Correction of Oral Contrast Artifacts in CT-Based Attenuation Correction of PET Images Using an Automated Segmentation Algorithm

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Abstract — **Oral contrast is usually administered in most x-ray computed tomography (CT) examinations of the abdomen and the pelvis as it allows more accurate identification of the bowel and facilitates the interpretation of abdominal and pelvic CT studies. However, the misclassification of contrast medium with high density bone in CT-based attenuation correction (CTAC) is known to generate artifacts in the attenuation map (μmap), resulting in overcorrection for attenuation of PET images. In this paper, we developed an automated segmentation algorithm for classification of regions containing oral contrast medium in order to correct for artifacts in CT attenuation-corrected PET images using the segmented contrast correction (SCC) technique. Our segmentation algorithm consists of two steps: (1) high CT number object segmentation using combined region- and boundary-based segmentation and (2) object classification to bone and contrast agent based on fuzzy classifier as knowledge-based nonlinear classifier. Thereafter, the CT numbers of pixels belonging to the region classified as contrast medium are substituted with their equivalent effective bone CT numbers based on the SCC algorithm. The generated CT images were down-sampled and followed by Gaussian smoothing to match the resolution of PET images. A bi-linear calibration curve was used to convert CT pixel values in HU to μmap at 511 keV. The visual assessment of segmented regions in clinical CT images performed by an experienced radiologist confirmed the accuracy of the segmentation algorithm for delineation of contrast enhanced regions. The mean attenuation coefficient of a small region in the generated μmaps before and after correction using the SCC algorithm was 0.151 and 0.098 cm^{-1}, respectively. Quantitative analysis of generated μmaps from a clinical dataset showed an overestimation of 19.7% of attenuation coefficients in the 3D regions classified as contrast agent. A clinical PET/CT study known to be problematic demonstrated the applicability of the technique. More importantly, correction of oral contrast artefacts improved the readability and interpretation of the PET scan and showed substantial decrease of the SUV (104.3%) after correction. In conclusion, we developed an automated segmentation algorithm for classification of irregular shapes of regions containing contrast medium usually found in clinical CT images for wider applicability of the SCC algorithm for correction of oral contrast artefacts in CTAC. The algorithm is being refined and further validated in clinical setting.**

I. Introduction

Oral contrast medium is usually administered in most CT examinations of the abdomen or the pelvis as it allows more accurate identification of the bowel and facilitates the interpretation of abdominal and pelvic CT studies. Although there is a general consensus that oral contrast materials enhance the diagnostic value of CT in most examinations of the abdomen or the pelvis, its application in hybrid PET/CT systems is not fully established. More recently Tateishi *et al.* showed that the contrast-enhanced PET/CT is more accurate than non-enhanced PET/CT in determining the regional nodal status of rectal cancer. Mainenti et al. also reported that PET/CT colonography is a feasible study. One of the technical problems faced is that the misclassification of contrast medium with high density bone in CT-based attenuation correction (CTAC) generates artefacts in the attenuation map (μmap) that results in overcorrection for photon attenuation, consequently overestimating the apparent reconstructed activity concentration of the radiotracer in the contrast enhanced region [1]. The issue of whether the use of oral contrast medium in dual-modality PET/CT scanning produces medically significant artifacts is still controversial with some studies corroborating [2] and others contradicting [3] the fact that the presence of contrast medium can be a source of error and artifact when the CT data are used for attenuation correction of PET images. There are different strategies for correction of the contrast agent artifact in CTAC [4-6]. One of the methods that allow for correction of oral and intravenous contrast medium artifacts in CTAC PET images called segmented contrast correction (SCC) method was proposed by Nehmeh *et al.* [7]. This method was evaluated using both phantom and clinical studies and proved to accurately recover lesion size and uptake. Although some studies have demonstrated the efficiency of the SCC algorithm, its

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performance is still limited to simple geometrical shapes reflecting the spatial distribution of contrast medium [1]. This limitation renders the algorithm useless in clinical area where we are usually facing irregular shapes of regions containing contrast medium typically found in clinical studies. The main problem for the clinical application of the SCC algorithm is the difficulty encountered in the segmentation and classification of bone and contrast enhanced fluids (CEF) from patient's CT images.

