DYNAMICAL SEGMENTATION OF THE LEFT VENTRICLE IN ECHOCARDIOGRAPHIC IMAGE SEQUENCES

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Abstract - **This paper presents a new methodology for the analysis of echocardiographic image sequences. The echocardiographic medical exam is a frequent practice in the cardiology clinic, and generally there is bi-dimensional echocardiographic equipment. We have developed a new processing chain that will allow a medical diagnosis issued from a 3D reconstruction of the ultrasound images. The project is divided into several 3D modules: Acquisition, Filtering, Segmentation, Reconstruction, and Visualization. Inside of the processing chain, the segmentation module of ultrasound images has always been a problem. In this paper, we propose two different methods for the 3D segmentation. A model of 3D Snakes and a front propagation model that allow an accurate segmentation and reconstruction of the internal wall of the ventricle. From these segmentation methods, some important medical parameters are computed : ejection fraction, cardiac index, ventricle volume, etc.**

Keywords - 3D Segmentation, 3D snakes, 3D front propagation, echocardiographic volumes.

I. INTRODUCTION

The modeling, the reconstruction, and the visualization of the organs and the internal structures of the human body, issued from echocardiographic images are important to improve the medical diagnosis and the therapy in order to follow the patients.

Cardiovascular illnesses constitute a problem of public health at world level and they frequently lead to disability and mortality in early and productive stages of life. For e.g., in Venezuela, they are the greatest cause of death among people whose age ranges between 25 and 64 years [1].

At the present time, the ultrasound is the best method of diagnosis for cardiovascular illnesses. Using this method, specialist doctors obtain space-time information of the heart. Classically, the 3D geometry of the heart is obtained by means of a mental reconstruction of video images of 2D echoes, which are observed in movement at different slice planes. This methodology is subjective and it is highly susceptible to errors. It requires a great knowledge of the anatomy of the heart by the cardiologist to obtain an exact interpretation of the 2D images of echoes.

In this paper, we present two dynamical segmentations included in a global chain of processing. The next sections present the different modules and especially the 3D segmentation methods. Figures show the 3D reconstruction of the left ventricle based on each segmentation method. A conclusion summarizes the originality and the efficiency of the methods.

II. METHODOLOGY

The proposed 3D segmentations are included in a chain of processing from the radial acquisition of the cardiac sequences to the extraction of medical parameters for the diagnosis. (figure 1.)
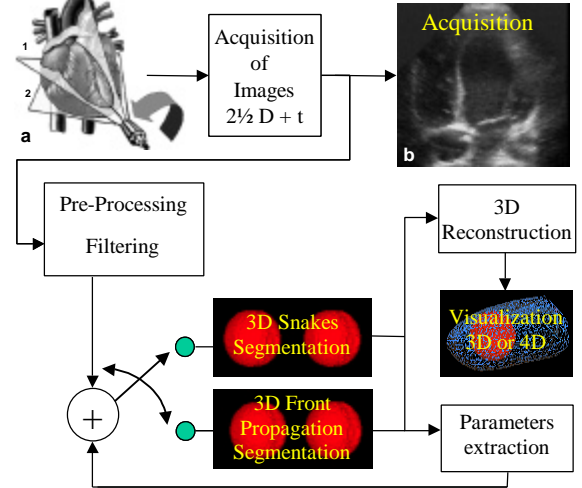

Fig. 1. The chain of processing from ultrasound image sequences.

A. Radial cylindrical acquisition

The acquisition module uses conventional ultrasound equipment, but it is modified in order to include an electromechanical device controlled by computer. The transducer turns 360° on its own axis. This system allows the acquisition of 2D image sequences, which were synchronized with the heart rhythm and with the breathing rhythm. The complex QRS was used with the purpose to synchronize the capture. We obtain 60 radial slices for each 3D volume of the heart anatomy. The frames quantity during the cardiac cycle varied between 13 and 16 frames. This workstation is installed in a cardiology consulting room of the Image Processing Center at University of Carabobo.

The complete description of the acquisition process, problems and solutions are explained in more details by the authors, Torrealba et al. [2]. The figure 1a shows the general idea of the acquisition with the trans-thoracic rotational sampling.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25OCT2001	N/A	-

Title and Subtitle	Contract Number
Dynamical Segmenttion of the Left Ventricle in Echocardiographic Image Sequences	Grant Number
	Program Element Number

Author(s)	Project Number
	Task Number
	Work Unit Number

Performing Organization Name(s) and Address(es)	Performing Organization Report Number
Ecole Nationale Supérieure des Télécommunications de Bretagne, Brest, France	

Sponsoring/Monitoring Agency Name(s) and Address(es)	Sponsor/Monitor's Acronym(s)
US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification	Classification of this page
unclassified	unclassified

Classification of Abstract	Limitation of Abstract
unclassified	UU

Number of Pages
4

B. Pre-processing

The radial acquisition system provides an anisotropy of data. A resampling step is necessary if we want to work with a regular grid [3]. We obtain 160 parallel slices with 232 by 232 pixels.

