed in Table 2.

Table 2. System Usability Scale (SUS) Questionnaire

Question No.	Question Text
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very cumbersome to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system.

o Overall Perceptions questionnaire: we have written a questionnaire with specific questions about the design and functionality of the Virtual Reality Remote Surgery Guidance's user interface. This questionnaire is found to score the sufficient and helpful level of using tools for remote guidance, it consists of nine questions in Table 3.

Table 3. Overall Perceptions Questionnaire Questions

Question No.	Question Text
1	How comfortable did you feel completing the tasks?
2	I found the colors used in the project harmonious and comfortable
3	I found using the controller (pointer) is easy to use
4	I felt nausea/dizziness while completing the tasks
5	The icons in the user interface were clear and easy to understand
6	I found the design and the position of the surgery site video, and the vitals monitor efficient
7	It was easy for me to draw/use the annotation system
8	It was easy for me to complete all the tasks
9	Feel free to add any notes or comments about your experience

Recruitment was done by a published announcement by email to recruit volunteers to participate in the study. Inclusion criteria included being 18 years or older, having normal or corrected-to-normal vision, and being able to perceive 3D stereoscopic images.

V.1.2 Experiment Procedures

This experiment was done at IRLab in the Petty Science Building at UNCG. The study was done with each participant at a scheduled time. Before starting the investigation, the participant had to sign a consent form and fill out a background questionnaire. And a study ID was assigned for each participant for any data collection instead of their personal information, so this experiment maintains confidentiality.

To start the formal study, the experimenter explained the overall purpose of the study, how to wear and use the VR devices, what the participants would see inside the VR headset,

what the procedure of this experiment was, and what their role was in the experiment. Then the user stood at a specific point in the lab to wear the VR headset and controllers. At the same time, there was live casting from the VR headset to the computer so that the experimenter could observe what the user was doing and if the user could complete the given tasks or not, and the experimenter calculated the time spent on each task.

After ensuring that the participant got familiar with the VR HMD (Oculus Quest 2), the experimenter asked the user to complete ten tasks (one by one) by giving them instructions. The tasks are outlined below and ordered from the simplest to the most complex, with an expected average time between 30 to 60 seconds for each task.

The participants wore the VR headset to do the tasks. The headset was streaming to the experimenter's monitor/screen. After the experimenter had finished reading/explaining a task to the participant, the experimenter ran a stopwatch until the participant finished the task. Then wrote down the task number and spent time. This was done for every task until finished the ten tasks.

After finishing all tasks, the participant was asked to complete the post-study questionnaires: Slater-Usoh-Steed presence questionnaire (SUS), a System Usability Scale questionnaire (SUS), and a Perceptions questionnaire.

The tasks are ordered the same as the experiment, the participant didn't have any training for these tasks before the experiment, and the instruction were oral:

1. Select the third video from the recorded mode, then start.

2. Turn 90 degrees to the left to see the whole surgery room and ensure you can still see the videos.

3. Zoom in/out the patient data monitor video.

4. Pause the specific surgery video.

5. Go to the patient data monitor video and draw a circle over it.

6. Take a screenshot of what you annotated.

7. Act as if you are a doctor, indicate something important to other doctors in the specific surgery site video, then take a screenshot.

8. Display the last screenshot you have taken.

9. Open any video and draw anything, then delete what you draw.

10. Return to the main menu.

V.1.3 Participants

For this evaluation, six volunteers participated in the experiment, four had no vision issues, and two had strabismus. There were three females and three males, ages ranging from 18 to 44. Most of the participants (66.67%) rated themselves as slightly familiar with VR, while the rest were either not familiar with VR at all (16.67%) or moderately familiar with VR (16.67%). Five out of six participants claimed they never felt dizzy in virtual reality games or applications, while one sometimes felt dizzy.

V.2 Results

This section reports the evaluation results in four categories: completion time and success rates, system usability, perceived sense of being in the VR environment, and overall perceptions. All these results are based on the ten tasks and the post-study questionnaires mentioned in the previous section.

V.2.1 Completion Time

The first assessment tool to evaluate the ease of handling the user interface is by calculating the spent time in each task of the ten tasks by every user. All these numbers can be found in Table 4, which displays the time for each task by different users in a column.

