Journal of Medical Systems (2019) 43:102
https://doi.org/10.1007/s10916-019-1239-z

MOBILE & WIRELESS HEALTH

Check for updates

Applications of Virtual and Augmented Reality in Biomedical Imaging

Santiago González Izard[1] · Juan A. Juanes Méndez[2] · Pablo Ruisoto Palomera[2] · Francisco J. García-Peñalvo[3]

Received: 8 January 2019 / Accepted: 6 March 2019

Abstract
Virtual and Augmented Reality has experienced a steady growth in medicine in recent years. At the same time, the radiological images play a central role in the diagnosis and planification of surgical approaches. The aim of this study is to present the first attempt to enhanced radiological image visualization using virtual and augmented reality for better planification and monitorization of surgeries. This application allows to move beyond traditional two-dimensional images towards three-dimensional models that can be visualized and manipulated with both Augmented Reality and Virtual Reality. We propose possible approaches to automate the segmentation of radiological images, using computer vision techniques and Artificial Intelligence.

Keywords Virtual reality · Augmented reality · DICOM · 3D visualization · Radiological images · Image segmentation

Introduction

On the one side, Computarized Tomopgraphies (CT) and Magnetic Resonance (RM) have been extensively used as a non-invasive tool for the visualization of complex and inaccessible brain structures in vivo [1–3]. However, they involve inter-slice distance, defined as the couch increment minus nominal slice thickness. The collimation is a very important physical part of CT scanners, and affects the total scan time, contrast resolution and thinnest available image [4]. In 2010, scientists from the University of California Davis Medical Center conducted a study to explore how the thickness of each slice affects when it comes to achieving a more precise volume. They determined that thickness effectively affects positively when obtaining more precise volumes [5].

Current workstations allow importing classical radiological images in different formats beyond the standard DICOM, merge them and build a three-dimensional reconstruction to facilitate the interpretation of the images. This 3D visualization is carried out in the workstation itself. Interestingly, the generation of 3D relies on a correct process of segmentation of specific region of interest. Currently available segmentation techniques can be divided into two main groups: region based segmentation techniques such as clustering, split and merge, normalized cuts, region growing and threshold; and edge or boundary based segmentation techniques such as Roberts, Prewitt, and Sobel's methods or soft computer approaches (fuzzy logic based, genetic algorithm and neural network) [6]. Among all of them, the thresholding technique is the simplest one and consists on separating the pixels or voxels into groups based on their level of gray. It is therefore of great importance to improve the accuracy of the segmentation that the level of gray obtained in each pixel of each image be as accurate as possible. One of the current challenges to improve radiological images is to develop algorithms capable of automatically perform the segmentation process accurately, and

This article is part of the Topical Collection on *Mobile & Wireless Health*

✉ Santiago González Izard
santiago@arsoft-company.com

Juan A. Juanes Méndez
jajm@usal.es

Pablo Ruisoto Palomera
ruisoto@usal.es

Francisco J. García-Peñalvo
fgarcia@usal.es

1 ARSOFT, Calle del Duero 12, Science Park, 37185 Villamayor, Spain

2 VisualMed System Group, University of Salamanca, Avda. Alfonso X El Sabio s/n, Salamanca, Spain

3 GRIAL Research Group, University of Salamanca, Paseo Canalejas 169, Salamanca, Spain

generating a mesh of 3D models susceptible to be imported into Augmented Reality and Virtual Reality (VR) systems for viewing and manipulation in the biomedical field [7, 8]. Another challenge is to reduce the number of polygons involved in the meshes without compromising quality, since Augmented Reality and Virtual Reality devices usually fail to work with meshes containing very high polygon loads.

On the other side, Augmented and Virtual Reality have received increasing attention in the last three decades. They offer different experiences that are very useful for medical training for example [9, 10]. Augmented Reality (AR) overlays virtual objects on the real-world environment, while Virtual Reality (VR) immerses users in a fully artificial digital environment. They offer a great promise and are expected to become mainstream within five years, although their application has been refrained due to their high development costs. However the development cost is decreasing and Return Of Investment is now attractive for the market, what is causing the use of these technologies to be spreading rapidly.

