VR to Correct Valgus and Varus in Surgery Operations

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Abstract. This paper describes how to create interactions between the virtual world and the medical environment to solve one of the problems frequently encountered during the design phases of operations , highlighting the importance of this project in the realm of Applied R&D+i for high-detail, patient-specific medical operations. In particular, rotations and translations required to solve valgus and varus problems of the tibia and femur are analyzed. Currently, prostheses are produced using non-specific software that requires the presence of an external operator. A virtual reality (VR) application to improve the interaction between the software and the surgeon, thus simplifying the prosthesis design process, is presented.
The method proposed in this paper applies mechanical design to the medical field, starting from the principles of Industry 4.0 for human-machine interaction. Virtual Reality implements mechanical concepts such as the hinge and its function in virtual environments like Unity. This approach allowed us to limit the movement of an object in space to rotations around an axis defined by the end user, making these rotations 'parametric', i.e. traceable to finite mathematical values. It was demonstrated that the design of wedge-shaped prostheses for realigning the tibia and femur during surgery has been thus simplified.

Keywords: Virtual Reality, Augmented Reality, Training, Parametric Operation, Surgery planification.

1 Introduction

Over the last years, technological development has enabled the implementation of innovative approaches in multiple sectors, such as industry, biomedical field, architecture, or design of spaces. In this respect, technologies based on Virtual Reality (VR) and Augmented Reality (AR) are constantly growing. This is due to the improvement of hardware and the necessity to both supplement reality with further information, as in AR, and to create increasingly realistic simulations, as in VR. In this scenario, the present project aims to define a room in a virtual environment, in which the user can manage 3D objects that comes from CT (computed tomography) reconstruction to mimic a pre-operative phase. The images were derived from real medical cases, which were segmented using 3D Slicer to create accurate 3D models to be implemented in VR. The case study concerns the medical field, specifically orthopedics, and involves the creation of technological instruments to operate on a bone so as to solve misalignment problems.

2 State of the Art

2.1 Industry 4.0 and AR/VR

Recent advancements in industrial development have significantly enhanced design, manufacturing, and production tools, thereby increasing efficiency across sectors. These improvements are pivotal to the evolution of traditional processes into more sophisticated and efficient systems, leveraging technologies central to the Fourth Industrial Revolution (Schwab, 2016). Among these, Augmented Reality (AR) and Virtual Reality (VR) stand out for their unique ability to modify and enhance reality, fostering innovation and simplification in industrial applications (Boston Consulting Group, 2015). AR technology, as described by Microsoft (2023), overlays digital information onto the real-world using devices equipped with cameras and sensors. This blending of digital and physical realms enables real-time interactions and the accurate 3D identification of objects. Conversely, VR creates immersive environments where users can interact with both objects and the simulated space, offering a nuanced perception of surroundings (Lowood, 2023). The applications of AR and VR extend across various sectors, revolutionizing traditional methodologies. In product design and development, these technologies enable faster and more detailed visualization than conventional PC-based software, facilitating the prediction of robotic arm movements in fabrication (Johns et al., 2020). Maintenance processes also benefit from AR's ability to detect failures through sensors and provide interactive guides (Eschen et al., 2017), while VR environments serve as safe training grounds, evident in Rolls Royce’s engine maintenance and Airbus’s cockpit familiarization programs (Wen, 2023). Furthermore, AR and VR enhance assembly processes by offering direct volume perception and enabling a more effective study of assemblies (Seth et al., 2011), leading to improved quality control and production monitoring. These technologies enable real-time access to data, significantly enhancing operational efficiency. In the realms of marketing and sales, AR facilitates product visualization in real settings, enhancing consumer decision-making and engagement. Additionally, in logistics, AR tools have proven to increase efficiency and reduce errors, as demonstrated by DHL’s vision picking system (DHL Successfully Tests Augmented Reality Application in Warehouse, 2014). This broad utility underscores AR and VR as central to the contemporary industrial landscape, heralded by the Fourth Industrial Revolution and the concept of Industry 4.0 as “a collective term for technologies and value chains organizations” (Erboz, 2017). Positioned at the forefront of driving shifts towards more interactive, efficient, and interconnected systems, this study aims to exploit AR and VR in the medical field, creating virtual environments for parametric movement realization.