Table 4. Completion Time Results

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 9	Task 10
User 1	19	12	27	5	107	n/a	65	12	10	5
User 2	27	5	13	10	27	44	43	18	17	6
User 3	36	15	12	40	33	32	9	5	66	4
User 4	12	13	37	21	10	46	41	3	21	5
User 5	13	15	24	9	36	64	37	8	27	3
User 6	8	9	27	9	17	52	26	9	22	4
Mean	19.16	11.5	23.33	15.66	38.33	47.6	36.83	9.16	27.16	4.5
Std Deviation	10.57	3.88	9.47	13.07	35.02	11.69	18.65	5.34	19.85	1.04
Min	8	5	12	5	10	32	9	3	10	3
Max	36	15	37	40	107	64	65	18	66	6
Median	16	12.5	25.5	9.5	30	46	39	8.5	21.5	4.5
1st quartile	11	8	12.75	8	15.25	38	21.75	4.5	15.25	3.75
3rd quartiles	29.25	15	29.5	25.75	53.75	58	48.5	13.5	36.75	5.25
STD Error	4.31	1.58	3.87	5.33	14.30	4.77	7.61	2.18	8.10	0.42

To analyze Table 4 into a plot shows the Mean of each task as solid column and how close the individual data values (time) are from the mean value (Std Deviation) is represented in Figure 23 below. In figure 23, the researchers use the Std Error instead of Std Deviation; while both look very similar in calculations, they represent two very different measures. Std Error illustrates how close a specific sample mean is to the true mean of the overall population.

Figure 23 represents tasks from one to ten on the X-axis and the average time users spend finishing each task in seconds (mean).

Figure 23 Completion Time Mean Ratings
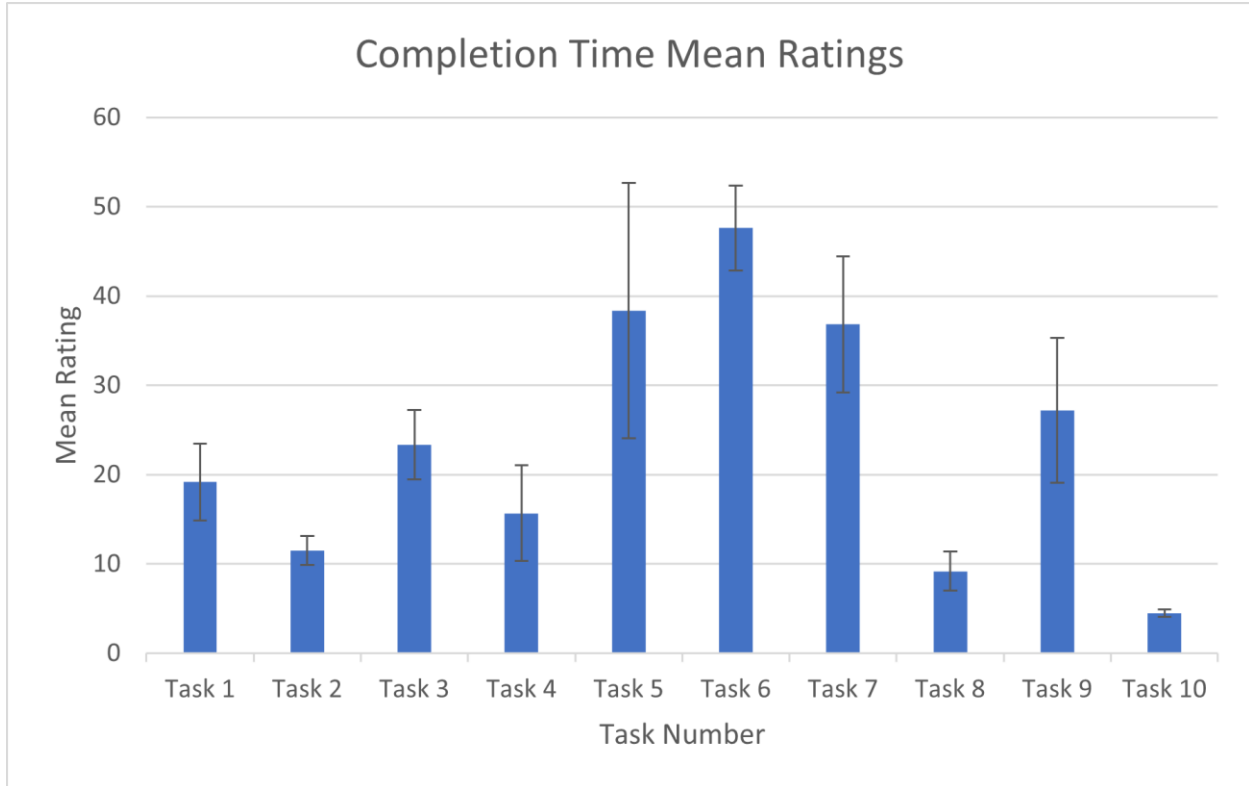
V.2.2 System Usability