The goal of this study is to integrate the advances in radiological image processing and 3D rendering, and Augmented and Virtual Reality in order to enhance the former with potential for improve the planification and monitorization of different surgeries.

Material and method

Hardware

The following hardware was used: Samsung Gear VR Glasses, with sensors to recognize user movement when rotating in the three axes; Samsung Galaxy S6, S7, Galaxy Tab S2, and Nexus; and Leap Motion to process spatial information in three dimensions and detect and understand hand movement and distance variation. Two device cameras provide two images with a small disparity. Having the coordinates displayed in space for every matrix dot, each dot in the matrix represents something detected as an intensity value [11–13].

Radiological images acquisition, segmentation of regions of interest, and 3D model's generation

OsiriX, 3D Slicer, Amira or MRIcron were used to segment regions of interest from the original sets of radiological images and generate a polygon 3D mesh of the region of interest [14]. We have generated from DICOM images cranium volumes, brain tracts and many others using these programs. Then, as the 3D mesh created was too heavy, we used Marching Cubes algorithm to create a simpler mesh with a smaller number of polygons, lighter and easier to render. Finally, the file was exported into FBX, 3DS or OBJ format [15].

Automated segmentation is one of the key steps involved in the 3D visualization of models from radiological images, as doing it manually takes time and makes it impossible in most cases. In order to solve this, our system includes the implementation of an advanced algorithm capable of automatically segmenting radiological images keeping accuracy (no fully implemented yet).

A first layer applies artificial vision to DICOM images in order to detect areas of interest based on the Threshold method. This is the most extended technique for segmentation, but there are many other techniques that can be applied.

A second layer applies a computing paradigm named cellular neural network, similar to neural networks, with the difference that communication is allowed between neighbouring units only. The output will indicate that in the image we have what we are looking for or not, however we do not know yet where that element is inside this image.

The third layer is connected to the last fully connected layer of the previous cellular neural network and gets the location of those pixels that are labeled as the element we are trying of segment from the input image.

Now we have, for each DICOM image, the pixels that make up the element we want to segment, however a 3D model is not composed of pixels, but by voxels, the minimum unit of information in a volume. In order to convert into a mesh that composes our final output, the 3D model of the segmented zone, we convert each pixel (x,y) of DICOM images, is converted into voxels by addition the dimension depth (z') is added to each pixel. Depth (z´) result from the formula z' = i*d, where *d* is the inter slice distance and *i* is the number of the pixel image in the DICOM sequence.

3D visualization tools

Finally, three different software applications were designed using multiplatform Unity3D graphics engine, compatible with many SDKs (Software Development Kits). These three applications are named AR VIEWER (Augmented Reality Viewer), VR Viewer (Virtual Reality Viewer) and PC Viewer (Personal Computer Viewer). Different scripts were implemented for improving interaction and visualization; Vuforia was used as the SDK for Augmented Reality, Oculus SDK for Virtual Reality and Leap Motion [11–13] as SDK for the PC version. This last SDK was used only for user interaction with hands recognition, and 3D visualization module for PC was implemented using Unity3D (no SDK as Vuforia or Oculus is required).

We have implemented Web Services for the cloud platform using Java language on a Microsoft Azure server we have configured for this project, using Apache Tomcat as the servlet container and MySQL for the database implementation, integrating database interaction with the Web Services using JDBC plugin.

