Respiratory Motion Correction in PET with Super-Resolution Techniques and Non-Rigid Registration

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***Abstract*–Respiratory motion causes image degradation and artifacts in positron emission tomography (PET) images and constitutes an important source or error for the interpretation and proper quantization of thoracic and abdominal studies. Current work towards the correction of respiratory motion effects is mostly based on the acquisition of respiratory synchronized data which, on the other hand, leads to images with low statistics and therefore increased noise level. Super-Resolution (SR) techniques deal with how to combine several images into an enhanced high-resolution image, and in this work we study the application of SR to respiratory-gated PET images to produce a respiratory motion compensated image that incorporates the information provided by all the gated frames acquired. A B-spline based non-rigid registration algorithm is used for estimating the deformations among frames. We present preliminary results on a simulated PET/CT image sequence, corresponding to a thoracic study where a number of different sized nodular lesions were included inside the lungs. The resulting PET image allows better discrimination of the lesions and improved contrast, compared to each of the gated frames and to simple averaging of all the frames after registration.**

I. Introduction

Respiratory motion causes image degradation and artifacts in positron emission tomography (PET) images and constitutes an important source or error for the quantization of thoracic and abdominal studies. Current work towards the correction of respiratory motion effects is mostly based on the acquisition of respiratory synchronized data which, on the other hand, leads to images with low statistics and therefore increased noise level [1].

Super-Resolution (SR) techniques deal with how to combine several images, each providing slightly different information, into an enhanced high-resolution image [2]. These algorithms have found applications in several fields and more recently have aroused interest in the field of PET imaging [3]–[5].

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In this work we study the application of SR to respiratory-gated PET images with the aim of producing a respiratory motion-compensated image that incorporates the information provided in all gated frames acquired. To-date results refer to motion compensation based on motion derived from dynamic CT frames (for a PET/CT system). Future work however will also refer to the study of standalone PET gated images.

In most of the existing literature on SR, the transformation between frames is assumed to be translational, affine or at most projective. For the application of the method to respiratory motion, the use of a more flexible transformation model is necessary. We therefore propose using B-spline based non-rigid registration, which accounts for the non-uniform deformations of the regions of interest during the respiratory cycle.

For this work we will be working with a simulated dataset, which in some aspects is a simpler task than using real data (e.g. the CT and PET sequences are perfectly aligned and synchronized), however we would like to emphasize that the aim of this preliminary work is to study the feasibility of employing SR techniques for combining several PET frames which present an unknown non-rigid deformation (SR with controlled translations and rotations of the phantom has been already demonstrated in [3], [4]).

II. Materials and Methods

A. Description of the Dataset

A simulated PET/CT image sequence has been used in this work for evaluating the proposed algorithm. The digital NURBS based 4D cardiac-torso phantom NCAT [6] was used, which generates images with anthropomorphic distribution of activity and also linear attenuation coefficient images, while at the same time models the respiratory motion.

The activity density images were used for the simulation of PET respiratory-gated acquisitions, while the attenuation images were taken as the CT anatomical frames. A total of 8 frames were generated over a full respiratory cycle of 5s. As it is shown in Fig. 1, a number of different sized nodular lesions were included inside the lungs.