The second assessment evaluates the effectiveness of the user interface by examining its usability. This depends on the System Usability Scale questionnaire (SUS) questionnaire and the rates of the participants' answers to questions from Table 2 above.

To get the advantage of this scale, it generates a single number for each participant, representing a measure of the system's overall usability.

To calculate this questionnaire in numbers, it is necessary to know its original scale is from strongly disagree = 1 to strongly agree = 5. The mean results of our experiment in the scale from 1 to 5 for each question is shown in Figure 24.

Figure 24. System Usability Scale Mean Ratings Per Question
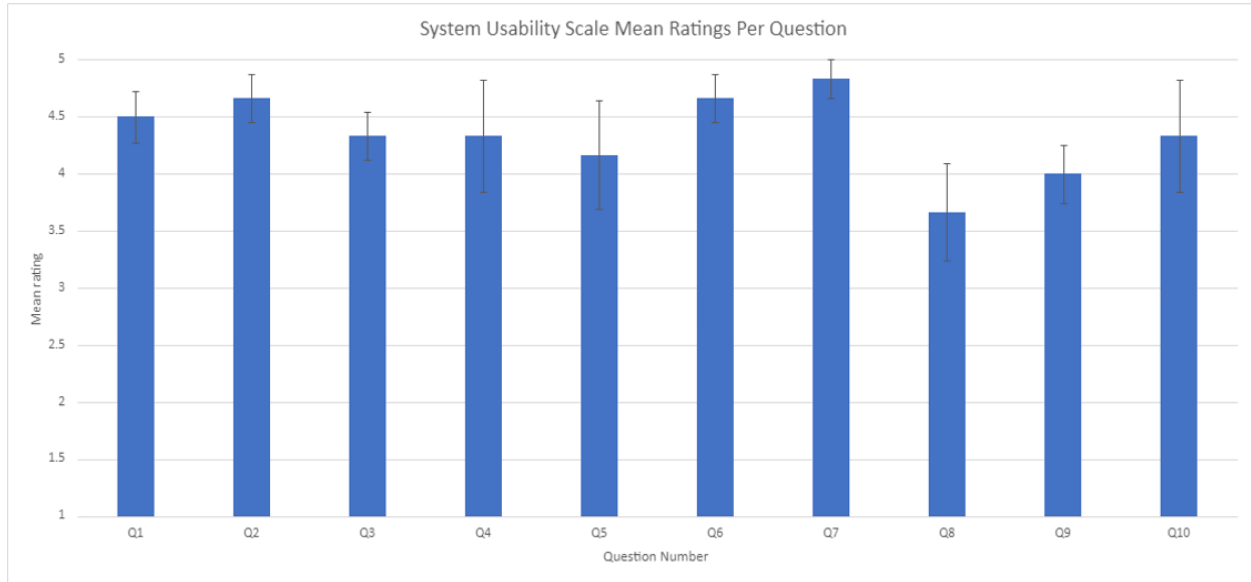
Each item's score contribution will range from 0 to 4 (not 1 to 5). To convert the responses in this questionnaire to this range, there are two roles: for odd-number questions (1, 3, 5, 7, and 9), the score contribution is the scale position minus 1. And for the even number questions scale is 5 minus the response, as shown in Table 5.

Table 5. System Usability Scale Questionnaire Results

Participants	Questions										SUS Score
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
User 1	4	3	3	4	4	4	4	2	3	1	80
User 2	3	4	3	4	3	4	4	3	3	4	87.5
User 3	3	3	3	1	1	3	3	3	3	3	65
User 4	4	4	4	4	4	4	4	3	3	4	95
User 5	4	4	4	4	4	4	4	1	4	4	92.5
User 6	3	4	3	3	3	3	4	4	2	4	82.5
Mean	3.5	3.6	3.33	3.33	3.16	3.66	3.83	2.66	3	3.33	-
Std Dev	0.54	0.51	0.51	1.21	1.16	0.51	0.41	1.03	0.63	1.21	-
Std Err	0.22	0.21	0.21	0.49	0.47	0.21	0.166	0.42	0.25	0.49	-

To find the overall SUS score value, multiply the sum by 2.5 to normalizing the scores and get results in range from 0 to 100. In this way the threshold is 68, any value under 68 is considered below the average, as represented in Figure 25.

