



AN INTERACTIVE HOLOGRAPHIC ENVIRONMENT FOR VISUALIZATION OF HEART STRUCTURE AND ACTIVITY

Gabriel Cyrino*¹, Diogo Cavalcante¹, Maurício Aureliano¹, Arthur Bucioli¹, Ian Avelar¹, Alexandre Cardoso¹, Edgard Lamounier¹ e Gerson Lima¹

¹FEELT - Universidade Federal de Uberlândia

Abstract - Traditionally, demonstrations of human anatomy are commonly used for analysis, study, and learning of the internal structures of the human body. However, visualization and simulation techniques of human organs are frequently explored. Through these techniques, is possible to observe and analyze hidden details of the human anatomy, that is fundamental for the aid of the medical diagnosis process, clinical treatments, analysis, study and learning of the internal structures of the human body. The reconstruction of three-dimensional high definition models using medical imaging has proven to be a great technique to optimize the process. With this aim, this work proposes the use of a holographic environment for the interactive visualization of a three-dimensional heart generated from a real Coronary Tomography (CT). For that, Augmented Reality and Information Visualization techniques were used to simulate and interact with the virtual heart through Microsoft HoloLens. In addition, a heart rate sensor has been developed, to monitor, in real time, the functioning of the heart, according to the heart rate of the user. The results demonstrate that it is possible to simulate the activity of a heart and to visualize more details of the anatomy and functioning of the organ through this holographic environment. As future work, it is intended to capture more important information based on CT scans and extend the project's scope to include other organs.

Keywords - Augmented Reality, Coronary Tomography, Heart Activity, HoloLens, Information Visualization, Mixed Reality.

I. INTRODUCTION

In biology and traditional medicine, demonstrations of organic structures are commonly performed for physicians, biologists and students. However, these demonstrations may not be very attractive, or they may not impact learning as they should. Thus, the visualization and simulation techniques of human organs are being increasingly explored. Through these techniques, it is possible to observe and analyze hidden details of the human anatomy. Besides being fundamental for the aid of the medical diagnosis process and clinical treatments,

these techniques are proving to be more impacting for analysis, study and learning of the internal structures of the human body.

With the use of the reconstruction of a three-dimensional model through medical images, the potential of these techniques can be greatly increased, especially when Virtual and Augmented Reality is also used for visualization and interaction, but not yet many systems that use these technologies. With this purpose, this work proposes the development of a holographic environment using Augmented Reality (AR) techniques for the visualization, simulation and interaction of a three-dimensional virtual heart through Microsoft HoloLens, and this heart model was reconstituted from a real Coronary Tomography (CT). Thus, it becomes possible to directly manipulate the virtual organ and interactive interfaces within the holographic environment.

A heart rate sensor was used, where the virtual heart model is animated according to a person's heart rate, allowing real-time monitoring of their heart rate.

Through this holographic environment it is possible to visualize and interact with the human heart in several layers and analyze different types of information, making the learning process of the human anatomy more intuitive and interesting, and in the future, a better support in medical diagnostics.

II. FUNDAMENTALS

A. 3D Visualization/ Interaction Interfaces

Several 3D visualization systems have been proposed in the Literature. This paper, however, focuses on the AR, Mixed Reality and Computational Holography, as described in the following.

1. Virtual Reality: Virtual Reality (VR) is described as an advanced user interface, based on the 3 Is pillars: interaction, immersion and imagination [1]. However, a VR based interface should allow the user to use their intuitive skills and knowledge to manipulate the virtual objects. [2]. VR applications are found almost everywhere, like games, simulations, specific training. A large area of knowledge that VR has shown to be

*gabrielcyrino@hotmail.com

promising in medicine, training prospective practitioners and viewing medical examination.

