3D Human Heart Anatomy : Simulation and Visualization based on MR Images

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Abstract— **Understanding the human heart anatomy is important in order to extract information and to understand how it works. Magnetic resonance imaging (MRI) can be a robust solution to extract some information about the heart anatomy. Data from multiple image planes can be combined to create a 3D model of the cardiac system. The shape of the human heart is an irregular shape that makes it difficult to model and it takes many hours to create a 3D shape of the human heart with a high details and precision. A new three-dimensional heart model has been developed including structural information from MRI. The method uses Marching Cubes (MC) Algorithm for the extraction of an equipotential surface (subsurface) of a 3D mesh structured and uniform model. In order to visualize the 3D virtual model created in a real environment, we use Augmented Reality techniques (AR).**

Keywords-3D heart; MRI; Marching Cubes; Segmentation; Augmented

I. INTRODUCTION

Cardiovascular diseases are the leading cause of death in many countries. Therefore, the study of the cardiac system has become a priority in computer science. Medical imaging technology gave the possibility to create a realistic 3D cardiac model from medical images.

The heart is the most vital organ in the human body that functions as the body's circulatory pump. Basically, the heart contains four chambers: two atria and two ventricles. The ventricles are responsible for pumping blood from the heart to the rest of the body, while the atria are the chambers that receive blood returned to the heart.

In this paper, we present a novel approach to create an anatomic model of the heart based on MRI.

The basic idea is to use medical imaging technology to create a virtual model of the heart. Our model can be used to get a 3D real time visualization of a specific patient heart and to help in diagnosis as a complement to medical imaging information. Our system allows users to create a 3D shape of the heart using MRI. In our study, we first use MRI to generate the virtual model. Then we use the AR to visualize it in the real world. The method uses the marching cubes algorithm to provide a 3D shape of the heart. The visualization of a 3D virtual heart in a real environment offer the possibility for the medical field students to better understand the anatomy of the cardiac system [1].

In Section 2 we describe the differences with existing works. In Section 3 we introduce the general architecture of our system and we prepare our data: MRI divided on multiple planes Sagittal, axial and coronal. In Section 4, to ensure a quality image of the model we apply a combined region growing and thresholding segmentation. In Section 5, we use the Marching cube algorithm to obtain the 3D model of the heart. Finally, we correct false faces in order to improve the model render quality.

II. RELATED WORK

In recent years, modeling of the human heart has been done successfully using medical imaging technology, as demonstrated by early works [2] and [3].

In this section, we provide a brief overview of some of the more distinctive work that has been done on cardiac 3D modeling. This will provide an overview of the main approaches for cardiac modeling.

Medical imaging provides the possibility to obtain important information, such as structural and functional. Using MRI or CT images we can create a 3D model of the heart. Neiderer et al. [4] created a specific-patient heart model. To create a specific-patient heart, it requires magnetic resonance images synchronized with ECG and breathing in order to reduce the noise and motion artefacts caused by to the cardiac cycle and breathing movements.

Heart tissue can also be personalized using MRI [5], such as the location and extension of the Myocardium. The CCS and the fiber orientation cannot be personized yet because of limited information. Also the mechanic behavior of the heart cannot be simulated with a high accuracy. With the

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exception of the work by Sermesant et al. [6], most models that have been built by the medical imaging/computer vision community incorporate only limited aspects of the physiology of the heart. Van assen et al. [6], made a significant amount of research on active shape based models for cardiac segmentation, they succeeded to create a 3D shape of the heart. In the other hand, Mitchell et al. [7], introduced a new model, it focus on modeling the entire cardiac volume, and not just the surface as surface models do. The main advantage of this method is: the shape deformations can be learned from a given training set. Sermesant created a model which simulates the electromechanical behavior of the heart in a numeric efficient way. By incorporating a priori knowledge about cardiac properties. Models based on tissue deformation [8], where the third dimension corresponds to time. This method estimate the cardiac wall motion with the help of a metric measuring the curvature properties of the surface. Matthews and baker [9] introduced a novel image alignment algorithm. This new algorithm can be used to align MRI slices in order to create 3D volume with it.

