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VR MEDICAL TRAINING: AN IMMERSIVE AND INTERACTIVE PLATFORM FOR SURGICAL SIMULATION AND ANATOMICAL EXPLORATION

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Abstract: VR Medical Training offers a realistic, risk-free environment where trainees can practice and refine their skills, including surgical techniques and procedural tasks. It is highly useful as a visualization aid, helping trainees understand complex medical procedures through interactive learning. The developed system provides a real-time 3D representation of various body parts in an immersive VR environment, offering structured learning tools through multiple interfaces and functionalities. Unity 3D serves as the foundation for creating the interactive experience, while Blender is utilized to develop anatomically accurate 3D models and animations of body parts and medical instruments. The key features of the application include instructions and tutorials displayed on a canvas, along with an incision guide for precise procedural practice. The platform significantly enhances medical training by providing an engaging, interactive, and effective learning experience.

Keywords: VR Training, Immersive Environment, Interactive Learning, Surgical Simulation

I. INTRODUCTION

Traditional medical education relies on textbooks and cadaver dissections, which, while valuable, have limitations in replicating real-life clinical scenarios and the dynamic functions of living human physiology. These methods are largely static and do not provide an interactive or risk-free environment for trainees to practice medical procedures. Additionally, medical students often lack exposure to a broad range of conditions in real-time, making it challenging to develop hands on expertise. There is a critical need for a safer, controlled training environment where students can refine their skills, gain confidence, and learn from mistakes without endangering actual patients.

The VR Medical Training platform addresses these challenges by offering an immersive, interactive, and risk-free learning environment. Built using Unity 3D and Blender, it features accurate 3D anatomical models, instructional tutorials, an incision guide, and real-time accuracy feedback to enhance procedural training. The platform includes a compact VR anatomy display, allowing users to explore human anatomy in detail and improve their spatial awareness of medical structures. By integrating advanced simulation technologies, VR Medical Training bridges the gap between theoretical knowledge and hands-on practice, empowering trainees to develop the skills and confidence needed for real-world medical challenges.

II. RELATED WORKS

VR has found applications in education, manufacturing, and emergency response. Realistic simulations provide safe, repeated practice in controlled environments, enhancing training effectiveness. Education is greatly aided by VR [3], especially in enhancing the understanding of abstract concepts and motivation among students. Software such as immersive programming trainers has proven to have positive impacts in usability and engagement. In medicine, the combination of VR and BCIs has produced innovative rehabilitation methods in gait training [4]. Such systems adjust to a patient's emotional status, increasing interest and the therapeutic outcome. For a study, subjects took part in a simulated lunar exploration where immediate feedback modifies the experience in terms of emotional reactions, resulting in enhanced muscular effort and therapeutic outcome by a large margin. This indicates the promise of adaptive VR environments in rehabilitation.

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According to Bassano et al [5], serious games and exergames utilize VR and Augmented Reality to amplify cognitive training and physical rehabilitation. These interactive computer programs monitor cognitive and motor function, providing individualized rehabilitation therapy. VR is also being developed for vocational and environmental rehabilitation for individuals with cognitive impairments [6]. Clinical trials show that increased immersion levels lead to higher levels of participation and better rehabilitation outcomes. Adaptability, however continues to be a problem, as a lot of systems do not have customization for specific patient requirements. Creating standardized yet flexible protocols would maximize VR's potential for customized rehabilitation.

In dentistry, VR is also improving data visualization for pre-surgical planning [7]. An advanced VR platform with ray marching volume rendering, enables experts to engage in real-time interaction with 3D dental anatomy through hand movements and controllers. Medical expert studies point to its ease of use and efficiency in enhancing surgical decision making, especially in oral and maxillofacial surgery. The other novel use consists of using auto-erased sketch communication cues within VR-based surgical planning. Studies[8] indicate that combining these cues with hand gestures and gaze pointers facilitates usability and understanding in addition to decreasing cognitive load. Using such functionality increases collaboration among healthcare professionals in VR environments. A VR-based simulator was created to instruct healthcare professionals on procedures like PPE use and nasopharyngeal swabbing [11]. Through the use of immersive technology, professionals can practice necessary skills safely without risking exposure to infectious environments, thus making VR a useful tool for hospitals and healthcare facilities. In paediatric therapy, interventions based on VR have yielded positive outcomes in attention and respiratory capacity among children diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) [12]. The study reported improvements in visual attention as well as pulmonary function across sessions. With the integration of gamification and therapeutic practice, VR offers a compelling and effective solution to cognitive and physical deficits in children with ADHD.

