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Virtual Immersive Training Model with Mixed Reality for Prosthesis Application in Orthopedics

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Abstract: Training medical professionals in Orthopedics faces several technical challenges. The equipment required for practical, hands-on training is often restricted to operating rooms. This constraint presents a significant issue, as developing the necessary skills to perform surgeries requires substantial practice time. This work developed a virtual training model using mixed reality, using a QR code to generate a virtual opaque hemisphere, within which the user operates two virtual tools that simulate an endoscope and a drill. A virtual monitor displays the endoscope's view to the user, who must then navigate the drill tip to successfully touch specific target cubes. The application has the potential to significantly enhance the orthopedic learning experience by reducing the time and resources.

1 Introduction

In the last decade, there has been a significant increase in technological innovation, especially in the field of Immersive Reality Products. Healthcare professionals have been looking for ways to apply these new technologies to support and improve procedures. Among these new technologies, Mixed Reality (MR) shows promise, with potential applications in medical training and education Gerup et al. (2020).

There has been a growing trend among Healthcare professionals to utilize Immersive Reality for these purposes Dhar et al. (2021), as it can be utilized to handle key problems in the training of medical professionals. This can be seen in the development of previous educational applications, which have utilized these new tools with great success Cercenelli et al. (2022), modernizing the field of medical education and leading to more interactive, engaging learning experiences for students.

In Orthopedics, the breadth of skills required to perform surgeries safely makes training new surgeons an exceptionally challenging and resource-intensive task. Beyond the extensive theoretical knowledge, there is a critical need for hands-on practical experience, especially in developing the fine motor skills necessary for precise surgical procedures. However, access to training equipment is often limited. The specialized tools and models required are typically confined to specific, often inaccessible rooms, and are not easily transportable. This restricts students' opportunities to practice, significantly impacting their ability to build the required expertise in a timely and efficient manner.

Mixed Reality Training Models enhances engagement through interactive, multi-sensory experiences, utilizing visual, auditory, and tactile feedback to create a more effective learning environment Freina and Ott (2015). The incorporation of immediate feedback mechanisms allows learners to monitor their performance in real time, facilitating quicker skill acquisition and mastery. Overall, this kind of models provide an innovative approach to training that maximizes learning outcomes while minimizing costs and risks.
The aim of this project is to use recent advances in Immersive Reality technology to create a virtual simulation environment that allows medical students to develop their motor skills, increasing the accessibility of the training exercises to medical students. The project also seeks to expand upon the existing training regiment, utilizing gamification concepts to increase the engagement of students with the training, which has been proven to increase the retention of knowledge and skills Condino et al. (2022).
This Mixed Reality Training Model for Prosthesis Application in Orthopedics can:
- Track the position and orientation of two physical objects: one to simulate the drill, and another to simulate the external camera.
- Create a Mixed Reality training environment that accurately simulates the real training environment.
- Allow the analysis and critique of user performance, applying gamification concepts.

2 Methods

There were several things to consider when it came to the properties of the simulator, perhaps most importantly the platform on which the app would be run. After researching the options available, it was decided that, for the purposes of this project, the Mixed Reality capabilities of the Microsoft Hololens2 would be best suited for needs. Head-Mounted displays are commonplace in similar applications of MR technology in the medical field Dhar et al. (2021). The Hololens2 also offers its own development kit that, together with the Unity Game Engine, streamlines the process of creating the Virtual Simulator.
Furthermore, there is the matter of positioning the training model within the simulation, with it having to be intrinsically tied to a place in the real world. The object used to position the training model should be portable and easily accessible, so it was decided to utilize a QR Code printed on a sheet of paper, whose tracking would be handled by a Third-Party framework known as Vuforia Engine, which is capable both of QR Code recognition and Object Tracking via its model target feature.
Lastly, there was the matter of what to base the simulator on. While there are already excellent Orthopedic Simulators in the market, like the Smith&Nephew Simulator, they suffer from a lot of the same issues as actual medical facilities, most notably being difficult to transport and not an accessible tool for most students. So, this project looked to the Smith&Nephew Simulator as a guideline to what an Orthopedic Simulator should provide to the user.
With these factors in mind, a Class Diagram was drawn that represents the architecture of the Simulator developed, and the differing ways in which the various components of the application interact with one another (Figure 1).

