Title:
An Augmented Reality Approach to Visualize Biomedical Images

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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 building upon [8]. As a matter of fact, the widespread availability of powerful and always cheaper tech devices has allowed the development of Virtual Reality (VR) and Augmented Reality (AR) techniques and 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 environment, whereas VR includes the user into a completely virtual world [7].

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 eventually play a major role also in other fields, such as design, education and even healthcare [12].

Focusing on healthcare, in 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. An example is the introduction in universities of table-sized touchscreens for visualizing and interacting with the patient's anatomy. Other studies have shown the possibility to use VR for designing patient specific products, such as the lower limb prosthetic socket [5], [13]. Compared to traditional learning methods, Augmented Reality has 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 [11]. Due to treatment difficulties, cardiovascular and neurological surgery are the most suitable medical branches for which training simulator systems have been initially developed [3-4], [9-10].

Despite the Augmented Reality applications are affected by always growing computational power within the newest devices, learning curves are expected to become higher and patient safety will be enhanced thanks to these technologies [2]. 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 [2]. 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 surgery [3], [6].

One of the last technological solutions currently adopted by universities and clinics is the Anatomage Table. It consists of a table-sized touchscreen connected to a workstation onto which thousands of patients' data can be visualized and studied. Trainees and clinicians can access different kinds of datasets such as Computed Tomography (CT) scans, Magnetic Resonance Imaging (MRI) data, 3D reconstructions as well as medical treatments guides [1]. Comparing this technology with AR applications, the immersion level and ease of use are greatly improved when using mixed reality devices 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.

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 visualization of medical images and make better diagnoses and treatment planning activities. These new applications open to new scenarios for enhanced activities of collaborative surgery. This paper is organized as follows: firstly, a description of the activities related to the visualization of patient's data and possible advantages brought by Augmented Reality are presented. Then, using a cutting edge AR device, the development of a software prototype concerning the Abdominal Aortic Aneurysm (AAA) pathology is described and its limits and constraints are outlined. Finally, concluding remarks and future improvements are presented.

Augmented Reality visualization approach of 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. This can be applied to medical processes involving a huge quantity of raw data as medical imaging techniques (e.g. computed tomography, magnetic resonance imaging). CT is one of the most common procedures creating cross-sectional images (slices) of specific areas of the patient's body. In Fig. 1 two workflows are schematically reported: on the left, it is represented the current process that physicians adopt for visualizing the medical images; on the right, it is depicted the proposed visualization approach using AR technologies. Doctors nowadays analyze DICOM standard format (standing for Digital Imaging and Communication in Medicine) by using digital processing software able to dynamically scroll the section images and artificially build not only the derived views on different section planes, but also a 3D model of the internal parts of the body. In clinics, the most technologically advanced visualization system is the above-mentioned table-sized touchscreen connected to a powerful workstation. This device allows doctors to look at the patient's anatomy, to enhance medical education applications and to plan clinical treatments [1]. Despite the smart table is the latest innovation approved by the Food and Drug Association (FDA), 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.

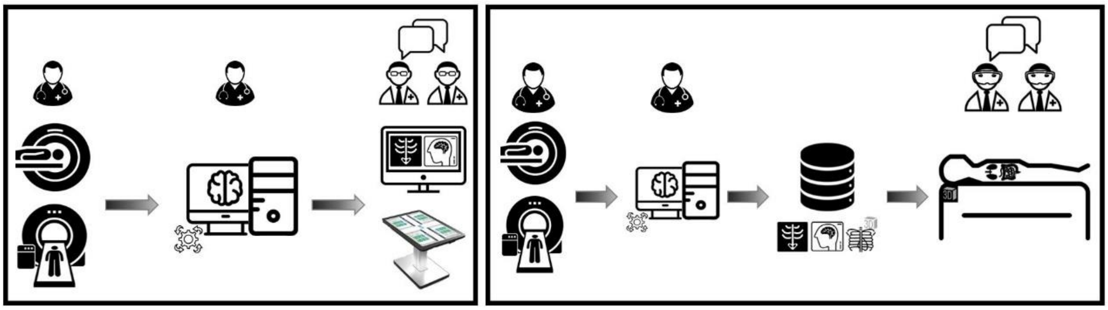

Fig. 1: Current CT scans workflow, on the left, versus the proposed visualization approach using Augmented Reality technologies, on the right.

Augmented Reality represents the best choice for improving the visualization of CT scans and 3D model reconstructions of pathological conditions. By mixing virtual objects with a real environment, the user can easily improve his experience changing his point of view and moving around the object in front of his eyes. 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. Taking into account the CT technique, data workflow and visualization can be improved as shown on the right side of Fig. 1. The first stage is the visualization of images provided by CT scans, available in

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DICOM format. Instead of having the traditional visualizer software, scans can be displayed through an HMD device. In diagnostic contexts this is crucial especially when fine details are observed. Few basic functions can be implemented allowing the user to dynamically scroll slices and place them anywhere in the room without any spatial restriction. As previously mentioned, using current techniques, it is possible to generate a three-dimensional model based on DICOM datasets. This virtual 3D model can be displayed and manipulated according to the user needs, with the advantages provided by the use of an HMD device. Specifically, moving, rotating or resizing our model can bring important advantages in the diagnostic phase. 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, overlap it accurately to the real patient's body. Watching a printed physical target, inside the field of view of the HMD, the user can see the virtual model in the correct position upon the patient's body itself. This opens up to a vast field of possible applications. 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. Diagnosis is just one aspect, but the enhanced visualization possibilities may turn out to be extremely useful even during the surgical operation.

