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Mixed Reality in Surgery: Development of a Mixed Reality Application for Surgical Training

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Abstract: Mixed reality (MR) technology combines the real and the virtual world in an innovative way, where the users can see and interact with both worlds at the same time, having several applications in surgical practice, planning, and training. A MR application was developed to be used in a head mounted display (Microsoft HoloLens 2) for surgical training of the anterior cruciate ligament reconstruction surgery, with the aim of indicating the position of the femoral tunnel. This application was tested by 11 surgeons of the *Centro Hospitalar Universitário de Santo António*, who have all completed the simulation successfully, with an average time of under a minute. These surgeons answered an inquiry of satisfaction, where they all highlighted the potential that MR has in surgical training.

1 Introduction

By using mixed reality (MR) technologies, users are able to see and interact with both the virtual and the physical world simultaneously. Therefore, this kind of technology is suited to be used in surgery, where the surgeon could potentially interact with both virtual and physical structures, which could provide them with more information (Cartucho et al., 2020; Teatini et al., 2021).

There are several MR headsets, such as Magic Leap 2, Meta Quest Pro, with Microsoft HoloLens 2 being the one used in this article (Magic Leap 2, 2022; Meta Quest Pro, 2022; Microsoft HoloLens 2, 2019). This headset also has an Industrial Edition, certified to use in industrial environments (Microsoft HoloLens 2 Industrial Edition, 2021). Even though Microsoft HoloLens 2 cannot be sterilized, it can be controlled using voice commands; which means that, during surgery, the surgeons would not have to touch the headset, in order to control it (la lastra et al., 2022; Microsoft, 2019; Microsoft, 2019a). This tool has some collaborative applications, such as the Microsoft Dynamics 365 Remote Assist, and the Microsoft Dynamics 365 Guides; as well as some applications more related to healthcare teaching, such as VSI HoloMedicine (used for surgical planning and training) and Gig Immersive Learning Platform (used for medical students to learn relevant subjects) (apoQlar, 2017; GigXR, 2019; Microsoft, 2019; Microsoft, 2019b).

Unity is a platform used, among other employments, to develop MR applications, in C#. The Mixed Reality Toolkit is a relevant toolkit used for this purpose. Visual Studio is used combined with Unity (Unity, 2022; Unity, 2023).

In a state-of-the-art analysis, it was found that MR has a greater utility in visualizing 3D structures of patients, for instance, in surgical navigation (Cartucho et al., 2020). MR tools, such as Microsoft HoloLens 2, might also be used for surgical simulation (Palumbo, 2022). Surgical simulation is a highly beneficial tool when teaching medical students, increasing their confidence in the procedures (Jurado, 2017). Moreover, it could be useful to have the surgeons communicating in real-time with a surgical team present in another room; something that MR could be valuable in (Arshad, 2023). MR also has its utilities in surgical planning (Singh et al., 2014; Su et al., 2022).

The Anterior Cruciate Ligament (ACL) reconstruction surgery is performed when a patient tears their ACL, with the goal of replacing this ligament with a draft in the patient's knee. In order to achieve this, a femoral and a tibial tunnel are done. Arthroscopic techniques are common in performing this surgery. Guide wires are used before there is any drilling of the bones. However, the biggest cause of error, in this type of surgery, is a misplacement of the femoral tunnel. An MR application was developed, with the goal of assisting in positioning the femoral tunnel, to be used in the surgical training of the ACL reconstruction surgery (Balaji et al., 2023; Beach Orthopedic Specialty Institute, 2024; CUF, 2024; Physiopedia, 2023; Ronak Patel, 2023).

2 Methods

An MR application was developed using Unity Hub and Visual Studio (Unity, 2024; Visual Studio, 2022), in order to be used as a simulation tool for the training of the ACL reconstruction surgery.

First, models of a femur and a motor were obtained. Afterwards, they were cleaned using Blender (Blender, 2023). A project was created in Unity, and the 3D models were added, with scripts in order to make them able to be manipulated. Afterwards, 2 QR codes with text were generated (MOTOR01, for the surgical motor, and FEMUR01, for the femur (QR Code Generator, 2024). These QR codes were attached to the physical objects, and, in order for the virtual objects to be overlaid with the physical objects automatically, a project was cloned from GitHub, authored by Joost van Schaik (Joost van Schaik, 2023). This project allowed for the continuous tracking of QR codes through HoloLens 2. The project was modified, in order to be used in the surgical training, i.e., the models of the motor and femur had to be scaled, mirrored and rotated in order to be overlaid with the physical models. A script was also added, in order for the motor to be continuously tracked, without the need to reset the position of the QR code. Then, a green dot was added to the virtual model of the femur, in order to indicate the position of the femoral tunnel, according to Pearle et al. (2015).

