Opacity-driven volume clipping for slice of interest (SOI) visualisation of multi-modality PET-CT volumes

Younhyun Jung, Jinman Kim, IEEE, Member, Michael Fulham, and David Dagan Feng, IEEE, Fellow

Abstract— **Multi-modality positron emission tomography and computed tomography (PET-CT) imaging depicts biological and physiological functions (from PET) within a higher resolution anatomical reference frame (from CT). The need to efficiently assimilate the information from these co-aligned volumes simultaneously has resulted in 3D visualisation methods that depict e.g., slice of interest (SOI) from PET combined with direct volume rendering (DVR) of CT. However because DVR renders the whole volume, regions of interests (ROIs) such as tumours that are embedded within the volume may be occluded from view. Volume clipping is typically used to remove occluding structures by 'cutting away' parts of the volume; this involves tedious trail-and-error tweaking of the clipping attempts until a satisfied visualisation is made, thus restricting its application. Hence, we propose a new automated opacity-driven volume clipping method for PET-CT using DVR-SOI visualisation. Our method dynamically calculates the volume clipping depth by considering the opacity information of the CT voxels in front of the PET SOI, thereby ensuring that only the relevant anatomical information from the CT is visualised while not impairing the visibility of the PET SOI. We outline the improvements of our method when compared to conventional 2D and traditional DVR-SOI visualisations.**

I. Introduction

Multi-modality biomedical imaging devices such as positron emission tomography and computed tomography (PET-CT) have introduced new clinical capabilities for staging cancer and assessing the response to treatment [1-2]. PET-CT allows visualisation of biological and physiological function (PET) within the spatial context of anatomy (CT) and it allows the depiction of abnormal function in structures which do not appear 'abnormal' on CT. Thus, a key element in PET-CT visualisation is to optimally identify the region of interest (ROI) on PET, such as a tumour, while preserving as much visibility of the underlying anatomy from CT, without compromising the visibility of the ROIs. The ability to efficiently assimilate the information contained in these two volumes simultaneously, however, has raised new visualisation challenges.

Direct Volume Rendering (DVR) is an effective 3D visualisation approach to present biomedical imaging data [3]. A key advantage of DVR over conventional 2D slice of interest (SOI) visualisation e.g., multi-planar reformatting (MPR) is its ability to display a 3D depiction of the full volumetric data. This allows, for instance, localisation of ROIs in the whole body [4], whereas this is not possible in MPR. Despite the advantage of DVR, the majority of medical imaging visualisations still rely on the 2D SOI views due to the inherent occlusion in DVR from rendering the entire volume, thus preventing the tumour ROIs, for instance, being visible.

In DVR, the transfer function (TF), which lets the user manipulate opacity and colour of the voxels in an image volume, can be used to control the visibility of the ROIs [5-8]. For multi-modality PET-CT volumes, Kim et al [9] proposed a combined manipulation of a pair of the conventional one-dimensional TFs for PET and CT volumes, and the resultant visualisations, ROIs from PET and their corresponding anatomy from CT, were combined together (data intermixing). Recently, Jung et al [10] presented an automated approach where any initial CT TF is optimised to maximally depict the CT anatomy without compromising the visibility of the ROIs. However, because these two methods cannot be applied to an individual structure (e.g., ROIs) but rather to the entire volume, it is difficult to localise the ROIs. Further, these methods do not consider the use of SOI and its combination to DVR methods. Volume clipping is another approach to localise the ROIs by 'cutting away' parts of the volume that occlude the ROIs [11]. Volume clipping, however, loses the information that is in the clipped volume, and the selection of an appropriate clipping depth is not intuitive, and time-consuming. These limitations reduce the practicality and usefulness of DVR with medical data.