To obtain a high quality virtual model of the heart, one needs to prepare the data carefully because the final rendered model depends on it. A major factor that can affect the model quality is the technique used to extract 3D sub-surfaces.

In this paper we offer a new method to create a high quality virtual model of the human heart. The model we propose is meant to improve the segmentation stage. We use both thresholding and growing region segmentation and to improve the rendered quality of the model, we used the marching cube algorithm. For the visualization stage, we used the game engine unity 3D to create an augmented reality system.

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III. DATA ACQUISITION

As described in Fig. 1, there are four primary steps in our approach to the 3D heart construction problem. Reconstructing a static heart model involves the following four successive steps:

a. Acquisition of MRI Data Sets.

b. Semi-automatic extraction of the structure information.

c. Interpolation and 3D reconstruction of the static heart model.

The overview of the system is shown in Fig. 1.

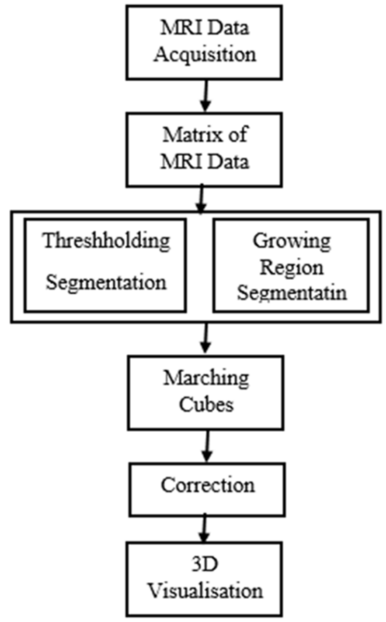

Figure 1. General Architechture of our system

We use MRI images for the construction of 3D heart proposed here. The images used for developing the 3D heart model are identical to the ones described in [11].

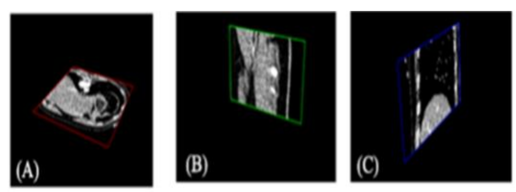

Figure 2. Different palnes, (A) Axial, (B) Sagittal and (C) Coronal

The shape of the 3D heart obtained using the MRI data was based on the axial, sagittal and coronal planes Fig. 2 of the human heart. We use 210 slices to cover the entire heart.

IV. SEGMENTATION

In this section, we describe the segmentation methods we used to correctly perform the segmentation of a 2D cardiac slices.

A. Thresholding

One of the most important tasks in 3D medical image reconstruction is segmentation because it affects directly the rendered quality and the results obtained. Each image slice is segmented individually to obtain the higher precision as we can get.

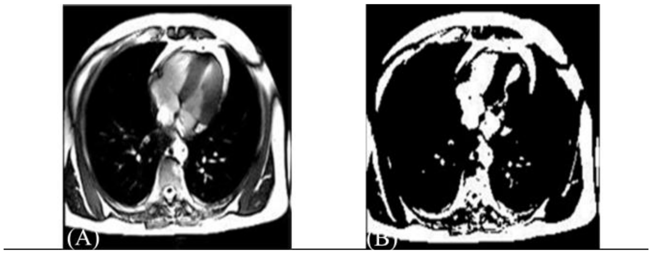

Figure 3. Result of segmentation using thresholing, (A) Original image, (B) Segmented image S=110

We start by fixing a constant S (a threshold [12]). If a pixel F (i, j) has a gray scale value higher than S, it will be assigned to category 1 (white color); otherwise, it will be assigned to category 2 (black color).