Fig. 1 illustrates the dataset used in this work. As we

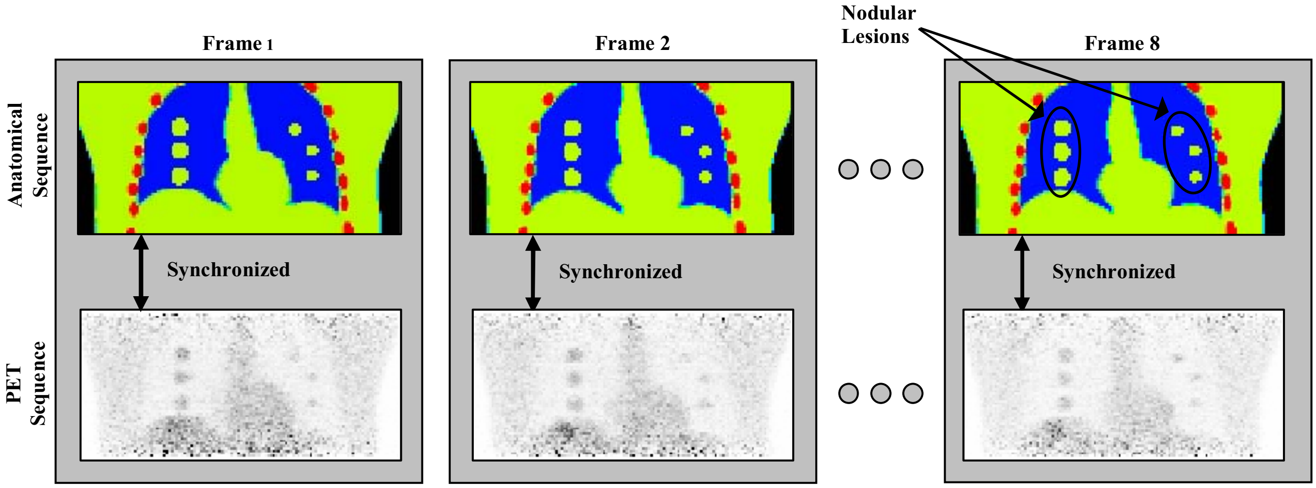

Fig. 1: Simulated dataset used in this work. Eight respiratory-gated frames are obtained for both the anatomical (top) and functional (bottom) sequences.

mentioned before, for this dataset no registration is needed between CT and PET images, which are already aligned and synchronized

B. Non-Rigid Registration

SR methods require that all image frames within the respiratory cycle are brought first to a common reference frame. The algorithm chosen for this task is the non-rigid registration algorithm described in [7], which models the deformation fields using B-splines and has been shown to be effective for respiratory deformations [8], [9].

As a prior step to SR, the first frame in the respiratory cycle was selected as a reference, and all the subsequent frames were registered to this reference frame both forward and backwards.

The motion-related deformation maps can be extracted either by using the anatomical image sequence (attenuation images) or with the gated PET frames alone. The former has the advantage of being a simpler task for the registration algorithm as the anatomical images contain more information, while the later would have the benefit of avoiding the need for anatomical images. Another alternative would be the use of external motion tracking data, something that however lies outside the scope of this present work.

Fig. 2 shows a coronal slice of two of the frames in the CT sequence before (left) and after (right) performing the non-rigid registration with the mentioned algorithm.

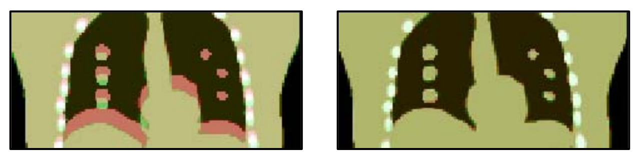

Fig. 2: Superposition of two different anatomical frames (one in red and the other in green) before (left image) and after (right image) the non-rigid registration

C. Super-Resolution Algorithm

As in other applications of Super-Resolution to medical images [3], [4], we use the iterative back-projection (IBP) algorithm [10], which consists of the following steps (see Fig. 3):

1. The current high-resolution estimate is transformed into each of the respiratory frames by applying the corresponding deformations (T_n in fig. 3) and then down-sampling it.

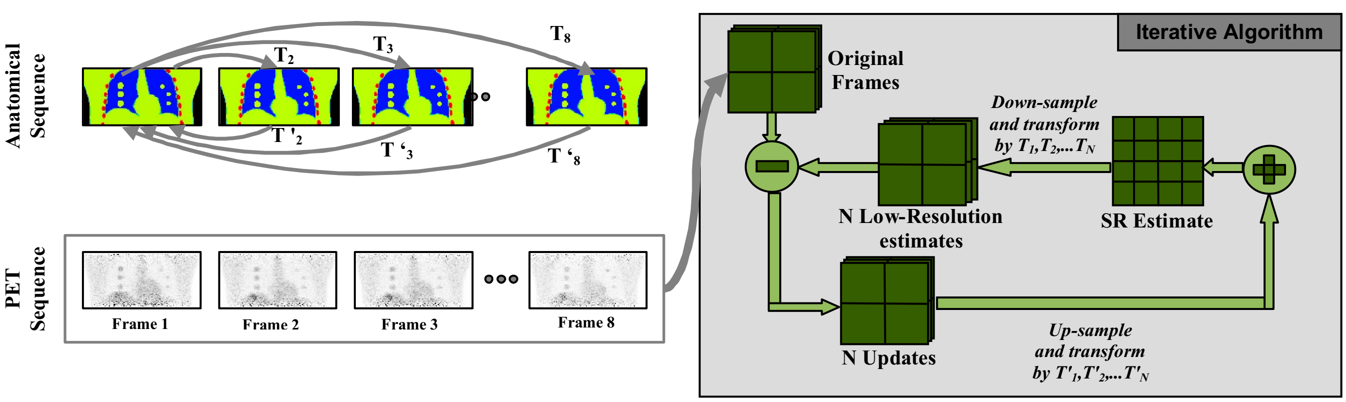

Fig. 3: Schematic representation of how the SR image estimate is obtained from the original image sequences

2. Each of the simulated low-resolution frames from previous step is then compared by subtraction to the respective original frame.
3. The N updates obtained in step 2 are taken back to the reference frame, i.e., each of them is up-sampled and deformed by the appropriate transformation (T'_n in fig. 3). This can be performed in a single step thanks to the B-spline representation of the deformation fields.
4. The high-resolution updates from step 3 are finally averaged and the result is added to the current estimate.

