



An Augmented Reality Approach to Visualize Biomedical Images

Luca Bergonzi¹ , Giorgio Colombo² , Davide Felice Redaelli³ , Marcello Lorusso⁴ 

¹Politecnico di Milano, luca.bergonzi@polimi.it

²Politecnico di Milano, giorgio.colombo@polimi.it

³Politecnico di Milano, davidefelice.redaelli@polimi.it

⁴Politecnico di Milano, marcello.lorusso@mail.polimi.it

Corresponding author: Luca Bergonzi, luca.bergonzi@polimi.it

Abstract. One of the technologies that is showing the most potential in an always widening range of applications, from entertainment to design and even healthcare, is Augmented Reality (AR). The most defining characteristic of AR consists of the possibility to overlap virtual object to be projected by a dedicated device upon a real environment. Throughout this work, the development of an application for the visualization of medical data in AR environments will be discussed. Nowadays, the most appropriate devices for such applications are Head Mounted Displays (HMDs). Investigating current visualization procedures of medical data deriving from CT or MRI scans, AR tools and features have the potential to streamline common activities, as diagnostic and surgery planning processes, providing a much more immersive user experience. In this paper, an effective visualization approach merging these new technologies and biomedical images is proposed. Using a cutting edge HMD device, an application that takes as input CT or MRI scans and gives as output an immersive visualization of patient's internal body structures has been developed. The range of possible use scenarios is very wide. In essence, the goal is to recreate the illusion for the user to be able to see through the patient's skin with no visual distortion, providing a much improved perception of the relative position of the inner body structures. Present techniques make use of DICOM data mostly in the diagnostic stage, whereas it is possible to integrate AR tools within the whole medical workflow and even to further stages of the disease treatment, including surgery planning and training activities. Additionally, the possibility to connect a multitude of HMD devices together that are able to display the same scene from different angles, depending on each own position, opens up to a great variety of collaborative working or learning situations. Although there is still a lot of scope for improvements, the paper details the potential of AR for a medical implementation, outlining specifications needed to evolve into something actually usable in a real-life scenario.

Keywords: Augmented Reality, Biomedical Data, CT, Abdominal Aortic Aneurysm

DOI: <https://doi.org/10.14733/cadaps.2019.1195-1208>

1 INTRODUCTION

In the last two decades, the digital revolution has become one of the defining aspects of our current era, to the point that nowadays it is largely regarded as the basis onto which the so called knowledge economy has been built upon [14]. As a matter of fact, the widespread availability of powerful and always cheaper devices has allowed the development of Virtual Reality (VR) and Augmented Reality (AR) applications, opening to new possibilities and solutions in common practices. The core difference between these two is represented by the fact that AR focuses on bringing virtual object and information into real-world environments, whereas VR projects the user into a completely virtual world [13]. The fields of application for these technologies are evolving both in quantity and quality, and despite the fact that they are usually advertised as the new frontier for the entertainment industry, they might play a major role also in other fields, such as design, education [8] and even healthcare [22]. Both VR and AR can involve all the human senses: sight, touch, hearing and even smell [21], [10]. However, the focus of the present work concerns only the visual feedback.

The first projects concerning AR in medicine date back to 1990s [19], [23], but the applications remained only at a research level because of the practical difficulties and the high costs of development. The technological growth of the last decade and the new interest of big tech companies in the fields of VR and AR brought to the production of many devices ranging from high end to budget level ones, such as VR cardboards to be used in combination with common smartphones. In the recent years, many researchers have committed to the development of educational and academic applications for training both students and specialists during difficult patient-specific procedures and to the study of possible benefits and disadvantages in moving toward new generation tools [24], [18]. Compared to traditional learning methods, Augmented and Virtual Reality have the potential to simulate surgical scenarios that are very hard to faithfully replicate and, at the same time, trainees can learn faster while getting used to specific surgical treatments [17]. Due to treatment difficulties, cardiovascular and neurological surgery are the most suitable medical branches for which training simulator systems have been initially developed [7, 9, 15, 16], but it is possible to extend the application to all the branches of medicine requiring patient-specific surgeries, such as the orthopedic field. Indeed, other studies have shown the possibility to use VR for designing patient specific products, such as the lower limb prosthetic socket [11], [20].

Augmented Reality applications are always affected by the growing computational power within the newest devices, consequently the slope of learning curves are expected to raise significantly and patient safety will be enhanced thanks to these technologies [6]. For example, it could be possible to create a database of all the different cases found around the world for specific pathologies or rare ones, so that any doctor and medicine student can analyze personally the situation and even test himself in performing a virtual surgery. Besides that, AR is playing an important role also as a navigation tool during surgical procedures to enhance visualization in the operating room and as a therapeutic tool in the treatment of patients [6]. Understanding the patient's unique anatomy is a major challenge in surgery and an opportunity for enhancement with image guidance. Specifically, AR could enhance the surgeon's understanding of the patient's anatomy even during the operation itself [7].

One of the last technological solutions currently adopted by universities and clinics is the Anatomage Table [3]. It consists of a table-sized touchscreen connected to a workstation onto which thousands of patients' anatomical data can be visualized, studied, interacting with them. Trainees and clinicians can access different kinds of common medical datasets such as Computed Tomography (CT) scans and Magnetic Resonance Imaging (MRI) data, but also visualize virtual 3D models [3]. Moving from this technology to AR visualization with head-mounted display (HMD) systems, the immersion level and ease of use are greatly improved since the 3D model can be viewed as-is in three dimensions simply moving around it in the real environment, instead of watching a flat projection on the screen. Moreover, subjective views of the models define a step forward for current procedures exploiting the immersive ability of the system, since the objects can be displayed in real environment.