2.2 Case study

The selected case study pertains to children who experience complex lower limb deformities due to genetic or metabolic skeletal disorders, specifically severe pathological genu varum. This condition can manifest as a result of various diseases, including but not limited to Infantile Tibia Vara (Blount disease), rickets, achondroplasia, and different types of epiphyseal or spondyloepiphyseal dysplasia. Conventional treatment for these deformities can be challenging, often fraught with complications and a high risk of recurrence, making early and effective intervention vital. The advent of Virtual Surgical Planning (VSP) and 3D printing technologies (Alessandri et al., 2022) has revolutionized the approach to these complex cases. Figure 1 illustrates a 3D model with detailed annotations, including angles and measurements, indicating the planned areas for surgical intervention. The annotations show specific dimensions for cuts or alterations to the bone, essential for virtual surgical planning. These innovations offer several advantages, such as more accurate surgical outcomes, reduced operative times, and minimized blood loss, improving upon the results traditionally achieved with 2D CT visualization and 3D segmentation.

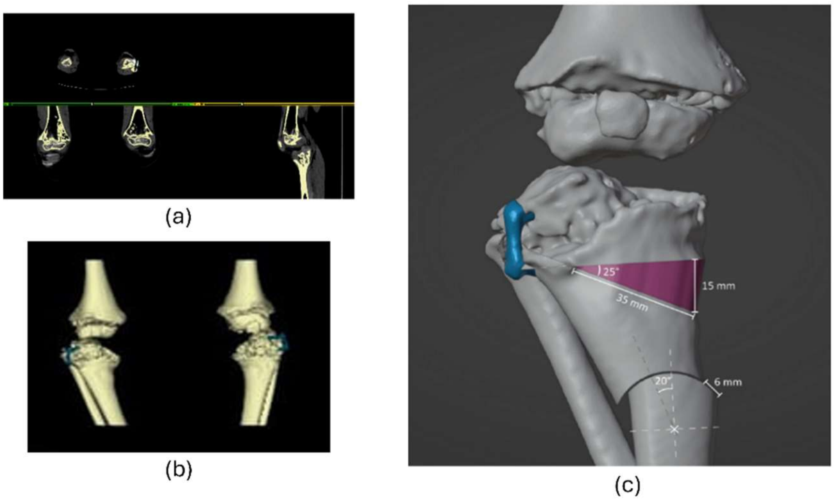

Fig. 1. (a) Shows the colored mask of a CT scan. (b) Depicts the 3D reconstruction of the CT scan from the segmentation process in (a). (c) Displays a preoperative analysis using Blender, which is a 3D software.

Moving forward the conventional 3D preoperative planning, this manuscript delves into the utilization of VR techniques for the prompt and precise correction of severe genu varum in pediatric patients. This technique aims to personalize the surgical process, adapting osteotomies and bone allografts to the individual anatomy of each patient. Through immersive VR, surgeons can engage with a fully three-dimensional, interactive representation of the patient's anatomy, enhancing their understanding and planning for the surgical procedure without the need of a specialized operator.

3 Methodology

The study concerns the development of a virtual reality (VR) room using Unity (version 2021.3.11f1), where the translation and rotation of the mesh are recreated to mimic a real pre-operative study. The headset used is HTC Vive Pro, which consists of a viewer and two joysticks that allow movement in the virtual environment.
The objective of the present work is to achieve not only relative movements and rotations between imported objects, but also cuts according to user-defined planes. The cutting of meshes by means of other meshes and the subsequent calculation of the new geometries that result from this process required a considerable degree of expertise in C# and high-performance computing.
Consequently, the study was limited to analysing the possibility of moving and rotating objects in a three-dimensional space, with such rotations taking place according to axes established and defined by the user. The scripting workflow is described in Figure 2.