B. Growing Region

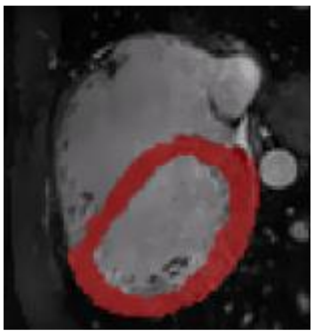

Figure 4. Growing region segmentation

The concept of ”region” means an assembly of points with similar properties. Image segmentation based on region aims to partition an image into a set of regions with common characteristics. Region growing [13] is a method that is based on grouping pixels or sub regions into larger regions based on predefined properties (similar properties). The main idea is to start with a set of seed points and grow the regions by comparing each seed to its neighbor (4 or 8) pixels that have similar properties to the seed.

V. 3D Reconstruction of the Heart

The principle of the 3D reconstruction models from three dimensional stacks of 2D parallel images [14] of an atomic structure is done by rendering techniques, such as surface or volume that is based on an automatic or manual segmentation structures to reconstruct it using the 2D images. Marching cubes [15] algorithm is one of the most used algorithm in medical images reconstruction. So far, the marching cubes algorithm is used in lot of applications due to its relatively simple principle and strong quality of results.

The algorithm of Marching Cubes is based on surfaces to extract an equipotential surface (subsurface) of a 3D mesh structured and uniform model [16]. The marching cube algorithm is applied to a cube after the other. Marching cubes is based on a divide and conquer method to locate the surface in a logical cube created from eight pixels. The objective of the Marching Cubes algorithm is to create the 3D model of the anatomical structure interest.

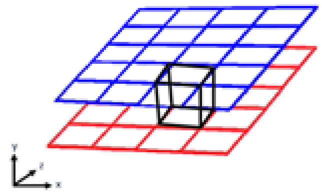

Figure 5. Marching Cubes

Principle:

- Create a cube Fig. 5
- Classification of the vertices on each cube
- Create an index for the cube
- Search Configuration corresponding for the 15 patterns
- Positioning the point of intersection of the surface with the cube using a Linear interpolation
- Calculate the normal for each vertex
- Interpolation normal for each vertex of the triangle
- Repeat steps for the other cubes

The grouping of surfaces obtained surfaces helps to obtain the approximation of the desired volume of the cardiac system. Paul Bourke invented a cube numbering system that allows to create an index for each case, based on the state of the vertex Fig. 6.

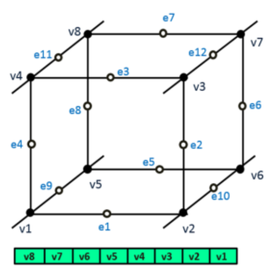

Figure 6. Cubes Numbering.

To create an index we must classify the vertices of cubes:

- 1 if it is inside the surface
- 0 if it is outside

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Then, we need to create a surface topology in the cube, and since there are 8 vertices in the cube and each vertex is represented by two binary states inside and outside (0 and 1), then we have 256 case of surfaces which can intersect in a single cube or 256 possible configurations. By giving numbers to these 256 cases, we create a table to extract surface-edge intersections in each cube, given the labeling of a cubes vertices. The table contains the edges intersected for each case. But through rotational, symmetries and inversion internal / external points can be reduced to 15 only configurations that give 15 different triangles shown in Fig. 7

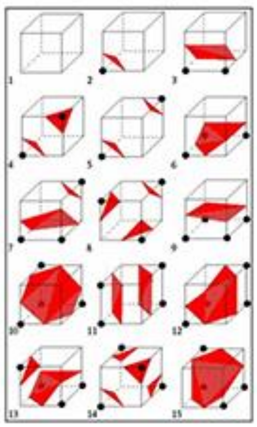

Figure 7. Trianguled Cubes.

Using the index to tell which edge the surface intersects, we can interpolate the surface intersection along the edge. We use linear interpolation, but have experimented with higher degree interpolations. Since the algorithm produces at least one and as many as four triangles per cube, the higher degree surfaces show little improvement over linear interpolation.