This paper aims to describe how AR could be implemented in one of these healthcare related contexts, in particular focusing on the visualization of abdominal aortic aneurysms. Moving from raw data, acquired by CT scans, to 3D holographic model of internal organs, clinicians can enhance their understanding and visualization ability of medical images, by comparing directly the stack of 2D images deriving from the medical investigation with the extracted 3D model, thus improving the diagnoses and plans for treatment activities. The following application can pave the way to new scenarios for enhanced medical activities such as collaborative surgery. This paper is organized as follows: firstly, description of the activities related to the visualization of patient's data with the possible advantages brought by Augmented Reality is presented; then, using a cutting edge device, the development of an HMD application concerning DICOM and 3D models visualization for the Abdominal Aortic Aneurysm (AAA) pathology is described and its limits and constraints are outlined; finally, concluding remarks and future improvements are presented.

2 AUGMENTED REALITY VISUALIZATION APPROACH FOR BIOMEDICAL DATA

The world of biomedical data analysis is becoming more and more influenced by the newest and always cheaper technologies concerning data processing and visualization, e.g. all the data derived from wearable devices (i.e. bracelets) or simply from smartphones. This can be beneficial in comparison to current procedures and it can be applied to medical processes involving a huge quantity of raw data as medical imaging techniques (e.g. computed tomography, magnetic resonance imaging). The proposed approach aims to represent a valid alternative that could effectively improve the quality of the workflow for the potential users.

2.1 Current Visualization Approach

The standard way clinics have to go through for visualizing medical images, to sum it up briefly, consists of a phase of data acquisition by means of specific machines and then a phase of visualization of images or models (Fig. 1). CT is one of the most common procedures creating cross-sectional images (slices) of specific areas of the patient's body. They are considered very useful for diagnostic and therapeutic purposes in various medical disciplines. Usually, the common way data are displayed is by means of a regular PC workstation running a software dedicated to the visualization of the data. This operation happens on a standard screen and the items are managed and manipulated by using traditional input methods, that is a keyboard and a mouse. Nowadays, doctors analyze the whole amount of data derived from the medical investigations (i.e. CT scans and MRIs), by dynamically viewing the patient's section images or 3D model of the internal parts of the body. In clinics, an interesting step forward is the Anatomage Table that has been previously mentioned [3]. Despite the fact that it's been intended for educational purposes, the user is able to upload real patients' data, showing a variety of different types of information and models and allowing to manipulate objects with simple hand gestures upon the touch sensitive screen. Moreover, its sheer size allows a 1:1 scale visualization of full body, making the user experience more immersive and realistic than on a traditional display. Speaking about collaborative working or learning, Anatomage physical layout has been thought out to simulate a real diagnostic context to which more people are able to take part. Despite the fact that this smart table represents the latest innovation cleared by the Food and Drug Association (FDA) [3], its immersion level is far off the most recent VR and AR methods. For this reason, the shift from an on-screen visualization to a mixed reality one not only can improve the doctor's workflow, but also open to new possibilities and functionalities.

2.2 Augmented Reality Advantages

Augmented Reality represents one of the best choice for improving the visualization of CT or MRI scans and 3D model reconstruction of pathological conditions. By mixing virtual objects with a real environment, the user can easily improve his experience by changing his point of view and moving around the object in front of his eyes. The user can watch virtual entities with a much stronger illusion of reality, being them

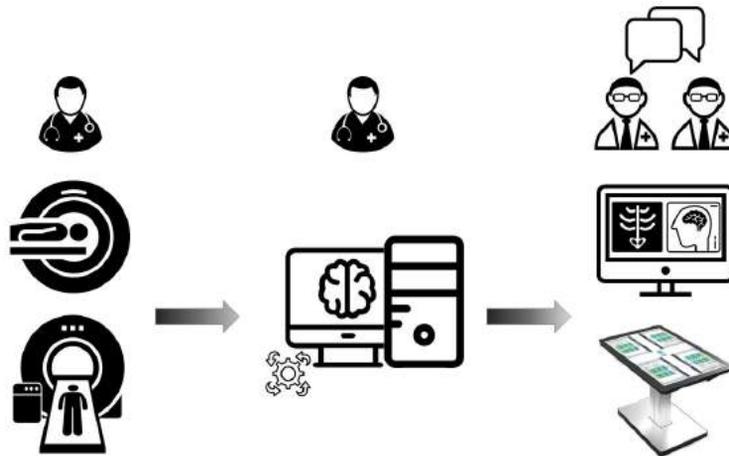


Figure 1: Current medical workflow.

