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Automated PET/CT Brain Registration for Accurate Attenuation Correction

Khawar Khurshid, Kevin L. Berger, Robert J. McGough, *Member, IEEE*

***Abstract*—Computed Tomography (CT) is used for the attenuation correction of Positron Emission Tomography (PET) to enhance the efficiency of data acquisition process and to improve the quality of the reconstructed PET data in the brain. Due to the use of two different modalities, chances of misalignment between PET and CT images are quite significant. The main cause of this misregistration is the motion of the patient during the PET scan and between the PET and CT scans. This misalignment produces an erroneous CT attenuation map that can project the bone and water attenuation parameters onto the brain, thereby under- or over-estimating the attenuation. To avoid the misregistration artifact and potential diagnostic misinterpretation, automated software for PET/CT brain registration has been developed. This software extracts the brain surface information from the CT and PET images and compensates for the translational and rotational misalignment between the two scans. This procedure has been applied to the dataset of a patient with visible perfusion defect in the brain, and the results show that the CTAC produced after the image registration eliminates that hypoperfusion artifact caused by the erroneous attenuation of the PET images.**

***Index Terms*— misregistration, PET, CT, attenuation correction, segmentation.**

I. INTRODUCTION

Recently, the use of combined PET/CT systems [1] has increased greatly in many radiological applications due to better image quality and higher throughput than that achieved with the conventional standalone PET scanners. CT-based attenuation correction is achieved in a fraction of the time required for a PET transmission scan with comparable or superior statistical quality [2]. By decreasing the total scan time, patient comfort and convenience is significantly improved. With better signal to noise ratio, the different regions of the brain can be imaged more accurately. Also, with the use of the CT, the abnormal metabolic activity can be accurately localized in a certain area of the brain with the help of the anatomical detail provided by the CT scan [3].

However, the disadvantage of PET/CT is the potential misalignment between the structures of the brain in the PET and CT data [4]. This misregistration can significantly affect the results and increase the chances of diagnostic misinterpretation. To avoid this, before a case study is interpreted, accuracy must be ensured because false positives may lead to an unnecessary invasive procedure. The main cause of this misregistration is the non-simultaneous acquisition of the PET and CT data, which means that one study is completed first, after which the bed position is changed and then the other study is performed. This sequential acquisition of data increases the chances of patient movement in between the two scans. This can result in an erroneous attenuation correction map, which in turn can create false areas of increased or reduced metabolic activity.

Currently, to minimize potential problems with misregistration, the patient is instructed to remain still during the acquisition process. However, in most of the cases, this proves difficult for the duration of the entire exam. A better approach, therefore, is to develop automated software that can align the PET and CT data and generate the attenuation map that is registered with the PET images. This attenuation map can then be used for PET reconstruction.

The automated software developed for the registration of PET and CT brain images is tested on the data acquired from a patient with significant perfusion defect in the left half of the PET brain. Overlaying the PET and CT images shows that the PET brain is projected outside the boundary of the CT brain and causes the erroneous attenuation. The software is then used to automatically align and rotate the PET and CT brain structures such that the brain region of the registered CT attenuation correction (CTAC) map completely overlaps the PET brain. Results show that the misregistration attenuation artifact is eliminated from the reconstructed PET images using the aligned CTAC, and a normal metabolic activity throughout the entire brain is demonstrated in the corrected images.

II. METHODS

The PET and CT data are acquired using a GE discovery STE scanner and exported as DICOM images for the post processing. The specifications and the parameters of the acquisition device and the PET and CT data are provided in [5]. The PET and CT images are aligned as described below.

A. Image Segmentation

In the first step of the segmentation process, the image data is low pass filtered to smooth out the boundary of the brain in the PET as well as the CT images. To segment the brain in the PET images, adaptive thresholding is applied based on the minimum and the maximum intensity of each image, where different intensity levels correspond to different anatomical structures in the PET brain images. The range of intensities representing the brain is selected after testing the range on several datasets. By applying an adaptive threshold based on the intensity range of the brain, unwanted structures are removed from the image. Figure 1 (a)-(d) show the result of the segmentation process on the PET data. Figure 1 (a) corresponds to the original PET slice 33 in the axial plane out of a total of 47 slices. Figure 1 (b) shows the segmented brain from the original images.

To segment the brain in the CT images, the lower and upper limit of the intensity range is defined for the brain. Starting from the center point of pixels belonging to this intensity range, a region growing technique is used and the entire brain region is filled iteratively from pixel to pixel until the threshold boundary is reached. Once all of the pixels inside the brain are iteratively marked, the rest of the image is set to zero. Figure 1 (c)-(d) shows the CT image before and after segmentation in slice number 33.

