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3D Shape Modelling of Left Ventricle: Towards Correlation of Myocardial Scintigraphy data and Coronarography Result

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***Abstract*—**The myocardial sintigraphy is an imaging modality which provides functional informations. Whereas, coronarography modality gives useful informations about coronary arteries anatomy. In case of coronary artery disease (CAD), the coronarography can not determine precisely which moderate lesions (artery reduction between 50% and 70%), known as the "gray zone", are haemodynamicaly significant. In this paper, we aim to define the relationship between the location and the degree of the stenosis in coronary arteries and the observed perfusion on the myocardial scintigraphy. This allows us to model the impact evolution of these stenoses in order to justify a coronarography or to avoid it for patients suspected being in the gray zone. Our approach is decomposed in two steps. The first step consists in modelling a coronary artery bed and stenoses of different location and degree. The second step consists in modelling the left ventricle at stress and at rest using the sphercical harmonics model and myocardial scintigraphic data. We use the spherical harmonics descriptors to analyse left ventricle model deformation between stress and rest which permits us to conclude if ever an ischemia exists and to quantify it.

***Keywords*—**Spherical harmonics model, vascular bed, 3D reconstruction, left ventricle, myocardial scintigraphy.

I. INTRODUCTION

RECONSTRUCTION, shape modelling and object description are among the main problems which can be faced in the analysis and interpretation of medical images field. Often, it is necessary to model anatomical structures to obtain much closer fit and compact representation.

Several approaches have been used for 3D anatomical structures modelling, more precisely, the heart, using several medical imaging techniques. Thus, in [4], the author has used hierarchical Fourier descriptors for the modelling of various shape 3D objects. In [1]–[3]–[10], spherical harmonics have been used as a 3D model of the heart using angiographic data [14]. In [6], algebraical surfaces have been applied to model the ventricle using SPECT (Single Photon Emission Computed Tomography) images. Generalized algebraical surfaces have been used, as well, by [3], for the left ventricle reconstruction using angiographic data, and more precisely superquadrics.

Variant approaches (hyperquadric, hybrid hyperquadric) have been used in [7]–[8] for cardiac 3D images analysis. Let's also mention, studies in [9] which have used the parametric superquadric model associated to free-form deformations to characterise the heart motion over time using tomographic images and superquadric model tacked as a reference shape and combined with displacement function.

In this paper, we propose to use the spherical harmonics model and data extracted from scintigraphic images to model the left ventricle. We use the spherical harmonics descriptors to analyse left ventricle model deformation between stress and rest which permits us to conclude if ever an ischemia exists and to quantify it. The diagnosis of the pathology will allow to provide a patient with an adequate therapy. More precisely, in order to extract set of 3D points which corresponds to epicardium and endocardium wall respectively, we have to segment the original data. Then, we fit the surface which is decomposed into a spherical harmonic basis on this set of 3D points through an iterative reconstruction process which leads to determine the optimal harmonic number. Finally we use the spherical harmonics descriptors to estimate if ever pathology exists or not.

This paper is organized as follows: in the first part, we present the spherical harmonics model [11]–[13]. We present in particular, initialization process of the iterative optimization as well as the computing error method applied for the fit of the surface on the given data.

In the second part of this paper, we present a coronary artery bed and stenoses model which permits to precise the location and the impact of the pathology. Finally, we present the results obtained from these reconstructions/fits algorithms using as input scintigraphic images sequence of a patient heart. improving the linearity correction and the use of treatment algorithms.

II. SPHERICAL HARMONIC MODEL (SH)

Harmonic surfaces are widely studied [11]–[13] and used in different applications (geodesy, biology …). A spherical topology surface can be parameterised by spherical coordinates (φ, θ) [15]. The spherical harmonic basis functions

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can be defined as:

$$U_m^l(\theta,\varphi)=\cos(m\phi)\ P_m^l(\cos(\theta)) \qquad (1)$$
$$V_m^l(\theta,\varphi)=\sin(m\phi)\ P_m^l(\cos(\theta))$$

Where P_m^l is the associated Legendre function.

The spherical harmonic surface can be written as an expansion of spherical harmonic basis functions. A set of coefficients is then used to express the surface in compact way:

$$S_N(\theta,\varphi,a_{l,m},b_{l,m})=\sum_{l=0}^{L}\sum_{m=0}^{l}a_m^l U_m^n(\theta,\varphi)+b_m^l V_m^n(\theta,\varphi) \qquad (2)$$

To fit a closed surface with the spherical harmonic model, we have to use the spherical coordinates. For this purpose, we compute the gravity centre of the data set and place the 3D reference at this centre. Then, we convert cartesian coordinates of 3D given points to spherical coordinates. The fitting scheme is based on the previous function (2). We can search for the minimum of the following energy:

$$E(\theta,\varphi,a_{l,m},b_{l,m})=\sum_{i=1}^{N}|\,\mathrm{S_N}(\theta_i,\varphi_i)\text{ - }\mathrm{r_i}\,|^2 \qquad (3)$$

Where N represents the set of data points ($i=1,\ldots N$), and r_i the distance of the data point from chosen origin.