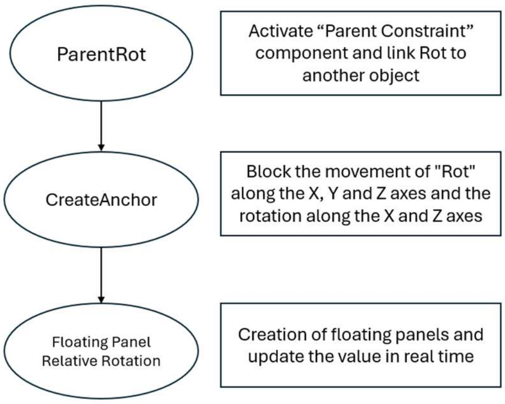

Fig. 2. Summary of the scripting workflow.

The process used to develop and implement a software for the VR, which would be focused on simulating dynamic object movements within a three-dimensional space, is described as follows. A standard component named "Parent Constraint" (PC) is employed to recreate the same type of constraint between two linked objects. The development of the script concerns the activation of this component during the Play mode and involves an object, named Rot, that can only rotate. Another feature of the script is the real-time definition of the object to be parented or unparented with Rot, thus enabling the rotation of only one object. This approach avoids the limitations of Unity during VR, which prioritize other processes and do not allow the use of parent-child to move two objects relative to each other.
The second script, named "CreateAnchor", addresses the limitation of movement along the axes X, Y and Z and rotation around the axes X and Z of Rot when a button that is connected to the script is pressed. This script is of equal importance to the previous one

because blocking the other movement and rotation only allows for the evaluation of the rotation along one axis. As a consequence, it is possible to calculate the angular rotation from the parented object between another.

The script was later applied to the case study. Initially, the mesh of the bone was imported, already cut along two particular planes, thus resulting in three parts: the upper part, designated as "Testa"; the central part, designated as "Centrale"; and the lower part, designated as "Corpo Osso". Subsequently, a floating menu was created with buttons to activate or deactivate the script "CreateAnchor" and to parent or unparent the part of the bone with "Rot".

The final stage of the process regards the development of a visual panel or auxiliary script with the objective of enhancing usability. Initially, a floating panel (Figure 3) was created for the upper and lower parts of the bone. Subsequently, a C# script served to calculate the relative rotation between the individual parts of the bone and the part "Centrale" along the three axes. In order to enhance usability, it was necessary to create a floating, directly linked to a C# script that could block or unblock both the movement and the rotation of the single part of the bone. The reason was to prevent any unwanted movements during rotations.

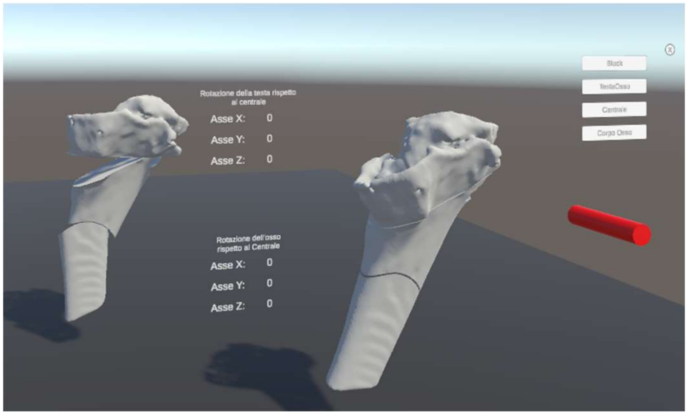

Fig. 3. An example of floating menu attached on the bones and the axis with its menu.

After ensuring functionality and addressing bugs, the project proceeded to field testing, marking a crucial phase in validating the proposed solutions and their application in dynamic simulation scenarios.

4 Results

The actual test consists of a misalignment problem on a tibia, resolved by a rotation in two separate points to bring the end of the bone back into the correct position. On a practical level, the process started with the uploading of a mesh from an external programme representing the portion of the tibia affected by the rotation, already divided into three sections (Figure 4). To assure the check on the whole procedure from a comparative perspective, the bone in the final position was also loaded.

