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# Augmented Reality in Robotic Mitral Valve Repair

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**Abstract.** Robotic-assisted cardiac procedures, especially mitral valve repair, benefit significantly from robotic devices, although positioning robotic ports in the chest currently depends solely on surgeon expertise. Augmented reality (AR) technologies have evolved to provide a composite view of the patient in the operating room with co-located virtual holographic representations of medical data, creating a more immersive surgical experience. This study aims to develop a preliminary AR prototype for testing in a hospital in Bergamo, Italy. From February to June 2024, an AR tool was developed to integrate AR HoloLens2® glasses with the Da Vinci® surgical robot, enabling surgeons to use CT scan holograms overlaid on patients for precise port positioning. The development focused on creating a Unity software integration and a custom 3D model of the patient's heart. Using Slicer3D® software, a pipeline was developed to create a 3D model from pre-surgical CT scans, which was successfully integrated into Unity for visualization on the patient's chest. The study demonstrated the feasibility of integrating AR into robotic-assisted surgeries, effectively combining technologies like DICOM, Unity, and Slicer for enhanced surgical workflows.

**Keywords:** Mitral Valve Repair, Robotic-Assisted Mitral Valve Surgery (RAMVS), Augmented Reality, Surgical Workflows.

## 1 Introduction

### 1.1 Context, scope and objectives

In heart surgery, precision is crucial, particularly when using advanced robotic tools like the Da Vinci system for minimally invasive operations. These surgeries require surgeons to accurately insert robotic arms, equipped with surgical instruments, through

small incisions in the thoracic area to have comfortable access to the heart. Surgeons then control these instruments remotely from a console, using hand commands to navigate and perform procedures within the patient's body. Optimal positioning of the small incisions is crucial for improving precision and outcomes. This paper aims to facilitate minimally invasive mitral valve surgery by incorporating Augmented Reality (AR) technology, specifically using HoloLens 2 glasses with the aim to guide the surgeon for positioning the incisions.

This research was carried out in the framework of a collaborative work between cardiac surgeons from hospital in Bergamo, Italy, and several European universities specialized in mechanical and computer engineering. The project aimed to explore how AR can be used to improve outcomes in robotic cardiac surgery, specifically the mitral valve surgical procedure. By using CT scans from Humanitas Gavazzeni Bergamo, Italy, the team tested how well these images can work with AR technology. This involves creating 3D models of the heart and ribs from CT scan DICOM files and superimposing these 3D models onto the patient's thorax. The incision ports are then positioned to see the area that can be operated by the Da Vinci Robot. This approach will help surgeons pinpoint the best places to insert the ports and arms of the Da Vinci robot. It offers a way to see how the tools are positioned in relation to the heart, which could greatly improve the accuracy of surgeries and reduce the need for additional incisions caused by mistakes, that could cause unnecessary trauma to the body. Essentially, the project seeks to demonstrate the practical benefits of integrating AR into surgical procedures, potentially setting a new standard in surgical precision.

Minimally Invasive surgeries (MIS) are favored over open heart surgeries due to their reduced risk and improved post-operative recovery. The increased risk in open heart surgeries stems from the procedure's invasiveness. The procedure involves opening the entire chest, breaking and cutting the thorax and diaphragm to make room for the placement of the polymeric ring. This will therefore increase the risk of the procedure because the whole open area is prone to infection. Furthermore, post-operatorial rehabilitation can be very dangerous as the many bones and incisions must heal without infection.

The mitral valve is a cardiac bicuspid heart valve positioned between the left atrium and the left ventricle, its role is to regulate the flow of blood between the two chambers, ensuring proper opening and closing of the valve lumen in perfect synchrony with the sinus heart rhythm. Mitral valve insufficiency or mitral regurgitation (MR) is characterized by the reversal of blood flow from the left ventricle to the left atrium, typically in the systolic phase of the cardiac cycle. It continues to be a significant issue in cardiovascular health worldwide.

The main surgical procedure is known as Annuloplasty (Figure 1). It is the placement of a complete or incomplete polymeric ring smaller than the annulus to reestablish coaptation of the margins [1]; it is often used in cases of type I MI or in combination with flap plasticity.

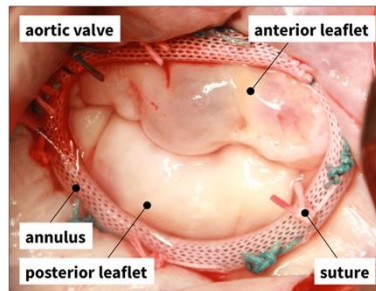


Figure 1 - Annuloplasty.

During robotic Minimally Invasive cardiac surgeries, two main surgeons are present: Primary Surgeon and Second Surgeon. The primary surgeon skillfully handles the surgical robot using joysticks, controlling the robotic arms inserted into the patient. The second surgeon assists at the surgery table, initially locating the incision points for the robotic arms and camera by palpating the patient to find the intercostal spaces (as shown in Figure 2). Once identified, the second surgeon makes three to four 8-10 mm incisions and one larger 1.2 cm incision to accommodate the robotic arms and instruments. Throughout the operation, the second surgeon remains at the table, performing tasks such as cutting excess stitching cord, removing fluid buildup, cleaning the camera, and stitching the incisions [2,3]. Additionally, a team of nurses and anesthesiologists supports the surgery.

