Interactive Fusion and Contrast Enhancement for Whole Body PET/CT Data Using Multi-Image Pixel Composting

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***Abstract*–The most important application of the dual-modality PET/CT is the ability to efficiently display the fused data. However, in PET/CT fusion, the amount of information displayed is often impaired as the CT data occupies greater range of contrast than that is possible to display without enhancements. A common approach to improving the CT information in the PET/CT fusion is by enhancing the contrast range of the CT data which can improve on the accuracy of structure localization and PET/CT interpretation. In this study, we present an interactive multi-image fusion which optimizes the display of the information from dual-modality PET/CT data. By interactively selecting a specific CT contrast range and assigning the resultant image as a layer, the multi-layers can be constructed and then fused using the multi-image pixel compositing. The enhanced CT data is further fused with the PET data for PET/CT diagnosis. The proposed algorithm is able to simultaneously display greater amount of information from the fused PET/CT data and reveal substantial details of the CT data that would not have been possible with standard PET/CT fusion. The preliminary results are encouraging and show potential in the PET/CT diagnosis and interpretation.**

I. Introduction

The four-dimensional (4D) whole body (WB) positron emission tomography (PET) and computed tomography (CT) dual-modality scanner (PET/CT) has led to a new paradigm in medical diagnostic imaging systems. In the co-registered PET/CT data, while the PET provides high sensitivity in lesion detection and tissue characterization, the CT provides the localizations of the anatomic landmarks and boundary definitions of lesions and organs. The combined WB PET/CT data add additional complexities in diagnostic interpretation. The PET/CT data are extended to 5D as the fusion of the two modalities is regarded as the 4th dimension and the large intensity range of CT data is considered as the 5th dimension [1]. Efficient and convenient display of the PET/CT data as a co-registered and fused image is the most important application of the PET/CT [1-2]. However, the amount of information displayed from PET/CT fusion is limited as the CT data occupies greater range of contrast than that is possible to display. Contrast enhancement is often employed to display multiple contrast ranges simultaneously [3-4]. The display of the multi-contrast ranges of the CT data was shown to be efficient in interpretation and to improve the accuracy of structure localization, such as the focal abnormality [4]. Different methods have been proposed to enhance the CT images, such as the multi-scale adaptive histogram equalization (MAHE) [3]. However, such approach was only applicable on a single slice of the CT data, since the equalization parameters were needed to be set for different structures that have different contrast ranges. Furthermore, the process was not interactive, thus being unable to permit the physician to control the enhancement process. An alternate approach is to fuse the different intensity ranges utilizing color lookup tables (LUT) from a single image modality [5-6]. Such fusion of image variations obtained from the same imaging modality was shown to be an effective method in facilitating the interpretation and improving localization of structures. The color LUT with appropriate contrast adjustments for specific imaging slice was demonstrated to improve the image display. However, these methods were based on the fusion of only two variations of the image, and thus limited in displaying larger variations evident in PET/CT data.

In this study, we propose an interactive multi-image fusion in order to optimize the display of 5D information from dual-modality PET/CT data. By interactively selecting a specific CT contrast range and assigning the resultant image as a layer, multi-layers can be constructed, such as a CT layer with contrast range in the bone, another contrast layer for the organs, etc., and then fused using the multi-image pixel compositing. The enhanced CT is further fused with the PET data for PET/CT diagnosis, providing a means to visualize multi-layers of CT with PET simultaneously. The proposed multi-image fusion allows for greater amount of information to be simultaneously displayed which may aid in the PET/CT interpretation. The proposed algorithm has been comparatively validated with the conventional alpha-blending fusion which is commonly used in clinical WB PET/CT navigation software.