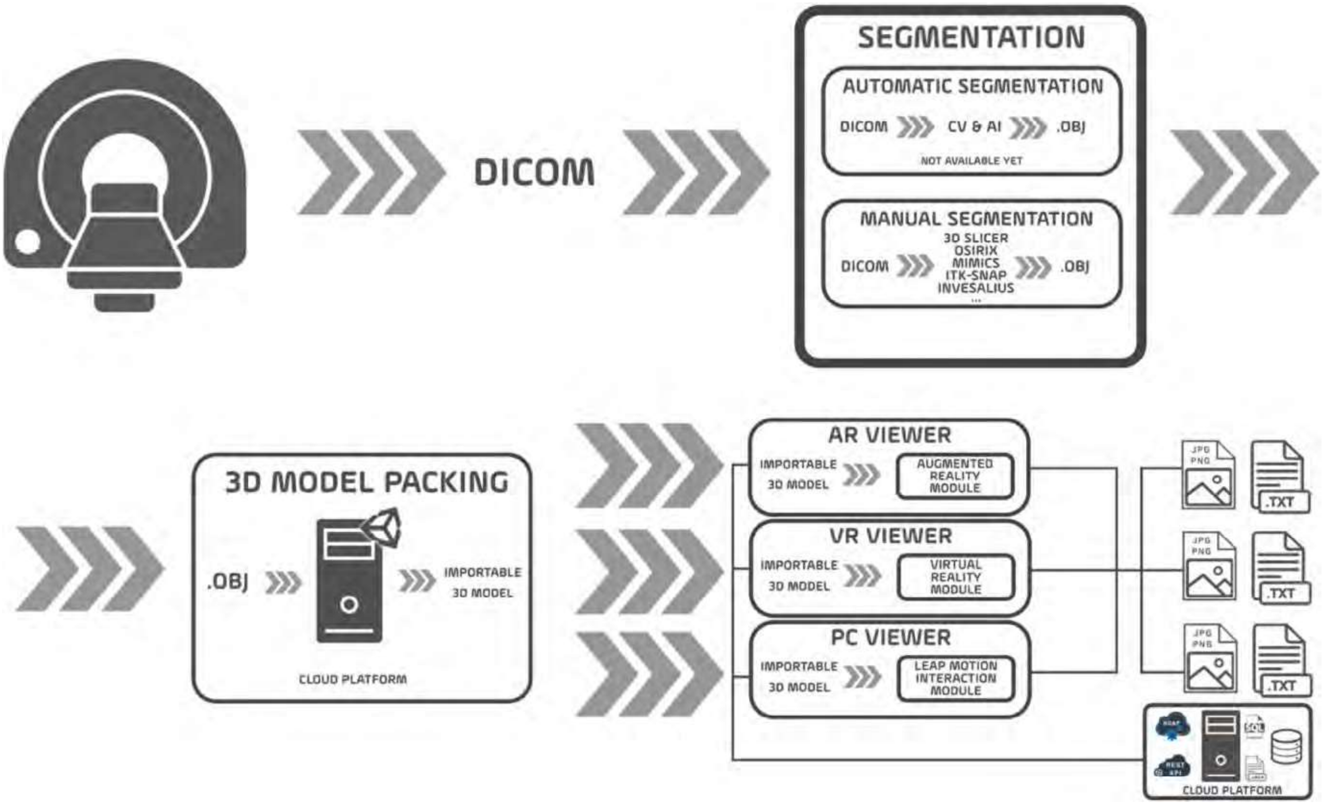

Fig. 1 General architecture of the designed system

Results

This study integrate Virtual and Augmented Reality with both computerized and magnetic resonance imaging to provide a more realistic and comprehensive display of anatomical structures. It includes 3 main features: 1) Augmented Reality system developed for Android and iOS devices; 2) Virtual Reality for Oculus and Gear VR devices and 3) a Desktop system for Windows, Linux and Mac OS X operating systems.

This new system was developed to integrate a) Augmented Reality to visualize and manipulate 3D models of anatomical structures on a real scale as if it had been printed in 3D, b) Virtual Reality to provide a complete immersion to study the 3D model with or without glasses, allowing even diving into the structure with hand movement recognition software, and c) desktop version to allow system utilization without mobile devices, manipulating the 3d models with hands detection using Leap Motion device. In sum, it offers a fast and efficient interaction including rotate, scale or cut the 3D models of complex internal structures (Figs. 2, 3 and 4). In addition, this system can be used by clinicians to store and explore clinical neuroimages from different locations using Augmented or Virtual Reality. Since all the data is stored in a cloud platform implemented on a Microsoft Azure server.