actual 3D holograms. The scenarios to which we can apply this concept can go much beyond mere diagnostic contexts. Compared to Anatomage visualization, the main difference involves the combination of 2D stacked images with 3D model visualization in a 3D environment, enabling interactions that require spatial information. Taking into account the CT, data workflow and visualization can be improved. The raw images available in the Digital Imaging and Communication in Medicine (DICOM) standard can be virtually stacked allowing a dynamic visualization of the sections. Also the 3D model, that is currently built and displayed on common displays, can be visualized and manipulated. By shifting the visualization technology of such models from a traditional display to a more intuitive 3D object in an AR environment, diagnostic evaluations, educational training activities and surgery planning procedures can be enhanced. The most suitable AR devices for this kind of applications are Head Mounted Displays (HMDs). The advantage is that they allow for a deeper immersion level within the augmented reality environment, in such a way that doctors can naturally check the patient's disease and make more specific diagnoses. In addition, by overlapping CT slices and virtual 3D models of the internal organs on the real patient or on a physical mock-up model acquired on the basis of the original CT dataset, surgery treatments can be planned more in detail, taking into account the actual body dimensions. Moreover, having no need of being constantly connected to a workstation, HMDs enable a wireless visualization, once patient's data have been uploaded on the device. It's not hard to imagine a future application in which doctors can wear an HMD device that would help them to see through the patient's skin. That would provide a much clearer sense of position about the relative placement between the internal organs displayed on the device and the patient's body, for a much more comfortable and seamless operation. This is crucial, since surgery is a field in which there's basically no room for error, especially for the treatment of delicate situations deriving for instance from cardiovascular diseases like aneurysms and similar. This opens up new scenarios of collaborative diagnoses and surgery planning activities bringing significant improvements to current practices.

2.3 Proposed Approach

The main focus of this project is the integration of AR for displaying medical images. HMDs can reshape the way clinics work in their operational contexts, adding possibilities that don't just represent an evolution in comparison to what is available to the present day, but can actually pave the way for a radically new approach

for specific situations. Considering a regular visualization workflow (Fig. 1) that make use of a traditional workstation PC, two things can be displayed. On one side there's the visualization of the CT data in the form of slices, and on the other, these images can be processed to generate a 3D model that can be visualized and manipulated by means of a dedicated application.

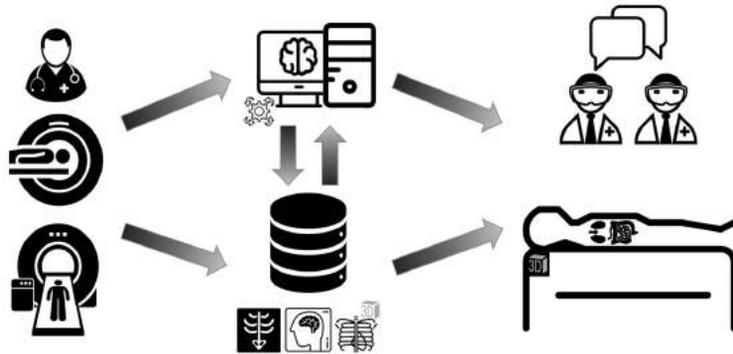


Figure 2: Proposed medical workflow.

Fig. 2 depicts the approach proposed in this paper. The first stage is the visualization of images provided by CT scans. Instead of having the traditional viewport of a DICOM visualizer software on a regular screen, slices can be displayed through an HMD device. The advantages can be many. For a start, not being confined to the working space of a regular screen, the scene can be presented in 1:1 scale, meaning that each slice is a faithful representation in terms of general dimensions of the real case. As a result, the user is able to see the section as it is. In diagnostic contexts this is crucial especially when fine details are observed. From a usability point of view, the user can just physically move closer to his target, without any need of zooming functions. Few basic functions can be implemented allowing the user to dynamically scroll slices and place them anywhere without any spatial restriction.

As previously anticipated, using current techniques, it is possible to generate a three-dimensional model based on DICOM datasets, that can also be exported and reused in a different context or environment. As a second step, a virtual 3D model can be displayed and manipulated according to the user needs, with the advantages provided by the use of an HMD device. Current software provides tools to drag, rotate and resize three-dimensional objects, but again the user experience is restricted to the space of a traditional screen. By importing the actual model on an HMD device without any further adjustment, the user can watch and make assumptions simply moving around that. Specifically, moving, rotating or resizing our model can bring important advantages in the diagnostic phase. Such features though can be really appealing in an academic environment as well. There are no spatial limits at all, so even more people can comfortably stand around the same model and observe it with no visual distortion.

The final goal of this approach is to overlap the 3D model or CT slices onto some real mock-up or, in the same way, place it accurately on the real patient's body. The general working principle is pretty intuitive. The user just needs to "frame" a real target, like a printed QR code, inside the field of view of the HMD, and from then on, the virtual model has been programmed to automatically show up above it. In a real operating environment, the user would just place the target in the correct position upon the patient's body itself, getting the illusion of seeing through his skin. This opens up to a vast field of possible applications. Using a 3D geometry of an aortic aneurysm with the surrounding body structures as a case study, subsequently presented, once the basic framework of this approach has been defined, it is possible to display other types of

information, from interactive CFD mappings across the aorta to other tools in order to enhance the diagnosis process. Diagnosis is just one aspect, but the enhanced visualization possibilities may turn out to be extremely useful even during the surgical operation itself. The user in fact can constantly rely on a virtual hologram that faithfully reproduces the real inner structures of the patient's body, providing an additional tool to better figure out the relative position of the organs. In the same way, that can be applied to educational contexts, where also trainees can have a better understanding of the operation if we imagine to overlap the virtual model on a mock-up of the patient's trunk.

Once the general characteristics of our application have been outlined, the additional feature that represents one of the most noticeable enhancements brought by the AR application is the collaborative environment. Having interconnected devices that show up the same scene from different point of views, possibilities granted by this approach get more various, from a diagnostic context up to an operational one. Technically, this is possible today with no particular troubles, since ubiquitous Internet connections allow to seamlessly stream the information among multiple devices. There's no other solution nowadays that allows such a deep level on involvement.