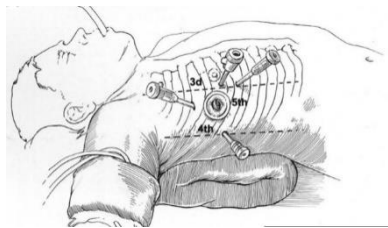


Figure 2 - Port Placement

## 1.2 Current process

Figure 3 shows the current procedure followed by surgeons. The surgical procedure starts by obtaining the CT scans the day prior to surgery, enabling the surgeon to gain insights into the patient's internal anatomy for precise planning. On the day of surgery,

the patient undergoes anesthesia, the patient is connected to a heart-lung machine for extracorporeal circulation and receives cardioplegia to halt heart activity. The surgeon then carefully examines the thorax to identify optimal entry points between the ribs, marking them for the robotic arms' incisions. Following the incisions, ports are placed to facilitate the docking of robotic arms. Subsequently, surgical instruments are introduced through these ports, marking the beginning of the robotic-assisted surgical process.



Figure 3 – New process (based on interview with surgeons)

To deliver the intra-atrial mechanical wrists containing needle holders, scissors, or tissue graspers, trocars are first placed in the third and fifth intercostal spaces during the procedure. This exposes the mitral valve. Then, through one of the 8 mm incisions a 3-dimensional camera inserted. After this, the annular closure can be positioned with the aid of a second surgeon. The primary surgeon then closes the exposed valve, and the secondary surgeon closes the entry points made for the ports of the surgical robot. The patient will enter the postoperative phase. Valve repair typically takes 3-6 hours.

Correct placement of these incision points is crucial, especially in smaller patients, as incorrect angles can limit the workspace of the lead surgeon. Currently, a marker is used to draw out the intercostal spaces as clearly seen in Figure 4 and Figure 5. These pictures were taken (with the permission of the medical team) minutes before the incisions were made. Here it can be seen how the second surgeon numbers the intercostal spaces and determines the entry points with bigger star like marks. Due to the anatomy of this patient in particular, the patient being 158cm tall, the incision points were of extreme importance. For this reason, using augmented glasses to visualize the intercostal spaces and other key features will undoubtedly help with the decision making.



Figure 4 - Intercostal spaces marked (side view)



Figure 5 - Intercostal spaces marked (top view)

### 1.3 Research Questions

In this research work, the following key questions were addressed:

- How can the positioning of incisions be anticipated to ensure the optimal placement of surgical instruments?
- What key elements must be considered to optimally place incision points?
- What tools or technologies appear to be effective and suitable for aiding surgeons in this preliminary stage of surgery?

To answer these questions, a comprehensive approach has been adopted, involving visits to hospitals to observe and analyze surgeries, as well as interviews with surgeons to gather insights and feedback. Based on this feedback, a new process is proposed after identifying any issues and refining the approach. The current process is compared with the new one, particularly focusing on how surgeons can utilize HoloLens technology. This comparison therefore helps to validate the efficacy of the new process. Moreover, to achieve comprehensive answers to the above-mentioned research questions, a state-of-the-art review in relevant areas is conducted to ensure the proposed approach is informed by the latest advancements and practices in surgical planning as well as augmented reality applications.

## **2 State of the art**

### **2.1 Augmented Reality Technologies in Minimally Invasive Surgeries**

The integration of Augmented Reality (AR) technologies into surgical procedures relies on the choice of display technologies, which are needed to provide clear visual information, ergonomic comfort, and compatibility with the surgical environment. AR display technologies are categorized into head, body, and world devices [4]. Head-Mounted Displays (HMDs) are often the preferred choice in surgical settings due to their user-friendly design, hands-free operation, and ability to overlay crucial visual data directly within the surgeon's line of sight, enhancing surgical efficiency and safety [5].

HMDs for AR can be classified as video see-through (VST) or optical see-through (OST). VST displays use special lenses that allow the user to view the real world through a camera. This camera's frames are combined with virtual objects. As such, the external environment is recorded in real time, and the final images, overlaid with virtual objects, are produced directly on the user's lenses. On the other hand, OST devices use an optical combiner or holographic waveguides. These lenses enable the overlay of images transmitted by a projector. This allows for normal visualization of the real world through the same lenses [4], ensuring that the user can still see the environment even if the system malfunctions. [6]

Since the introduction of HMD for AR, they have evolved from heavy, obstructive, and wired devices to become lighter, see-through, and wireless [22]. According to different reviews ([4], [7], [8], [5], [9]), for surgical use OST-HMDs are preferred, and of the available OST-HMDs the most widespread one is Microsoft's HoloLens (first and second generation), as it is one of the first complex and versatile pioneers on the

AR device market, accessible with relative ease [7] . Additionally according to multiple studies, the HoloLens 2, composed of high-quality materials, offering superior position tracking, exceptional hand tracking, and realistic 3D viewing, stands as the best head-mounted display headset for AR on the market [10] .