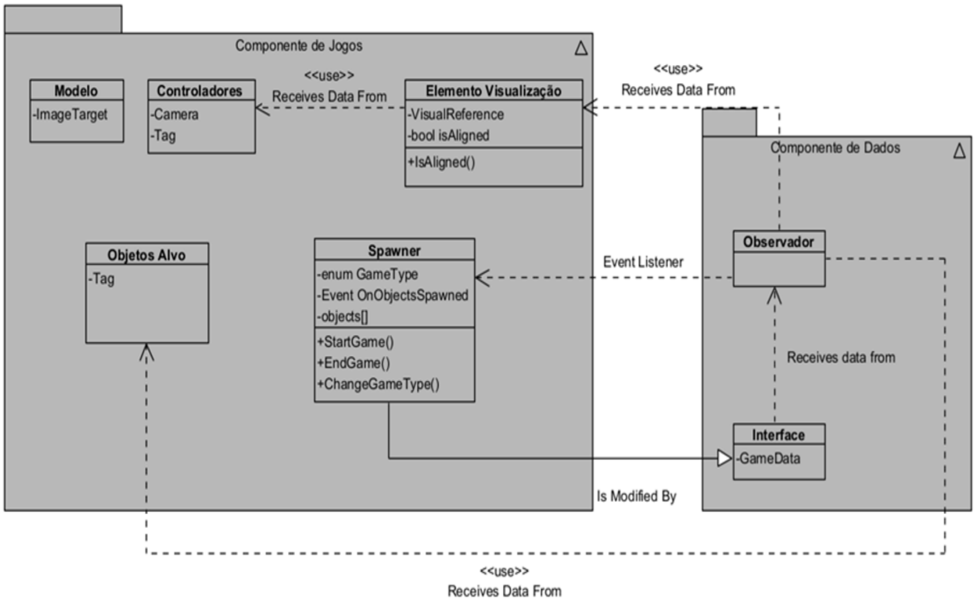

Figure 1 - Architecture of the Orthopedic Simulator (Class Diagram)

The application is divided in two components: the "Game Component", which handles the Virtual Simulation, from the spawning of target objects to the tracking of the controllers and the external simulated camera. Then, there is the "Data Component", which observes the many events occurring on the simulation and collects information, utilizing it to later review and display user performance. With this architecture in mind, a simulator was built where the user, utilizing medical tools overlayed over tracked physical objects, had to destroy target cubes contained within an opaque training model. The holographic tools in question simulate a drill, which will be used to destroy the target cube, and an endoscope, which will communicate with the external camera to offer the user a window into the inside of the training model (Figure 2).

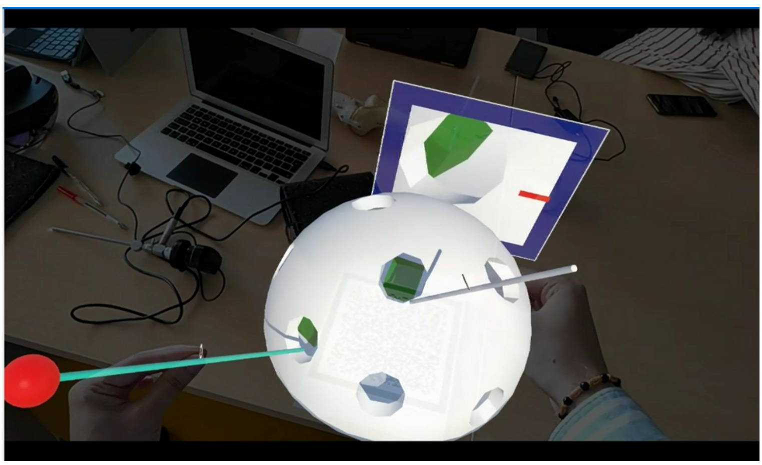

Figure 2 - Mixed Reality Orthopedic Simulator

3 Results

After the implementation of the simulation, a trial run was conducted with a small group who had never used the simulator before, as well as an Orthopedic Doctor who has been providing insight into the project. Through both of their feedback, the initial run of the simulator was determined to be a good starting point for the development of more complex training tools. However, it also has some key limitations, which limits its current effectiveness.

Track the position and orientation of two physical objects:

Although Vuforia supports the tracking of physical objects, this tracking is more appropriate for large, immobile objects (such as a car), so objects like a controller have a volatile behavior and are quickly ”lost” by the program. This behavior has a negative impact on the quality of the final product, due to the importance of tactile feedback when training surgeons. However, allow the rest of the application to be used normally.

This led to the decision to utilize virtual tools instead, which the user could grab using the device’s built-in hand-tracking. This is because the Hololens2 lacks accessible physical controllers, which while it reduces the number of accessories required, also means that there were very few options available to increase the haptic feedback of the simulator, which negatively impacted the user experience.

Create a Mixed Reality training environment that accurately simulates the real training environment:

The overall training environment was considered an appropriate recreation of the real training environment currently utilized in medical training. It allows the user to train controlling an object while looking only through an external camera without needing specialized equipment, which was one of the major drawbacks of the conventional training environment. The virtual controllers, while lacking in haptic feedback, were otherwise responsive and stable enough to allow precise movement from part of the user, and the sheet of paper was very easily tracked by the program, which made it work without issue even as the arms of the surgeon might partially obscure it.

