Triple-modality Normalized Mutual Information based Medical Image Registration of Cardiac PET/CT and SPECT Images

Comparison with Triple MI and Dual NMI Methods

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Abstract. An extension of the normalized mutual information similarity measurement was proposed to register cardiac PET/CT and SPECT images representing coronary artery disease in the heart. 23 PET/CT images obtained by a hybrid camera, and their corresponding SPECT were processed. The SPECT was registered to the PET/CT image pairs by a triple NMI based auto-registration. For validation and comparison an triple MI based registration among the PET-SPECT-CT images was performed. Two further dual NMI based auto-registrations between the SPECT-CT and SPECT-PET were performed as well. Based on the comparative results gained by a medical expert, our triple NMI method gave the best transformation parameters with a minimal number of iterations to superimpose the images.

1 Introduction

Nuclear heart scans based on SPECT and PET help diagnosing heart diseases such as coronary artery disease by providing different information about the stage of the heart, while CT provides anatomical information for better localization. Examining all the three images indicates the necessity of a registration step, since one of the functional images is performed with a stand alone camera. In our cases PET/CT heart image pairs obtained by a hybrid camera and their corresponding stand alone SPECT were collected and processed. Previous works have shown that involving three images to an extended mutual information based registration increases the accuracy of superimposing them even if the images are quite different [1, 2]. It is known that dual MI methods might fail the registration due to their sensitivity in overlap changing, while dual NMI methods are proven to be overlap invariant [3]. Although the same negative behaviour of the triple MI methods has not been recorded yet, the unknown overlap ratio of our images might bring uncertainty in triple MI based results. Due to this uncertainty we superimposed the SPECT image with a higher dimensional normalized mutual information based auto-registration to avoid possible overlap related misregistrations. Comparison with the triple MI [1] and classic dual NMI methods [3]

was done. A program was implemented in IDL 7.0 to validate the registration methods mentioned above with the triple fusion of our patient data.

2 Materials and methods

2.1 Patient data

23 PET/CT and SPECT heart images were collected representing possible coronary artery disease. The PET/CT images were already superimposed, since they were obtained by a hybrid camera. During the PET/CT acquisitions the patients were not moved to avoid additional misalignments. The SPECT images were obtained in a different time with a SPECT camera.

2.2 Registrations

All images were resampled to (1 x 1 x 1) mm voxel size and their grey values were stretched between 0 and 255 to decrease the size of their joint histogram [4]. Downhill-Simplex method [5] was performed for function minimization with functional tolerance 0.0001. The cost function of the registration was a triple normalized mutual information similarity measurement (triple NMI) based on equation 1. In the triple NMI measurement the PET and the CT images were both reference of the registration, while the SPECT was the reslice image.

$$\frac{H(A) + H(B) + H(C)}{H(A, B, C)} \tag{1}$$

Where $H(A)$ is the Shannon entropy of the image A and $H(A, B, C)$ is the Shannon entropy of the joint probabilities of images A, B and C [4].

To compare our method a triple MI [1] similarity measurement (equation 2) and a dual NMI [3] similarity measurement (equation 3) was also implemented. The triple MI included all the three images in the registration, while the dual NMI method registered both CT - SPECT and the PET - SPECT image pairs one-by-one.

$$H(A) + H(B) + H(C) - H(A, B, C) \tag{2}$$

$$\frac{H(A) + H(B)}{H(A, B)} \tag{3}$$

Where $H(A, B)$ is the Shannon entropy of the joint probabilities of images A and B.

2.3 Fusion and validation

All the PET/CT and the superimposed SPECT images were fused in a triple fusion window to represent the result of the registration methods (Fig. 1). Validation of the registrations was done manually based on visual assessment by a medical physician in the fusion window. The additional manual modifications of the automatic registration parameters were recorded to determine the errors for each registration methods. The number of iterations, the shifting and rotation errors were calculated for all registration methods.

Table 1. Comparative results of our triple NMI method with the triple MI and the two dual NMI registrations. Values represent the means and the standard deviations respectively.

Registration method	Shift error (mm)	Rotation error (degrees)	No. iterations
Triple NMI	2.20 ± 0.65	0.54 ± 0.22	177 ± 45
Triple MI	2.89 ± 0.97	0.46 ± 0.46	192 ± 75
Dual NMI (CT-SPECT)	4.71 ± 1.23	5.12 ± 2.14	218 ± 68
Dual NMI (PET-SPECT)	3.56 ± 9.86	1.98 ± 1.65	202 ± 72

3 Results

Comparative results of the registration methods on our patient data are represented by Table 1.

4 Discussion

Although the dual modality fusion and registration is the most common method to visualize and superimpose multimodality data, the necessity of registering and fusing three modalities becomes essential when a patient has three different images to investigate a given disease. In our case three different modalities - SPECT, PET and CT - were needed for better diagnosis related with coronary artery disease of the heart. Since heart SPECT has poor anatomical information, registering it to the CT by a dual mutual information similarity measurement is a challenging task, and often additional processing is needed to provide an acceptable auto-registration [6]. The similarity ratio of PET and SPECT is higher, since they are both functional images, but due to their low spatial resolution a dual registration between them might not be effective enough. Building on the

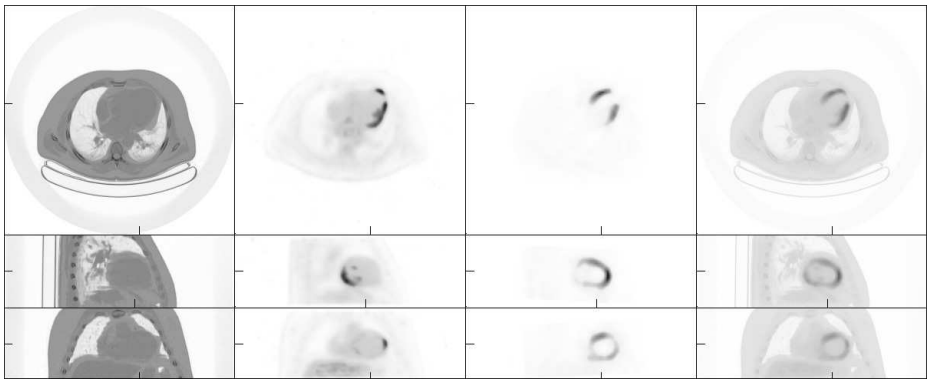

Fig. 1. Validation window based on the superimposed CT , PET, SPECT cardiac study and their triple fusion.

fact that the hybrid camera-made PET/CT images are already superimposed, it is a logical step to involve both of them to an extended mutual information based auto-registration next to the stand alone SPECT. Table 1 represents that if all the three images are involved in a triple NMI registration the shift and rotation error as well as the number of iterations can be minimized, since the presence of two reference images increases the certainty of the auto-registration. Although the triple MI registration did not fail because of overlap changing, our triple NMI measurement produced better registration parameters. The next step of our work will be the evaluation of our method on a higher number of clinical data.

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