In high-precision surgical contexts, registration accuracy is crucial. Evaluations of user accuracy when performing clinically relevant tasks suggest that accuracies of approximately 2 mm are feasible. Current wearable AR devices, like the HoloLens, face challenges in aligning the displayed objects with the physical world. [11]. The HoloLens uses simultaneous localization and mapping (SLAM) for spatial tracking, but its tracking accuracy varies from several millimeters to more than a centimeter, thus not acceptable in surgical interventions [12], and it requires identifiable surfaces to work properly. Furthermore, the spatial maps generated by current generation of HMDs lack the accuracy needed for most clinical applications. Therefore, additional measures are necessary to ensure stability and correct image registration. [11]

Based on collecting reviews discussing software development for HoloLens ([10], [13], [14]), the most preferred and widely used development platform for building custom HoloLens applications is Unity, combined with the use of Visual Studio and Mixed Reality Toolkit.

## **2.2 3D Model Creation**

The process of converting CT scan data into 3D models, especially for the heart and thorax region, involves a sequence of steps utilizing software tools like 3D Slicer. The methodology for this conversion, outlining the critical phases of segmentation, volume rendering, and model refinement necessary for surgical planning [15].

After careful research and evaluation of various software options, 3D Slicer was selected as the preferred tool for converting CT scan data into 3D models, particularly for the heart and thorax region. This decision was based on 3D Slicer's robust capabilities and versatility in handling detailed medical imaging data. Its efficient importation of DICOM images, comprehensive segmentation tools, and advanced volume rendering techniques make it an indispensable platform for accurate 3D model generation. By leveraging 3D Slicer's powerful features, the process ensures meticulous anatomical representation, which is crucial for precise surgical planning and medical analysis.

The initial step in generating a 3D model from CT scans begins with obtaining a high-resolution, cross-sectional images of the patient's thorax. Then, through the recognition of key structures of the heart and chest, the 3D model can be built. Finally, to display the newly created model, the file is exported as a '.obj' file type to Unity.

### 2.3 Superimposition and Registration Techniques

Enhancing the precision of surgical instrument placement involves superimposing 3D heart models onto the patient's chest, aiming to reduce surgical errors and the need for follow-up incisions. Traditional procedures often rely on 2D scans but using HoloLens 2 allows for projecting accurate 3D images of the heart directly onto the patient's body. Tools such as Mixed Reality (MR) and the Mixed Reality Toolkit (MRTK) support precise positioning and stable 3D model creation. Various tracking and registration techniques for 3D models can be applied to improve surgical outcomes, enhancing accuracy and patient care [11][16][17][18].

Based on the research, the most suitable application for the project currently is the use of QR codes to bring the 3D model onto the patient, followed by manual alignment to position the model accurately. A built-in AR environment and localization tools help keep the model fixed in place. While these methods are somewhat effective, there is a need for more automated and precise solutions to further improve surgical accuracy and efficiency.

### 2.4 State of the Art Conclusion

From the review of the state-of-the-art technologies in augmented reality for heart surgery, we can conclude that the most effective approach to address the research questions involves the following steps:

1. Propose modifications to current medical process: Integrate specific steps dedicated to the generation of 3D volumes of patients' organs, enhancing the precision and accuracy of surgical planning and execution.
2. Develop an AR Application: Create a specialized AR application for surgeons using Microsoft HoloLens 2, Unity, Visual Studio, Mixed Reality Toolkit, and 3D Slicer. This application will aid in the visualization and precise placement of 3D heart models during surgery and port placement of the Da Vinci Robot, thereby improving surgical outcomes.

## 3 Methods and Materials

### 3.1 Participants

This project brings together a diverse team of two surgeons and six international students, combining their expertise in medicine, mechanical engineering, informatics, and electronics. The two surgeons at Humanitas Gavazzeni, Bergamo assisting the development team are: the primary surgeon who operates the Da Vinci Robot through a console, whilst the secondary surgeon assists at the surgery table and locates incision points. The core team consists of three students from the University of Bath, UK and Aalto University, Finland, enrolled in an international study abroad course provided by

Grenoble INP – Génie Industriel. They are supported by two students from Grenoble INP, France and one from University of Bergamo, Italy. Two professors from University of Bergamo and Grenoble INP – Génie Industriel coordinated activities with the hospital and the technical parts. The research is conducted at Grenoble INP Génie Industriel, utilizing the advanced resources of the G-SCOP research laboratory and the Vision-R platform. This collaboration aims to integrate and apply the students' varied skill sets to achieve innovative outcomes.