This means that the simulator is a more portable, more accessible training environment for students, lessening the need for specialized training rooms with specialized equipment, and giving students easier access to these training tools.

Allow the analysis and critique of user performance, applying gamification concepts:

Over the course of a training session, the application constantly monitors their actions, recording certain key factors, like the precision of their camera movements, and scoring them based on user performance. It is then capable of displaying this performance, at any time, for the user to evaluate their progress.

Through the implementation of gamification concepts, such as scores, time assessments and number of targets destroyed, the simulator also provides a more engaging experience for the user, allowing them to keep track of their improvements over time.

4 Discussion

The trial run of the orthopedic training simulation, conducted with a small group and an orthopedic doctor, provided valuable feedback that highlighted both the potential and limitations of the initial design. A key issue encountered was related to tracking physical objects, specifically the controllers. While Vuforia can track large, stationary objects effectively, smaller, movable objects like controllers often become unstable and are quickly lost by the system. This instability directly impacts the training experience, as tactile feedback is critical in the development of surgical skills. The volatility of tracking led to a compromise, shifting from physical controllers to virtual tools that could be manipulated using hand-tracking built into the Hololens2. While this solution reduces the complexity and need for physical accessories, it also limits the haptic feedback, which is an important aspect of simulating the real-world feel

of surgical instruments.
The simulation environment itself was deemed an accurate recreation of current medical training environments. It offered a major advantage by allowing users to train with external cameras and virtual tools without requiring specialized equipment, a significant improvement over conventional methods that rely on fixed, high-cost training setups. However, the lack of sufficient haptic feedback in the virtual controllers did present a challenge in maintaining the level of realism needed for practical skill development. Despite this, the overall responsiveness of the system was sufficient for allowing precise movements, and tracking objects like paper sheets—often used as part of the training was effectively handled even when obstructed by the surgeon's arms.
Another positive aspect of the simulator is its portability and accessibility, offering students the ability to practice without needing access to fully equipped training rooms. This significantly broadens opportunities for learning and hands-on experience. The portability factor is a step forward in making surgical training tools more universally accessible.
The application also introduced gamification concepts, which enhanced user engagement. By monitoring user performance in real-time and offering metrics such as precision, time assessments, and task completion, the simulator provides immediate feedback that allows students to track their progress and improve over time. These elements of gamification add an interactive dimension to the training, making it more dynamic and potentially more motivating for users to improve their skills.
While the simulation system shows great promise as a training tool, especially in terms of accessibility and immersive experience, some limitations—particularly the loss of tactile feedback and the instability of tracking—must be addressed for the tool to reach its full potential in orthopedic surgical training. Continued refinement and the development of more advanced haptic feedback solutions could significantly improve the tool's effectiveness in replicating the real-world demands of surgery.

5 Future Developments

The main limitation of the work, and where it has the most room to grow, is the tracking of physical objects. Since this objective has not been realized, future work on the application should focus on achieving this goal, either through additions to the existing solution, like external marks to enhance Vuforia's Model Target recognition, or by applying new solutions that solve the tracking problem differently, such as utilizing controllers that communicate directly with the display.
Another point to develop is the addition of more complex training. With this application as a baseline, it is possible to iterate and evolve it to construct more intricate, complicated training models, which on top of the gamification concepts, should reduce the barrier to entry when it comes to performing more complex procedures.
As of the present moment, the current focus of the project is to port the simulator to a more modern Head-Mounted Display, like the Meta Quest 3, that should not only increase the overall performance of the program, but also provides the simulator with physical controllers with built-in haptic feedback, which allows for more accurate tracking of the users movements and increases the immersion of the simulator.

6 Conclusion

Immersive Reality is an ever-growing and innovative market, with new advancements being made every single day. Tools which were not available prior to the development of the simulator are now being released, and previously inadequate tools keep on improving their capabilities. Not only that, but the devices required are not only becoming more powerful than

previous iterations, but also cheaper and more accessible for the general public, which allows them to be used within educational environments that have a tighter budget, and can often be cheaper than acquiring specialized equipment for training.
Overall, the simulator shows great potential. Despite its limitations, it further points to the possibilities that are being unlocked with the growing technological innovation on the market, as well as the rise of Serious Games Condino et al. (2022), and tools that help medical professionals create them, like the MAGES 4.0 SDK Zikas et al. (2023), which increase the potential that these technologies have to revolutionize and improve the way that our medical professionals are taught, leading to more effective, better trained and more confident surgeons.
The simulator represents a promising advancement in orthopedic training, offering a more portable and accessible alternative to conventional training environments. However, there remain significant challenges in terms of tracking and haptic feedback that need to be addressed for the system to fully replicate the tactile experience of surgery. Moving forward, improving these technical aspects will be essential for creating a truly effective and immersive training tool that meets the needs of both novice and experienced practitioners.

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