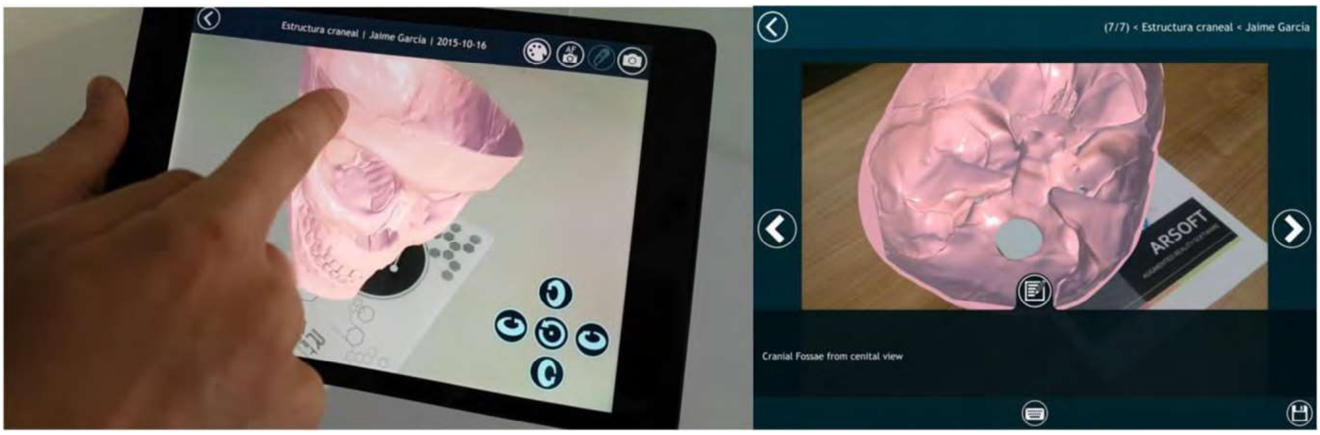

Fig. 2 Augmented reality cranium visualization after cutting it off

Fig. 3 Selecting different options for 3D model manipulation with virtual reality platform

In Fig. 2 user is visualizing with Augmented Reality a cranium that has previously being cut in order to study its interior. It has also been painted, what allows to better recognize the morphology of the bones. In one of the images we can also see a screenshot that has been taken with some annotations, what can be very helpful in order to review these notes during the surgery.

In Fig. 3 the user is interacting with the Virtual Reality system. Interaction modules are very different from one application to another, as we can check in the next figure (Fig. 4), where Leap Motion device is being used to manipulate a 3D representation of the brain tracts of a patient. Both, the cranium and the brain tracts, are 3D models generated from DICOM images following the process described in Fig. 1 with manual segmentation.

Discussion

The vertiginous development of technology over the last decade, that we will undoubtedly continue to see in the coming ones, has allowed us to count on 3D models that accurately reproduce the human body of a patient. as well as having the devices and computer systems with which we can not only visualize these models, but also interact with them in a completely different way from the one so far. The improvement of graphic processing and rendering capabilities allow us to visualize complex 3D models, with meshes composed of millions of polygons, which was impossible until very recently. In addition, the miniaturization of electronic components allow to transfer all this graphic power to mobile devices and even glasses, and that is the reason of why Augmented Reality and Virtual Reality can be now implemented in medical processes without interfering in the work of professionals. In this article we have presented a new system that may become a window into the future, in which 3D models will be very present in our everyday lives, including of course medical field.

Most tools currently available in radiological imaging are focused on the 2D images. This system offers an alternative to complete segmentation and visualize the results with a real three dimensions view.