In this study, we propose a new PET-CT visualisation method where DVR of the CT volume is automatically clipped and embedded onto a user selected SOI from its counterpart PET volume. The clipping depth is adaptively computed by averaging the opacity information of the CT voxels in front of the PET SOI such that it allows only relevant anatomical structures to be visualised while minimising the obstruction of the SOI. Hence, the manual interactions required in generating the clipping depth for PET-CT visualisation are reduced. We compare our method in the visualisation of multi-modality PET-CT volumes in real-time volume rendering (>18 frames per second in high-resolution rendering), to the conventional 2D and conventional DVR-SOI visualisations.

This research was funded in part by ARC grants.

Y. Jung, J. Kim, M. Fulham and D. Feng are with the School of Information Technologies, University of Sydney, Australia. Y. Jung (e-mail: yjun6175@uni.sydney.edu.au), J. Kim (e-mail: Jinman.kim@sydney.edu.au)

M. Fulham is also with the Sydney Medical School, University of Sydney and the Department of Molecular Imaging, Royal Prince Alfred Hospital, Australia (e-mail: Michael.fulham@sydney.edu.au)

D. Feng is also with Med-X Research Institute, Shanghai Jiao Tong University, China (e-mail: david.feng@sydney.edu.au).

978-1-4244-7929-0/14/$26.00 ©2014 IEEE

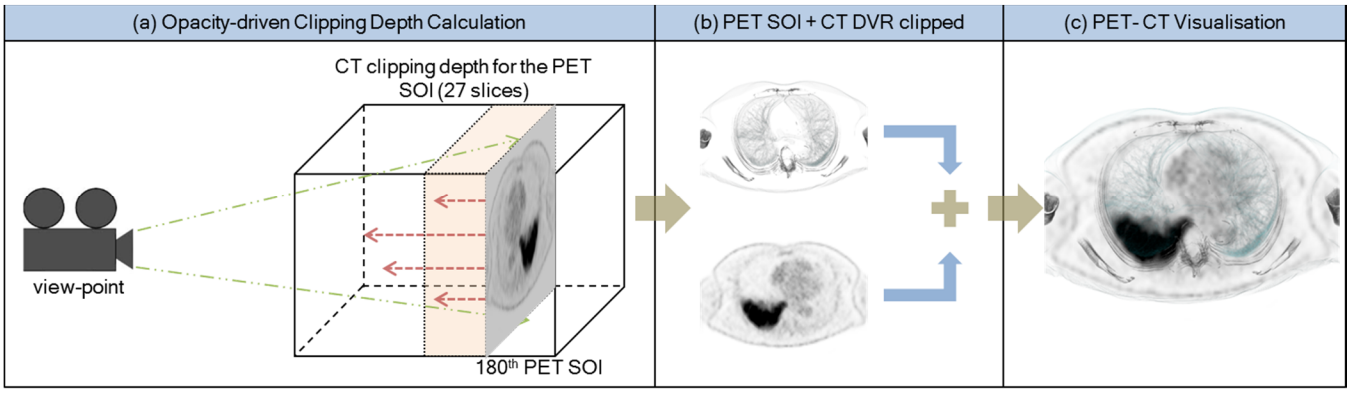

Figure 1. An overview of our PET-CT visualisation method. The DVR image of the CT volume is clipped with the clipping depth of 27 slices, (see light orange cuboid) which is automatically computed using the opacity information of the CT voxels in front of the 180th PET SOI along view-point, prior to it being embedded onto SOI.

II. Materials and Method

A. Opacity-driven Volume Clipping

Figure 1 illustrates our multi-modality PET-CT visualisation method with automated opacity-driven clipping depth computation. As an initial step, a SOI from a PET volume is selected by the user, and the TF of the counterpart CT volume is defined to depict anatomical structures of the CT volume that are relevant to the PET SOI. Any preset TF may be applied; in this example, the TF to highlight lung and the bony skeleton is implemented. We adopted the concept of opacity accumulation of 'volume ray-casting compositing algorithm' [3] so that the clipping depth of the CT volume is calculated depending on the level of its occlusion to the PET SOI. Each pixel from the PET SOI casts a ray to the view-point (see red arrows in (a)), and opacities of the CT voxels along the ray are accumulated according to:

$$a_i = a_{i-1} + (1 - a_{i-1}) * a(s(i)) \qquad (1)$$

where a_{i-1} is the accumulated opacity, $s(i)$ is the intensity value of the i_{th} CT sample voxel along the viewing ray, $a(s(i))$ is the opacity value of the i_{th} sample point, defined by a TF. Once the accumulated opacity reaches a 'threshold', the distance between this location and the volume ray-casting location is computed and considered as the depth of the ray which ensures that the relevant CT information to the PET SOI is visible. Here, we balance the amount of visual information from the PET SOI and the CT DVR to be equal by using the fixed threshold of 0.5. By summing and averaging the individual depth of the j_{th} ray, d_j, the clipping depth of the CT volume, D, is calculated:

$$D = \frac{\sum_{j \in SOI} d_j}{N} \qquad (2)$$

where N is the total number of rays casted from the PET SOI. Note that we do not consider the background, which does not contribute the final rendering, to calculate the accurate clipping depth. The volume rendered CT image is clipped with the derived depth and embedded onto the SOI of the PET by combining them with the same ratio as used in the depth computation. The resultant visualisation in (c) allows displaying its surrounding lung tissues and bony structures in the form of 3D spatial cues while minimising any obstructiveness to viewing the functional information in the SOI.

B. Datasets and pre-processing

PET-CT studies were acquired from a Siemens Biograph TruePoint PET-CT scanner (Siemens Medical Solution, Hoffman Estates, IL, USA) at the Department of Molecular Imaging, Royal Prince Alfred (RPA) Hospital, Sydney, Australia. All studies had 410 slices with slice thickness of 3 mm to cover the body from the top of the head to the upper thighs. PET image slices were reconstructed to 168 x 168 matrix with pixel size of 4.07 mm^2, and CT slices were reconstructed to 512 x 512 matrix at 0.98 mm^2. The hardware co-registered PET was then resampled to the CT dimensions. The CT scans were processed to remove the background and bed/linen via adaptive thresholding and image subtraction from a bed template [12]. The voxel intensity of the CT was in Hounsfield units (HU) with the intensity range of -1000 (air) to about + 2000 (bone/contrast media) which was mapped to 0 to 4095 (12-bits) for rendering. For PET, we applied linear intensity normalization and matched the intensity range of the CT.

C. Implementation

Real-time performance for our visualisation was achieved by using graphical process unit (GPU) optimised volume rendering engine (Voreen) [13]. Voreen is an open source texture based volume rendering library that allows interactive visualisation of volumetric data with high flexibility for integrating new algorithms. Parallel processing, together with programmable vertex fragment streams [14] was used to perform volume ray-casting for the clipping depth and the volume rendering in a single rendering pass. All renderings in this paper were performed on a PC with nVIDIA GTX 590 @1.2G GHz; Intel i7 CPU @3.2 GHz; running 64-bit Windows 7.

III. Results and Discussions

Figure 2 displays renderings from a 2D SOI visualisation of PET volume and a combined conventional DVR of CT volume when compared to our method in a coronal view. In this patient study, a relevant ROI is a high grade tumour in the right lower lobe of the lung (indicated by blue arrow).

