Multimodal Cardiac Image Fusion by Geometrical Features Registration and Warping

M F Santarelli, V Positano, P Marcheschi, L Landini*, P Marzullo, A Benassi

C.N.R. Institute of Clinical Physiology, Pisa, Italy
*Department of Information Engineering, University of Pisa, Italy

Abstract

Multimodal image fusion is an important step in multiparametric analysis from different cardiac images recorded over time from different imaging modalities. In fact, low resolution images, such as PET or SPECT can be integrated with high resolution images as MRI or CTI, to show both perfusion and structure information in the same representation.

A fundamental step in this integration process is to bring the modalities involved into spatial alignment, a procedure referred as multimodal image fusion.

In the present paper we describe a method for multimodal cardiac images fusion, consisting on segmentation, registration and warping phases.

1. Introduction

Anatomical modalities, i.e., depicting primarily morphology, include X-ray, CT(computed tomography), MRI (magnetic resonance imaging), US (ultrasound), etc. Functional modalities, i.e., depicting primarily information on the metabolism of the underlying anatomy, include (planar) scintigraphy, SPECT (single photon emission computed tomography), PET (positron emission tomography), and fMRI (functional MRI). Some of these imaging techniques are still in the research study, while others make it possible to get dynamic sequences of 3D images. In particular, the recent progress in MRI technology, allows to provide dynamic 3D images (i.e. 4D images) with a sufficient time resolution to detect moving objects as the heart during the cardiac cycle.

As an example, precise measurement of regional myocardial function and perfusion in humans could be employed to measure coronary reserve, the physiologic significance of a coronary obstructive lesion, the functional capacity of coronary collateral vessels, or the effectiveness of a treatment procedure such as coronary bypass surgery or angioplasty. In such cases, information concerning anatomy must be correlated with that referring to functionality. It requires registration of 3D images for a given patient coming from multimodality 3D images.

In order to obtain comparative information on the perfusion-contraction match, it is required a manipulation of data in order to visualize, on a single image, the information relevant to the same myocardial site of interest (registration and fusion).

Among a wide variety of methods, we focused our interest in the following automatic fusion procedure to be applied on cardiac images: 1) automatic extraction of geometric features, i.e. myocardial borders, in both anatomical and perfusion images, as described in [1]; 2) automatic registration by minimising the distance between the extracted contours, using the Iterative Closest Point (ICP) algorithm, [2]; 3) application of warping procedure to registered images, [3].

In the present work, the proposed method has been fruitfully applied to register SPECT and MR images of the left ventricle.

2. Method

In multimodal analysis of medical images the information gained from two images acquired in the clinical track of events is usually of a complementary nature, proper integration of useful data obtained from the separate images is often desired. A fundamental step in this integration process is to bring the modalities involved into spatial alignment, a procedure referred to as registration.

In order to classify the registration methods, several criteria can be used [4]. The main criteria are related to the dimensionality of the images (2D, 3D or dynamic 3D images), the nature of registration basis, the nature of the transformation (rigid, affine, projective or curved), the user interaction (manual, semi-automatic and automatic methods), the modalities involved and the subject (intrasubject, intersubject or atlas). About the nature of registration basis, in our work we avoid extrinsic methods,

Computers in Cardiology 2001;28:277-280.

i.e. based on foreign objects introduced into the imaged space designed to be well visible in the pertinent modalities, because this kind of methods are invasive in nature. Instead, intrinsic methods are based only on the image data. Intrinsic method can be based on a limited set of salient points (landmarks), on alignment of segmented structures (segmentation based) or on measures computed from the image gray values (voxel based). The voxel-based methods operate directly on the image gray values and are effective in mono-modality registration due the high degree of similarity between images.

The method we propose for image registration and fusion is based on the following steps: 1. image segmentation according to the GVF-based snake algorithm; 2. ICP application on segmented data; 3. data fusion by means of warping strategy.

2.1. Image segmentation

Image segmentation is necessary in order to extract the useful contours from the MR images and the relevant SPECT images. Contour detection from SPECT image is not a so awful task thanks to the net difference between the perfused myocardium and the background. As far as the MR images, the low contrast between myocardium wall and the other regions makes more difficult the contour detection. Anyway, for both imaging modalities we used an automatic segmentation procedure, previously described for MR images [1], [5], where it has been proven it well detects myocardium contours also on MR images. Such method is based on a GVF-snake applied to nonlinear anisotropic prefiltered images.

2.2. Iterative Closest Point (ICP) evaluation

The ICP algorithm was first introduced by Besl and McKay [2]; it is a general purpose method for the registration of two generic point sets representations including line segments sets, implicit curves, parametric curves and generic surfaces.

This method relies on iteratively computing the closest point on a curve to a given point.