2. **Augmented Reality:** Augmented Reality (AR) is the insertion of virtual objects into the physical environment, shown to the user, in real time, with the support of some technological device, using the real environment interface, adapted to visualize and manipulate the real and virtual objects. [2]. However, AR allows the user to see the real world, with virtual objects superimposed or composed with the real world. Therefore, AR complements reality instead of completely replacing it [3]. Every AR solution generate virtual elements in the real world and make the user want them to be part of the medium to which they are inserted [4]. AR can be used in several areas acting among them: education, training, fun, medical. Although there are many restrictions on applications, AR has shown promising results for medical training and viewing of medical exams as we move from static 2D imaging to a dynamic 3D visualization.
3. **Mixed Reality and Computational Holography:** Mixed Reality (MR) can be defined as the amplification of sensory perception through computational resources [5]. It allows for a more natural interface when working with computer-generated data and images across computing data and real-world information. One of the most important characteristics of MR is that the interaction occurs within the real environment that surrounds the user, thus guaranteeing the conditions necessary to interact with this data naturally. Accordingly, MR uses the association of Virtual Reality and real environment, offering the user a better perception of the environment and favoring their interaction with it. A holographic model can be brought to life by a holographic 3D display (a display that operates through the interference of coherent light [6]). Consequently, in recent times the term "computer generated holography" is increasingly being used to denote the whole process chain of synthetically preparing holographic light wavefronts suitable for observation. Due to wearable computer technology, it is possible to bring up, in real time, indoor mapping and interaction with holograms in a MR environment, enabling the user to work with digital content as part of the real world.
4. **Microsoft HoloLens:** The Microsoft HoloLens is a wearable holographic computer based on MR and built into a headset that lets the user see, hear, and interact with holograms within an environment such as a living room or an office space. Microsoft has built the headset without the need to be wirelessly connected to a computer and has used high-definition lenses and spatial sound technology to create an immersive, interactive holographic experience [7]. Microsoft HoloLens can map the entire user environment while displaying three-dimensional virtual objects set in that environment. The same still has Cortana which is the personal assistant of Windows that can be activated by means of voice command using keywords. In addition to voice

commands interactions with virtual objects can also be obtained through hand gestures and keyboard input or other vesicular devices. The result is the best mixed-reality experience to date by a stand-alone and unconnected device [8].

B. Coronary Computed Tomography Angiography

Coronary Computed Tomography Angiography (CCTA) uses an injection of iodine-rich contrast material and computed tomography scanning (CT) to examine the arteries that supply blood to the heart and determine whether these have been narrowed by plaque buildup. The images generated during a CT scan can be reformatted to create three-dimensional images that may be viewed on a monitor, printed on film or transferred to electronic media [9].

C. 3D Model Reconstruction from Imagery Techniques

In the current paper, the tomography technique was chosen as the subject of interest, as this is one of the most commonly used techniques for obtaining 3D models of the human heart.

In a computerized tomography, gray tones represent the tissue density. Therefore, it is possible to select a particular density for further analysis, as well as to generate 3D models. Each frame of the tomography represents a slice of the patient's upper body, in a specific position. In turn, this position is changed on the next frame, in order to obtain a slice of another portion of the body, covering the whole area of interest. The 3D model is generated by joining data contained in all slices into a solid geometric object.

The process of generating a 3D solid model from tomography images requires a technique for detecting the boundaries of tissues, and thus to generate the appropriate 3D representation. One of the most popular algorithms, widely used by 3D reconstruction software is Marching Cubes [10]. This algorithm works by dividing the space into cubic cells and then processing the content of each cell individually, which results in one of 14 predetermined 3D patterns. At the end of this process, a high-density surface is generated by the algorithm. An alternative algorithm, called Marching Tetrahedra is also proposed. However, it requires more computational power, since instead of processing a single cube per cell; the algorithm interacts with 6 tetrahedral [11].

In this work, this process was used for 3D composition of a real CT only to validate the application. A representative model of a heart was used in the environment to better demonstrate the layers of information and interactions developed. In the system development section this is best discussed.

D. Visualization of Information

There are several ways for information to be created and transmitted. Sites, drawings, texts, images, videos and others, are also used to transmit and generate information [12]. Thus, some information can be easily perceived when the message is very short and objective, however, in most cases, it becomes difficult to clearly extract critical information transmitted in text, image, and others.

In this sense, the use of Information Visualization techniques aims to facilitate the analysis and perception of information by its receiver. Combining aspects of computer graphics, human-computer interfaces and data mining, Visualization of Information allows the presentation of data in graphical forms so that the user can use their visual perception to better analyze and understand the information.

In summary, Information Visualization techniques seek to graphically represent data and information from a given application domain, such as the visual representation created, to explore the capacity of human perception, and from the relations graphically displayed, to transform into new knowledge [13].

In this work, some Information Visualization techniques were used to compose the information layers present in the holographic environment. These layers will be discussed in the system development section.

III. RELATED WORK

The diagnosis of heart disease is generally based on the anatomy and physiology image due to their diversity among different people. For the most part medical imaging cardiac diagnostic exams do not provide enough intuitive visual support and not very practical use and require some experience for understanding.