The application had to be optimized. The number of triangles in the motor's mesh was reduced using Blender. This has increased the frame rate of the application, in order to be closer to the ideal (60 frames per second), and it decreased the GPU (Graphics Processing Unit) usage (from nearly 100% to approximately 40%). This indicates that the application is likely to be GPU bounded, meaning that it runs mostly on the GPU. Improving the polygon count, by decreasing the number of the triangles in the motor's mesh, improved the GPU usage. It would have been beneficial to also decrease the number of triangles in the femur's mesh; however, through Blender, the femur lost a lot of quality, thus making it more difficult to see the detailed position of the femoral tunnel (Intel, 2024; Microsoft, 2022; Microsoft, 2022).

This application was tested by surgeons of the *Unidade Local de Saúde de Santo António*. They followed a protocol, in which, at first, they would utilize an arthroscopic camera connected to a computer, in order to view a blue dot marked in the physical model of the femur, and hit the dot with a puncture tool; afterwards, they would repeat the procedure using the MR application, where, using the MR headset, they would hit the green dot in the virtual femur's model with the tip of the drill (both physical and virtual, since they were overlaid). The surgeons had to repeat this protocol 2 times, while being timed, in order to compare the simulation times.

13 surgeons in total have tried the MR application and have replied to an inquiry of satisfaction; however, two of them did not follow the exact protocol. Moreover, there was one surgeon who followed the protocol, but did not reply to the questionnaire. Therefore, 11 surgeons in total have followed the protocol and replied to the inquiry, so, they will be the ones to be considered.

The questionnaire had 4 sections in total. The first section was adapted from literature (CuraMedix, 2021), and the questions were about MR technology. The following section had the same questions as the NASA Task Load Index (NASA, 1988), but with a 5-point Likert scale (Susan Jamieson, 2023). The third section had questions about the Microsoft HoloLens 2, where the surgeons were asked about the level of comfort, among other relevant issues, such as if the holograms overlaid well with the physical objects. The final section was open ended, where users were asked for improvements and changes in the application. This questionnaire could have been fully standardized, to be able to compare results easily. A questionnaire, such as the User Experience Questionnaire (User Experience Questionnaire, 2005), could have been used; however, a more personalized approach was considered, since the goal was to have a tailored opinion from the surgeons.

3 Results

The time which the surgeons took to complete the simulation was measured, namely the time they lasted to complete the task with the arthroscopic camera (first and second iteration), and the time required for completing the task with Microsoft HoloLens 2 (first and second iteration). Overall, 4 average times were obtained, all under a minute. The average time spent to complete the first part of the simulation (arthroscopic camera) was 54.5 seconds in the first iteration, and 39 seconds in the second iteration. As for the time required with the Microsoft HoloLens 2, this was 20.5 seconds in the first iteration, and 18.5 seconds in the second iteration.

Therefore, the surgeons have generally decreased the time spent in the second iteration of both tasks, which points towards a better familiarity with the tasks. This could be important in a simulation setting, since it could demonstrate that the surgeons are learning.

As for the questionnaire, the surgeons agreed that MR tools would be worth investing in, and that this type of technology could be a benefit towards the patients and the hospital. The potential of these tools, according to the surgeons, relies mostly on surgical training.

Moreover, all the surgeons considered they completed the task using MR successfully, albeit with varying degrees of effort. Finally, they agreed that the Microsoft HoloLens 2 are easily adjustable, interactive enough, and are useful to be used in surgical training. Some surgeons highlighted that, sometimes, the application did not have a fast enough response (maybe if the surgeons had had some training beforehand in MR tools, it would have been beneficial; as well as having less triangles in the femur's mesh, in order to optimize it); and that the application could be more personalized for each patient, which would have been solved by using personalized models of the femur, obtained through imaging techniques.

4 Conclusion

The developed MR application was considered promising to the surgeons who used it. However, it could have some future improvements, such as being more personalized for each patient (by adding a 3D reconstruction step, using imaging data from the patients), and it could also indicate the direction of the femoral tunnel, instead of only its position.

As shown in literature and in the questionnaire, MR tools have potential to be used in healthcare, namely in the surgical training, and it could present benefits to the hospitals and the patients.

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