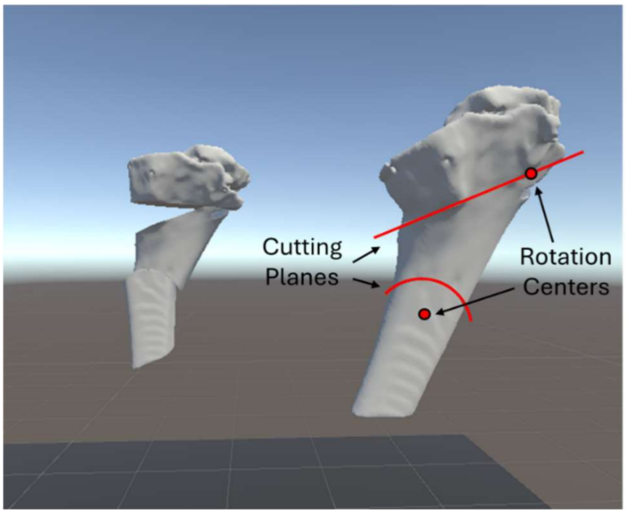

Fig. 4. On the left, the tibia in the final position as reference; on the right, the tibia in the initial position that can be manipulated in VR environment.

Firstly, the possibility to grab objects in a three-dimensional space, rotate them, and lock them in specific positions was tested. Secondly, the test was conducted on the scripts for the reciprocal locking of objects in relation to the rotation axis positioned by the user.

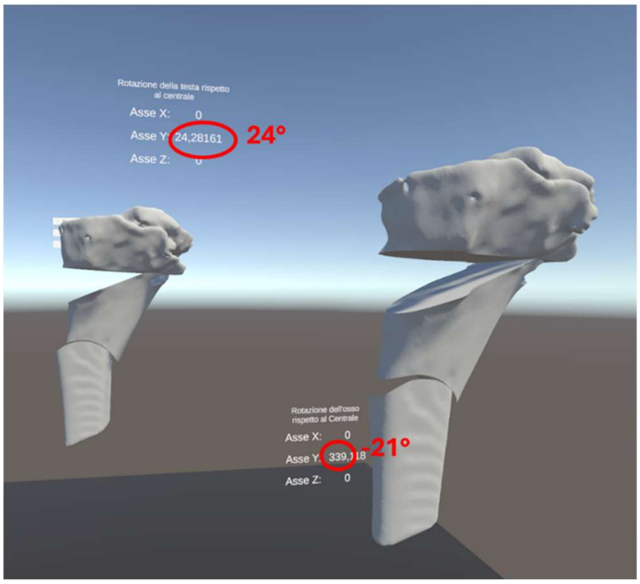

Fig. 5. The tibia in the correct position with data on rotations.

Thus, using the tools, the focus moved towards the positioning of the head of the bone by means of a rotation of 24° on the Y axis and -3° on the X axis in relation to the central part. Subsequently, the lower part of the bone was affected by a rotation of -21° on the Y axis and -3° in relation to the X and Z axes, referring to the central part once again (Figure 5). In this way, it was possible to replicate the actual result of the clinical case by working on a three-dimensional simulation, which allowed to see the effects directly.
Figure 6 shows that the use of virtual reality technology greatly facilitates the rotational manipulation of complex structures such as the showcased bone model. This is further highlighted by the side-by-side comparison between the Blender case and the VR case, where the ease and intuitiveness of VR's interactive environment are matched by the precision and reliability typically associated with Blender's detailed modeling capabilities. The concordance of results between the two platforms underscores the potential of VR as a complementary tool for accurate three-dimensional analysis enhancing the user-friendly experience avoiding the knowledge of complex 3D software.