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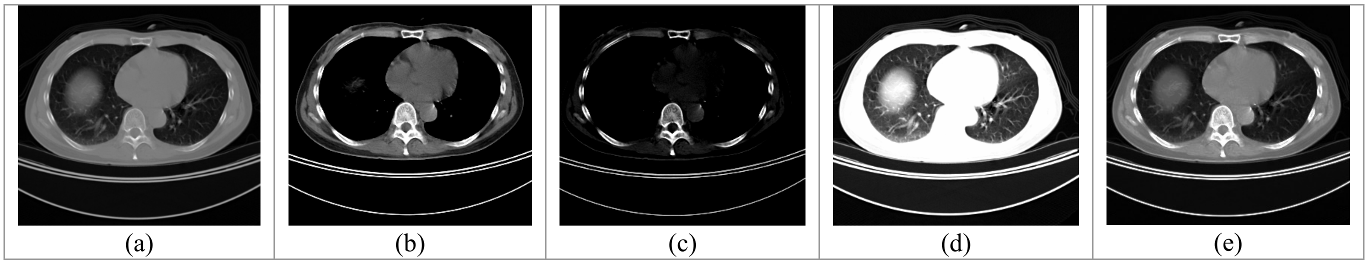

Fig. 1 (a) Default contrast setting of a chest CT data; Three different contrast settings (layers): (b) Soft tissue, (c) Bone and (d) Lung; (e) The enhanced multi-layer CT by fusing (b-d) with equal weighting.

II. Materials and Methods

A. PET/CT Data Acquisition

The clinical WB PET/CT data used in this study were acquired on a Siemens/CPS PET/CT scanner. The resolution of the images is at 16-bit and the total numbers of imaging slices for PET and CT images are $128 \times 128 \times 263$ and $512 \times 512 \times 262$, respectively.

B. System Design

The DICOM-compliant navigation system is constructed in Java programming language with the advantages of platform-independence, comprehensive image processing libraries (Java Advance Imaging), and the support for databases integration.

The proposed multi-image fusion can be performed by adjusting the brightness/contrast of the CT data. The fusion between the CT contrast layers and between PET and CT can be interactively adjusted in real-time. Other navigational tools included in the system are scaling, interpolation, LUT, and other common tools needed for image navigation.

C. CT Contrast Enhancement and Multi-layer Fusion

The CT image is adjusted in contrast to a user-defined range to select a specific structure(s) of interest, resulting in a CT contrast layer. The contrast in CT is controlled by the intensity window level and window width settings (intensity transformation). These settings dictate how the actual measurements of tissue attenuation are translated into a gray-scale image. Intensity windowing allows a selected sub-range of the image intensity values to receive the full contrast of the display devices. All parts of the image with values below the selected intensity window range are set to black and above are set to white. For example, wide window width may be used to provide an accurate representation of the bone structure, whereas narrow widths can potentially be more useful for visualizing soft tissue structures. The effect of this process is illustrated in Fig. 1. The chest CT image with default window width is show in Fig. 1(a). The user-defined layers specifications are demonstrated in Fig. 1(b-d) with the intensity window ranges were selected on the basis of tissue class (i.e. soft tissue, bone and lung). The corresponding schematic diagram of the histogram and the intensity window settings are presented in Fig. 2. The default intensity window (red solid line) covers the whole contrast range. As the anatomical tissues may occupy significantly different dynamic intensity ranges (lung tissues usually occur at the low intensity region, soft tissues occur at the middle and bone occurs at high intensity region) on display due to difference of X-ray attenuation, in which case some information in the dark parts may be hided behind from the bright parts [4]. Therefore, the intensity of the bone in Fig. 1(a) needs to be compromised in order to display the surrounding soft tissues and lung tissues. For presenting the soft tissue in full contrast of the display device, in this example, the window selection (yellow square dot) allows the full range of contrast across the part of the histogram representing the soft tissue of the chest. The similar selections also applied to bone (green dash line) and lung (blue dash dot line). In this study, we treated each window selection as a CT layer. The number of layers is chosen according to user requirement, and the adjustments are performed in real-time.