3 DEVELOPMENT OF AUGMENTED REALITY APPLICATION

This section discusses the integration and the development of the previously described process, focusing on advantages and constraints to compare the latest AR technologies with the current medical imaging techniques. In order to test the applicability of the proposed approach, a test case on an Abdominal Aortic Aneurysm (AAA) is presented considering actual data coming from a real patient. The AAA is a localized dilatation of abdominal aorta over a specific quantity with a risk factor that is always greater as the dimension increases [12]. The visualization of aneurysm characteristics is considered crucial for diagnoses and treatment planning activities. The starting point of this application is the sample dataset that we've decided to adopt. It includes the data of a CT scan of a patient affected by a severe form of AAA. Specifically, only a section of his body has been scanned, that is the trunk, in such a way to incorporate in a clear way only the region affected by the disease. It's a very effective way to demonstrate the advantages of our final application, since it serves for a variety of typical use scenarios from the diagnosis stage to the actual operation one once correctly programmed.

Following sections will explain the three steps required for the development of AR application, taking into account issues related to this visualization approach. The first regards the images processing required for HMD device visualization. Then, the 3D model processing will be explained, and finally, developed features of AR application will be clarified. The software Unity 3D [4] has been used as the building platform to make up the application, and, in regards to the HMD device, Microsoft HoloLens [2] has been employed.

3.1 CT Raw Images Processing

This visualization approach has to take into account issues concerning the processing of the patient's data and the subsequent extraction of the digital images. Usually, CT scans are available in the DICOM standard format and the default dataset includes only the scans of the axial plane (the one that follows the patient's spine). In order to be compatible with the majority of software used for the development of AR applications, DICOMs have to be pre-processed using a visualization software such as Slicer 3D [1](Fig. 3). Two main activities must be carried out: the images generation and conversion.

The first is the generation of the images (slices) on the three planes, building the coronal and sagittal views by interpolating the information contained in each slice referred to the axial view. Once the DICOMs are imported from the directory in which they are stored, the software displays all the dataset properties and automatically shows up the three views in three separate sub-windows. The sample dataset considered for this test case is made up by 500 slices and that guarantees a sufficient level of detail also for the other two views that have been generated by interpolation. This process is relatively quick and completely automated, so no

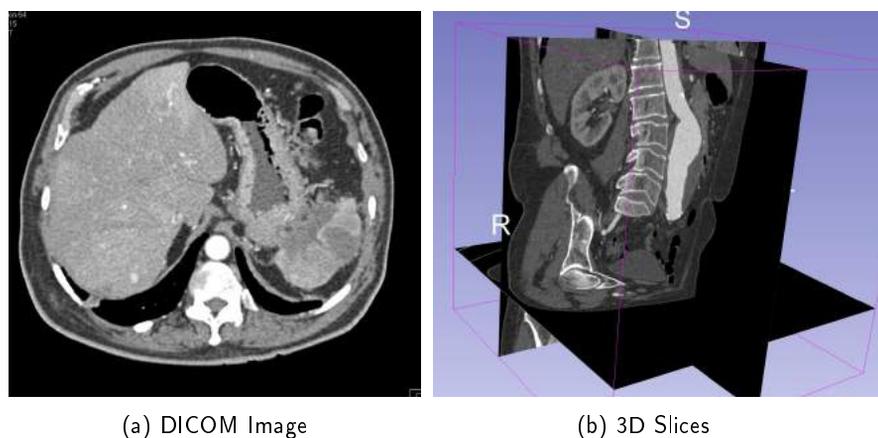


Figure 3: From DICOM Images to 3D Slices.

further operations are needed by the user.

Secondly, DICOMs must be converted and exported in a sequence of images for each of the 3 views. PNG has been considered as standard image format, so that they could be easily imported in application development software for the final implementation. Currently, this process is not completely automated. The important criteria to take into account for images processing are images resolution and quantity. The user must capture images corresponding to the slices for each plane, setting the appropriate settings for the developing application. Nowadays, Augmented Reality applications rely on the computational power of the device in which the application will be deployed. For this reason, using Microsoft HoloLens, probably due to limited processing power, the adequate resolution and images quantity are crucial to build the AR environment without visualization issues. In this test case, images have been downscaled from their original 512x512 pixel size to 300x300, without losing significant details. As anticipated, the dataset included by default 500 images running parallel to the axial plane. The idea of extracting the same amount of images also from the two derived views, which results in 1500 images to be managed by the HMD device, turned out to be unsuccessful for the same reason as before. As a result, the number of images has been reduced from 500 to 300 per view.

Currently, relying on user experience in images generation and conversion, this pre-processing phase is not completely automated, but further work can be done to integrate the images elaboration within an automatic process.

3.2 3D Model Processing

Once images are ready to be integrated with HMD devices and augmented reality application, the 3D reconstruction must be carried out taking into account typical issues of images segmentation. Predictably, this process turned out to be very time consuming, since there's no automation in the extraction of the geometries from the DICOM files, so most of the operations have to be carried out manually. In order to build the 3D model a visualization and extraction software for medical images must be used (e.g. 3D Slicer), providing tools to generate virtually stacked images, and interpolating the information to create additional orthographic views.

