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COMPUTER-ASSISTED ECHOCARDIOGRAPHIC DIAGNOSIS

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Abstract: In this paper we present a method to quantify the cardiac blood irrigation through echographic images for heart disease diagnosis. This method relies on the registration of acquired images with a heart model in order to provide a robust segmentation of the cardiac walls, giving the doctor precise and non subjective anatomical information, as well as to advance towards future works oriented to automatic diagnosis. *Copyright © 2002 IFAC*

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1. INTRODUCTION

The monitorisation of the amount of blood irrigating the cardiac walls can provide precise information in order to diagnose various heart diseases, such as ischemic or infarted myocardium. A common method used for this purpose is based on the visual analysis of contrasted echocardiagraphy. This technique provides video sequences of the heart with highlighted blood, that cardiologists can use to evaluate the irrigation process.

Other imaging techniques used for myocardium perfusion analysis are Cardioimaging (or Isotopic) Gammagraphy and Magnetic Resonance Imaging (MRI). The former, based on γ radiation provides low-resolution images and is, for this reason, of little use. The latter technique, despite providing higher resolution images, has as drawbacks its cost, that limits its repetitive use, and the fact that it can not be used in every patient or in every circumstance, since for instance, the equipment can not be moved to an Intensive Care Unit.

Being echocardiography the most widely used imaging method, interpretation of Ultrasonic Images still demands much expertise, as these images tend to be fuzzy, and neither the field of view nor the heart itself remain still while the scan is in progress.

Currently, most of the diagnosis carried out from these US images are performed visually, thus resulting in a highly subjective process. Nevertheless, there are a few commercial systems that provide quantified information from the image processed data, but they usually are not easily available and furthermore, they are closed systems, and consequently physicians can not always extract the desired kind of information from them. Therefore, a quantitative and objective measurement of the amount of blood and its distribution over the heart walls, that is the heart irrigation, would be desirable.

Important research is being done in the field of cardiac image processing, as reviewed in (Ratib, 2000), and different computer vision techniques have been applied to echocardiographic image enhancement (Adam, 1999), (Nagy, 1999). However, the accurate detection of the ventricular walls, especially the outer contour, is a problem that remains open.

The aim of this work is the development of an automatic processing method to segment the heart walls and measure the amount of irrigation in them, providing the cardiologist with dynamic data of the inflow of contrasted blood throughout the echocardiographic scan[1].

2. US IMAGES

An ultrasound (US) image is formed from speckle noise whose characteristics are defined by the tissue, the measurement device and the transducer's beam form.

Such images are adequate to visualize different body parts or structures, but, unfortunately, it is not possible to distinguish enough some of them. The visualization of blood in the cardiac muscles requires the use of an echocontrast. The echocontrast consists of a microbbuble flow, being the diameter of the bubbles 3,8 μm, a contrast element injected into the blood flow by the cardiologist at regular time intervals of approximately 12s. Blood visualization in the heart US image is produced when the bubbles explode. Consequently, irrigation visualization lasts only a few seconds.

A set of heart images obtained from the echocardiographic scanner used in the experimentation phase, a HP-5500 based on a 3 MHz US transducer providing a frame rate of 25 fps, is shown in Figure 1. The images visualized have been taken from different points of view, thus showing an

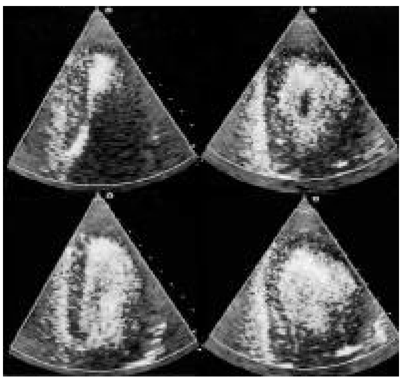

Fig. 1. Different views of the heart acquired with microbubble contrasted echography.

