Title:
An Augmented Reality Approach to Visualize Biomedical Images

Authors:
Marcello Lorusso, marcello.lorusso@mail.polimi.it, Politecnico di Milano
Luca Bergonzi, luca.bergonzi@polimi.it, Politecnico di Milano
Giorgio Colombo, giorgio.colombo@polimi.it, Politecnico di Milano
Davide Felice Redaelli, davidefelice.redaelli@polimi.it Politecnico di Milano

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

DOI: 10.14733/cadconfP.2018.xxx-yyy

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, e.g. all the data deriving from wearable devices (i.e. bracelets & similar) or simply from smartphones. 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. They are considered very useful for diagnostic and therapeutic purposes in various medical disciplines. 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 the whole amount of slices deriving from the medical investigations (i.e. CT scans and MRIs), 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 real patient's anatomy, to enhance medical education applications and to plan clinical treatments [1]. Despite the smart table is the latest innovation according to 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.

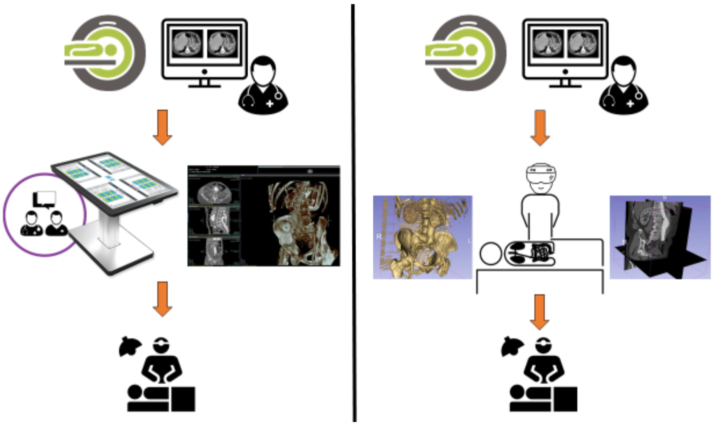

Fig.1: Current CT scans workflow, on the left, versus the proposed visualization approach using Augmented Reality technologies, on the right.

Augmented Reality represents the best choice for improving the visualization of CT scans and 3D model reconstruction 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. Taking into account the CT technique, data workflow and visualization can be improved as shown on the right side of Fig. 1. The raw images available in the DICOM standard format (standing for Digital Imaging and Communication in Medicine) can be virtually stacked allowing a dynamic visualization of the section images. 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 internal parts on the real patient or a physical mockup 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 wireless visualization, once patient data have been uploaded on the device. This opens to new scenarios of collaborative diagnoses and surgery planning activities bringing significant improvements to current practices.

Development of AR application concerning AAA case study:

This section discusses the integration 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 is presented considering actual data coming from a real patient.

The AR application has been developed passing through three required steps, taking into account issues related to this visualization approach. The first concerns the processing of the patient's data and the subsequent extraction of the digital images. In addition, 3D models of internal organs are generated from the segmentation of the CT scans. 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 to obtain a clear and readable 3D model is still very time consuming, since it has to be performed manually by mesh editing. The second step regards the development of the AR application allowing the user to control and manipulate objects in order to retrieve as much useful information as possible. In this stage, Unity 3D has been adopted. Format conversion of the 3D model are necessary at this point, since Unity only reads two de-facto standard formats (FBX, OBJ). The last step consists of the deployment of the application on an HMD device in accordance with its computational power. In this occasion Microsoft HoloLens™ has been used. Due to the image dataset weight and the complexity of the entire model retrieved by CT scans, the device workload must be reduced as much as possible. As a result, for what concern slices visualization, only 300 scaled down images have been uploaded out of the 500 initially available. Plus, just essential organs have been displayed in the 3D model, i.e. abdominal aorta with aneurism, bones and kidneys.

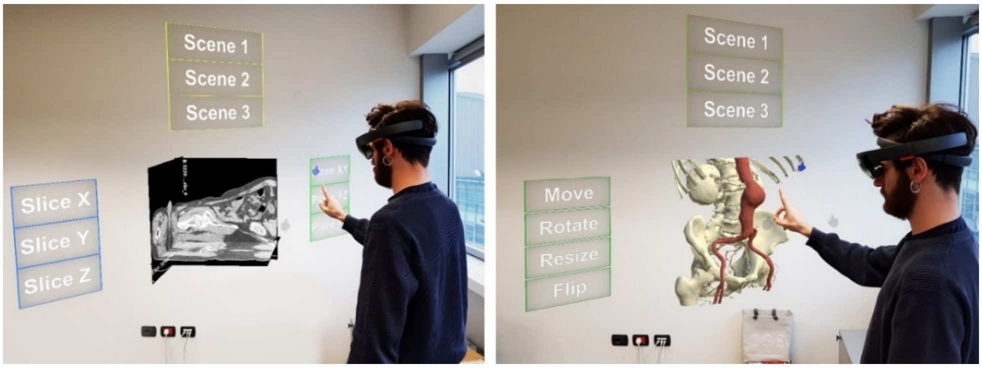

Fig. 2: Augmented Reality visualization of CT slices and 3D models with Microsoft HoloLens™.