The preliminary activity to achieve the 3D model extraction concerns the selection of data volume that includes useful body structures. The procedure to get an actual surface model to be exported in a standard format (e.g. STL) is based on a threshold controller, defining the right range of color to precisely select areas of interest (i.e. aorta and surrounding organs). In general, these settings are arbitrary since the environmental

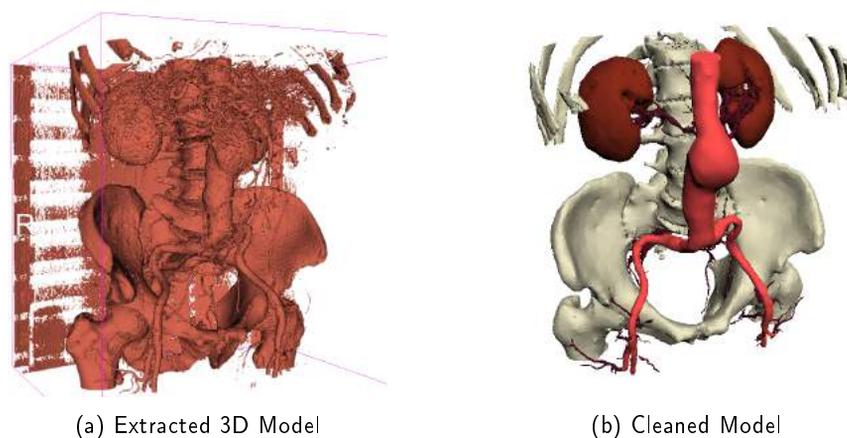


Figure 4: 3D Model Processing.

conditions and the patient's characteristics change from case to case. Some trial and error has to be undertaken before achieving reasonable results. From this phase it's impossible to achieve a 3D model with body structures already positioned and separated as different surface bodies (Fig. 4a). This process is done in a subsequent phase called segmentation.

The outcome of the first processing step is not adequate for the visualization within augmented reality applications. Beside the structures to display, the model also contains excess geometries that can hide objects to be investigated. In addition, the file can be extremely heavy even on the PC used to process it, and this could be a major problem for AR visualization with HoloLens. As a result, the model needs to be cleaned up and simplified. The cleaning phase consists of removing all the flying and non useful particles included in the 3D model previously extracted. Since this is not an automatic procedure at the moment, the user decides the relevant information to highlight during the cleaning process. In this case, the focus is the abdominal aortic aneurysm and so the segmentation activities require more attention close to the aorta. In addition, in order to build a lighter and manageable model, topological optimization must be done. Using dedicated software, a semi-automatic re-meshing process has been carried out to reduce the number of triangles that forms the entire model from several millions to few thousands. Also surface refinement and smoothing is necessary to better visualize the model through the HMD device. In order to integrate enhanced functions in the AR application, a subdivision of the body structures in separated objects must be done. In this case the model has been subdivided in four parts: the aorta, the minor blood vessels, the bones and the two kidneys.

Finally, the model is ready to be exported in a standard format and to be managed by Unity 3D software for deploying it into the HoloLens application (Fig. 4b).

3.3 Application Features

The creation of the application is the most important stage of the project implementation, proving what has been outlined in Sec. 2. This application has been entirely developed using Unity 3D software, integrating the main functions according to HoloLens capabilities. The features introduced by the integration of models previously prepared and the HMD device are three: the standalone visualization, the on patient visualization, and the collaborative vision of the previous two.

As Fig. 5 shows, when the application starts, the user can select the preferred visualization mode. "Scene1" and "Scene2" correspond, respectively, to the CT slices and 3D model displaying and manipulation modes. "Scene3" concerns the data visualization depending on a real target to follow, and allowing a more precise

interaction with the area of interest. In addition, all the modes of use can be shared through multiple HMD devices, enabling an enhanced collaborative environment.



Figure 5: Visualization modes menu.

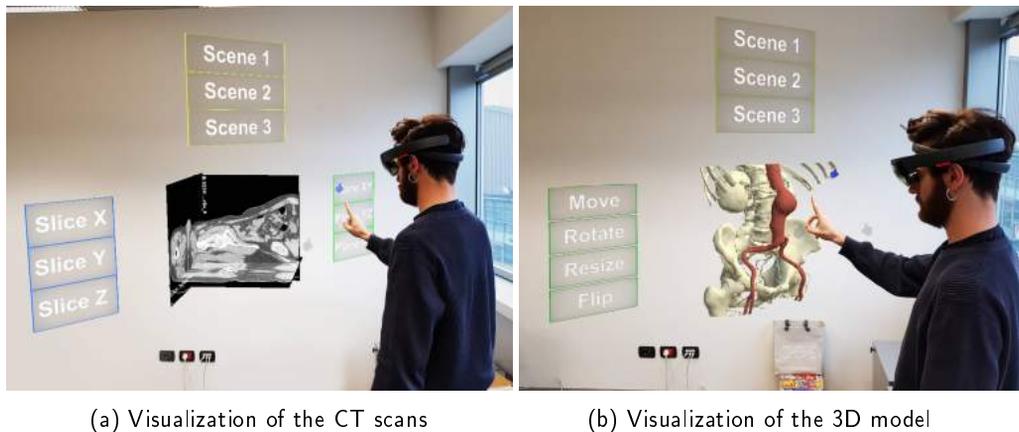
3.3.1 Standalone Visualization

The standalone visualization regards the dynamic interaction with the CT slices and the 3D model of the patient's internal body structures. This feature represents the transposition of current techniques into an HMD device, enabling an higher immersion level and easier way of interaction. This can help to bring doctors closer to new technologies.