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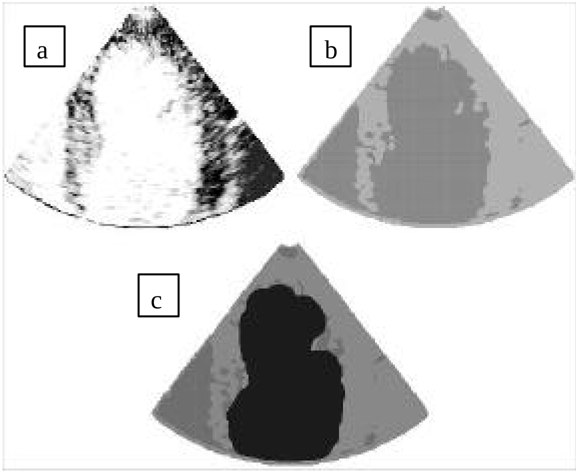


Fig. 2. Contrasted echocardiographic image (a), and subsequent segmentation of the ventricular cavity using morphologic operations (b), and region growing (c).

appreciable variability on their shape, a dispersion that can not be avoided since, depending on the patient anatomical structure, the point of application of the transducer in order to avoid occlusions in the acquisition phase must change.

The contrast fluctuations in these images can be used to monitor dynamically the blood irrigating the cardiac muscles throughout the whole heartbeat sequence.

3. SEGMENTATION STRATEGIES

Our goal is to segment the heart walls in a video sequence that consists of a complete echocardiographic scan. The segmentation process must extract the heart cavities as well as the cardiac muscle.

Given the noisy but contrasted nature of the data acquired, a first step in the segmentation process consists in making a coarse classification of the whole set of images. This is achieved through gaussian filtering and thresholding, which has proved to be a reliable, if not very accurate, way to obtain images of the heart cavities. Figure 2 shows an example of the segmentation carried out using this approach. Notice the noisy nature of the data (a), which may induce some mistakes in the ventricular cavity detection (b and c).

However, determining the outer contours of the heart with this kind of technique has proved to be a much more difficult task, as the edges tend to be blurred and imprecise, even to the experienced observer.

Several filters have been tested to distinguish the cardiac cavities from the heart walls (median, minimal, anisotropic diffusion, etc.), as well as some morphological operations (opening and closing). The latter seem to work better, as stated in (Nagy, 1999), but the obtained segmentation of the outer heart walls is still far from satisfactory. Other techniques found in the literature include fuzzy clustering (Sanchez, 2000) and 3D deformable mesh models (Montagnat, 1999), but none of them seems to provide a way to determine the outer heart walls, except perhaps (Papademetris, 1999), that adjusts a spline contour to both inner and outer face of the cardiac muscles, but needs some interaction with the physician.

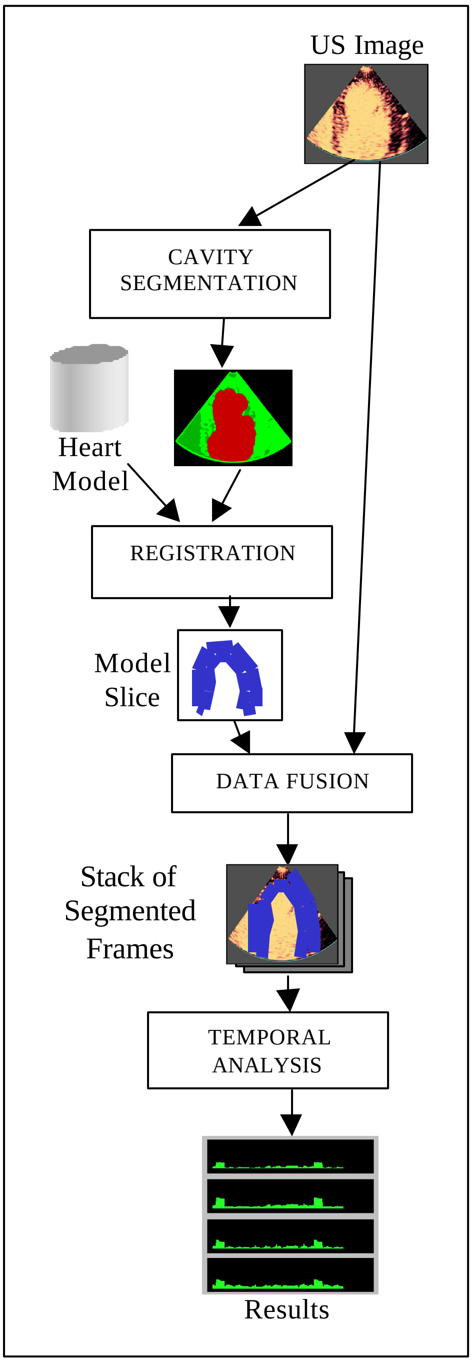


Fig. 3. Flow chart of echographic irrigation quantification algorithm.