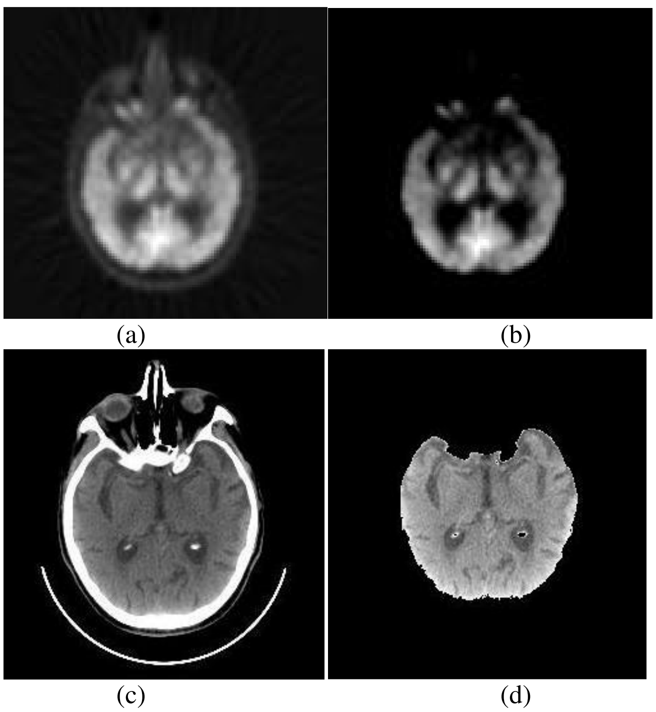


Fig. 1. The result of the segmentation process applied to the PET and CT images, (a) shows the original PET slice number 33 in the axial plane, (b) shows the PET brain with the skull removed, (c) shows the corresponding original CT slice number 33, and (d) shows the CT brain segmented from the image.

B. *PET/CT Image Registration*

DICOM Header Decoding

All of the information needed to overlay PET and CT is provided within the header of the DICOM files. The information of interest is the total number image resolution, pixel spacing, slice thickness, and starting location of the scans in x, y and z axes. Using this information, the PET and CT data are modified so that each pixel is equivalent to 1mm in both modalities. By doing so, the size of the CT image changes from 512 by 512 to 500 by 500, and the size of the PET image changes from 128 by 128 to 419 by 419. The total area stored in the CT image in transverse plane is 500 mm by 500 mm, whereas the total area stored in the PET image is 419 mm by 419 mm.

Image Registration

Once the preprocessing is complete, edge detection [6] is applied to the filtered images to obtain the boundaries of the PET and CT brain. The registration process is performed in the axial plane first to obtain the shift values along the x and y axes followed by the registration in the sagittal plane for the shift values along the z axis. Using the axial image, the average distance of the left and right boundary between the PET and CT brain is calculated. The magnitude of the average provides the amount of shift required for the CT, and the sign of the average value provides the direction in which the CT needs to be shifted. Then, the average distance for the top and bottom boundary between the PET and CT brain is calculated which gives the amount of shift required for the CT along the y axis.

To register the PET and CT images along the z axis, sagittal plane images are used. In this case, the top boundary of the PET brain is aligned with the corresponding boundary of the CT brain. The average distance between the boundaries of the brain from two different modalities is calculated and the CT image is shifted based on the average distance of the two edges.

The boundaries of the brain in the axial plane are determined by traversing the image from all sides, and the first non zero pixel found is marked as the boundary of the brain. This process is same for both the PET and CT image. For the sagittal plane, the PET and CT images are traversed only from the top and the first non zero pixel is marked as the top boundary of the brain.

In brain studies, the registration along the x, y, and z axes may not be sufficient to generate a CT attenuation correction map that overlaps with the PET brain completely. The reason for this error is that the head rotates in the sagittal plane. This effect is depicted in the figure 2 (d), which shows the result of translational registration along the z axis. Although the top boundaries of the PET and CT brain are aligned, part of the PET brain is now projected onto the sinus cavity of the CT image. To compensate for this motion, the CT data has to be rotated in the sagittal plane to completely overlap the brain structures of the two modalities.

The CT image is rotated in the sagittal plane based on the brain and sinus cavity boundary due to the attenuation error associated with the air parameter. If the PET brain boundary is projected onto the sinus cavity in the CT, then the CT image is rotated counter clockwise until the PET brain is no longer overlapping with the sinus cavity in the CT image. In the other case, if the PET brain boundary is well inside the sinus boundary of the CT, the CT image is rotated clockwise until the edges of the PET and CT brain along the sinus cavity overlap.