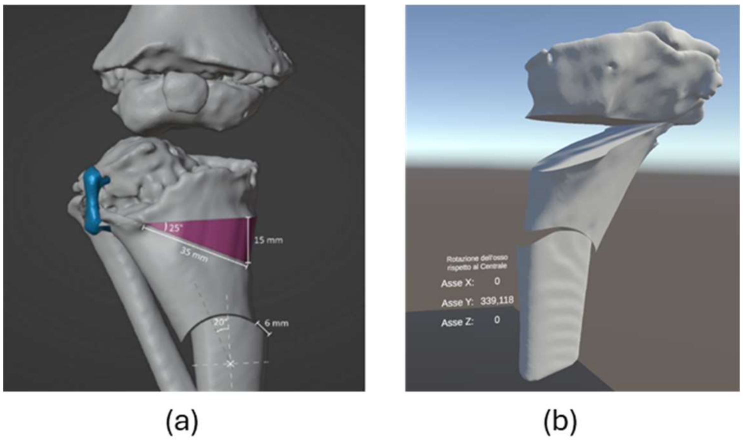

Fig. 6. Figure (a) shows a bone fragment model developed in Blender with highlighted selection, while figure (b) presents a virtually identical result in a VR Unity environment, demonstrating the model's consistent replication across different software platforms.

5 Conclusions

In conclusion, the aim of this study was to create an environment in which to work with meshes, being able to grab them with hands thanks to Virtual Reality tools and follow real bone movements in real world operations. Afterwards, it was possible to perform rotations of 24° at the head of the bone and -21° at the underside using peculiar tools.
According to future perspectives, tools to make cuts on the meshes and recalculate them will be furtherly developed, as well as to carry out Boolean operations that will also allow to change the shape of objects. In this sense, it is likely to approach parametric

design from a methodological point of view, which is already commonly used in CAD environments. While challenges remain in ensuring the precise positioning and accurate reconstruction of 3D models from CT scans, the integration of Mixed Reality in surgical environments holds substantial promise for enhancing real-time clinical practices. This technology offers the significant advantage of working with patient-specific anatomical details, providing surgeons with unparalleled accuracy and immediacy during procedures tailored to the unique needs of each patient.

References

1. Boston Consulting Group. (2015). Industry 4.0. BCG Global. https://www.bcg.com/capabilities/manufacturing/industry-4.0, last accessed 2024/02/10.
2. DHL successfully tests augmented reality application in warehouse. (2014, June). DHL. https://www.dhl.com/global-en/delivered/digitalization/dhl-successfully-tests-augmented-reality-application-in-warehouse.html, last accessed 2024/02/10.
3. Erboz, G. How To Define Industry 4.0: Main Pillars Of Industry 4.0. Managerial Trends in the Development of Enterprises in Globalization Era, Nitra, 761–767, (2017).
4. Eschen, H., Kötter, T., Rodeck, R., Harnisch, M., & Schüppstuhl, T. Augmented and Virtual Reality for Inspection and Maintenance Processes in the Aviation Industry. Procedia Manufacturing(19), (2017).
5. Johns, R. L., Anderson, J., & Kilian, A. Robo-Stim: Modes of Human Robot Collaboration for Design Exploration (pp. 671–684), (2020).
6. Lowood, H. E. Virtual reality (VR) | Definition, Development, Technology, Examples, & Facts | Britannica. Britannica. https://www.britannica.com/technology/virtual-reality, last accessed 2023/05/23.
7. Microsoft. (2023). What is Augmented Reality (AR) | Microsoft Dynamics 365. https://dynamics.microsoft.com/en-us/mixed-reality/guides/what-is-augmented-reality-ar/, last accessed 2024/01/07.
8. Schwab, K. (2016, January 14). The Fourth Industrial Revolution: What it means and how to respond. World Economic Forum. https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/, last accessed 2024/01/25.
9. Seth, A., Vance, J. M., & Oliver, J. H. Virtual reality for assembly methods prototyping: A review. Virtual Reality, 15(1), 5–20, (2011).
10. Wen, Q. (2023, January 25). What is mixed reality? - Mixed Reality. https://learn.microsoft.com/en-us/windows/mixed-reality/discover/mixed-reality, last accessed 2024/02/05.
11. Alessandri, Giulia, Leonardo Frizziero, Gian Maria Santi, Alfredo Liverani, Dante Dallari, Leonardo Vivarelli, Giovanni Luigi Di Gennaro, Diego Antonioli, Grazia Chiara Menozzi, Alessandro Depaoli, and et al. "Virtual Surgical Planning, 3D-Printing and Customized Bone Allograft for Acute Correction of Severe Genu Varum in Children" *Journal of Personalized Medicine* 12, no. 12: 205, (2022)