Epicardial Coronary Angiography from Microbubble-Based Tridimensional Echocardiography: A Feasibility Study

DM Lage[1], JM Tsutsui[1], SS Furuie[2]

[1]Heart Institute (InCor) Faculdade de Medicina da Universidade de Sao Paulo, Brasil
[2]Escola Politecnica da Universidade de Sao Paulo, Brasil

Abstract

Conventional coronary angiography has been the current gold standard for evaluation of coronary stenosis severity. However, this is an invasive procedure, based on ionizing radiation (X-Ray) and dependent of nephrotoxic contrast agents. In the past three decades, echocardiography has emerged as an important medical image modality in Cardiology. With the advent of microbubble-based contrast agents and array transducers, 3D-echocardiography now presents itself as a relative low-cost, non invasive and non ionizing alternative method to visualize arteries and their dynamics. This paper investigates some segmentation techniques to emphasize and isolate epicardial coronaries in tridimensional microbubble-contrasted echocardiographic images, since available computational tools do not provide adequate processing.

1. Introduction

Conventional coronary angiography has been the current gold standard for evaluation of coronary stenosis severity. However, this is an invasive procedure, based on ionizing radiation (X-Ray) and dependent of nephrotoxic contrast agents. Thus, several efforts for alternative angiography techniques have been developed in the last years. Although available techniques already exist, as magnetic resonance and computerized tomography, they require high-costs technology [1].

In the past three decades, echocardiography has emerged as an important medical image modality in Cardiology. Due to its ease of use and its multiple attractive features, this technology sparked significant interest in the research community. A large number of works resulted from this interest, most of which endorsing echocardiographic image unique capabilities in different scenarios [2]. In addiction, with the advent of microbubble-based contrast agents and array transducers, 3D-echocardiography now presents itself as a relative low-cost, non invasive and non ionizing alternative method to visibilize arteries and their dynamics [3].

This paper investigates some segmentation techniques to emphasize and isolate epicardial coronaries in tridimensional microbubble-contrasted echocardiographic images, since available computational tools do not provide adequate processing. A preliminary step was to test 4 different image segmentation algorithms based on fuzzy-connectedness theory that seems to be a suited approach for the problem [4]. Three of them are from literature [4 - 5] and one original contribution. Basically, the proposed approach consists of delimiting the object from a seed and a guide-seed voxels, both defined by the user. These selections provide enough data to improve the fuzzy-connectedness attributes and parameters computation, since they optimize all, weights estimation, fuzzy-affinity calculation and shortest-path algorithm.

2. Methods

Echocardiography provides good information for a segmentation algorithm. However, this algorithm needs a filter as a preprocessing step. Then, it is necessary to evaluate both steps to assume a relevant algorithm. In a revious work [6], we compared three ultrasound-based ilter as they are described in literature: Wiener filter [7], an Anisotropic Diffusion-based [8] and a local statistical-based one [9]. The test consisted on applying Speckle noise in three different Signal-Noise-Ratio (SNR) and quantifying the noise reduction due to all methods. We now assume the local statistical-based filter, as it has showed better results.

We evaluated four segmentation methodologies based on Fuzzy Connectedness theory. According to this theory, the segmentation is based on a local attribute, named affinity and a global attribute, named connectivity. So, the similarity between two elements on an image domain consists on a high-valued connectivity. In other words, this similarity depends on finding a path between two image elements only passing through high-valued affinity elements. As segmentation output, we find a mask with greatest connectivity elements related to an element seed posed by a user.

The affinity property is an association function of an image element to a fuzzy set in the image domain. This function must represent the "hanging-togetherness" of all image elements related to a user selected one and can be quantified in different ways [4]. In this work, we assume four different ways, as described.

Generalized FC (GFC) – This approach is originally described in [4]. It proposes that affinity property is defined as a composition of two features: homogeneity and intensity. The affinity equation between the spels 'c' and 'd' is defined as:

$$\mu_\kappa = \frac{1}{2}\mu_\psi(c,d) + \frac{1}{2}\mu_\phi(c,d), \quad (1)$$

Where the homogeneity contribution is defined as:

$$\mu_\psi(c,d) = \exp\left[-\frac{1}{2}\cdot\left(\frac{|f(c)-f(d)|-m_1}{s_1}\right)^2\right], \quad (2)$$

Where m_1 and s_1 are the mean and the standard deviation of the local homogeneity of the object. The intensity contribution is defined as:

$$\mu_\phi(c,d) = \exp\left[-\frac{1}{2}\cdot\left(\frac{\left(\frac{f(c)+f(d)}{2}\right)-m_2}{s_2}\right)^2\right], \quad (3)$$

Where m_2 and s_2 are the mean and the standard deviation of the local intensity of the object. In both equation, f(x) represents the intensity value of a spel 'x'.