### **3.2 Hardware**

Microsoft HoloLens 2, released in 2019, is a cordless head-mounted device featuring a see-through visor, which permits users to interact with both the real world and digital overlays without any hindrance. The HoloLens 2 represents a significant improvement over its predecessor enhanced hardware and software include a broader field of view ( $43 \times 29^\circ$ ), reduced weight (566g), and extended battery life (3 hours). [10] Its intuitive interaction system, which includes head, hand, and voice controls, makes it particularly suitable for sterile environments such as operating rooms, where maintaining a sterile field is crucial. [19]

### **3.3 Software**

#### **Unity 2021.3.4f1**

Unity is a powerful and versatile game development platform widely used for creating both 2D and 3D games, as well as interactive experiences across a variety of platforms. Initially released in 2005, Unity has grown into one of the most popular and influential tools in the game development industry, known for its user-friendly interface, extensive asset store, and robust community support. [14] Unity's integrated development environment (IDE) is designed to be intuitive and accessible, providing a range of tools for asset management, scene creation, scripting, and debugging. The engine supports C# as its primary scripting language, which is widely used and appreciated for its readability and performance. [20]

#### **Visual Studio 2021**

Visual Studio is an IDE from Microsoft that supports multiple programming languages, including C#, which is the primary language used for scripting in Unity. Visual Studio is often used in conjunction with Unity because it provides a powerful environment for writing, testing, and debugging code. [21]

#### **Mixed Reality Toolkit**

Mixed Reality Toolkit (MRTK) is an open-source project that offers a set of components and features to speed up the development of mixed reality applications in Unity. Specifically designed to work seamlessly with Microsoft's HoloLens and other AR/VR

devices, MRTK includes a variety of scripts and components that simplify the incorporation of common Mixed Reality functionalities in projects. These functionalities include spatial interactions, gestures, and UI controls. MRTK is directly integrated into Unity projects, enabling developers to create more intuitive and refined mixed reality experiences. [22]

### **3D Slicer 5.6.1**

The choice of software for creating 3D models from medical imaging data depends on various factors, including the specific requirements of the task at hand, user expertise, available resources, and preferences. After thoughtful consideration here's why 3D Slicer might be the preferred choice over other software options:

Firstly, it is an open source and cost-free software. 3D Slicer is an open-source platform that is freely available to download and use, making it an accessible option for individuals and institutions that may not have the budget for commercial software licenses like Mimics. Furthermore, the community support benefits from a large and active community that contributes to its development. This includes a wealth of shared know-how, tutorials, and forums for troubleshooting. Moreover, 3D slicer is a multi-platform software thus it can run on multiple operating systems, including Windows, macOS, and Linux, ensuring broad accessibility for users with different system preferences. Finally, 3D Slicer is often utilized for research purposes due to its extensive analytical and visualization tools. It also has functionalities that are useful in clinical settings, such as preoperative planning and image-guided therapy.

However, it's important to note that while 3D Slicer may be advantageous for many users, there could be cases where other software packages might be more suitable, depending on requirements such as ease of use, specific features, performance, regulatory certification for clinical use, or integration with other systems.

## **4 Work and Development**

### **4.1 3D Model Generation**

#### **Format and Accuracy of 3D model**

The obtained CT scans are formatted in a '. DICOM' file type. This file type Digital Imaging and Communications in Medicine (DICOM) is a technical standard for the digital storage and transmission of medical images and related information.

#### **Thorax Segmentation**

To create an accurate 3D model, a good understanding of human anatomy must be known (Figure 6). This is due to the multiple heart and chest segments that will have to be individually recognized. Generally, for the 3D model, the more segments added to distinguish the better. However, too many segments may lead to some segments being

mixed up. A balance must be struck. In this project, the list of segments that provided a high-quality 3D model whilst keeping it manageable are:

- |                            |                   |                 |
|----------------------------|-------------------|-----------------|
| 1. Heart                   | 7. Left Clavicle  | 13. Right Rib 3 |
| 2. Aorta                   | 8. Right Clavicle | 14. Right Rib 4 |
| 3. Pulmonary Venous System | 9. Left Rib 3     | 15. Right Rib 5 |
| 4. Left Atrial Appendage   | 10. Left Rib 4    | 16. Right Rib 6 |
| 5. Superior Vena Cava      | 11. Left Rib 5    | 17. Right Rib 7 |
| 6. Inferior Vena Cava      | 12. Left Rib 6    | 18. Sternum     |

Using the segment editor, various segments for different parts of the thorax are created and named accordingly. The paint option is used to color each segment for better recognition. The 'Grow from seeds' option is then selected to generate a 3D representation of the painted segments. Once completed, the 3D model is ready for export as shown in Figure 7.

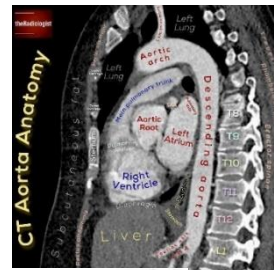


Figure 66 - CT scan labeled.