To compare and discriminate two surfaces S and S', the following distance D can be defined:

$$D^2=\sum_{n=0}^{L}\sum_{m=0}^{l}(a_m^l-a''^l_m)^2+(b_m^l-b''^l_m)^2 \qquad (4)$$

III. Vascular Bed

To model the vascular bed, we used different 2D views of the heart extracted from the General Anatomy Atlas [16]. Each coronary artery branch is decomposed into elementary tubes having a selected diameter, length and filling. These tubes are placed according to the representation of the arteries. They are modified in length, diameter and orientation in order to fit the model on the original shape artery. To model stenosis of different location and dimensions, we have defined elementary volume spheres. Any obstruction is represented by the piling up of some selected elementary volumes. Finally, we have developed an interface which allows users to visualize and manipulate the vascular bed with an orientation linked to the reference defined by the three main axes: Short Axis (SA), Horizontal Long Axis (HLA) and Vertical Long Axis (VLA) (fig.1a, fig. 1b).

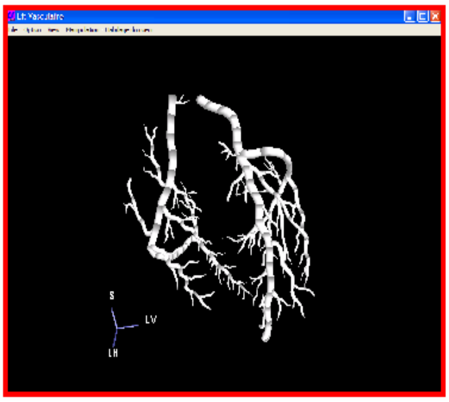

Fig. 1a : Modelled vascular bed,

Fig. 1b : example of an obstruction modelled with elementary volumic spheres,

Fig. 1 Modelled vascular bed and an example of an obstruction modelled with elementary volumic spheres

IV. Scintigraphic Images

Myocardial sintigraphy is an imaging modality which provides functional information. We used myocardium SPECT images performed at stress and rest with ^{201}Tl (fig. 2a). The myocardial perfusion is estimated by comparing images at two different instants rest and stress and it is indicated when ischemia is suspected. The diagnosis is obtained by comparing the topology of myocardium blood flow at these tow different instants.

V. Results

We start by segmenting the 3D images. This segmentation has enabled us to obtain two 3D point sets representing the surface of anatomical structures of respectively both the epicardium and the endocardium wall. These 3D point set will be used as input for the reconstruction algorithm (fig. 2b).

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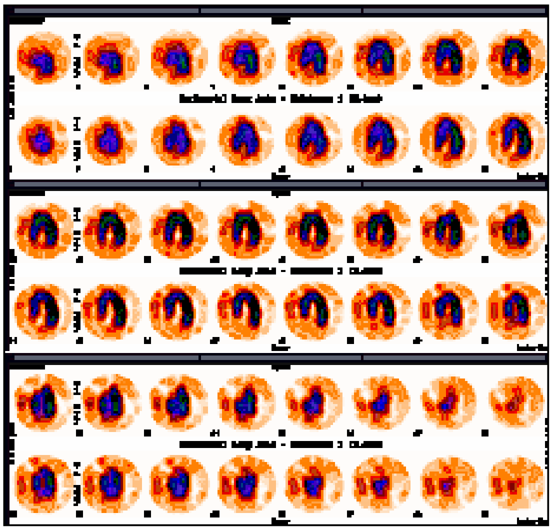

Fig. 2a : scintigraphic image sequences at stress and at rest for one voluntary,

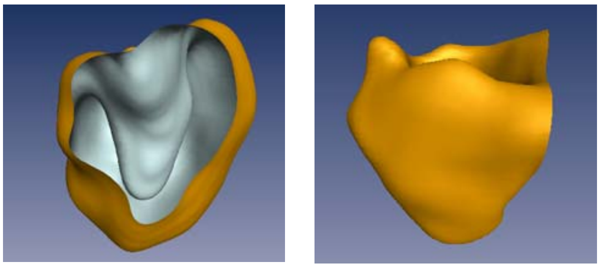

Fig. 2b: Rendered surface of left ventricle at stress and at rest respectively,

Fig. 2 Rendered surface of left ventricle at stress and at rest respectively after segmentation of scintigraphic image sequences of voluntary 1

Then, we have used the spherical harmonics descriptors to analyse and quantify left ventricle model deformation between stress and rest which permits us to conclude if ever an ischemia exists and to quantify it using a distance D value calculated (4).