III. METHODOLOGY

The system uses VR technology to create an immersive and interactive 3D representation of human anatomy, providing users with a realistic training experience for performing surgical procedures and emergency response scenarios.

A. System Overview

Interactive VR Environment: The system is built on Unity 3D, a powerful game development engine that provides the core infrastructure for creating a dynamic and interactive virtual environment. The 3D environment includes various anatomical models of human body parts, such as organs, muscles, bones, and blood vessels, designed to simulate real-life medical scenarios. The platform offers an immersive experience where users can interact with the models using VR headsets and controllers, allowing them to practice various medical procedures in a controlled and safe setting.

Anatomically Accurate 3D Models: The system uses Blender to make and construct extremely detailed, anatomy realistic 3D models of the human body. The model provide accurate visualizations to help people understand the shape and structure of different body parts and how to interact with them in medical procedures. The models are animated to demonstrate physio rational processes, including blood circulation, organ mobility, and other essential biological functions, enriching it with a more engaging experience.

Learning Tools:

Instructions and Tutorials: Step-by-step instructions and tutorials are integrated into the VR experience, guiding users through different medical procedures. These instructions are displayed on a canvas in the VR environment, ensuring they are easily accessible while the user is engaged in practice.

Incision Guide: For surgical training, the platform includes a precise incision guide that helps trainees practice making accurate cuts on the 3D models. This guide assists in developing the skills necessary for real-world surgery, where precision is crucial.

Anatomy Display: VR Medical Training application includes a compact VR anatomy display to aid trainees in understanding human anatomy. This feature provides a simplified, interactive 3D representation of anatomical structures. Users can explore different body parts in detail, enhancing their spatial awareness of medical structures. The display is designed to complement training modules by offering a quick reference for anatomical visualization.

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Simulation of Surgical Procedures: The VR training platform allows the simulation of medical procedures such as a surgery. By interacting with realistic 3D models, users can practice the proper techniques for handling medical instruments, performing incisions, stitching wounds, and responding to medical emergencies.

Risk-Free Learning Environment: The VR system eliminates the risks associated with practicing on real patients. Trainees can repeat procedures multiple times without consequences, allowing them to refine their skills and gain confidence in their abilities.

User Interface and Feedback: The system is designed with an intuitive user interface that ensures ease of use, even for those with minimal experience in VR. The interface includes easy navigation controls, clear instructions, and accessible tools for modifying the training environment.

B. Implementation

The VR Medical Training App is designed to provide an interactive and immersive training environment for medical students and professionals. It allows users to practice surgical procedures in a risk-free, simulated setting while exploring detailed human anatomy. The system consists of a home screen where users can navigate to two primary modes: the Surgical Room and the Human Anatomy Scene.