In [14] a software was developed that consists of a higher level of a combination of previously recorded angiograms with the visible coronary arteries and an increase through a semi-transparent crossfade view of the angiogram. The toolkit of this software that works by removing specularities from the bright surface of the heart and reconstructing the colors of the original image, color-based coronary artery segmentation in cardiac imaging sequences, angiographic segmentation, symbolic representation, magnification, and visualization based on OpenGL, generating the three-dimensional model to be represented.

In [15] was presented a method called volume differential rendering, to accelerate the process of volume animation for visualization of flow. Consistency of data between the simulation time steps are used to prevent unnecessary throwing of the plane's rays from the image. In this case the differential volume rendering algorithm with electric wave propagation simulation data within a ventricular myocardial cellular automata model was used to visualize the wave propagation of a 3D heart.

The three-dimensional reconstruction of a cardiac contour by Magnetocardiography proposed by [16] worked with reconstruction of 3D cardiac contour using only measurement data, without other imaging techniques. The cardiac outline was reconstructed by a combination of spatial filtering method and coherence mapping. The strength of cardiac activities was estimated for the first time by the recursively updated matrix minimum restriction spatial filter.

The visualization of the segmented heart and integral breast clearly and accurately for pathology research, pre-surgical planning and clinical approach was proposed by [17]. In this study the visualization of the segmented heart was obtained by

cryosection images. In addition, the result also visualizes the entire thorax to represent the spatial characteristics of the heart in the thorax. In order to provide a satisfactory quality of visualization in the form and limit of the heart, first the cardiac data was obtained through cryosection data. In the volume rendering process, a new transfer function was created combining spectral occlusion with gradient information to highlight the heart without loss of chest data. Through the implementation of some popular transfer functions, comparison with these results shows that this proposed hybrid transfer function clearly visualizes the cardiac outline and internal structures.

Lorenz and von Berg [18] proposed a comprehensive heart model, including four chambers and attached vessel trunks, which were built semi-automatically by model initialization and minimization of model adaptation energy. Ecabert et al. [19] introduced a method for segmentation of the entire heart, in which the generalized Hough transform was used to locate the heart. The parametric and deformable adaptations were then performed to coincide with the border of a heart.

IV. SYSTEM DEVELOPMENT AND RESULTS

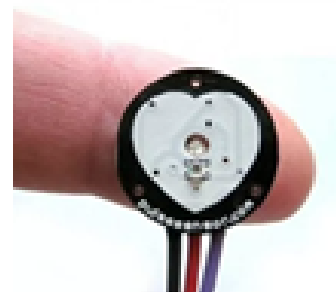
Basically, the project involved 4 different hardware components, which are:

- Pulse sensor and heart rate monitor.
- ESP-8266 Wi-Fi module (NodeMCU).
- OLED Display SSD1306.
- Microsoft HoloLens.

A. Pulse Sensor and Herat Rate Monitor

Pulse Sensor is a heart rate monitor which has an easy connection to the microcontroller, it has an operating voltage of 3 or 5VDC, dimensions of 16x2.7mm and should be used together with a Velcro, adhesive that allows the sensor to be attached to the user's finger. 1 shows the Pulse Sensor.

Figure 1: Pulse sensor.

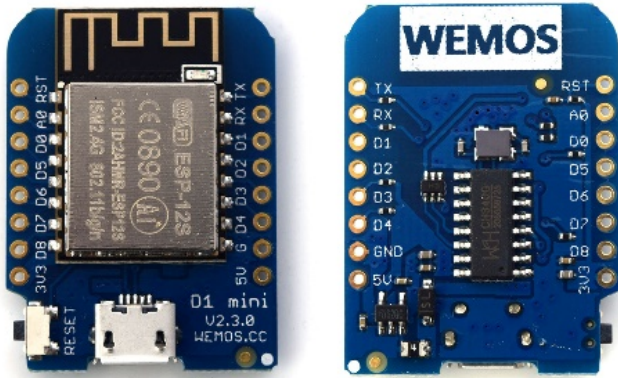


B. ESP-8266 Wi-Fi module (NodeMCU)

The ESP-8266 module is a microcontroller with integrated Wi-Fi that can be programmed by the native SDK, using Arduino IDE. The version of the Arduino used was 1.8.2. Through integrated Wi-Fi, data can be sent and received

through Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) protocols. The ESP-8266 module is also responsible for eliminating all noise picked up by the pulse sensor and heart rate monitor. For this work the Wemos D1 mini version of the ESP-8266 module was used. Figure 2 shows an image of the module.