The connectivity between 'c' and 'd' is given:

$$\mu_K(c,d) = \max\left(\min_{1<i<N_p}\left(\mu_\kappa(s_{i-1},s_i)\right)\right) \quad (4)$$

Where N_p is the number of spatial elements between 'c' and 'd'. All spel that result in a connectivity higher than a threshold θ is assumed as an object element.

Relative FC (RFC) – This approach is originally described in [4] and proposes an alternative to the threshold problem in the GFC approach. This alternative proposes the selection of two seeds that defines two objects. Thus, all image elements must be classified as most similar to one seed.

Dynamic Weighted FC (DyWFC) – This approach is originally described in [5] and proposes that the equation of affinity must have a dynamic weight adjust. So, the equation (1) changes to:

$$\mu_\kappa(s_{i-1},s_i) = \omega_1 \cdot \mu_\phi(s_{i-1},s_i) + \omega_2 \cdot \mu_\psi(s_{i-1},s_i) \quad (5)$$

Where the weights are defined using homogeneity and intensity components as:

$$\omega_1 = \frac{\mu_\phi(s_{i-1},s_i)}{\mu_\phi(s_{i-1},s_i)+\mu_\psi(s_{i-1},s_i)}, \qquad \omega_2 = 1-\omega_1. \quad (6)$$

Guided FC (GuFC) – This approach is our original contribution. It is a DyWFC-based approach and proposes the selection of two seeds: an object seed (s) as in GFC and a guide-seed (g). We propose that the object seed must be placed in a basal region, while the guide-seed must be placed in a distal region of the coronary artery. The guided-seed aims to guide the region-growing process and to provide relevant data to the threshold estimation. Basically, after a shortest-path algorithm between 's' and 'g', a set is formed using all elements of the optimum path. This set is necessarily formed by elements of the object. Then, all spel conectivities to 's' are set to 1. After a normalize process, we assume all element with connectivity higher than the original connectivity between 's' and 'g' as object elements.

This approach also changes the weight dynamic adjust to a numerical method-based static adjust. The adjust consists on setting values to ω_1 and investigating the connectivity between 's' and 'g': $\mu_K(s,g)$. When a high connectivity level is reached (> 95%), then we assume ω_1 as the static significant weight, as $\omega_2 = 1-\omega_1$. Otherwise, if the high connectivity level criteria is not reached, we change ω_1 continuously until it achieve a stability. The algorithm of ω_1 search assumes that this value is in [0,1] range. So, we investigate the connectivity on both value and the mean value. The next ω_1 value is chosen as the mean value of the two most expressive values. Figure 1 shows a real case of this search. In this case, the chosen ω_1 is 0.79296875 and the threshold connectivity, that corresponds to the highest $\mu_K(s,g)$ is 0.95448.

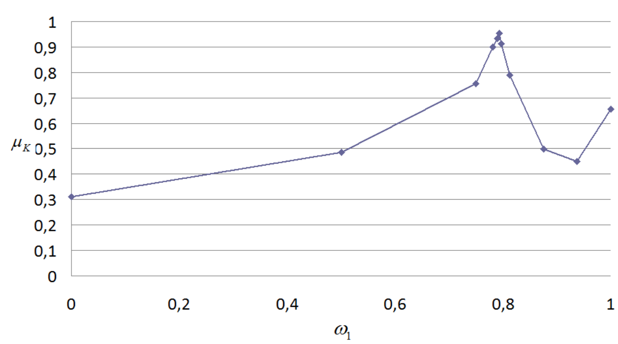
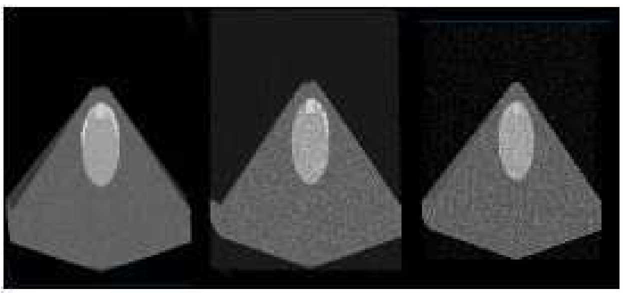


Figure 1. The weights estimation based on the highest connectivity achieved.