Once the user has selected "Scene1", the slices visualization is activated (Fig. 6a). The application is designed in such a way that images of CT slices are downloaded from a database and placed in a predefined position, dividing each cut plane. In this way, doctors can upload whoever patient's images and visualize them through the HoloLens, without the need of modifying the entire application. Once loaded, the user is free to select the plane to move by selecting the respective button on the holographic menu appearing on the left of the scene. Once this is done, a pinch gesture can be detected by HoloLens, and from there the user is free to drag the plane at the preferred distance. At the same time, the ability to freely intersect the three planes is preserved, since they can be moved independently if the user decides to switch from one to another when pushing the corresponding button on the left menu. Another feature that is possible to enable regards the opportunity to activate or deactivate each of the three planes independently by means of another toggle menu that's situated on the right of the scene. Each of the three buttons turns on or off the related plane. In this way, if the user wants to focus on one plane without being hindered by the other ones in some specific situation, he's free to do it.

In "Scene2" the virtual 3D model can be manipulated (Fig. 6b). As in the previous case, when the scene has been selected, the 3D model is loaded from the repository. Describing it more in detail, at the centre of the scene it is possible to see a 1:1 scale 3D model of the internal organs. The user is able to manipulate the model by using three different commands. The first option is a simple "Move" button that once pushed lets the user grab the model and drag it around the environment according to the movements of his hand. Alternatively, the user himself can move around the model. The second option is for rotating the model around the vertical axis (normal to the ground). This time the user is limited to a horizontal pinch and drag gesture

that works from right to left and from left to right for clockwise and anti-clockwise rotations respectively considering the model's top view. Finally, a resize option is possible. Starting from 1:1 scale, it lets the user resize the object to make it bigger or smaller without any limitation according to the cases. This option can prove to be very useful for analyzing fine details that would be much harder to detect in normal conditions. Additionally, it is possible to hide some 3D items in order to better observe others. If the user wants to display only the aneurysm without any other distracting element, it is possible to turn off the other body structures such as the bones, the smaller blood vessels or the kidneys. Each of these commands can work one after the other while retaining the modifications the user has done previously. In other words, the scene will not reset when switching from one command to the other, so it will be possible to move the object, rotate it and resize it restarting from its updated position, rotation or size.



(a) Visualization of the CT scans

(b) Visualization of the 3D model

Figure 6: HMD visualization of CT scans to 3D model.

3.3.2 On Patient Visualization

The third scene integrates features described in 3.3.1 with the visualization of virtual objects onto the real body of the patient. The algorithm used for object detection is provided by Vuforia [5]. As the previous scene, slices and 3D model are downloaded from the database in which they are stored. It is still possible to activate or deactivate functionalities and certain elements of the model according to the user's need. The application is built so that nothing is appearing as long as HoloLens does not detect a simple QR code that's been printed on an ordinary sheet of paper measuring about 10x10 centimeters. It has been chosen because the device is able to detect it with no issues. Once the QR code is found within the HoloLens field of view, the same 3D model adopted in "Scene 2" automatically shows up (Fig. 7a), since it's linked to the position of the real QR code and it follows it constantly. This is the moment in which the user is supposed to be placing the QR code, and so the hologram as well, upon the patient's body. Then, the user can steadily place the 3D model onto the correct position. At the same time the real QR code might represent a visual obstacle, so a feature to unlink the virtual model from the physical QR code has been added. In this way, the target can be dismissed with no issues unless some repositioning is required. Also a re-linking feature has been added to restore the original configuration between QR code and virtual model. In this scenario the user will just see two buttons hovering upon the QR code without the 3D model. The same thing can be done when placing CT slices onto the body of the real patient and matching those images with the skin boundaries (Fig. 7b). Since the purpose of the paper is to evaluate the capabilities of this visualization approach, the alignment accuracy with the real body has been adjusted manually calibrating the virtual objects according to target dimensions.

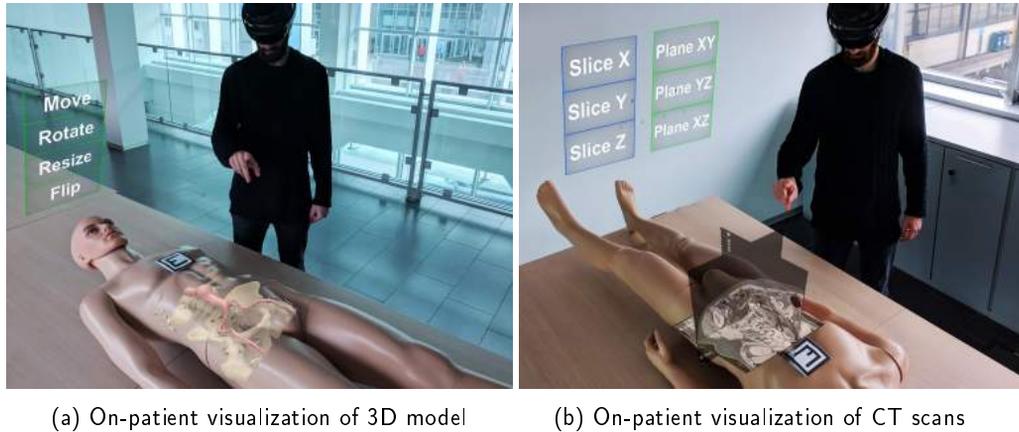


Figure 7: HMD on-patient visualization of CT scans to 3D model.