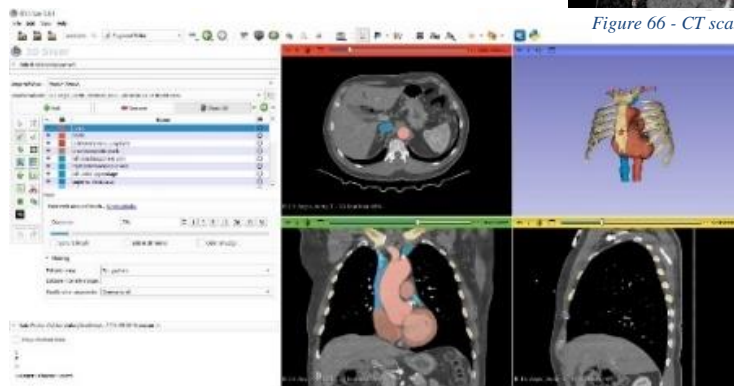


Figure 77: Segmentation Screen

#### 4.2 Scaling using reference points

For correct placement of the 3D model, three reference points are used. These will be located on the Right/Left Clavicles and sternum. The patient will be attached with three special radiosensitive objects before taking the CT scan. The position of these objects will then be marked on the patient's thorax. The radiosensitive objects are then recognized in 3D Slicer to create the reference points shown in Figure 8, by adding a new segment and naming it accordingly.

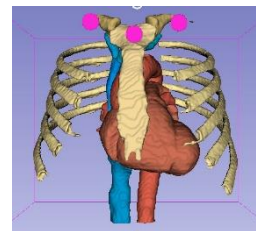


Figure 8 - 3D Model with References

The three circles acting as reference points in the 3D model are used to align with markers on the patient's thorax, serving as a scaling method to ensure the 3D model matches the patient's actual size.

### **4.3 Importing 3D Model to Unity**

Upon creating a 3D model in 3D Slicer and exporting it into Unity in a '.obj' format, it becomes apparent that the coordinate system and origin of 3D Slicer models differ from those in Unity. This discrepancy results in the 3D model being placed at random coordinates within Unity. To resolve this issue, a parent object called "Root" is created in Unity. The 3D model is then made a child object of this Root, which aligns the model with the correct coordinate system. By following the Root object's coordinates, the 3D model is accurately positioned within the Unity environment, ensuring consistency and precision.

### **4.4 Development in Unity**

#### **QR Code Tracking**

HoloLens 2 is used to scan the surroundings to find QR codes and precisely place 3D models by utilizing built-in cameras, along with the MRTK extensions and the NuGet package manager. The system uses the MRTK extensions to retrieve the spatial information associated with a QR code once it has been recognized.

#### **Manipulation of 3D Model**

To manually resize and move the 3D model once it is positioned over the QR code, several components are added to the parent object of the 3D model. These components include a rigid body, box collider, near interaction grabbable, and object manipulator. These additions allow the 3D model to be accurately superimposed over the patient's body by matching the reference points on the model and the patient. To assist the surgeon, two buttons are provided: one to fix the model in place once it is accurately superimposed and the surgeon is ready to proceed to the next step, and another to move the model if further adjustments are needed. This ensures precise alignment and flexibility during the surgical procedure.

#### **Ports Placement**

A button is provided to select the hand that will be used for port placement. Based on the chosen hand, the index finger of that hand receives a sphere collider, enabling the surgeon to place incision ports onto the 3D model using hand and voice commands. Each port is visually represented by a shaded cone at its end, illustrating the surgical area covered and ensuring that tools can easily reach the necessary areas during the procedure. Utilizing the built-in MRTK functionality, the centers of the ports are fixed, but they can be rotated to view different angles, allowing for precise and flexible planning of incision points.

### Issues Faced During Development

During the project, several issues were faced, including installing the correct version of Unity compatible with HoloLens 2, adapting the coordinate system of 3D Slicer to Unity, and resolving scaling issues through trials to view the model in the AR environment and align it with the patient's body. The development process was also constrained by time and a steep learning curve, which limited the efficient use of external libraries. These challenges required considerable effort and learning to overcome, impacting the overall development timeline.

## 5 Results

### 5.1 New process

To address the issues encountered during surgery preparation, the project introduces a new solution that utilizes HoloLens 2 to project a 3D model of the heart onto the patient's chest, created from their CT scans. These proposals have as consequence the generation of a new medical process (Figure 9).