3. Results

All segmentation methods were evaluated as a preprocessing step to the ultrasound-based angiographic technique. All methods have reached good results, in special our proposed one.

This evaluation consists on calculating accuracy and precision [10] for a training set composed of 240 simulated images. Those images were created assuming real cases attributes from both Philips SONOS 7500 and Philips iE33 equipments. The images incorporated different coronary geometry, structural spatial distribution, resolution, contrast and Speckle-noise level (as in [9]). Those equipments had provided images that were submitted to the segmentation process and qualitatively evaluated, Figure 2.



(A) (B) (C)

Figure 2. 2D-reduction of the 3D-simulated images, assuming attributes from SONOS 7500 equipment. We vary the noise-level to simulate different conditions of acquisition. Low noise level (A); Mean noise level, considered the closest to the real case (B); High noise level (C).

For the 240 images training set, we reached 85,5% to 92,0% accuracy for literature methods, while a 95,2% accuracy have been reached for the proposed method, revealing a significant improvement in the results, Figure 3. This is a very good rate and an incentive to future work on the area.

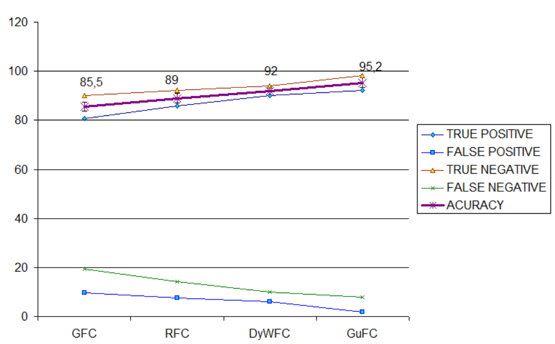
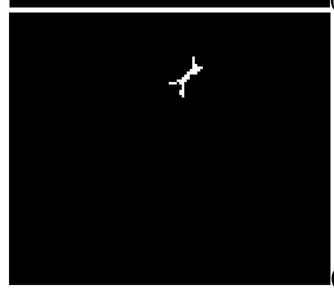


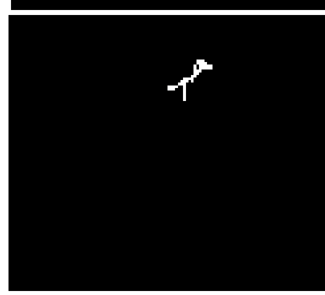
Figure 3. Segmentation results achieved. We assume the evaluation proposition from [10]. Rates values are in %.

When assessing real images, results showed good perspective to our aims. Figure 4 illustrated 2D-reduction of the 3D-echocardiography images. These image was acquired using the micro-bubble contrast agent.


(A)


(B)


(C)


(D)

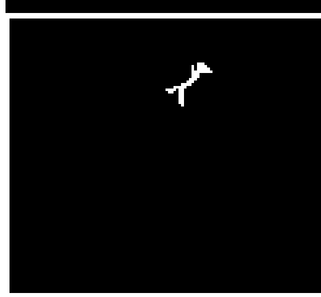

(E)

Figure 4. 2D-reduction of the original 3D echocardiography (A); the segmentation result of GFC method (B); the RFC method (C); the DyWFC method

(D); and the GuFC method (E).

4. Discussion and conclusions

Alternative methods to reconstruct epicardial coronary angiography depend on good results of segmentation methods. These methods are preliminary steps and good results can propose the feasibility of the reconstruction.

Fuzzy Connectedness-based segmentation methods proved themselves to be robust when assessing 3D-echocardiographic simulated images. The connectivity estimation assuming attributes from the image modality and the geometry of the object simplified the estimation of the better combination of features. Thus, the researcher is able to create new methods by choosing different features.

In our proposed method, we treated the second seed selected as a guide-seed. This change showed encouraging results for new computational tools in the future. Thus, the second seed can provide enough information to a new feature, incorporated to the connectivity definition. This allows the method to identify the correct spatial position of the object. So, the reconstruction process will be aided by the result of segmentation.

All methods evaluated resulted good accuracy rates, which is a good perspective to the angiographic reconstruction as a next step, in future works.

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Address for correspondence

Name: Danilo M Lage
Full postal address:
Av. Dr. Eneas de Carvalho Aguiar, 44 2º andar – Serviço de Informática – CEP: 05403-900, São Paulo (SP) Brasil.
E-mail address: danilo.lage@incor.usp.br