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Figure 25. Overall Usability Scores

Overall Usability Scores
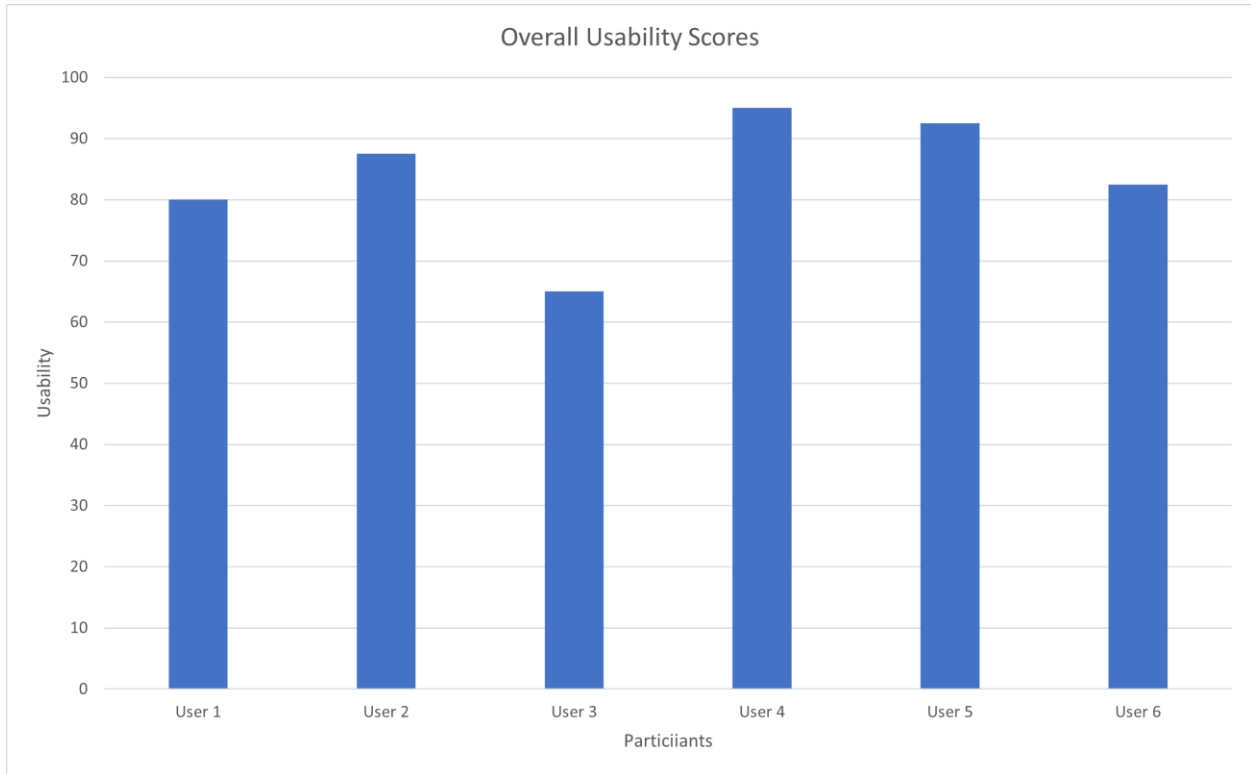
V.2.3 Presence in Virtual Environment

The third assessment depends on the Slater-Usoh-Steed presence questionnaire to evaluate the user's immersion in the virtual environment while using the application. This questionnaire consists of six questions found on the Usoh et al. (2000) research page 501 and Table 1 above. Each question has a scale from 1 to 7, where 1 is not at all, and 7 is very much. The results of the responses to this questionnaire are shown in Table 6. The mean of responses for each user is represented in Figure 26.