The pre-processing is an important module in this chain, since the segmentation will be better if we have no noise images. With this objective, we filtered and compensated the defects of the acquisition system and we used a 2D Lee filter [4], modified and extended to the third dimension in order to eliminate the speckle noise and to keep the most significant edges of the volumes (figure 2).
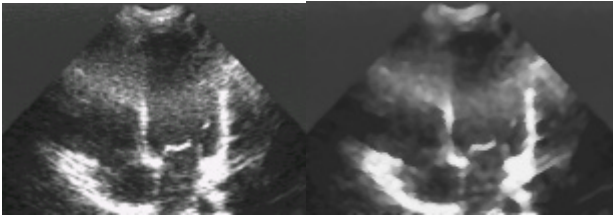

Fig. 2. Original image and filtered image by the 3D Lee filter.

C. Segmentation by dynamical models.

In the medical images, the segmentation consists in the localization of a closed interface between the inside and the outside of the considered object, e.g. an organ. Among the segmentation methods, it exists efficient ones in which the interface corresponds to the dynamical boundary between two media [8]. The interface's shape is modified with constraints depending on data and it stops and fits the boundary between two media.

This idea can be derived at several scales. From a microscopic point of view, the cells divide the space in the internal part, that belongs to the cell, and an external part that belongs to the medium where it lives. At the middle level, we have the organs with a more or less complicated interface. From a macroscopic point of view we have individual where it is easier to split the 3D space (inside - outside).

In the next sections, we present two methods of segmentation using this concept.

C.1. 3D snakes Segmentation.

Kass et al. [5] developed the technique of the "Snakes" minimizing the flexion energy in order to extract the contours of an image. The results obtained by Kass were very sensitive to the initial conditions and the well-known drawback was : "Snake" should be placed near the solution.

All techniques using snakes have the same principle of the minimization of energy. This energy is the sum of an internal energy that takes into account the rigidity of the snake and an external force issued from data (gradient image).

The internal forces impose regularity conditions on the snake. Therefore, it is possible to obtain smooth surface in very noisy images. An original external energy P is determined automatically and stabilizes the snake on the boundary:

$$P = r \cdot k(x, y, z) \qquad (1)$$

where r is a constant fixed by the operator and $k(x, y, z)$ depends on the image gradient :

$$k(x, y, z) = \frac{1}{1 + |Grad\_Mod|} \qquad (2)$$

$$Grad\_Mod = \exp^{(|\nabla G * I(x, y, z)| - a)/g} \qquad (3)$$

where a is the mean value of the gradients inside the initial surface (sphere) and g is a normalization parameter.

In regions where the gradient of the image is high, the variable $k(x, y, z)$ becomes a value near to zero. That means the propagation of the interface should stop on the boundary. At the contrary, in homogeneous regions, the gradient is small and the variable $k(x, y, z)$ is maximum. This new formula used in this work allows a quick saturation of the function and the snake quickly stops on the boundaries of the object. The use of the exponential in the formula $k(x, y, z)$ contributes to a quick saturation and it is similar to the sigmoïde function used in neural networks. Figure 4 shows the result of this method on the LV of the heart.

C.2. 3D Front of Propagation Segmentation.

More recently, a physical shape model was introduced by Malladi et al. [7]. They developed a propagation model based on a non-intersecting closed curve or surface, where the propagation speed depends on the curvature. Here also, the propagation front splits two regions (inside and outside) and it is called "interface" in the Sethian's literature [8]. The front propagates itself inside of the image adapting and fitting the walls of the structure or 3D object. This modern technique solves two problems of the snakes a) It allows the segmentation of objects with many bifurcations and protuberances, and recovers complex shapes inside of the image. b) It is not necessary to prior know the topology of an object for recovering it.

In the snake methods, the model is a set of points connected between them and the main drawback is the management of the topology of the model, especially when it can be split or merged, for e.g. in order to avoid holes in the volume to segment or when the volume contains several objects. The front propagation method gives a solution.