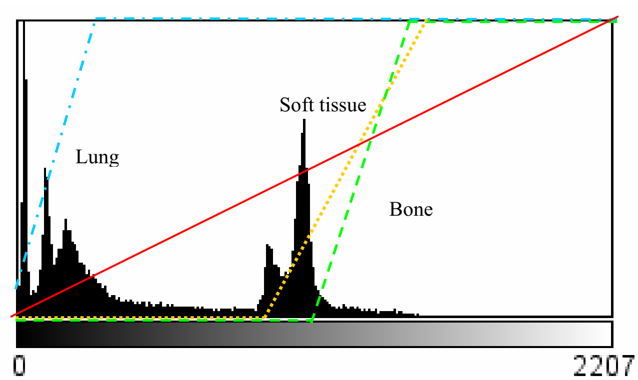

Fig. 2. The histogram of the chest CT slice and transformation functions for three different contrast range specifications: Default; Soft tissue; Bone; Lung.

With the aim to display various window selections simultaneously, the alpha-blending fusion technique was adopted in this study. The selected CT layers are fused according to

$$dst = \alpha A + (1-\alpha)\left(\sum_{i=0}^{I} \beta_i B_i\right) \qquad (1)$$

where the destination image, *dst*, is the composition of the PET image A and the sum of the CT layers B. The B_i $(i=1,2,\ldots I)$ is the i^{th} CT layer where I is the total number of contrast layers. The α is the opacity channel that is multiplied to images A and β_i is the opacity channels multiplied to the corresponding CT layers. The sum of all β equals to 1. The fused CT image from three layers is shown in Fig. 1(e) with equivalent fusion proportions.

III. Results and Discussion

Fig. 3 presents the overall system design illustrating the whole-body PET/CT data. The fusion of the data was set to 50-50, respectively of PET/CT. The whole-body PET was mapped with red-temperature LUT and the CT has been contrast enhanced using two layers to emphasize the localization of the liver with the surrounding bone structures and anatomical boundary of the liver. The control bar is shown on the left side of the image.

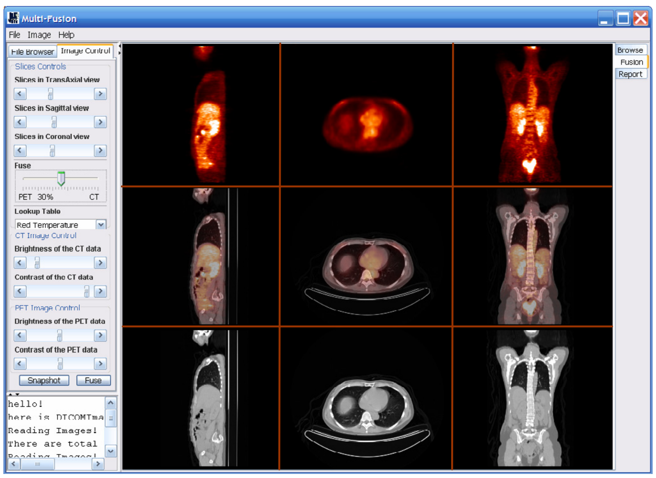

Fig. 3. Whole-body PET image mapped with red-temperature lookup table is shown in the 1st row of the image; The multi-image fusion is shown in the 2nd row; The enhanced CT is shown in the 3rd row. The CT has been contrast enhanced using two layers to emphasize the localization of the liver with the surrounding bone structures and anatomical boundary of the liver. The images are presented in Sagittal, Trans-axial and Coronal views respectively from left to right.

In Fig.4, the comparison of the proposed multi-image fusion Fig. 4(f) to the conventional fusion Fig. 4(c) (with the same PET image) is exemplified using a single trans-axial slice comprising of the lung section. The fusion ratio of PET/CT was again set to 50-50. Notice that in Fig. 4(f), with the prior multi-layer fusion of the CT images, multiple contrast ranges (soft tissue, bone and lung) can be identified. In contrast, the conventional fusion of the PET/CT was hampered from the loss of details as shown in Fig. 4(c).