Table 6. Slater-Usoh-Steed Questionnaire Results

Participants	Questions					
	Q1	Q2	Q3	Q4	Q5	Q6
User 1	6	6	6	6	7	6
User 2	5	4	1	1	6	3
User 3	4	5	1	7	2	6
User 4	7	7	7	4	5	5

User 5	6	7	5	1	6	3
User 6	5	6	1	7	2	7
Mean	5.5	5.8	3.5	4.3	4.6	5
Std Dev	1.04	1.16	2.81	2.80	2.16	1.67
Std Err	0.17	0.19	0.46	0.46	0.36	0.27

Figure 26. Slater-Usoh-Steed Questionnaire Mean Ratings
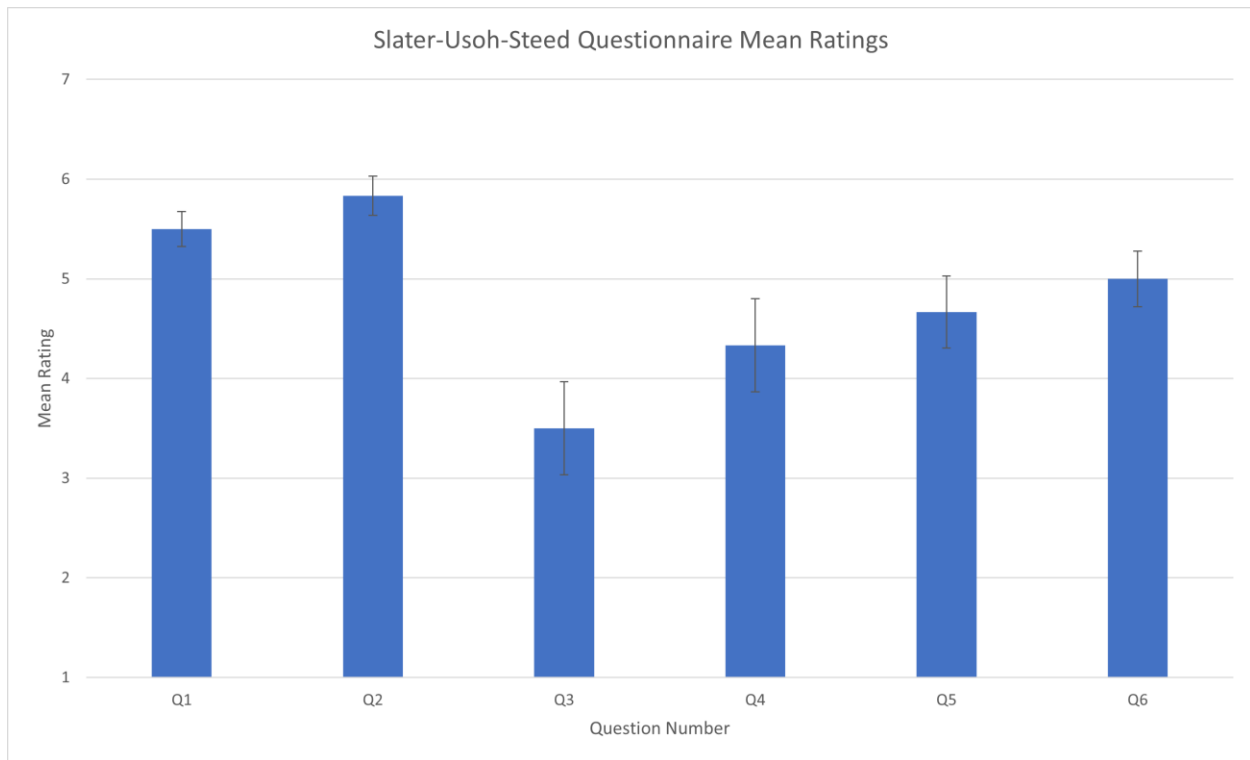
V.2.4 Overall Perceptions

The last assessment we used depends on the Overall Perceptions questionnaire we built, and all its questions are in Table 2. This questionnaire consists of nine questions, eight of them have a scale from 1 to 5. All the results we collected are shown in Table 7. And the average scales of each participant's answers are viewed in Figure 27.