In this study, an algorithm for segmentation and classification of irregular shapes of regions containing contrast medium usually found in clinical CT images is proposed for wider applicability of the SCC algorithm to correct for oral contrast related artefacts in CTAC. The basic principle consists is finding regions with high density and classifying them to bone and oral contrast materials followed by application of appropriate calibration curves for generation of artifact free attenuation map to be used for PET attenuation correction purposes.

II. Materials and Methods

A. Segmentation

The proposed segmentation algorithm consists of two steps: (1) high CT number object segmentation is performed using combined region- and boundary-based segmentation and (2) object classification into bone and contrast agent is carried out using a fuzzy classifier as knowledge-based nonlinear classifier. Region-based techniques rely on the assumption that adjacent pixels in the same region have similar visual features such as grey level or texture. Our method utilizes traditional region growing methods along with a threshold-based similarity criterion. A seed is placed on the high CT number (HCTN) objects and starts to grow by combining neighbouring voxels until no more voxels can be included. The combining rule is based on whether the intensity of a voxel is greater than a preset threshold. The whole connected HCTN objects can then be extracted when the seed growth stops. As the CT number of bone marrow is slightly higher than soft tissue, this method segments only the HCTN parts of bones and the bone marrow will be missed. So the recognition and segmentation of the inner parts of bone is necessary and unavoidable. It is well known that region-based segmentation can not use borders property and leads to some miss-segmentation, whereas boundary-based segmentation can help to solve these problems. Boundary-based techniques use the assumption that pixel values change rapidly at the boundary between two regions. We also used the canny edge operator as an edge detector. In this study, we used region-based segmentation with thresholding and region growing in combination with boundary-based segmentation.

B. Classification

During the classification stage, some features like volume, mean, maximum and recursive layer mean are used to classify objects into bone and contrast agent using a fuzzy classifier as knowledge-based nonlinear classifier. The recursive layer mean is one of the most important features that rely on the fact that the marrow's bone density is less than outer bone area, but CEF has a uniform density distribution under accepted diet protocols regardless of some rare cases. This feature is computed using object's outer surface CT values after erosion in a recursive algorithm. In addition, the object volume feature was used as an important feature especially in large objects. The fuzzy classifier rules are extracted based on expert knowledge in the sense that rules and membership functions are defined using results from supervised classification. The Fuzzy Logic Toolbox of Matlab 7.4.0 (The MathWorks Inc., Natick, MA, USA) was used in the definition of fuzzy logic inference.

C. Segmented Contrast Correction algorithm (SCC)

During the CTAC procedure, the attenuation coefficients of contrast agent materials need to be converted from the x-ray CT effective energy (75 keV for this scanner calculated at 120 kVp tube voltage) to 511 keV. However, commonly used energy mapping algorithms are based on the assumption that image contrast in the CT data is contributed by mixtures of air, soft tissue, and bone. The presence of contrast medium complicates this process since two regions that have the same CT number in HU may indeed have different compositions, for example bone/soft tissue and contrast agent/soft tissue. As a result, and based on the bi-linear calibration curve method for energy mapping, the region containing contrast medium can be misclassified as high-density bone and thus can be associated with an incorrect scaling factor. This problem can be solved using the SCC algorithm which consists of the following steps. First, the regions containing contrast agent are segmented and second the CT value in each pixel within the segmented region is substituted with the corresponding effective bone CT number in order to generate the corrected CT image. The effective CT number for bone is the value that produces the correct attenuation coefficient for regions containing contrast medium in the estimated μmap, when converted from CT energy to PET energy using commonly used energy mapping algorithms. This method was evaluated using both phantom studies and Monte Carlo simulations in our previous publications and proved to accurately recover lesion size and uptake [1].