For the two examples (fig. 3, and fig. 4), we have analysed scintigraphic data of one healthy voluntary and a pathologic case respectively. Fig. 3 shows an example of rendered surface of the epicardium wall at stress and rest respectively for one healthy voluntary (fig. 3a, fig. 3c), epicardium modelisation with SH model at stress and rest respectively (fig. 3b, fig. 3d). For this case the distance D value calculated is 0.33.

Fig. 4 shows an example of rendered surface of the epicardium wall at stress and rest respectively for one patient (fig. 4a, fig. 4c), epicardium modelisation with SH model at stress and rest respectively (fig. 4b, fig. 4d). For the pathologic case the distance D is 0.18.

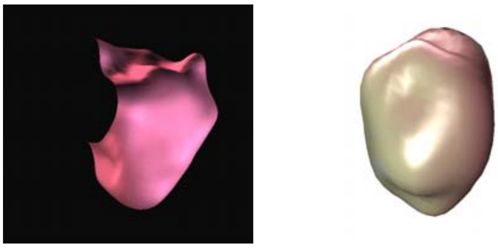

Fig. 3a : Rendered surface of the epicardium wall of voluntary 1,
Fig. 3b : Epicardium modelisation with SH model at stress,

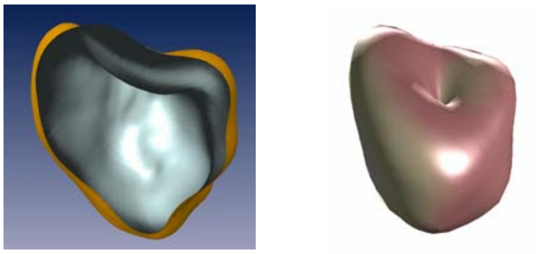

Fig. 3c : Rendered surface of the epicardium wall voluntary 1,
Fig. 3d : Epicardium modelisation with SH model at rest,

Fig. 3: distance D: 0.33.

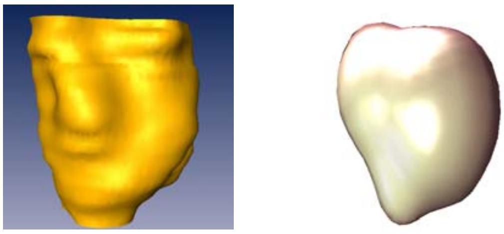

Fig. 4a : Rendered surface of the epicardium wall of patient 1,
Fig. 4b : Epicardium modelisation with SH model at stress,

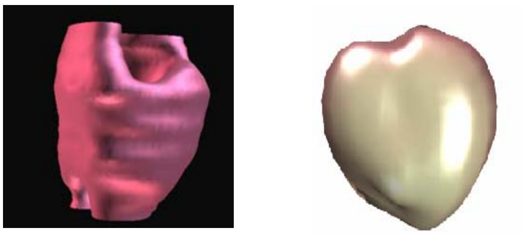

Fig. 4c : Rendered surface of the epicardium wall of voluntary 1,
Fig. 4d : Epicardium modelisation with SH model at rest,

Fig. 4 distance 0.18

VI. Conclusion

In this work, we have used the spherical harmonics model and a 3D point set extracted from myocardial scintigraphy to model the left ventricle in order to justify a coronarography or to avoid it. The spherical harmonics descriptors obtained at stress and at rest respectively are used to analyse and quantify left ventricle model deformation between stress and rest. Precisely, a numerical distance is calculated. A significant difference is obtained between distances relating to the voluntary data and pathologic.

We have developed a tool which permits us to superpose the result of scintigraphic analyse on the vascular bed to precise the location and the impact of the pathology. We aim at correlating data from scintigraphic (functional imagery) and coronography information (morphological imagery) in order to to estimate the impact of stenosis on myocardial tissue irrigation or for concluding on a dimension of the coronary artery obstruction using only a myocardial scintigraphy.

We defined a protocol for recruitment of typical patients with CAD in order to enrich our data base. The patients recurred are those having moderate lesion (between 50% and 70% of obstruction) and having undergone a coronary angiography and myocardiac perfusion SPECT.

Once this training is acquired, our tool will allow us to estimate, using only myocardial perfusion SPECT data as input, the potential evolution of the lesion and the necessity of perfoming a coronarography.

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