3.3.3 Collaborative Environment

An important aspect to point out is that each of the three scenes can potentially be watched simultaneously by two or more interconnected devices. As Fig. 8 shows, technically speaking, it is possible to connect two or more HoloLens to the same scene sharing their network and linking them together with server-client hierarchy. The devices have to be connected to the same Wi-Fi network to communicate. The connection between two devices is always enabled in such a way that, starting the application, the client HMD can join the environment created by the server. This opens up to many possibilities in regard to collaborative working or learning experiences, pushing the boundaries much further than the solutions described at the beginning of this chapter. Considering Anatomage for a comparison, two major advantages can be pointed out. Firstly, the field of use is not confined to the diagnosis phase but can comprise further stages up to the operation itself for the reasons we've already mentioned. Secondly, the users are not limited to the physical space of a screen, that despite being big, does not provide the same freedom of movement and faithfulness as a HMD device.



Figure 8: Collaborative scenario.

4 FUTURE DEVELOPMENTS

All in all, encouraging results have been obtained. Relying on the description of a workflow that provides a preliminary diagnosis tool to evaluate the patient's diseases, the proposed visualization approach has the potential to boost current medical procedures, even though several aspects of this project still need improvements or refinements, spanning from computational power issues to a more integrated automation process.

Firstly, HoloLens capabilities do not cope with the required tasks due to limited computational power. Managing a great number of images, as explained in 3.3.1, the application can hardly display large amounts of files. Hence, images had to be resized in order to end up with an application capable of running smoothly. For the same reason, also the 3D model had to be resized, moving from millions elements mesh to a few thousands one. Building an application with a low frame rate ends up causing an unpleasant visual experience for the user. In the on-patient visualization, the device must track the surrounding environment and manage heavy 3D models at the same time, causing frame drops and noticeable flickering unless objects to be displayed have been previously adapted and lightened. Hopefully, newer generations of the device will help overcoming these performance and usability problems.

Then, data preprocessing phase can be improved increasing the level of automation of images and models adjustments. The integration of the whole process in a completely automated application represents the next step to achieve. Nowadays, preparing objects to be displayed in augmented reality environments is very time consuming. The exploitation of smart and autonomous algorithms for data processing seems the most optimistic perspective in relation to these purposes. An algorithm that would be able to make an effective segmentation of the organs, while getting rid of all the unnecessary geometries and delivering a ready-made 3D model, would be a boost for the application of the proposed scenario in real diagnostic and operational contexts. It is still quite hard to implement it effectively and such operations cannot be directly performed on HMD devices, since datasets and models are generally quite demanding in terms of sheer performance.

Moreover, validation tests onto real patients in medical environments must be the concerns of future developments. Accuracy issues will be evaluated comparing the 3D model or CT images of the patient with its real body shape.

5 CONCLUSIONS

The possible applications for Augmented Reality technologies are wide-spreading in a great variety of sectors including healthcare. In this paper, a novel approach for displaying and manipulating patient specific medical images and the relative 3D models has been proposed. The potential of such application is not limited to the diagnostic stage, but can also enhance surgery planning or training activities, representing a great step forward in comparison to current methods. As of now, the most suited category of products for such tasks are Head Mounted Displays (HMDs) devices.

The developed application concerns the integration of enhanced visualization features of medical images and 3D models applied to a case study regarding the abdominal aortic aneurysm disease. Various stage have been required to end up with a correctly running application. Firstly, the DICOM images have been acquired and converted in a more common image format. In parallel, a 3D model has been extracted from the dataset and cleaned up in a latter stage. Afterwards, the application has been created and deployed to run on our reference HMD device. The application is made up of three scenes showing up as many enhanced features. The first one is dedicated to the visualization and manipulation of the slices as flat images, whereas the next displays a 3D model of the internal organs. Secondly, it is possible to overlap the previously mentioned model as a three-dimensional hologram upon the real patient in a real use scenario. The last feature involves the integration of collaborative functions enabling doctors to see simultaneously the patient's disease, improving diagnostic and surgery planning procedures. Speaking about the pros, the application showed great potential in relation not only to diagnostic scenarios, but also other stages of the disease treatment including surgery planning and training activities. On the other hand, when considering academic contexts, it is possible to

apply the AR technology for a more immersive and interactive user experience, that additionally is fully compatible with collaborative working and learning environments, once several devices have been programmed and connected to show a certain scene. To sum it up it's been a very interesting project that will be hopefully brought on in the future, so that its major issues can be overcome in order to get closer and closer to a fully operative application to be tested and maybe adopted in real life contexts. To achieve this result, a combined effort with more IT oriented figures would definitely boost the application development in relation to possible ways to automate the data processing phase, which is currently the area of the project with the most scope for improvements.