D. Attenuation Correction and Image Reconstruction

After segmentation and classification of the regions, the CT numbers of pixels belonging to the region classified as contrast medium are substituted with their equivalent effective bone CT numbers using the SCC algorithm. The generated CT images were down-sampled followed by Gaussian smoothing to match the resolution of PET images. A bi-linear calibration curve was used to convert CT pixel values in HU to μmap at 511 keV [8]. The assessment of the accuracy of CTAC in the presence of oral contrast medium was performed for some clinical CT colonoscopy data sets acquired for the detection of colorectal neoplasia in an average-risk screening population and one clinical whole body PET/CT examination. The CT data sets were used to test our segmentation and SCC algorithm during the generation of the attenuation map at 511 keV required for the CTAC procedure whereas the PET/CT data were used to evaluate the clinical feasibility of the technique and to assess the impact of overestimating the attenuation map (during the CTAC procedure) on the resulting PET reconstructions.

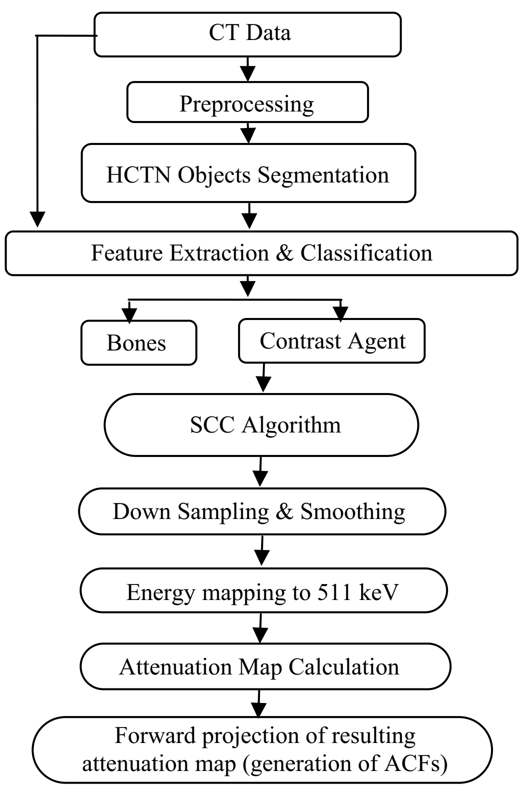

Figure 1. Flowchart illustrating the different steps of the algorithm used for segmentation and correction of oral contrast artefacts.

A PET/CT study deemed to be problematic was referred to the Nuclear Medicine Division of Geneva University Hospital for a whole-body diagnostic PET/CT scan. The patient has previously had oral Barium administration for esophageal, gastric and duodenal transit assessment, which was known to remain in the abdomen during the PET/CT scan. PET/CT data acquisition was performed on a Biograph Sensation 16 (Siemens Medical Solutions, Erlangen, Germany) using a standard protocol recommended by the manufacturer. The PET acquisition was started approximately 60 min after injection of 370 MBq of [^{18}F]-FDG. The PET emission study (3 min per bed position) followed immediately the CT study used for attenuation correction. Diagnostic quality CT imaging was performed under standard conditions (120 kVp, 180 mAs, 16×1.5 collimation, a pitch of 1.2 and 1 sec per rotation). Fig. 1 shows a flowchart describing the different steps of the algorithm.