We consider the interface as the final localization of a closed surface $\Gamma`(t)$, propagating along its normal direction with a speed V depending on the mean curvature. The level set methodology of Sethian, consists in seeing the propagating interface as the zero level set of a higher dimensional function y. The initial function $y(\bar{s}, t = 0)$, verifies

$$\Gamma(t = 0) = \{\bar{s}(x, y, z) / y(\bar{s}, t = 0) = 0\} \qquad (4)$$

2

The fact that the zero level set of y matches the propagating surface $\Gamma(t)$ can be expressed by

$$y\left(\vec{s}(x,y,z),t\right)=0 \qquad (5)$$

In order to obtain the equation of the motion of the level set function; we derive the previous equation with regard to time, using the chain rule:

$$y_t + \nabla y\left(\vec{s}(x,y,z),t\right)\vec{s}\,'(x,y,z)=0 \qquad (6)$$

Simplifying the equation, we obtain:

$$y_t + V\left|\nabla y\right| = 0 \qquad (7)$$

where $V = \vec{s}\,'(x,y,z)\cdot\vec{n}(x,y,z)$ and $\vec{n}$ is normal to the surface defined by:

$$\vec{n} = \frac{\nabla y}{\left|\nabla y\right|} \qquad (8)$$

Changing the continuous equations into the discrete ones, we obtain:

$$\frac{y^{n+1}_{i,j,k} - y^{n}_{i,j,k}}{\Delta t} + V\left|\nabla_{i,j,k}y^{n}_{i,j,k}\right| = 0 \qquad (9)$$

and finally :

$$y^{n+1}_{i,j,k} = y^{n}_{i,j,k} - \Delta t\, V\left|\nabla_{i,j,k}y^{n}_{i,j,k}\right| \qquad (10)$$

With the purpose to stop the front propagation on the borders of the image, we use the same parameter $k(x,y,z)$ described in the Snakes section (*C.1*)

$$y^{n+1}_{i,j,k} = y^{n}_{i,j,k} - \Delta t\, V\, k(i,j,k)\left|\nabla_{i,j,k}y^{n}_{i,j,k}\right| \qquad (11)$$

where the speed V depends on the c mean curvature as

$$V = b_0 + b_1 c \qquad (12)$$

The constant numbers are specific of the data. In our case, we fixed $b_0 = 1$ and $b_1 = 0.20$.

In order to accelerate the convergence, it is possible to initialize the level set with a fast marching method which corresponds to put $b_1 = 0$ in (12).

Figures 5 and 6 give the reconstruction of the LV with the front propagation segmentation.

D. Heart sequences segmentation.

After the segmentation, we compute four parameters: the center (x_o, y_o, z_o) and the minimum radius of the biggest sphere that fits inside of the LV. These parameters are used in the next segmentation of the data volume. Therefore, we perform a 4D segmentation (3D+t) and a tracking of the heart movement. As a perspective, we can use the (3D +t) segmentation result as the (3D +(t+ Δt)) initialization.

III. RESULTS

A specialist in cardiology supervises the segmentation of the first 3D volume of data with the purpose of evaluating the accuracy of the developed segmentation methods. Each one of them is used to segment the test volume and the sequence of the original data. The objective is to check the accuracy of each method and to compare the segmentation

obtained with the original data. The figure 3 shows, the scheme of radial cylindrical geometry of the acquisition, the apical original image after filtering (3a) and, the segmented image by the specialist (3b) that we used as the test image. Using the methods developed in this work, we segmented the sequence of original volumes.
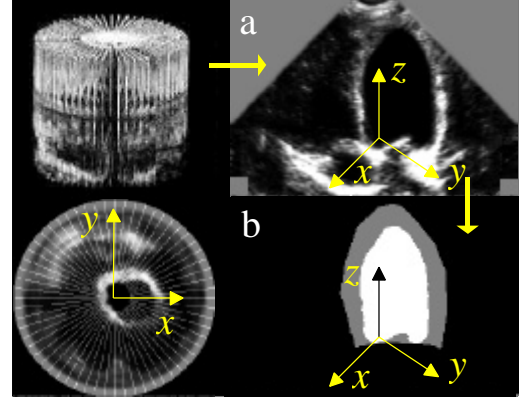

Fig. 3. Acquisition geometry of the apical view of the LV. (a) Original image after filtering. (b) Test image segmented by the specialist.

A basic segmentation, as a preset threshold for example, presents some well-known disadvantages: the obtained regions contain holes and rough frontiers.

The segmentations, described above, allow a coherence in the topology of the regions and smooth frontiers. That is important in 3D data, and especially with medical data.