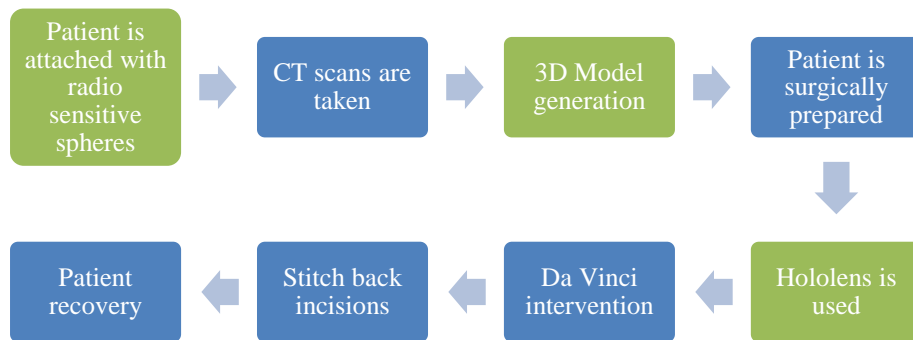


Figure 9 - New Process workflow

First, the patient is attached with radio sensitive spheres. These radio sensitive spheres will help create the three reference points. After the CT scan is taken, the spheres will be removed, and their location will be marked with a pen on the patient's body. After this, the CT scan files will be exported, and a 3D model of the patient's chest and heart will be generated. After the patient has been surgically prepared (put through external circulation and ventilation) the augmented reality glasses are used. The surgeon will be able to see a holographic representation of the patient's heart and chest. Following this, the surgeon can place virtual incision ports onto the chest, to visualize the surgical area covered by it. Using this information, they will decide precisely where the entry points for the Da Vinci robot must be made. The surgery will then begin.

## 5.2 Process during the use of HoloLens 2

On the day before surgery, a 3D model is created using the patient's CT scan DICOM files and imported into the Unity software, then deployed to the HoloLens 2. After preparing the patient for surgery, the surgeon wears the HoloLens and begins the procedure.

First, the hand selection menu appears as shown in Figure 10 and 11, allowing the surgeon to choose the preferred hand used later for port placement. A QR code placed on the patient is scanned using the built-in cameras to position the 3D model onto the patient (Figure 12 & 13). The model is manually resized and aligned using hand gestures to match the reference points on the patient's body (Figure 14). Once the surgeon is satisfied with the alignment, the “Fix Model” button is clicked in the floating menu, securing the model's position in the AR environment (Figure 15), and removing the box collider for a clear view. If further adjustments are needed, the “Move Model” button can be used to reactivate interaction with the model.

With the model correctly superimposed and fixed, the surgeon uses the index finger of the selected hand to mark points for port placement. By positioning the finger at the desired location and using the saying “Place,” a virtual port with a conical shaded area is placed (Figure 16), indicating the surgical area that the Da Vinci Robot’s tools can cover. The ports can be rotated to view different angles, with the center fixed to a point, acting as the axis of rotation. If a port is misplaced, the surgeon can hold the end of the port and say “Remove” to delete it from the virtual environment (Figure 17). This process allows the surgeon to visualize and confirm the optimal locations for incisions, minimizing errors and unnecessary cuts, thereby reducing trauma to the patient.

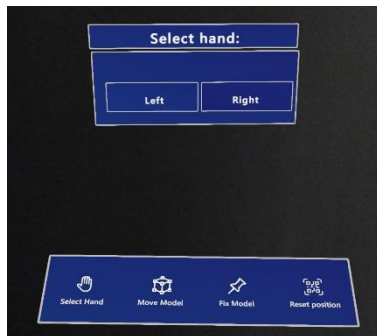


Figure 11 - Hand Selection Menu

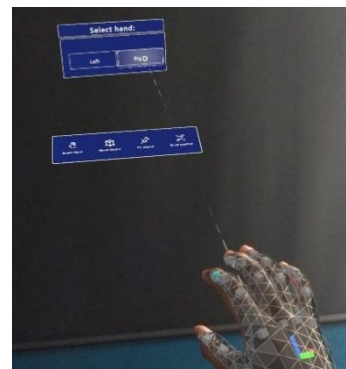


Figure 10 - Selecting Gesture



Figure 13 – QR Code

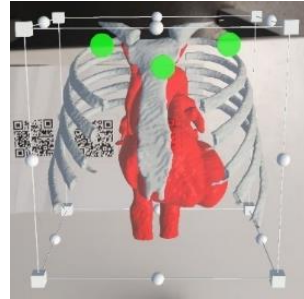


Figure 12 – 3D Model Superimposed

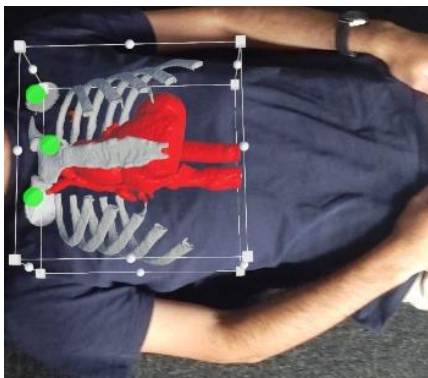


Figure 14 - Move Model



Figure 15 - Fixed Model

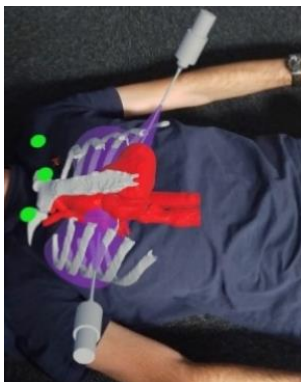


Figure 16 - Ports Placement Using Voice Command



Figure 17 - Ports Remove Using Voice and hand Commands

## 6 Discussion

Due to the team's minimal knowledge of human anatomy, building the 3D model proved to be tedious and time-consuming. The process required the students to learn and practice multiple times to achieve accurate results. Even after thoroughly understanding the procedure, it remains lengthy, and repeating it for every patient's CT scan can be repetitive and tiring.