Fig.5 shows the enlarged display of the fused image of a trans-axial slice in the lower abdomen region, which reveals substantial improvement in the ability to identify CT structures from the application of the proposed fusion Fig. 5(b) when compared to the conventional fusion Fig. 5(a). The potential advantage from using the multi-layer fusion is that the organ boundaries and the bone structures, which occupy different contrast ranges, can be clearly identified simultaneously. This provides landmarks and boundary definitions for the low resolution PET image in the diagnosis of PET/CT image. However, the noise in the multi-image fusion Fig. 5(b) is more noticeable. This is attributed to the fact that the information (including noise) in three different contrast layers was fused. Nonetheless, the additional noise appeared not to obscure the visibility of the image, and thus, may not have affect in the diagnosis method in comparison to the conventional fusion.

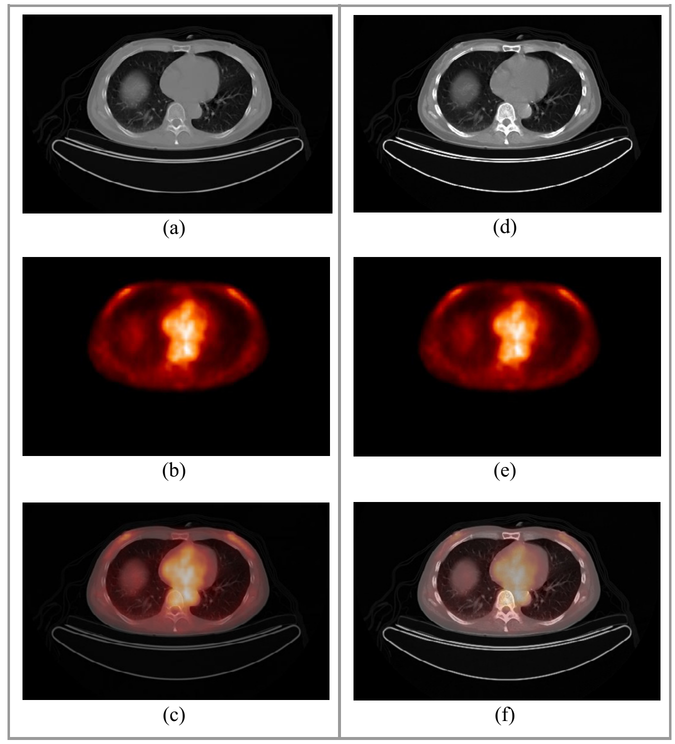

Fig. 4. Comparison of the multi-image fusion with conventional PET/CT fusion (trans-axial view). (a) CT image with default contrast range (full intensity range); (b & e) PET image mapped with red-temperature lookup table; (c) Conventional PET/CT fusion; (d) Multi-layer fusion resulting from three CT contrast layers as shown in Fig.1. (f) Multi-image PET/CT fusion.

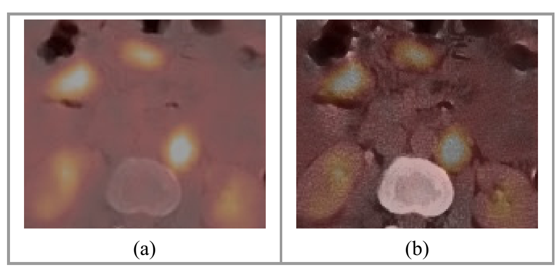

Fig. 5. Enlarged views of the trans-axial slice in lower abdomen region. (a) Conventional PET/CT fusion with default CT contrast range; and (b) Proposed multi-image fusion with the fusion of two CT contrast layers.

IV. Conclusion and Future Work

We have presented an interactive multi-image pixel compositing fusion method for dual-modality PET/CT. We further demonstrated the use of contrast range adjustments in order to enhance the CT display. The proposed method for the fusion of enhanced CT and PET could be an effective approach in interpretation and diagnosis. The preliminary results are encouraging. The ordinary alpha-blending fusion compromises the information during the fusion of two imaging modality. This is attributed to the fact that the structures of interest may only appear in one modality, and thus, when this modality is fused, it is blending to a non useful structural information. To optimize the information presented from fusion, our further studies will involve the investigation of adaptive alpha-blending fusion. Furthermore, the applications of opacity transfer function which may permit greater flexibility in the adjustment of CT contrast in the selection of structures will also be studied.

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