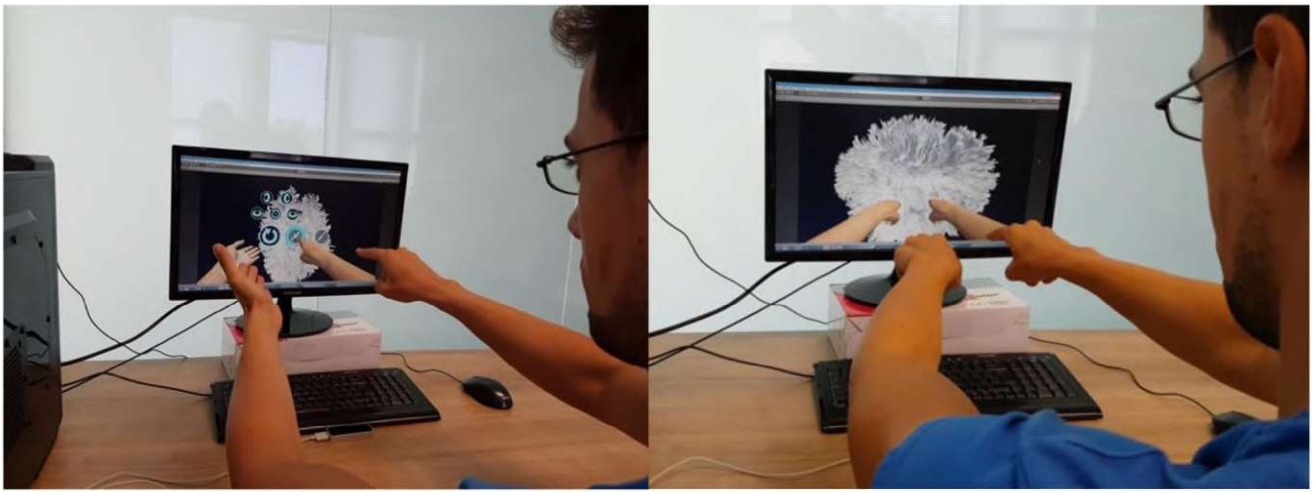

Fig. 4 Manipulating 3D model of brain tracts using hands detection with leap motion

Although there are programs able to generate 3D models from DICOM, as far as we know this is the first tool that fully integrates Augmented and Virtual Reality technology with radiological imaging and is specifically designed to study radiological results and even plan surgeries. These technologies allow to study the 3D models from all the different perspectives and with depth recognition, what is impossible when you are visualizing 3D models in a 2D screen. Also, AR and VR allow to interact with the volume in a realistic way without having to print it, saving time and money, and being able to cut the model to study internal anatomical structures (impossible when you have printed it).

Future research in biomedicine should benefit further from cloud platforms, Artificial Intelligence and machine learning developments and algorithms: IBM Watson, Azure and Microsoft AI Platform, AWS (Amazon Web Services). In the next years many artificial intelligence algorithms will be implemented in order to make automatic segmentations of different anatomical structures, and even to automatically detect deformities, cancer and many diseases, helping doctors with the diagnosis [16].

Conclusions

The main result of this study is the development of an original system for efficiently combine Virtual and Augmented Reality with Computerized Tomography and Magnetic Resonance images. It provides a powerful new tool for visually assessing and manipulating anatomical structures of real patients in 3D, enhancing the classical approach based on 2D images.

As different surgeons conclude after using our system, the visualization of radiological images using Augmented and Virtual Reality provide a better interpretation of the radiological results and can be a breakthrough for surgical planning. In the next decade, all medical professionals from developed countries will visualize the radiological results with these technologies, thanks to the price's drop in Augmented Reality glasses and other related devices and their widespread use in society.

Acknowledgements The authors would like to thank ARSOFT company for their technical work and the Education in Knowledge Society PhD Programme of the University of Salamanca for their support.