III. RESULTS

A. Registration

The automated registration process is applied to the selected dataset, and the shift values are calculated along the x, y, and z axes required to align the PET and CT images. The rotation angle is also calculated in the sagittal plane to compensate the rotation of the head. The largest shift of 12 mm is required along the z axis followed by a shift of 9 mm along the x axis. For this dataset, no shift is required along the y axis. The reason for the lack of a y axis shift is due to the fact that for this kind of mislignment, the patient has to lift his or her head from the table, which has the lowest probability among all of the possible patient motions.

Figure 2 shows the result of the registration process along the three axes as well as the rotation in the sagittal plane. Images (a)-(d) correspond to the translation registration of the PET and CT images, whereas 2 (e) shows the rotation of the CT attenuation map to compensation the rotation of the head by the patient. The white contours in these images correspond to the boundary of the brain from the PET images, and the grey scale image in the background is the corresponding CT image. Figure 2 (a) shows the PET brain contour from axial slice number 33 overlaid onto unregistered CT slice 33. During the exam, the patient moved his head, and the left boundary of the PET brain was projected outside of the CT brain. After the automated registration process is applied, the geometries of the PET and CT brain are aligned, and the PET brain lies within the boundary of the CT brain. The result of this registration process in the x-y plane is shown in figure 2 (b).

The alignment of PET and CT along the z axis is shown in figure 2 (c)-(d) using sagittal slice number 64. In figure 2 (c), the PET brain contour is overlaid onto the unregistered CT image, and a significant part of the PET brain lies outside the top boundary of the CT brain. This region of the PET brain can be erroneously attenuated if the unaligned CT attenuation correction map is used. The registration process aligns the top boundaries of the PET and CT brain region, and the result is shown in figure 2 (d).

Although the top boundaries of the PET and CT brain are aligned after the z axis shift of the CT as shown in Figure 2 (d), the PET brain is now projected onto the sinus cavity of the CT image. To solve this problem, the CT is rotated in the sagittal plane and the result of the alignment in shown in Figure 2(e). After rotation, entire PET brain is projected inside of the CT brain boundary.

B. Reconstruction of PET

The PET images are then reconstructed with the registered CT attenuation correction map, and the original and the reconstructed PET data are compared. The result of the reconstruction using the aligned CT is shown in Figure 3 (b). Figure 3 (a) shows the original PET axial slice number 33, in which the left half of the brain is significantly hypoperfused. Once the PET and CT are aligned and the PET images are reconstructed, the perfusion defects are eliminated and the result is shown in Figure 3 (b). The reconstructed PET image shows uniform perfusion, indicating a healthy brain without any perfusion deficits.

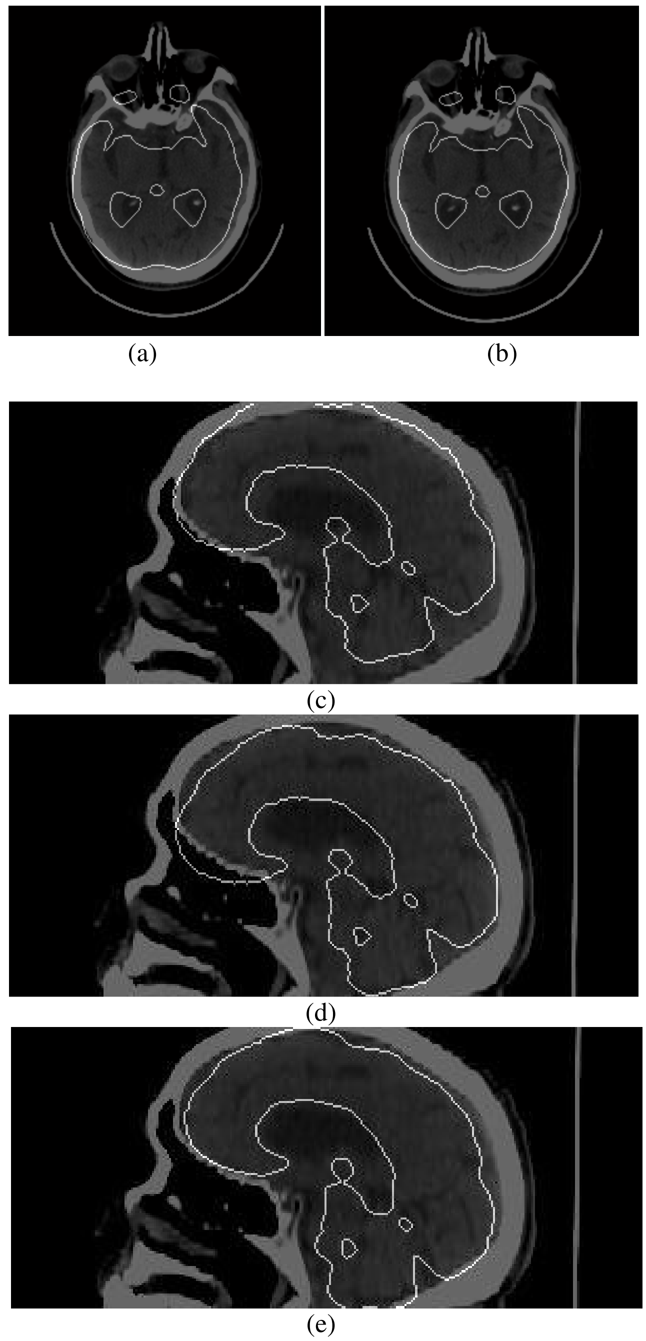
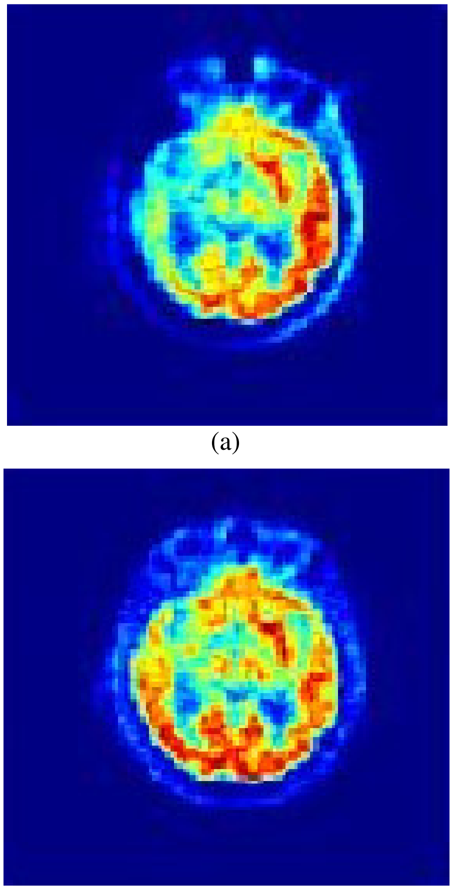