Figure 2: Wemos D1 mini module (ESP-8266)



C. OLED Display SSD-1306

An OLED display SSD-1306 was added to the circuit for the heart rate monitoring, being connected to the ESP-8266 module and displaying the information generated from the pulse sensor. Figure 3 shows the OLED display.

Figure 3: OLED Display SSD-1306 showing heart rate according to sensor.



D. Microsoft HoloLens

Microsoft HoloLens is responsible for receiving the data on the microcontroller and sending it to the application. HoloLens has four microphones for detecting voice commands. In this way, the application also made use of these commands that were previously implemented. The UDP protocol was used to transmit Wi-Fi data between the devices. Figure 4 shows the HoloLens.

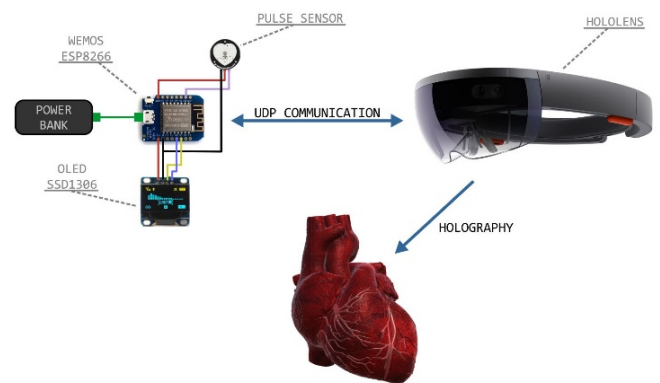
Figure 4: Microsoft HoloLens.



E. Application Architecture

First, the data are captured by the Pulse Sensor that reads the heart beats using an amplified optical sensor. This data is sent to the ESP-8266 microcontroller through a single signal pin. Then, the microcontroller interprets the signals sent through an algorithm implemented in C language, in Arduino. These signals are displayed on the OLED display and routed through the Wi-Fi connection to Microsoft HoloLens, which receives the data and sends it to the application installed on the device, which contains the three-dimensional heart model in its various layers and an interaction interface. In the application the data are interpreted so that the organ replicates the actual beat rhythm. The heart is then projected into the real environment by means of a holography, along with the interaction interface. The application allows the user to perform interactions through voice commands (3-axis rotation, translation and movement) that have been implemented. Figure 5 exemplifies the scheme used.

Figure 5: Scheme of the developed environment.



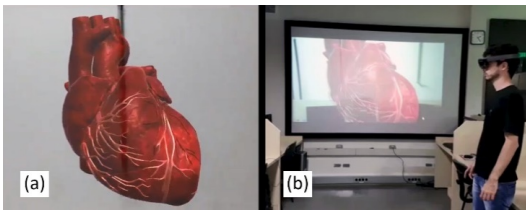
It is possible to interact with the 3D heart through voice commands and observe the internal structures of the heart, all excited in accordance with the heartbeat in real time. In addition, holography can be reduced to the actual size of a heart, so it can be projected onto a person's chest for better understanding. The voice commands implemented in the environment are presented in the Table 1.

Table 1: Voice commands and their respective actions.

Voice Command	Action
"Rotate X"	Rotates the heart on the X axis.
"Rotate Y"	Rotates the heart on the Y axis.
"Stop"	Stops the heart rotation.
"Inside On"	You can see inside the heart.
"Inside Off"	You can see outside the heart.
"Reset"	Resets the heart position.
"Plus"	Increases the scale of the heart.
"Minus"	Decreases the scale of the heart.
"Far"	Pushes away the heart.
"Near"	Brings the heart closer.

The Figure 6 shows the holographic environment with the heart in external view (a) and the interaction with HoloLens (b).

Figure 6: Holographic environment with heart being designed and interaction using HoloLens (b) - the background is showing user's view (b).



The 3D heart consists of several layers that shows the internal structure, their names and their meaning. The primary layers can be accessed via the "Inside On" and "Inside Off" voice commands and the secondary layers are accessed through user gestures. These gestures are pincer movements made with the index finger and thumb above the projection of the chambers and components of the heart, such as atriums, ventricles, veins and valves. Figure 7 shows the primary layers and Figure 8 shows some of the secondary layers. These figures were captured through HoloLens.