ORCID

Luca Bergonzi, <http://orcid.org/0000-0003-0664-1098>

Giorgio Colombo, <http://orcid.org/0000-0002-9999-8960>

Davide Felice Redaelli, <http://orcid.org/0000-0002-8513-8222>

Marcello Lorusso, <http://orcid.org/0000-0002-0251-7770>

REFERENCES

- [1] 3d slicer. <https://www.slicer.org/>.
- [2] Microsoft hololens. <https://www.microsoft.com/it-it/hololens>.
- [3] Table. <http://www.anatome.com/table/>.
- [4] Unity. <https://unity3d.com/>.
- [5] Vuforia. <https://www.vuforia.com/>.
- [6] Barsom, E.; Graafland, M.; Schijven, M.: Systematic review on the effectiveness of augmented reality applications in medical training. *Surgical Endoscopy*, 30(10), 4174–4183, 2016. <http://doi.org/10.1007/s00464-016-4800-6>.
- [7] Bartesaghi, S.; Colombo, G.; Morone, S.: Spatial augmented reality and simulations to improve abdominal aortic aneurysm diagnosis and monitoring. *Computer-Aided Design and Applications*, 12(6), 803–810, 2015. <http://doi.org/10.1080/16864360.2015.1033347>.
- [8] Bordegoni, M.; Carulli, M.; Shi, Y.; Ruscio, D.: Investigating the effects of odour integration in reading and learning experiences. *Interaction Design and Architectures*, 32, 104–125, 2017.
- [9] Burke, E.; Felle, P.; Crowley, C.; Jones, J.; Mangina, E.; Campbell, A.G.: Augmented reality evar training in mixed reality educational space. In *Global Engineering Education Conference (EDUCON)*, 2017 IEEE, 1571–1579. IEEE, 2017. <http://doi.org/10.1109/EDUCON.2017.7943058>.
- [10] Carulli, M.; Bordegoni, M.; Cugini, U.: Integrating scents simulation in virtual reality multisensory environment for industrial products evaluation. *Computer-Aided Design and Applications*, 13(3), 320–328, 2016. <http://doi.org/10.1080/16864360.2015.1114390>.
- [11] Colombo, G.; Facoetti, G.; Rizzi, C.; Vitali, A.: Mixed reality to design lower limb prosthesis. *Computer-Aided Design and Applications*, 13(6), 799–807, 2016. <http://doi.org/10.1080/16864360.2016.1168223>.
- [12] Forsyth, J.M.: Abdominal aortic aneurysm. *InnovAiT: Education and Inspiration for General Practice*, 9(5), 298–302, 2016. <http://doi.org/10.1177/1755738015625085>.
- [13] Furht, B.: *Handbook of augmented reality*. Springer, 2011. <http://doi.org/10.1007/978-1-4614-0064-6>.

- [14] Gardien, P.; Djajadiningrat, T.; Hummels, C.; Brombacher, A.: Changing your hammer: The implications of paradigmatic innovation for design practice. *International Journal of Design*, 8(2), 44–53, 2014. <http://doi.org/10.1111/j.1948-7169.2011.00139.x>.
- [15] Ghandorh, H.; Mackenzie, J.; Eagleson, R.; de Ribaupierre, S.: Development of augmented reality training simulator systems for neurosurgery using model-driven software engineering. In *Electrical and Computer Engineering (CCECE)*, 2017 IEEE 30th Canadian Conference on, 1–6. IEEE, 2017. <http://doi.org/10.1109/CCECE.2017.7946843>.
- [16] Jensen, K.; Bjerrum, F.; Hansen, H.J.; Petersen, R.H.; Pedersen, J.H.; Konge, L.: Using virtual reality simulation to assess competence in video-assisted thoracoscopic surgery (vats) lobectomy. *Surgical Endoscopy*, 31(6), 2520–2528, 2017. <http://doi.org/10.1007/s00464-016-5254-6>.
- [17] Kamphuis, C.; Barsom, E.; Schijven, M.; Christoph, N.: Augmented reality in medical education? *Perspectives on Medical Education*, 3(4), 300–311, 2014. <http://doi.org/10.1007/s40037-013-0107-7>.
- [18] Kesim, M.; Ozarslan, Y.: Augmented reality in education: current technologies and the potential for education. *Procedia-Social and Behavioral Sciences*, 47, 297–302, 2012. <http://doi.org/10.1016/j.sbspro.2012.06.654>.
- [19] Ploder, O.; Wagner, A.; Enislidis, G.; Ewers, R.: Computer-assisted intraoperative visualization of dental implants. *augmented reality in medicine. Der Radiologe*, 35(9), 569–572, 1995.
- [20] Regazzoni, D.; Rizzi, C.; Vitali, A.: An overview of open source software systems for smart development of virtual environments. In *International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management*, 358–368. Springer, 2017. http://doi.org/10.1007/978-3-319-58463-8_30.
- [21] Sherman, W.R.; Craig, A.B.: Understanding virtual reality interface, application, and design. *Presence*, 12(4), 441–442, 2003. <http://doi.org/10.1162/105474603322391668>.
- [22] Van Krevelen, D.; Poelman, R.: A survey of augmented reality technologies, applications and limitations. *International Journal of Virtual Reality*, 9(2), 1–20, 2010. <http://doi.org/10.1155/2011/721827>.
- [23] Viirre, E.; Pryor, H.; Nagata, S.; Furness 3rd, T.: The virtual retinal display: a new technology for virtual reality and augmented vision in medicine. *Studies in Health Technology and Informatics*, 50, 252–257, 1998. <http://doi.org/10.3233/978-1-60750-894-6-252>.
- [24] Zhu, E.; Hadadgar, A.; Masiello, I.; Zary, N.: Augmented reality in healthcare education: an integrative review. *PeerJ*, 2, e469, 2014. <http://doi.org/10.7717/peerj.469>.