III. Results

Fig. 2 illustrates the segmentation process and application of the SCC algorithm to a clinical study. In Fig. 2b, the regions containing contrast medium are labelled with green colour whereas the bony regions are labelled with pink colour. The visual assessment of segmented regions from clinical CT images performed by an experienced radiologist confirmed the accuracy of the algorithm for delineation of contrast enhanced regions. Fig. 2c-d shows the extracted bone and contrast agent objects whereas Fig. 2e shows the original CT image after substitution of CT numbers in the contrast enhanced regions with their equivalent effective bone CT numbers using the SCC algorithm. Fig. 2f-g shows the μmap generated from CT images before (Fig. 2a) and after (Fig. 2e) applying the SCC algorithm. The overestimation of attenuation coefficients in the regions containing contrast medium is obvious in Fig. 2f. Fig. 2h shows a profile through μmaps shown in Fig. 2f-g to illustrate the difference between attenuation coefficients in the generated μmaps before and after SCC. Quantitative analysis of the generated μmaps from a clinical study showed an overestimation of 19.7% of attenuation coefficients in the 3D regions classified as contrast agent. The visual assessment of segmented regions from clinical CT images performed by an experienced radiologist confirmed the accuracy of the algorithm for delineation of contrast enhanced regions. Although some very small regions were mis-classified in some cases, our experience is that they are too small to have considerable impact on the calculation of attenuation correction factors (ACFs) given that these factors are generated by 3D forward projection of estimated μmaps. Another possibility is to correct manually those regions using the developed graphical user interface (GUI) to change the assignment of the class from bone to CEF and vice versa.

The clinical PET/CT study known to be problematic demonstrated the applicability of the technique in a clinical environment (Fig. 3). The overestimation of calculated μmap and activity concentration in PET images is due to the presence of the high density contrast agent in the CT images. The corrected μmap using on SCC algorithm and reconstructed PET images are also shown in Fig. 3. It can be seen that the correction of oral contrast artefacts improves the readability and interpretation of the PET scan. Note also that there is a substantial decrease of the SUV (104.3%) after correction.