Funding This project has been funded by the Spanish Ministry of Science, Innovation and Universities, as part of the Spanish National Program of Research, Development and Innovation for Challenges of Society, as part of the National Plan for Scientific and Technical Research and Innovation, with expedient number RTC-2017-6682-1.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. Altobelli, D. E., Kikinis, R., Mulliken, J. B., Cline, H., Lorensen, W., and Jolesz, F., Computer-assisted three-dimensional planning in craniofacial surgery. *Plastic Reconstruct. Surg.* 92(4):576–585, 1993; discussion 586-7].
2. Brammer, M., The role of neuroimaging in diagnosis and personalized medicine–current position and likely future directions. *Dialogues Clin. Neurosc.* 11:389–396, 2009.
3. Inoue, D., Kabata, T., Maeda, T., Kajino, Y., Fujita, K., Hasegawa, K. , Yamamoto, T., and Tsuchiya, H., Value of computed tomography-based three-dimensional surgical preoperative planning software in total hip arthroplasty with developmental dysplasia of the hip. *J. Orthopaed. Sci.*, 2015.
4. Seeram, E., Computed tomography: Physical principles, clinical applications, and quality control, fourth edition [chapter 11]. ISBN: 978–0–323-31288-2, 2016.
5. Prionas, N. D., Ray, S., and Boone, J. M., Volume assessment accuracy in computed tomography: A phantom study. Journal of applied clinical medical physics, volume 11, number 2, Spring 2010.
6. Zaiton, N. M., and Musbah, J., Aquel. survey on image segmentation techniques. *Int. Conf. Commun. Manag. Inform. Technol. (ICCMIT 2015)*, 2015. https://doi.org/10.1016/j.procs.2015.09.02.
7. Zaitoun, N. M., and Aqel, M. J., Survey on image segmentation techniques. *Int. Conf. Commun. Manag. Inform. Technol. (ICCMIT)*, 2015. https://doi.org/10.1016/j.procs.2015.09.027.
8. Sharma, N., and Aggarwal, L. M., Automated medical image segmentation techniques. *J. Med. Phys.*, 2010. https://doi.org/10.4103/0971-6203.58777.
9. González Izard, S., Juanes Méndez, J. A., and Palomera, P. R., Virtual reality educational tool for human anatomy. *J. Med. Syst.* 41:76, 2017. https://doi.org/10.1007/s10916-017-0723-6.
10. S. González Izard , J.A. Juanes Méndez , J. M. Gonzalvez Estella , M.J. Sánchez Ledesma , F. J. García-Peñalvo , P. R. Palomera, Virtual simulation for scoliosis surgery, proceedings of the 5th international conference on technological ecosystems for enhancing Multiculturality, 1–8, 2017. Cádiz, Spain. doi:https://doi.org/10.1145/3144826.3145404.
11. Belda, J., Leap Motion (II): principio de funcionamiento. Showleap Technologies, 2015. From http://blog.showleap.com/2015/05/leap-motion-ii-principio-de-funcionamiento/
12. Marin, G., Dominio, F., and Zanuttigh, P., Hand gesture recognition with leap motion and kinect devices. *Image Process. (ICIP), 2014 IEEE Int. Conf.*, 2014. https://doi.org/10.1109/ICIP.2014.7025313.
13. Manolova, A., System for touchless interaction with medical images in surgery using leap motion. Radiocommunications and Videotechnologies Department Faculty of Telecommunications, Technical University of Sofia. Communications, Electromagnetics and Medical Applications (CEMA'14).
14. Andriy, F. et al., 3D slicer as an image computing platform for the quantitative imaging network. *Magnet. Reson. Imag.* 30(9):1323–1134, 2012. https://doi.org/10.1016/j.mri.2012.05.001.
15. A. Silvetti, C. Delrieux, S. Castro (2001). Una implementación eficiente del algoritmo Marching Cubes. http://hdl.handle.net/10915/23546
16. Al-Shayea, Q. K., Artificial neural networks in medical diagnosis. *IJCSI Int. J. Comput. Sci.* 8(2):2011, 2011.