The hardware is also a limiting factor for this project. Although the HoloLens 2 was a technological breakthrough in augmented reality glasses, it is becoming outdated and lacks the high precision needed for superimposing 3D models and self-localizing in the AR environment. The five-year-old device sometimes struggles with accuracy, particularly in recognizing smaller objects within the 3D environment through its mesh collection system. This is especially problematic in an operating theatre, where the patient is surrounded by many surgical tools and machines.

The current method employs built-in cameras to scan QR codes using the Mixed Reality Toolkit (MRTK) and NuGet functions. However, the effective scanning range is limited, forcing surgeons to bend closer to the QR code on the patient, which is not ideal.

The current project relies on manually superimposing the 3D model onto the patient by aligning reference points on both the patient and the 3D model. This method helps with scaling issues but is time-consuming and less accurate. Additionally, the surgeon must master the hand gestures of the HoloLens 2 and patiently position the model, which can lead to frustrations and minor delays if not done correctly.

The project could not be tested during surgery, limiting the opportunity for professional feedback, particularly in validating the positions of the 3D models. Without real-world application testing, the exact placement of the 3D models couldn't be properly verified. Additionally, the project wasn't tested with different CT scans, which could affect the accuracy of the 3D models and potentially reveal unforeseen errors. Testing in a surgical room would have provided insights into how different light intensities and CT scan variations impact the project's effectiveness.

## 7 Conclusion and perspectives

The study explores the integration of AR with robotic-assisted mitral valve repair, focusing on the use of HoloLens 2 glasses to enhance surgical precision. The project developed a preliminary AR prototype that works by manually overlaying 3D models of the heart, created from pre-surgical CT scans using Slicer3D software, onto a patient's chest. It also simulates incision port placement, aiming to improve the accuracy of port placement for the Da Vinci surgical robot, reducing the risk of errors and the need for

additional incisions. The AR application enhances visualization and decision-making, offering significant potential to standardize and improve surgical outcomes. This paper also proposed a set of new steps that are to be integrated into the current surgical procedure in order to accommodate for the new technologies.

From a perspective standpoint, integrating AI-assisted tools to automate recognizing different heart structures could significantly streamline the process of creating 3D models from CT scans, making it more consistent and efficient. Utilizing specialized markers such as Vuforia or ArUco, known for their high precision, accuracy, and range, could greatly enhance the superimposition of models onto the patient. Automating this process through marker-based calculations would allow for precise scaling and direct superimposition, resulting in a faster and more efficient workflow compared to the current manual alignment method. Additionally, simulating different Da Vinci robot surgical tools in the AR model would provide valuable visualization of how these tools would function during surgery. The project's adaptable nature ensures it can be easily transferred to a more advanced device as soon as one becomes available, thanks to its high compatibility with different types of software.

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## 9 References

1. N. B. Langer and M. Argenziano, "Minimally Invasive Cardiovascular Surgery: Incisions and Approaches," *Methodist DeBakey Cardiovascular Journal*, vol. 12, no. 1, pp. 4–9, Jan. 2016, doi: <https://doi.org/10.14797/mdcj-12-1-4>.
2. L. W. Nifong *et al.*, "Robotic mitral valve surgery: A United States multicenter trial," *The Journal of Thoracic and Cardiovascular Surgery*, vol. 129, no. 6, pp. 1395–1404, Jun. 2005, doi: <https://doi.org/10.1016/j.jtcvs.2004.07.050>.
3. Y. J. Woo and E. A. Nacke, "Robotic minimally invasive mitral valve reconstruction yields less blood product transfusion and shorter length of stay," *Surgery*, vol. 140, no. 2, pp. 263–267, Aug. 2006, doi: <https://doi.org/10.1016/j.surg.2006.05.003>.
4. E. Barcali, E. Iadanza, L. Manetti, P. Francia, C. Nardi, and L. Bocchi, "Augmented Reality in Surgery: A Scoping Review," *Applied Sciences (Switzerland)*, vol. 12, no. 14, Jul. 2022, doi: [10.3390/app12146890](https://doi.org/10.3390/app12146890).
5. M. Doughty and N. R. Ghugre, "Head-Mounted Display-Based Augmented Reality for Image-Guided Media Delivery to the Heart: A Preliminary Investigation of Perceptual Accuracy," *J Imaging*, vol. 8, no. 2, Feb. 2022, doi: [10.3390/jimaging8020033](https://doi.org/10.3390/jimaging8020033).