Table 7. Overall Perceptions Questionnaire Results

Participants	Questions							
	Q1	Q2	Q3	Q4	Q5	Q6	Q8	Q9
User 1	3	3	4	4	2	5	4	4
User 2	5	4	5	5	4	4	5	5
User 3	4	4	5	5	4	4	2	2

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User 4	4	5	5	5	4	4	5	4
User 5	5	5	4	5	4	5	5	4
User 6	4	5	4	5	4	5	5	4
Mean	4.16	4.33	4.5	4.83	3.66	4.5	4.33	3.83
Std Dev	0.75	0.81	0.54	0.40	0.81	0.54	1.21	0.98
Std Err	0.30	0.33	0.22	0.16	0.33	0.22	0.49	0.40

Figure 27. Overall Perceptions Questionnaire Mean Ratings
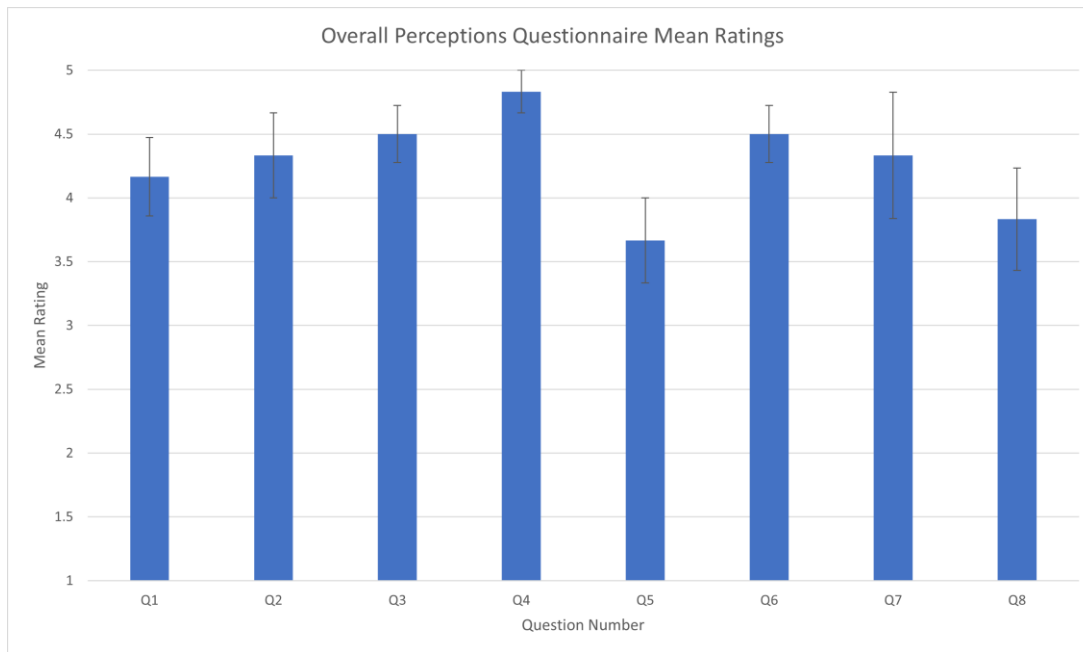
V.3 Discussion

This study's main goal is to move forward to make the Virtual Reality Remote Surgery Guidance project become real. This thesis does this by establishing high tested usability user interface and creating streaming connections between virtual reality applications and a web application. In addition, we experimented with evaluating the 3D user interface of the VR application, trying to have a high degree of usability, sufficient and helpful tools, and a sense of VR presence.

As mentioned before in the research questions and hypotheses:

RQ1. What is the overall usability of the VR software?

H1. The interface will be regarded as having a high degree of usability.

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RQ2. Are the VR user interface tools perceived as sufficient and helpful for the users to offer remote guidance to a surgery team?

H2. Users will perceive the VR user interface tools as sufficient and helpful

RQ3. Does the experience induce a sense of presence?

H3. Users will feel a high degree of presence during the VR experience.

Prior research found that the overall score of the System Usability Scale can be considered average at a score of 68 (*System Usability Scale*). The results of the overall System Usability Scale score indicate the usability of the User Interface (UI) was above the average for most of the participants. Besides, SUS mean rating per question is, on average equal to 4.5 out of 5. From Slater-Usoh-Steed, all the users were above the average in the results, which means the presence of being inside a virtual environment was good for the recorded video mode in the application, but sure with some notes.

In line with the hypothesis, there are many tools that the users found useful and helpful for annotation and connection to the doctors inside the surgery room. They assessed the icons as understandable, and the colors were harmonious and integrated.