In summary, marching cubes creates a surface from a threedimensional set of data.

VI. RESULTS

We have applied MC to data obtained from MRI, as well as data generated from analytic functions. We present three case studies that illustrate the quality of the constructed surfaces and some modeling options. Each image was rendered at 512 by 512 resolution.

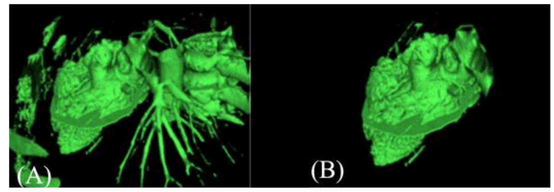

Figure 8. 3D Reconstruction using MRI, (A) without segmentation, (B) with segmentation

This 3D model is obtained after the elimination of the segmentation phase. We notice the existance of bones, veins and arteries. To isolate the 3D model of the human heart should always go through a segmentation phase. Sometimes this phase is made in a manual way. We found that the quality of rendered increases with increasing the number of pictures in the matrix that will interpolate. The heart appears as a single object whose geometry is complex. The appearance of false 3D geometric facets is due to the segmentation problem.

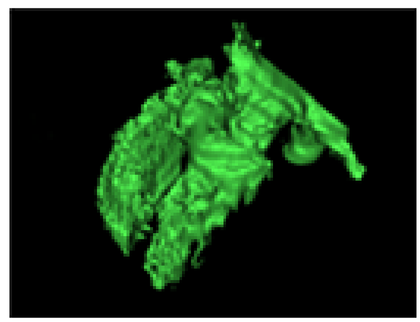

Figure 9. 3D construction using 24 slices

Linear interpolation between the different cuts is limited because of limitation of images. This affects the quality of 3D model of the cardiac system. One can notice the presence of the right and left ventricle, but the fabric is separated is not built.

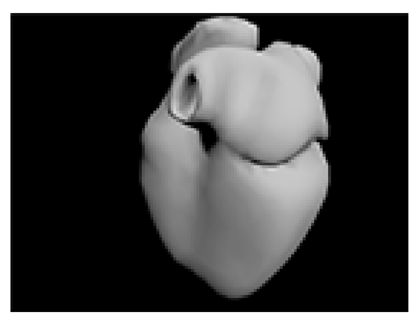

Figure 10. 3D construction using 210 slices with manual segmentation

This 3D model Fig. 10 is obtained after eliminating false faces. After using 210 images in the reconstruction phase, the model appears with a realistic effect. The phase of eliminating false faces remains manual for now . These false faces are generated in an automatic way to the noise of acquisition.

In this work, we have created a 3D Model of the human heart based on MRI, then we used the AR [17] to visualize the 3D model we have created in a real scene. The visualization system was developed using the Vuforia package in the game engine unity 3D, which provides efficient implementations and a high render quality of many advanced graphic techniques for the visualization of the heart geometry. This system is also based on high quality and real time rendering. To get the accurate position of data we use a 2D Marker Fig. 11, which we use to manipulate parameters of the visualization.

Figure 11. Marker used to track localization

Since we track the marker in each frame (100 times per second) we need to provide a way for users to easily initiate abort interaction with the simulation.

VII. CONCLUSION

We create a 3D human heart model based on MRI. We have applied MC algorithm to data obtained from MRI. Although the model was trained on a small sample of representative images (Fig.10), it shows excellent behavior for a wide range of images. 3D computational models of cardiac anatomy and function have benefited significantly from the revolution of medical imaging systems. Compared with previously published, the model proposed here is a human heart model with a high degree of realism and anatomical details developed to improve the understanding of the anatomy of the heart. Like most literary models this model is an approximation of heart. The level of realism and detail achieved is due in large part to the quality of images used in the construction of the model. Visual information about cardiac conduction system is still limited because of data transformation from 2D images to 3D information. As a future work, we are going to create a 3D moving heart based on TDM images.

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