Figure 7: The two primary layers: The exterior and the interior of the 3D heart.

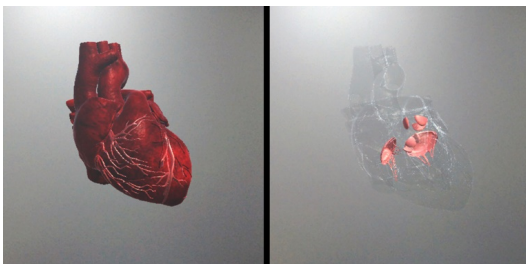
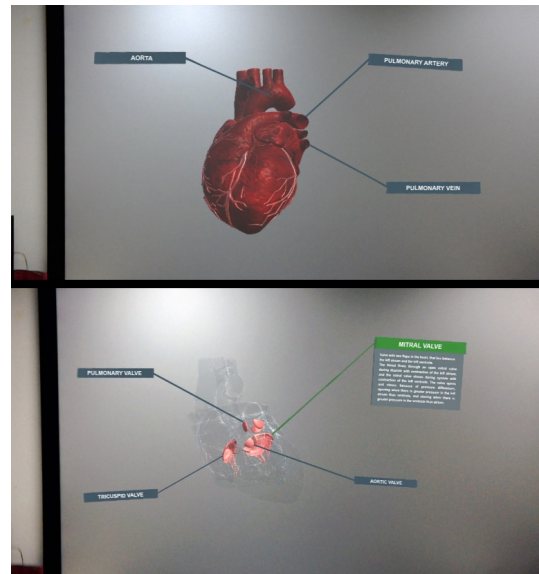
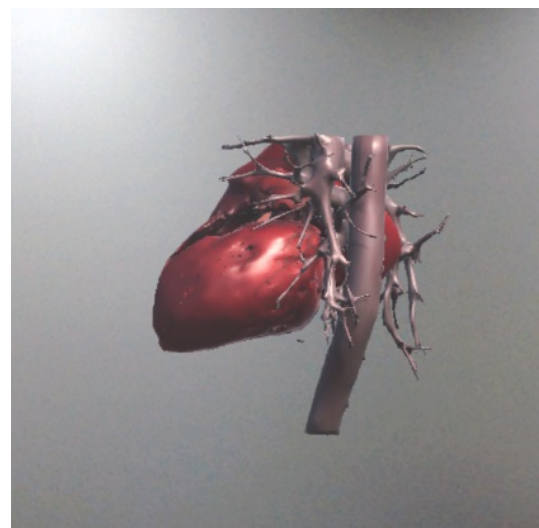


Figure 8: Two of the secondary layers: one showing some information of the external structure and other showing some internal information. The Mitral Valve information box was expanded as example.



For demonstrative and educational purposes, this virtual heart was modeled to be used in this application. As a future work, the three-dimensional model of the heart will be generated from the CT of a patient and the information of the secondary layers (related to the heart structure) will be obtained according to the patient and shown in the respective parts of the virtual heart projected in the environment. This will be useful for medical diagnosis. Figure 9 shows a proof of concept with a 3D heart generated from a real CT using some reconstructions techniques, through HoloLens.

Figure 9: 3D Heart Hologram of a Computational Tomography scan.



V. CONCLUSIONS

Demonstrations of organic structures are commonly used in both medical and educational environments and one of the major shortcomings present in these representations is the methodology used for organic visualization. In general, in this

context the demonstrations are not very attractive and do not impact on learning as they should.

The objective of the proposed work is to improve the visualization techniques of organic structures. Thus, a holographic environment was developed using AR/MR techniques for the visualization, simulation and interaction of a three-dimensional virtual heart through Microsoft HoloLens. It was possible to observe that the generation of this model allowed a more impressive visualization that provided a better understanding about the structure of a heart, as well as the animation of the same one aligned to the heart beats in real time obtained by the implemented sensor, making possible the interactive manipulation of the organ in holography.

The results have proved to be satisfactory, because interacting with the human heart in the holographic environment in several layers and analyzing different types of information, the learning process of the human anatomy becomes more intuitive and interesting. As future work, is intended to use more advanced techniques of reconstruction of models and capture detailed information based on CT analysis, showing this information in real time in holography. It is also intended to extend the scope of the project, including new organs of human body.

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