<u>Development of AR application concerning AAA case study:</u>
This section discusses the integration of the previously described process, focusing on advantages and constraints of the latest AR technologies in comparison with the current medical imaging techniques. In order to test the feasibility of the proposed approach, a test case on an Abdominal Aortic Aneurysm is presented considering actual data coming from a real patient. The AR application has been developed passing through three required steps: the first is the image processing required for HMD visualization; then, the 3D model processing is explained; finally, developed features of AR application are clarified.

Usually, CT scans dataset include only the scans of the axial plane and, initially, the coronal and sagittal views have to be built interpolating the information contained in each slice referred to the axial view. Secondly, DICOMs must be converted and exported as 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 for the final implementation. Currently, this process is not completely automated. The important criteria to take into account for images processing are image resolution and quantity. Using Microsoft HoloLens™, probably due to limited processing power, images resolution has been downscaled to 300x300 pixel size and quantity has been reduced to 300 images per view, starting from the original 500.

Fig. 2: Standalone visualization of CT slices and 3D models with Microsoft HoloLens™.

The 3D model reconstruction must be carried out taking into account typical issues of images segmentation. Relying on grayscale images, this process has to be carried out selecting every significant organ, bone and blood vessel depending on a previously defined threshold level. These operations have been conducted by means of an open source software for image processing, namely Slicer3D. This tool though does not have the capability to smartly detect and isolate different types of body structures; that means that the clean-up procedure is still very time consuming, since it has to be performed manually by mesh editing. Also surface refinement and smoothing are necessary to obtain a better model to be exported in a standard format (i.e. FBX, OBJ) and deployed by Unity 3D into the HoloLens application.

Fig. 2 shows the standalone visualization with regards to 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 a higher immersion level and easier way of interaction. 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. Once loaded, the user is free to select which plane to move and to drag it at the preferred distance. It is also possible to activate or deactivate each of the three planes independently. In addition, the 3D model can be manipulated. The user is able to manipulate the model by moving, rotating or resizing it. These options can prove to be very useful for analyzing fine details that would be much harder to detect in normal conditions.

The greatest step forward is represented by the use of HMDs' capability to merge real objects and custom fitted virtual models. Fig. 3 shows the second visualization mode available within the AR application. Aligning CT scans or 3D reconstructions with the patient's body shape, doctors can make more accurate assumptions considering the actual position of the internal organs. The latest devices are able to track the surrounding environment and automatically match the virtual object with the real target. For this purpose, it is necessary to program the device in Unity 3D to enable the detection of a physical target positioned close to the physical object in order to get a correct alignment. Since the purpose of the paper is to evaluate the capabilities of this visualization approach, the alignment accuracy with the real body is limited to the manual calibration of the virtual objects according to target. Moreover, it is possible to connect two or more HoloLens to the same scene sharing their network and linking them together with server-client hierarchy. By using the same Wi-Fi network to communicate. This opens up to many possibilities, pushing the boundaries much further than traditional solutions, allowing to view the projected object from different points of view and to make detailed evaluations.

Fig. 3: Augmented Reality visualization of 3D model within the patient body.

The automation of the overall process, starting with the medical images and ending with the deployment of the app on the HMD device, could be considered as the next step to innovate current procedures in clinics. Creating an embedded application that includes so many features is very challenging, since exporting a clean and comfortably readable 3D model still requires a great amount of manual work. Despite this, the proposed approach and its preliminary application are necessary to evaluate the potential added value to current medical procedures.

Conclusions:

As Augmented Reality technologies become more powerful and cheaper, applications are reaching higher standards and the field of healthcare is one of the most suitable for their diffusion. The aim of this paper is to propose an enhanced approach for doctors to visualize and manipulate medical images and patient-specific 3D models of internal organs. Thus, it is clear that AR applications have also the potential to enhance surgery planning or training activities. This is the reason why they represent an important step forward in comparison to the most advanced display methods currently in use like table sized touchscreen, since they can provide a much more immersive experience. The most appropriate AR devices for such cases are Head Mounted Displays (HMDs).

For the purpose of this work, a case study has been devised. Three main passages are required: the acquisition of the images derived from the CT scan and the relative 3D models obtained by segmenting the DICOM files, the development of an app into which such data could be implemented and, finally, the deployment and optimization of this app for an HMD device. The AR application different visualization modes: one allows the stand-alone visualization of CT slices and the 3D model that can be useful for doctors' specific diagnoses; another allows to overlap 3D holograms on the patient body, also in a collaborative way, that can help physicians in surgery planning activities. The results have been encouraging, though a lot of scope for improvement is still present. Firstly, HMD devices cannot handle highly demanding applications due to their limited computational power, whereas traditional display methods do not have this issue since they are usually connected to very powerful PC workstations. The main aspect that needs improvements though is the entire process of acquisition and implementation of data for the AR application, since there is not a way to automatically obtain cleaned up 3D models that could be suitable for a good visualization. Relying on the description of a workflow providing a preliminary diagnosis tool to evaluate the patient's diseases, the proposed visualization approach has the potential to boost current medical procedures adding value to the standard visualization techniques.

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