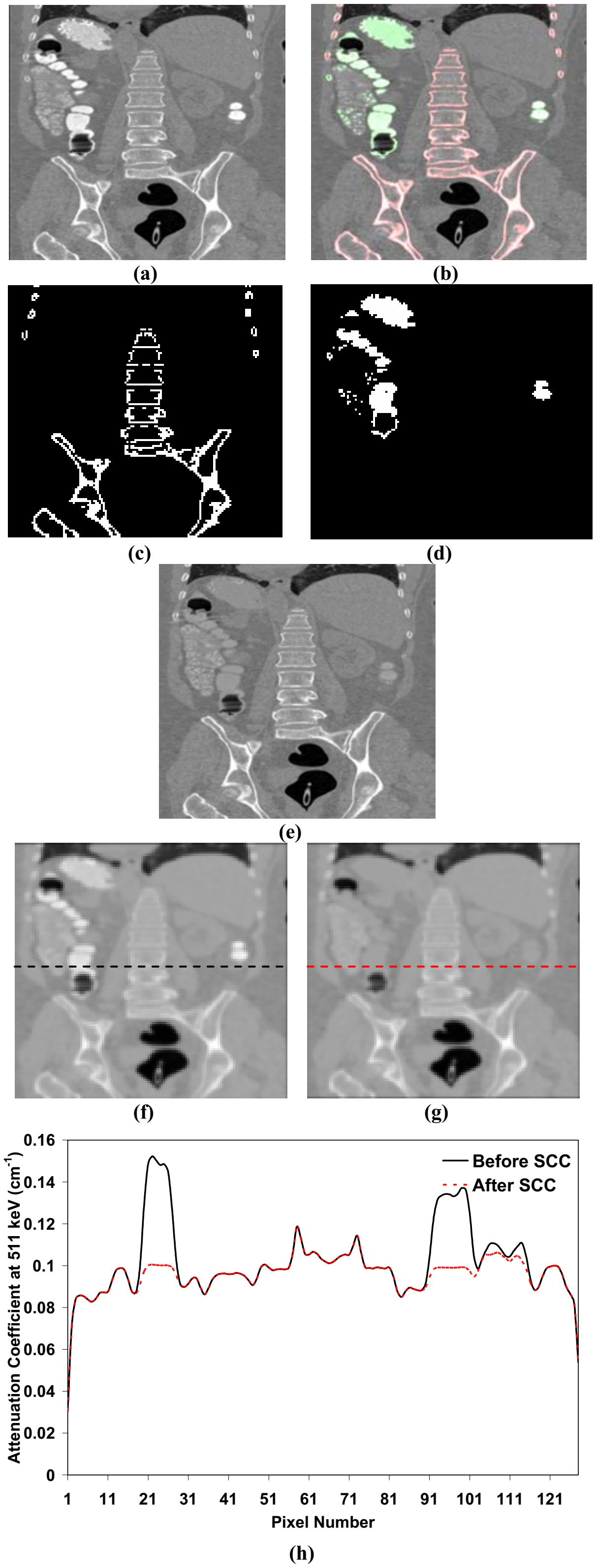

Figure 2. Original contrast enhanced CT image (a), segmented CT image (b), bone objects (c), contrast agent objects (d), original contrast enhanced CT image after applying SCC to the regions segmented as containing contrast agent (e), generated μmap from original CT (f), and generated μmap after SCC (g). Horizontal profiles (position shown in f-g) through generated attenuation maps before and after applying SCC (h).

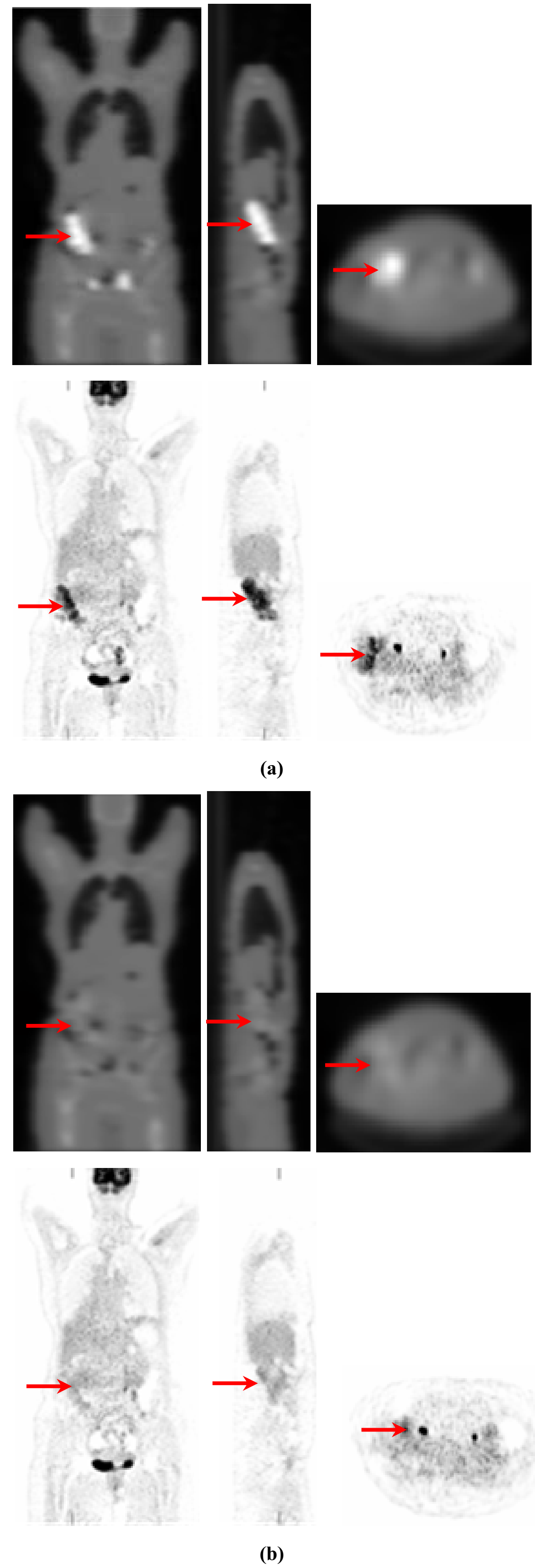

Figure 3. Illustration of generated μ*map* (top row) and CT-based attenuation corrected PET images (bottom row) in different views before (a) and after (b) correction of oral contrast artifacts (indicated by red arrows).