For initializing the iterative algorithm, a first guess for the high-resolution image is needed. This could be just a uniform image, however here we have used the up-sampled average of all the registered frames in the PET sequence.

The IBP algorithm was chosen because it has been tested in previous works involving SR and PET [3], [4], and also for its simplicity. Nevertheless, a more general and powerful algorithm such as Maximum A Posteriori might provide better results and will be investigated in future works.

III. Results and Discussion

Fig. 4 and 5 show some of the results obtained by:

- Estimating the deformation fields between frames by registration of the anatomical images sequence.
- Applying the SR algorithm to the PET images, using those deformation fields for warping the different frames.

In Fig. 4 a coronal slice passing through the nodular lesions in the lung is shown. Three images are compared: one of the original PET frames, the average of all PET frames after warping them to the reference frame and finally the output of our algorithm after 6 iterations.

The last image allows better discrimination of the lesions and shows improved contrast. This can be more clearly appreciated in Fig. 5, which shows a line profile of those slices passing through the three lesions in the right lung.

On-going work refers to the application of the non-rigid registration method directly to the set of the PET respiratory gates, without counting on the information provided by the attenuation images (CT). Results comparing these two different methods will be reported, as well as comparison with other non SR-based motion correction algorithms. Issues related to the quantification capabilities of the proposed methodology will be also investigated.

Other future lines include the application of the proposed methodology to real clinical data, as well as switching to a more general SR framework (such as Maximum A Posteriori) which allows greater flexibility in the choice of regularization and optimization.

IV. Conclusions

A Super-Resolution based respiratory motion correction employing motion deformation maps derived from non-rigid transformations of the respiratory frames has been implemented and its performance has been evaluated.

To-date results appear promising and encourage us to continue investigating the application of SR techniques for addressing the motion compensation problem in PET imaging.

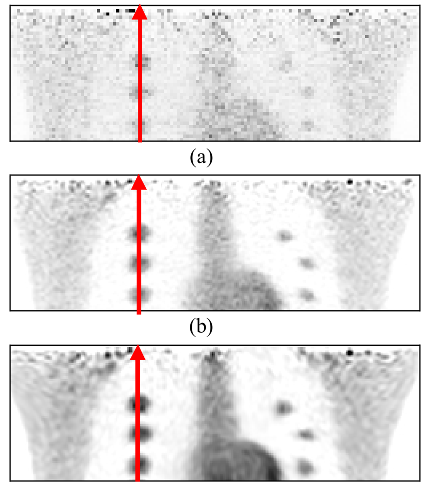
(a)
(b)
(c)

Fig. 4: Comparison of coronal slices for one of the original frames and two motion corrected images. (a) Original PET frame. (b) Average of all registered PET frames. (c) Output of the proposed algorithm

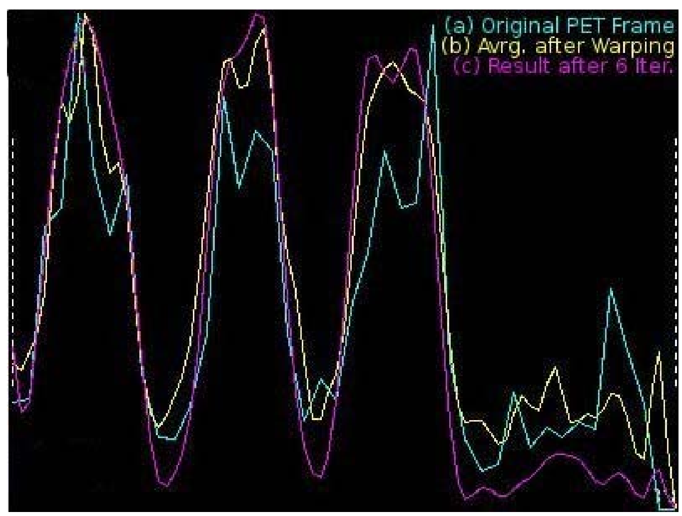

Fig. 5: Line profile through three lung lesions (red arrow in Fig. 4)

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