B. First Method of 3D Segmentation.

Using the Snakes segmentation method, a smooth surface is obtained. The internal and external forces to the Snake maintain a tension looking for the local minimum in a connected surface. There are small differences between the registration of the automatic segmentation shown in blue with the general surface of the object shown in red (L). This segmentation method provides a smoother object, a regular mesh, and it is a robust segmentation. It is difficult to fix the parameters because the surface cannot be too smooth. Figure 4 gives the reconstruction from the Snakes method applied in the test volume and the filtered volume. The computing time is 1,5 sec with a Pentium 3, 500 MHz computer.
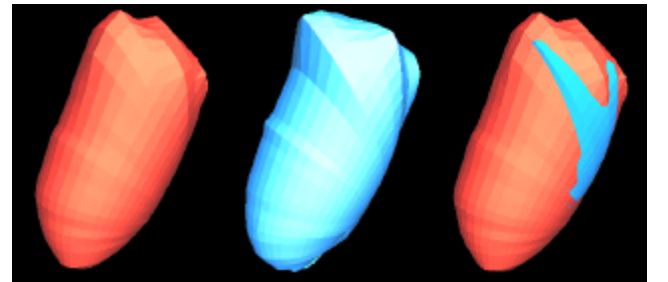

Fig. 4. LV reconstruction from the Snake method applied in the test image (red volume) and in the original filtered image (blue volume), and registration of both.

B. Second Method of 3D Segmentation.

The second segmentation method uses a front propagation. The figure 6 shows the results of the propagation of the front. To accelerate the convergence and the computing time, the distance function was calculated only on a thin layer around the surface of the volume that propagates. By the same motivation, the level set is initialize with the result of a fast marching method [8]. Figure 5 shows three steps of the process, beginning with a small sphere that propagates until to stick the walls of the LV as well as possible.
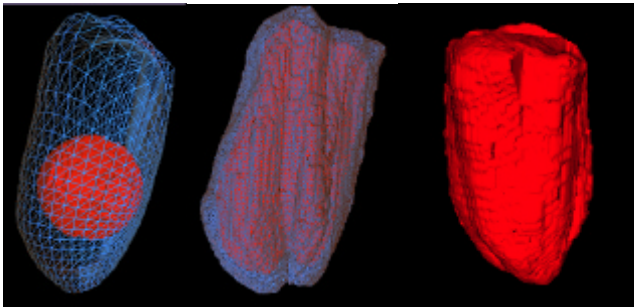

Fig. 5. a) Initial sphere. b) Some instants before arriving to the final shape (blue). c) Volume detected with a fast marching method.
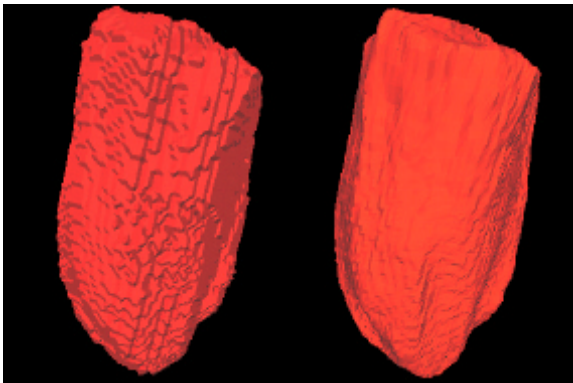

Fig. 6. a) Initial surface. b) Volume detected with a front propagation method.

That is the best method to obtain the shape and the volume of the internal cavity of the LV. The only disadvantage is the computing time. The computing time of the front propagation method is around 4 minutes, without mesh computing (using marching cubes method) or 3D visualization.

IV. CONCLUSION

Two segmentation methods were presented in this work. These methods can be applied to other objects. The only important condition is to separate the 2D or 3D space in an internal and external area. The computing times expend 1.5 sec, until 240 sec. A linear relationship does not exist between the segmentation method chosen and the time of calculation. While more robust is the method requires more time of calculation. Some necessary parameters are obtained to do the complete segmentation of the sequence and to track the heart movement in each cycle. These geometric parameters obtained are not exactly the doctors requirements for their diagnosis. So, issued from the 3D reconstructions, it is possible to compute primordial medical parameters such as: ejection fraction, cardiac index, the volume of the LV and additionally the temporary parameters as ejection time of the LV, etc. This set of parameters added to the model and the 3D rendering of the original images, improves the information. The physician would make a better diagnosis of the cardio-vascular illnesses.

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