IV. Discussion

The use of CT-based attenuation correction on current PET/CT scanners has several advantages including the decrease of the overall scanning time and the improved accuracy in lesion localization and detectability in addition to creating a noise free attenuation map. However, the technique might result in a significant bias in the generation of the ACFs in regions containing high concentrations of contrast medium. Our results show the propagation of this bias at the level of the attenuation map and the attenuation corrected PET images. Although several studies have shown that the SCC algorithm is efficient, its application is still limited to simple shapes reflecting the spatial distribution of contrast medium. One of the main challenges in the implementation of SCC algorithm is the accurate segmentation and classification of regions containing contrast media. In this study, we developed an automated segmentation algorithm for classification of regions containing oral contrast medium in order to correct for artifacts in CT attenuation corrected PET images.

The Visual assessment by an experienced radiologist confirmed the accuracy of CEF segmentation results obtained using the hybrid classification technique. The overall CEF correctly classified using the hybrid method is 90.6% ± 9.4%, where the percentage of voxels falsely classified as CEF is 1.3% ± 2.6%, clearly supporting the robustness of method. The hybrid proposed segmentation method occasionally failed to result in correct segmentation when the CEF was too close to the bony structures. This failure is more important for large volume objects resulting from the undesired connection of bone and CEF and leads to a complex object that is actually a mixture of bone and CEF. To overcome this problem in our segmentation algorithm, a morphological object erosion approach was applied to eliminate the undesired narrow connections. Visual assessment also showed that the proposed hybrid segmentation algorithm has the ability to effectively align CT images acquired from different patients, even though the images contained a large amount of anatomical variability and different oral contrast diet. However, miss-segmentation and miss-classification of small object is still encountered, thus resulting in negligible errors in the final result. Its acceptability in clinical setting is evidenced by the low standard deviation associated with the averaged overall error. In order to make more precise classification especially in whole body imaging, more features must be extracted in the presence of cortical bone that has attenuation values rather constant across individuals. It must be noticed the Mamdani classifier is based on expert knowledge and rules that have significant impact on the obtained results. Other more powerful classifiers described in the literature will be evaluated in our future work. In addition, since large volume objects may consist of CEF and bone, more analysis of these objects for elimination of wrong object connections using algorithms such as distance transform map could be effective. Also, using more accurate border management techniques such as border generation with more sophisticated edge detection operators and more precise border to region conversion would be an asset.

V. Conclusion

In this study, we have developed an automated segmentation algorithm for classification of irregular shapes of regions containing contrast medium usually found in clinical CT images for wider applicability of the SCC algorithm for correction of oral contrast artefacts in PET/CT. Our proposed algorithm consists of two steps: segmentation of HCTN objects and classification of segmented objects to bone and CEF. The proposed hybrid method is able to make complete segmentation of bone and CEF leading to correct classification while region growing leads to incomplete bone segmentation and therefore produces a lot of defragmented bones that are classified as CEF. The visual assessment of segmented regions in clinical CT images performed by an experienced radiologist confirmed the accuracy of the segmentation and classification algorithm for delineation of contrast enhanced regions. The mean attenuation coefficient of a small region in the generated μmaps before and after correction using SCC algorithm was 0.151 and 0.098 cm^{-1}, respectively. Quantitative analysis of generated μmaps from a clinical dataset showed an overestimation of 19.7% of attenuation coefficients in the 3D regions classified as contrast agent. Correction of oral contrast artefacts improved the readability and interpretation of the PET scan and showed substantial decrease of the SUV (104.3%) after correction. The algorithm is being refined and further validated in clinical setting.

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