Fig. 4. Coronal view of the unsegmented MRI heart model.

Consequently, we tried to support the segmentation of the outer heart walls with some kind of anatomical knowledge. This solution implies the use of an adaptable heart model, which would have to fit with the segmented image. However, since the image can change significantly depending on the point of view with which it has been obtained, the shape of the model can change excessively.

For this reason, it has been necessary to rely on a registration process that enables the segmentation process to choose among the different possible perceived heart shapes. The global segmentation procedure is shown in the schema of Figure 3.

4. HEART MODEL

A magnetic resonance tomographic heart volume has been used as the model, corresponding to the end of the diastole. The model shown in Figure 4 belongs to a young, healthy male without any heart disease history.

Two copies of the model are kept: the original volume to perform the registration, and a manually segmented version that will be used to obtain the heart walls once the matching between the US image and the set of model cuts has been done and an adequate cut selected.

To reduce the computational cost of the registration process, a set of images is extracted from the model, simulating echographic acquisitions at standard angles. This will allow us to reduce the 3D registration to a limited number of 2D ones, thus significantly reducing the execution time required.

5. 2D HEART MODEL SELECTION

From the set of 2D models, the next step is to find which of these model heart planes fits with the US images acquired from the patient. In other words, a detailed anatomical image of the viewed region is

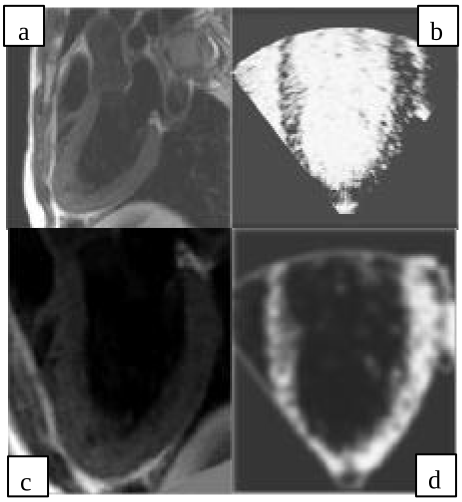


Fig. 5. MRI model slice (a) and corresponding echographic image (b). Aligned versions of this images have been obtained by registration (c,d)

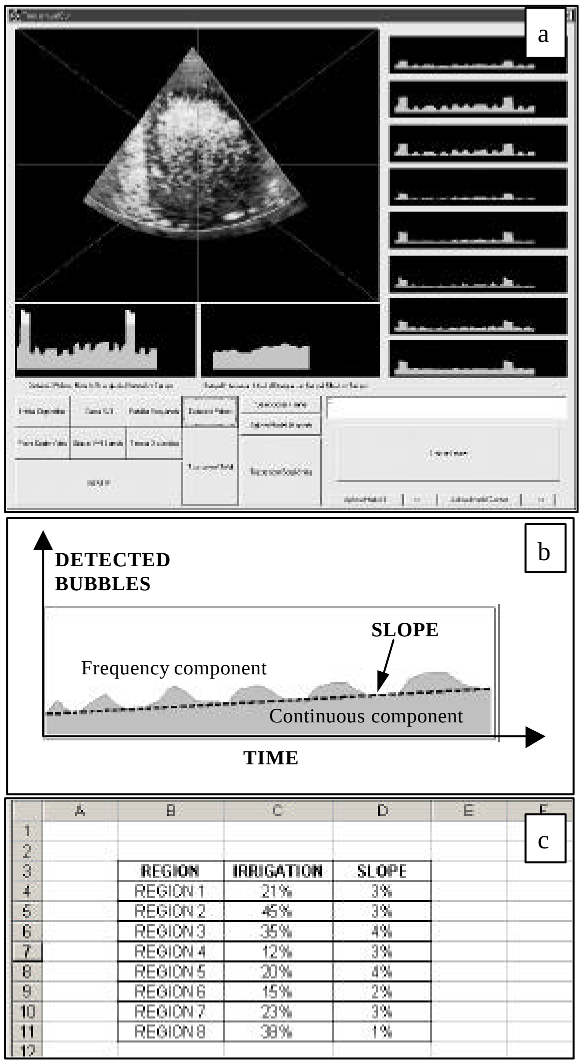
needed to superimpose over the echographic data we have. Thus, the irrigation information contained in the echocardiographic scan can be studied in its proper anatomical context, making segmentation much easier, as shown in Figure 5. This is achieved by registering the diastolic images of the echocardiogram with a set of magnetic resonance images corresponding to the most usual viewpoints in heart scans and choosing the one which provides the best matching. Further refinement would be possible by using this information to initialize a registration search in the 3D volume, though this improvement in the process has not been implemented yet.