Fig. 2 shows the first visualization mode involving the integration of medical information within the AR application using CT scans or 3D models. Slices can be dynamically scrolled with hand gestures helping the user to analyze the images of the scanned section; in addition, even the 3D model can be interactively manipulated or resized highlighting the area affected by the disease. Major disadvantages of using HMDs in comparison to traditional workstations and flat monitors are related to the computational power needed to manage such complex models and to the lack of automation to carry out real-time calculations for different datasets. Nevertheless, this AR application for medical purposes allows not only to provide an enhanced integration of current features, but also to pave the way for the development of customized training applications or surgery plans based on real projections on the patient's body.

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. Adapting 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 label positioned onto the physical object in order to get a correct alignment. Moreover, HMDs can enable collaborative planning process allowing to view the projected object from different points of view and to make detailed evaluations on the treatment process.

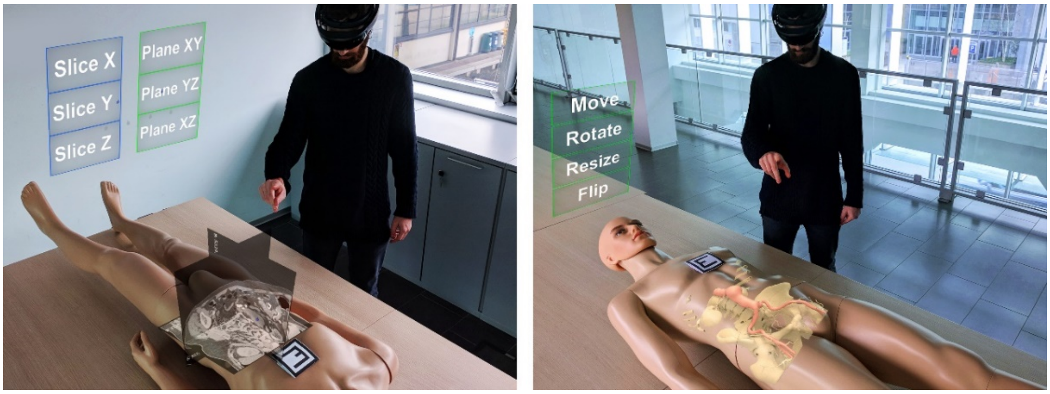

Fig. 3: Augmented Reality visualization of 3D model within the patient body.

This AR application has the potential to become one of the most useful tools for both diagnosis and training. 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 enables two visualization modes: one allows the stand-alone visualization of CT slices and the 3D model that can be useful for doctors' specific diagnoses, and the second allows to overlap 3D holograms on the patient body 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.

References:

[1] Anatomage, http://www.anatomage.com/table/.

[2] Barsom, E. Z.; Graafland. M.; Schijven, M. P.: Systematic review on the effectiveness of augmented reality applications in medical training, Surgical Endoscopy, 30(10), 2016, 4174–4183. http://doi.org/10.1007/-s00464-016-4800-6

[3] 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), 2015, 803–810. http://doi.org/10.1080/16864360.2015.1033347

[4] Burke, E.; Felle, P.; Crowley, C.; Jones, J.; Mangina, E.; Campbell, A. G.: Augmented reality EVAR training in mixed reality educational space, Global Engineering Education Conference, EDUCON, 2017, 1571–1579. http://doi.org/10.1109/EDUCON.2017.7943058

[5] Colombo, G.; Facoetti, G.; Rizzi, C.; Vitali, A.: Mixed reality to design lower limb prosthesis, Computer-Aided Design and Applications, 13(6), 2016, 799–807. http://doi.org/10.1080/-16864360.2016.1168223

[6] Douglas, D. B.; Wilke, C. A.; Gibson, D.; Petricoin, E. F.; Liotta, L.: Virtual reality and augmented reality: Advances in surgery, Biology, Engineering and Medicine, 2(5), 2017, 1–8. http://doi.org/10.15761/-BEM.1000131

[7] Furht, B.: Handbook of augmented reality, Springer Science & Business Media, 2011. http://doi.org/10.1007/978-1-4614-0064-6

[8] 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), 2014, 119–139. http://doi.org/10.1111/j.1948-7169.2011.00139.x

[9] Ghandorh, H.; Mackenzie, J.; Eagleson, R.; De Ribaupierre, S.: Development of augmented reality training simulator systems for neurosurgery using model-driven software engineering, In Canadian Conference on Electrical and Computer Engineering, 2017. http://doi.org/10.1109/-CCECE.2017.7946843

[10] 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 and Other Interventional Techniques, 31(6), 2017, 2520–2528. http://doi.org/10.1007/s00464-016-5254-6

[11] Kamphuis, C.; Barsom, E.; Schijven, M.; Christoph, N.: Augmented reality in medical education?, Perspectives on Medical Education, 3(4), 2014, 300–311. http://doi.org/10.1007/s40037-013-0107-7

[12] Krevelen, D. W. F. van; Poelman, R.: A Survey of Augmented Reality Technologies, Applications and Limitations, The International Journal of Virtual Reality, 9(2), 2010, 1–20. http://doi.org/10.1155/-2011/721827

[13] Regazzoni, D.; Rizzi, C.; Vitali, A.: An overview of open source software systems for smart development of virtual environments, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 2017. http://doi.org/10.1007/978-3-319-58463-8_30