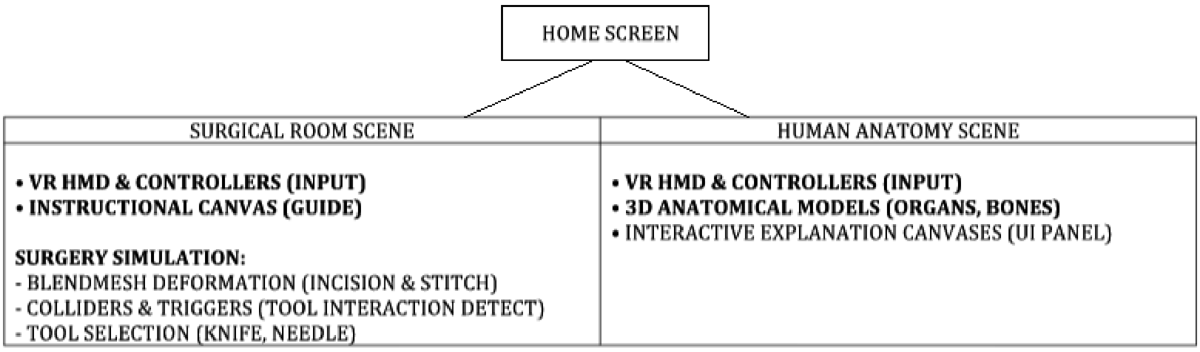

Fig. 1 Implementation Diagram

In the Surgical Room, users perform a leg surgery simulation on a 3D human model. A canvas panel provides step-by-step instructions, guiding users through the surgical process. The procedure involves picking up a surgical knife to make an incision and using a needle to close the wound. The BlendMesh deformation system dynamically modifies the leg's surface, making the incision and stitching realistic and responsive to user actions. Colliders and triggers detect interactions between tools and the leg model, ensuring accurate procedural execution.

In the Human Anatomy Scene, users can explore various 3D anatomical models of the human body. Clicking on buttons near body parts activates interactive explanations, which display detailed descriptions of their structure and function, improving anatomical knowledge retention.

C. Results and Discussion

The VR Medical Training App was tested on Meta Quest 2, ensuring an immersive and realistic simulation for medical trainees. The system demonstrated high responsiveness, with smooth interactions between virtual tools and the 3D anatomical models. The BlendMesh deformation system effectively simulated incisions and suturing, with minimal lag in rendering dynamic deformations. The 3D models of human anatomy and surgical tools were rendered in high quality, maintaining clarity during close interactions. The frame rate remained stable during both normal interactions and complex animations, including BlendMesh deformations. The system maintained consistent performance, ensuring a smooth and immersive user experience without noticeable drops.

Usability and Training Effectiveness

The app provides an intuitive user interface, allowing seamless navigation between the Surgical Room and Human Anatomy Scene. Step-by-step guidance through the canvas panel ensures that trainees follow the correct procedural workflow, improving skill acquisition. The interactive anatomical exploration enhances learning retention by providing real-time explanations upon clicking buttons near body parts. The simulation allows multiple repetitions of surgical procedures, reinforcing learning and enabling users to refine their techniques.

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Fig. 2 Home Screen

Fig. 3 Anatomy Display

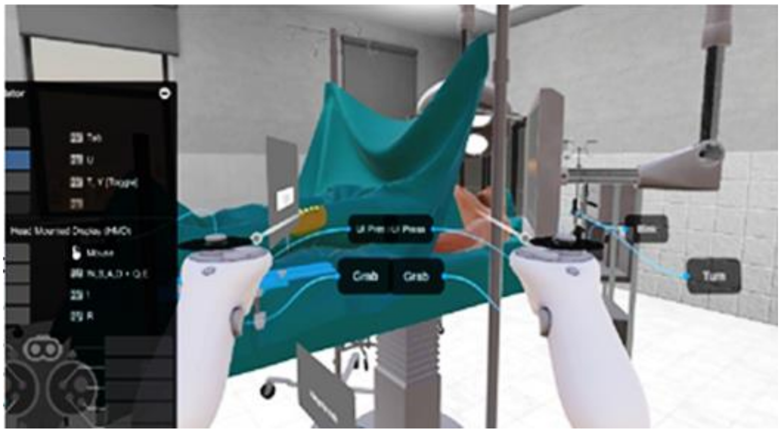

Fig. 4 VR Surgery

IV. CONCLUSION

The VR Medical Training app created successfully provided an immersive, interactive, and educational experience on Meta Quest 2. Its intuitive user interface ensures easy navigation, allowing even beginners to adapt quickly. Being optimized for standard hardware, the system eliminates the need for expensive equipment, making it widely accessible. Utilizing Unity 3D for real-time rendering and Blender for detailed 3D modeling, it delivers high-quality, realistic anatomical simulations. This combination creates an immersive, risk-free learning environment, enabling students to practice clinical skills effectively. Future improvements could focus on further optimizing mesh deformation and reducing processing overhead to maintain consistent frame rates.

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