The iteration starts with the computation of the closest points on the first curve, detected on MR image, to the second one, detected on SPECT image; secondly, the least squares rotation and translation by means of the closest points is computed using the Horn [6] quaternion solution; then, the registration is applied on the first curve; we compute finally the mean square error between the two registered curves, if this error is below a certain value stated before then the iteration is stopped, else it is started again on the registered curves. At the end of the iteration we have the rotation matrix and the translation vector that register the two curves each other with a selectable precision. The convergence theorem [2] guarantees the achievement of a local minimum. To be sure that the desired global minimum is achieved the two curves must be roughly aligned, as it happens for cardiac images thanks to the knowledge of the patient position and the easy detection of intrinsic markers (valves, ventricles, etc.).

2.3. Warping

Warping is a non-rigid alignment of data sets that are mismatched in a non-linear or non-uniform manner.

Warping operation allows the displacement of the structures extracted from an image modality onto others relevant to another image modality [3]. In our case, warping operation has been performed in order to fuse the myocardial perfusion evaluated from SPECT data, into cardiac anatomic information extracted from MR images. This process is intended to: compute the desired displacements of all pixels in the source (MR) image and resample the image to create the "fused" image; such operations provide a spatial normalization of the data so that to be able to compare structures in multimodal image analysis.

3. Measurements

Two patients underwent to both MRI and SPECT images analysis. In particular, the first one resulted a normal subject while the second one resulted to have an ipoperfused region, as detected from SPECT test.

MRI data sets have been acquired using a GE Signa Horizon LX System 1.5T. Images have been obtained by using ECG-gated Cine Fast Gradient Echo sequence, 10 short axis slices of 128x128 pixels each one (voxel resolution of 2.9x2.9x5mm).

SPECT data sets were acquired by using a Siemens, Orbiter SPECT machine. Images size were 64x64 pixels each one.

In figure 1 typical MRI (left) and SPECT (rigth) acquired images are shown.

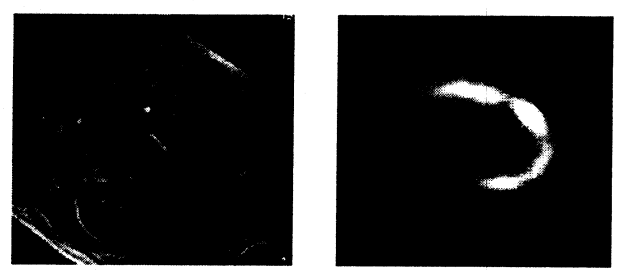

Figure 1. An example of starting images: long axis views of MRI (left) and SPECT (right) images.

Information relevant to images dimension and pixel resolution has been extracted from DICOM header data sets.

As far as slices selection, it has been manually performed by a cardiologist, expert in MR and SPECT images.

4. Results

The proposed method has been tested on two patients, one normal subject and the other one with an ischemic region on the left ventricular wall. Figures 2 and 3 graphically show example results we have obtained.

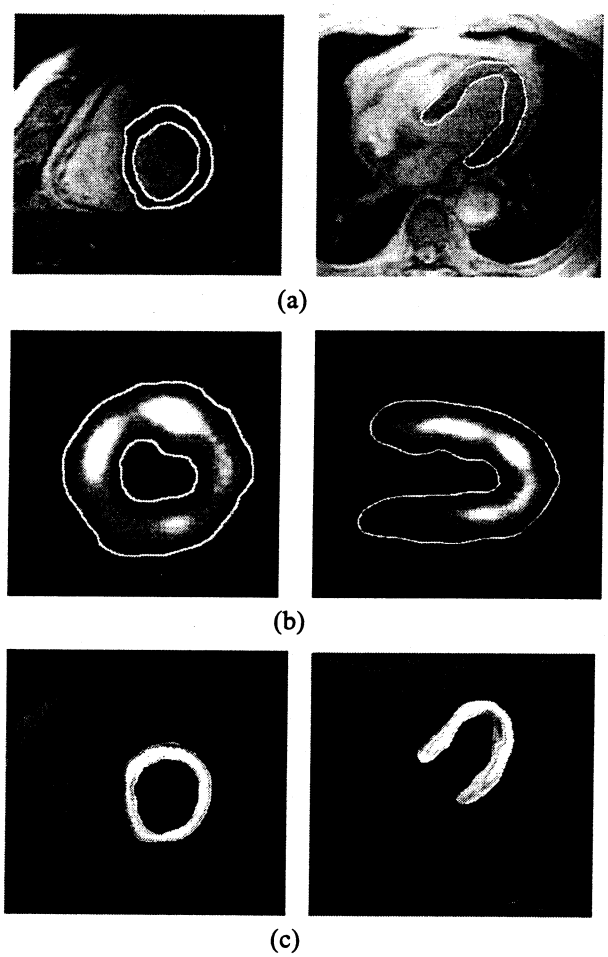

Figure 2. results relevant to a normal subject; left side: short axis view; right side: long axis view; (a): MRI (b): SPECT; (c): resulting fused images.