The heart model - US image registration is performed through minimization of a normalized mutual information criterion with a gradient-descent algorithm (Thévenaz, 2000). The magnetic resonance image that best fits the echocardiogram, according to this criterion, will tell us what the position and orientation of the ultrasound sensor was. This information is used to get the contour of the heart walls from our manually segmented model, which will act as a mask to find the cardiac walls on the ultrasound image.

With the heart properly segmented, accurate measurements of the quantity of blood reaching the heart muscle can be performed, and any anomalies reported to the cardiologist.

6. IRRIGATION EVALUATION

The described method has been applied to quantify the amount of contrasted blood reaching some predefined areas of the heart walls for every frame of the image sequence. That means that a graph of the blood concentration along the heartbeat sequence is obtained. Figure 6 shows these graphs: we have defined eight regions of interest, and the evolution of the irrigation curve along time in each of them is shown in the respective plots at the right hand side of the image. Every graph has a continuous component and a frequency component. The frequency component is an indication of the heartbeat evolution, and the continuous component is a direct measure of the irrigation of that part of the heart walls. Applying a low-pass filter to these signals, we obtain a slope directly related to the irrigation. This is the information to be presented visually to the cardiologist, and saved in a standard spreadsheet file format, for further analysis and statistical evaluation.



REGION	IRRIGATION	SLOPE
REGION 1	21%	3%
REGION 2	45%	3%
REGION 3	35%	4%
REGION 4	12%	3%
REGION 5	20%	4%
REGION 6	15%	2%
REGION 7	23%	3%
REGION 8	38%	1%

Fig. 6. Irrigation information graphs extracted from the echographic scan (a). Detail of one of the graphs, showing the continuous component increase, tightly related to the quality of the blood flow (b). Quantitative data obtained from image analysis (c).

7. DISCUSSION AND FUTURE WORK

We have developed a method to assist in the diagnosis of cardiac diseases through echocardiographic images. We believe this method to be a promising tool that can greatly help cardiologists in the visualization and interpretation of echographic images, thus increasing the capacity to detect various diseases at their early stages.

We have used our algorithm to segment various electrocardiographic scans with quite satisfactory results. In most cases, the algorithm converges to a visually good registration, and the irrigation information provided by the echographic images is coherent with the underlying anatomical structures. However, on certain occasions the registration still fails to converge. This happens when the quality of the original images is not high enough for the initial segmentation to provide an adequate initialization of the algorithm. Further work might be necessary in order to improve these first steps, making them robust enough to overcome image flaws.

Future work will include building new heart models to better fit different patients (women, children and old people), giving medical doctors the option to select which one is the best in each case. Another possibility would be to integrate the whole sequence of acquired data into a 3D interactive model displaying the irrigation of the cardiac walls. This way the acquisition could be performed by an assistant, who would scan the whole heart, leaving the medical doctor the task of interpreting the post-processed data.

From the segmented images that differentiate the various irrigated areas, cavities and cardiac muscles, the goal is to work on an adequate interface that, operating over an open software, enables the cardiologist to select the kind of information and quantified data to be used for his or her own diagnosis, or, going further, for an automatic diagnosis of some predefined pathologies or alarm warnings in surveillance systems.

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