Figure 2. The result of the registration process applied to the PET and CT images, where (a) shows the unregistered PET slice number 33 in the axial plane overlaid onto the corresponding CT slice, (b) shows the registered PET and CT axial slice 33, (c) shows the unregistered PET and CT slice 64 in the sagittal plane, (d) shows the result of translation in the sagittal plane for PET and CT slice 64, and (e) shows the result of the counter-clockwise rotation of CT slice 64 to align the boundary of the PET/CT brain along the sinus cavity.



(a)

(b)

Figure 3. The result of the reconstruction of PET data, where (a) shows the axial slice number 33 reconstructed using misaligned CT; and (b) shows the same PET axial slice reconstructed using the aligned CT.

IV. DISCUSSION

The misregistration between PET and CT is the major drawback for the CT based attenuation correction of the PET. In PET/CT studies of the human brain, the misregistration occurs mainly due to the physical motion of the patient, as most patients are unable to keep their heads still during the entire exam. The misregistration between the PET and CT brain geometries results in erroneous attenuation correction parameters for the PET reconstruction. The reconstructed PET images obtained using the misaligned CT attenuation map show areas of abnormal metabolic activity in the brain, where the PET brain is projected outside the CT brain.

One approach to address the PET/CT misalignment problem is to repeat the CT scan of the brain in case of a misalignment between the PET and the original CT. In this approach, the PET and CT is downloaded to the processing unit and overlaid. If the brains geometries of the PET are CT align properly, then this CT is used for the reconstruction of the PET. However, if the PET and CT have a significant misregistration, then the patient has to go through another CT scan of the brain. In this case, the patient is exposed to an unnecessary radiation dose that can be avoided if software-aligned PET and CT is used. Also, this process can be very time-consuming and inefficient in terms of clinical resources.

In contrast, software based PET/CT brain registration has the advantage of being fast with no need for operator intervention, which increases the potential for routine clinical application. Only one CT scan is needed in this case, which is aligned with the PET and then used as the attenuation correction map. This approach also reduces the radiation dose.

VIII. CONCLUSIONS

In PET/CT studies of the human brain, the misregistration between the PET and CT data is the most important problem for the attenuation correction of PET data. The misregistration between the two modalities is due to the motion of the patient and the inability to keep the head still during the entire exam. The misregistration between the the two modalities results in erroneous CT attenuation correction map. If the unregistered CTAC is used for the PET reconstruction, the resulting PET data shows variable amount of artifactual perfusion defect depending upon the amount of misregistration. To avoid such errors in the PET images, automated software aligns the geometries of the PET and CT brain based on the average distance between the contours and generates a new CT attenuation map. The PET images are then reconstructed using the aligned CTAC and the attenuation artifacts due to the misregistration error are eliminated.

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