In particular, figure 2 shows resulting images relevant to the normal subject. Left side figures show short axis views respectively of: 2a MR image with overimposed the automatically detected left ventricle contour; 2b SPECT image with contour detected; 2c the fused image.
The images on the right of figure 3 show the long axis views of the same subject, as on the left.

On figure 3 images relevant to the pathologic subject are shown, with, on the left , short axis views and on the right long axis views. Figure 3a shows MR images, 3b SPECT images and 3c fused images.

From the figures it is evident how the ischemic region is not detectable by considering only MR images; it is worth to note that also when cine-MRI was analysed, diagnosis of the presence of an ischemic region was not possible; only with SPECT exam it was possible to determine the presence of the pathology. On the other hand, it should not be possible to exactly evaluate the localization and the size of the ischemic region by evaluating the SPECT image alone.

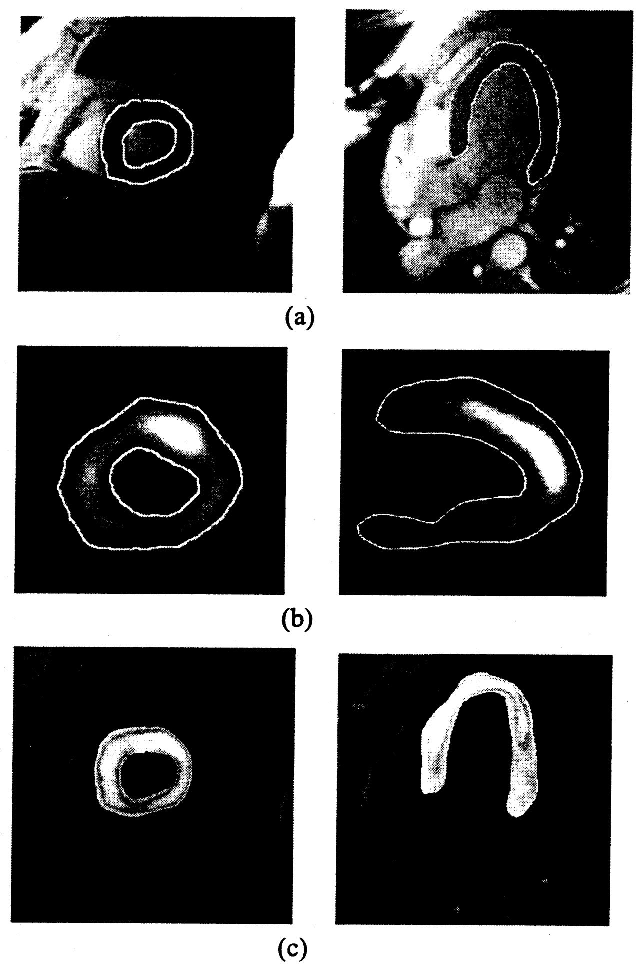

Figure 3. results relevant to a pathologic heart; left side: short axis view; right side: long axis view; (a): MRI (b): SPECT; (c): resulting fused images

5. Conclusions

We have shown a method for multimodal cardiac image registration and fusion based on myocardial wall segmentation, ICP evaluation and warping operations. We have tested such algorithm on MRI and SPECT data; from preliminary analysis such method seems to be an efficient tool for a more immediate diagnosis on contemporary myocardial functional and perfusion studies.

References

[1] M. F. Santarelli, V. Positano, L. Landini, A. Benassi. A New Algorithm for 3D-Automatic Detection and Tracking of Cardiac Wall Motion. Computers in Cardiology, IEEE, Los Alamitos; 1999; pp.133-6.

[2] P. J. Besl, N. D. McKay. A Method for Registration of 3-D Shapes. IEEE Transaction on Pattern Analysis and Machine Intelligence; 1992; 14(2):239-256.

[3] D. Ruprecht, H. Muller. Image Warping with Scattered Data Interpolation. IEEE Computer Graphics and Applications; 1995; 15(2):36-43.

[4] P. A Van Den Elsen, E. J. D. Pol, M. A. Viergever. Medical Image Matching – A Review with classification. IEEE Engineering in medicine and biology; (1993); 12(1); 26–39.

[5] M.F. Santarelli, V. Positano, L. Landini, M. Lombardi, A. L'Abbate, A. Benassi, M.J. Graves, R.A.R. Coulden. A new method for automatic tracking and analysis of MR Images of the heart. Proceedings of Int. Soc. Magn. Res. Med.; 2000; p. 1549.

[6] B. K. P. Horn, Closed-form solution of absolute orientation using unit quaternions J.Opt.Soc.Amer. A. ;1987; 4(4); pp.629-642,

Address for correspondence:

M.F. Santarelli
CNR Institute of Clinical Physiology
CNR Research Area – Via Moruzzi, 1
56124 PISA (ITALY)
e-mail address santarel@ifc.cnr.it