6. L. Qian, J. Y. Wu, S. P. Dimaio, N. Navab, and P. Kazanzides, "A Review of Augmented Reality in Robotic-Assisted Surgery," *IEEE Trans Med Robot Bionics*, vol. 2, no. 1, pp. 1–16, Feb. 2020, doi: 10.1109/TMRB.2019.2957061.
7. K. Moga, D. B. O. Boesl, and T. Haidegger, "Augmented/Mixed Reality Technologies Supporting Digital Surgery," in *SISY 2021 - IEEE 19th International Symposium on Intelligent Systems and Informatics, Proceedings*, Institute of Electrical and Electronics Engineers Inc., Sep. 2021, pp. 183–189. doi: 10.1109/SISY52375.2021.9582533.
8. M. T. Vervoorn, M. Wulfse, T. P. C. Van Doormaal, J. P. Ruurda, N. P. Van der Kaaij, and L. M. De Heer, "Mixed Reality in Modern Surgical and Interventional Practice: Narrative Review of the Literature," *JMIR Serious Games*, vol. 11. JMIR Publications Inc., 2023. doi: 10.2196/41297.
9. E. Bollen, L. Awad, B. Langridge, and P. E. M. Butler, "The intraoperative use of augmented and mixed reality technology to improve surgical outcomes: A systematic review," *International Journal of Medical Robotics and Computer Assisted Surgery*, vol. 18, no. 6, Dec. 2022, doi: 10.1002/RCS.2450.
10. A. Palumbo, "Microsoft HoloLens 2 in Medical and Healthcare Context: State of the Art and Future Prospects," *Sensors*, vol. 22, no. 20. MDPI, Oct. 01, 2022. doi: 10.3390/s22207709.
11. C. M. Andrews, A. B. Henry, I. M. Soriano, M. K. Southworth, and J. R. Silva, "Registration Techniques for Clinical Applications of Three-Dimensional Augmented Reality Devices," *IEEE J Transl Eng Health Med*, vol. 9, 2021, doi: 10.1109/JTEHM.2020.3045642.
12. A. Pose-Díez-De-la-lastra et al., "HoloLens 1 vs. HoloLens 2: Improvements in the New Model for Orthopedic Oncological Interventions," *Sensors*, vol. 22, no. 13, p. 4915, Jul. 2022, doi: 10.3390/S22134915/S1.
13. A. Oun, N. Hagerdorn, C. Scheideger, and X. Cheng, "Mobile Devices or Head-Mounted Displays: A Comparative Review and Analysis of Augmented Reality in Healthcare," *IEEE Access*, 2024, doi: 10.1109/ACCESS.2024.3361833.
14. J. A. Sánchez-Margallo, C. Plaza de Miguel, R. A. Fernández Anzules, and F. M. Sánchez-Margallo, "Application of Mixed Reality in Medical Training and Surgical Planning Focused on Minimally Invasive Surgery," *Front Virtual Real*, vol. 2, Oct. 2021, doi: 10.3389/frvir.2021.692641.
15. R. M. Ghosh *et al.*, "Clinical 3D modeling to guide pediatric cardiothoracic surgery and intervention using 3D printed anatomic models, computer aided design and virtual reality," *3D Printing in Medicine*, vol. 8, no. 1, Apr. 2022, doi: <https://doi.org/10.1186/s41205-022-00137-9>.
16. G. M. Costa, M. R. Petry, J. G. Martins, and A. Paulo, "Assessment of Multiple Fiducial Marker Trackers on HoloLens 2," *IEEE access*, vol. 12, pp. 14211–14226, Jan. 2024, doi: <https://doi.org/10.1109/access.2024.3356722>.
17. M. Birlo, P. J. E. Edwards, M. Clarkson, and D. Stoyanov, "Utility of Optical See-Through Head Mounted Displays in Augmented Reality-Assisted Surgery: A systematic review," *Medical Image Analysis*, p. 102361, Jan. 2022, doi: <https://doi.org/10.1016/j.media.2022.102361>.
18. L. Ma, T. Huang, J. Wang, and H. Liao, "Visualization, registration and tracking techniques for augmented reality guided surgery: a review," *Physics in Medicine and Biology*, vol. 68, no. 4, Feb. 2023, doi: <https://doi.org/10.1088/1361-6560/acaf23>.
19. S. L. Perkins, B. Krajancich, C.-F. J. Yang, B. A. Hargreaves, B. L. Daniel, and M. F. Berry, "A Patient-Specific Mixed-Reality Visualization Tool for Thoracic Surgical Planning," *Ann Thorac Surg*, vol. 110, pp. 290–295, 2020, doi: 10.1016/j.athoracsur.2020.01.060.

20. Microsoft, "Unity development for HoloLens," <https://learn.microsoft.com/en-us/windows/mixed-reality/develop/unity/unity-development-overview?tabs=arr%2CD365%2Ch2>.
21. Microsoft, "Visual Studio Tools for Unity", <https://learn.microsoft.com/en-us/visualstudio/gamedev/unity/get-started/visual-studio-tools-for-unity?pivot=windows>
22. Microsoft, "Mixed Reality Toolkit 3," <https://learn.microsoft.com/en-us/windows/mixed-reality/mrtk-unity/mrtk3-overview/>.