We faced two types of implications in this experiment: experimental issues where the evaluation was done with seven participants but reported results for six participants only because one participant didn't take it seriously. And in the interface issues, there were many notes from the experimenter while observing the participants during the tasks. For example, five participants out of seven had a problem with drawing the first time especially drawing a circle, but this ratio was reduced, and drawing became easier the second time. None of the participants could get that the play/pause button takes screenshots; during the task, some participants kept trying/clicking on all buttons until they found it out, but others couldn't complete taking a screenshot task. All

of them didn't understand the logic behind making the play/pause button take screenshots. Furthermore, they were wondering why zooming out screenshots has a different way than zooming out the videos. This makes a bad user experience (UX) impression. Also, four out of seven participants, while trying to click on the patient monitor video to zoom it in, by mistake, clicked on the home button and got out of the application.

The participants in the questionnaire put some important notes to be considered; one of them saw that the videos were very responsive to his head movements, and he felt some discomfort and dizziness. Two other participants express their need for help or direct instructions when using this application. Although four participants found the surgery room from the video very similar to a real place, others declare that the video shape makes it look slanted.

Even though the results from the questionnaires about the sense of presence in VE results were acceptable, one participant commented that he/she felt small in their surroundings, and another said he felt like he was in the hospital, but nothing smelled like a real hospital.

Some recommendations to consider enhancing or fixing the user interface of the VR application: the first one is about fixing/changing the way of taking screenshots, may keep the play/pause button be able to take screenshots easier for the surgeon, but may add another button for screenshots only will improve the usability of UI. Second, change the position of the home button. Third, deal with the zooming in/out by using the same way and buttons for videos and screenshot to enhance the level of UX.

CHAPTER VI: CONCLUTION AND FUTURE WORK

This research aimed to create a virtual reality (VR) with a 360º video application that offers the first step toward connecting a remote surgeon from a developed country with a geographically distributed surgery room in an underdeveloped country. The main focus of this work was to create an efficient and usable 3D user interface for the remote surgeon. Based on quantitative analysis and surveys of the user interface in the VR application experiment, it can be concluded that the existing 3D user interface is easy to use but needs minor improvements in buttons and VR immersion sides. Moreover, the live communication mode of this application needs to be tested with an actual surgery room.

While the Unity game engine is a suitable choice for building a VR application, this approach found Unity Render Streaming (URS) package, which uses WebRTC, is the most efficient way to create live streaming between a VR application and a web application. Also, we made heavy use of the iterative design process through the design of several prototypes to discover the best one to be applied in the user interface for both sides: the VR application (surgeon side) and the web application (surgery room side).

In addition to all recommendations from the preceding chapter and to better understand the implications of this research's results, future studies could address many ideas and techniques that can be added to enhance this project and take it to the next level in the future as follows:

1. Test the project in an actual surgery room to examine the system's performance in real cases. This type of test should be done on a low-level complexity surgery, which doesn't need any instructions from a specialist. But this test aims to determine the effectiveness of communication between the surgeon and the surgery room during the actual surgery.

2. Instead of using a screen/monitor to communicate with the remote surgeon, doctors may wear Augmented Reality (AR) glasses. These glasses should allow them to see both the annotations from the remote expert and the surgery patient. Try closing the surgery room loop by using Augmented Reality (AR).

3. Find a way to show the remote surgeon to the doctors in the surgery room. Until now, the doctors inside the surgery room can only see the remote surgeon's interfaces without his face or reactions. So, finding a way to show the remote surgeon during the communication will motivate the surgery team.

4. Multiuser experience in the "View recorded video" mode in the VR. The main aim of this mode in the project is to give medical students and doctors a chance to watch or review recorded surgeries so that multiple users can watch and share learning from recorded surgery. Even more, this project would be used in classes where teachers and students tend and interact with videos via VR.

5. There is a technique called Depth Video Stream (Serrano et al., 2019), which could be used to enhance the remote surgeon environment. This technique immerses the specialist giving him the feeling of being with other doctors inside the surgery room.

   Returning to the main contribution of this work, which was to design the most efficient user interface possible for the Virtual Reality Remote Surgery Guidance project, this thesis addressed the project's first steps to bring it to light. In addition to running 360º videos from an Insta360 Pro camera inside VR applications, it could stream three videos and audio simultaneously. It could make successful streaming between Unity and web applications. Moreover, this application built a usable annotation system, which can draw many things and take screenshots. Finally, this work found a 3D user interface after a long prototyping process,

then executed the design. The last step was to test and evaluate its compatibility, ease to use, and immersion in VR.

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