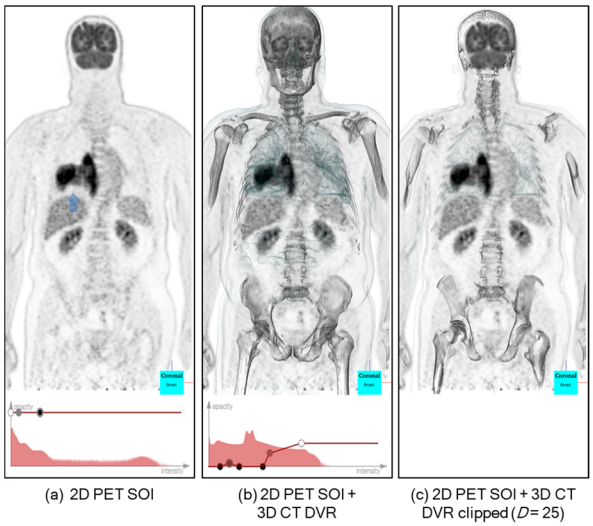

Figure 2. Whole body PET-CT visualisations: (a) is a 2D coronal view of a SOI from a PET volume; (b) is the DVR of the full CT volume embedded on the PET SOI; (c) is the clipped CT DVR with the opacity-driven clipping depth (D = 25). PET and CT volumes are rendered with intensity-based one-dimensional TFs in (a) and (b), in bottom row. The same TFs were also applied in (c).

A PET SOI shown in (a) depicts only the underlying functional abnormalities without the corresponding anatomical detail that is presented in the counterpart co-aligned CT volume. In (b), by combining the DVR of the CT anatomy with the SOI, the resulting rendering provides visual cues to help localise the ROI in the 3D rendering offered by the DVR. In (b), however, the bony skeleton and bowel from the DVR are excessively rendered, resulting in the unnecessary distortion that disturbs the visibility of the ROI. For our method (c), the automatically calculated clipping depth (D = 25) applied to the CT volume removes non-relevant CT occlusions from the skeleton and bowel and thus, enhances the view of the PET SOI together with the relevant anatomy.

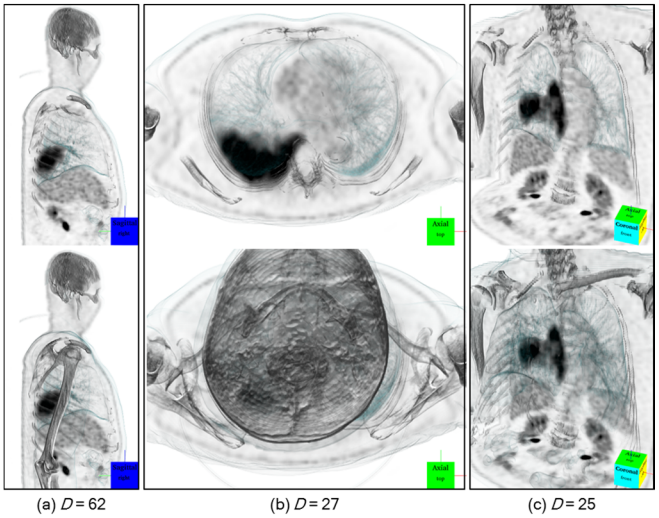

Figure 3. An example of our method (top row) which preserves visibilities for structures that are close to the SOI when compared to embedding the 3D CT DVR onto the 2D PET SOI (bottom row) in a MPR view. Note: the adaptive clipping depth calculated for the different view-points and removal of the non-relevant CT anatomy to the PET SOI.

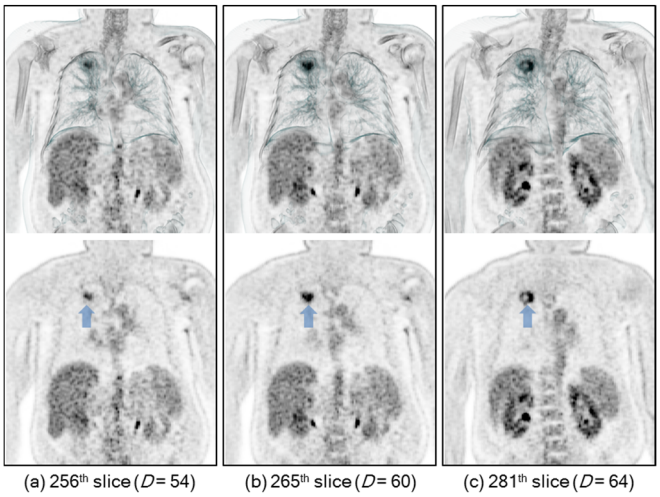

Figure 4. Slice-by-slice volume navigation with our automated clipping depth calculation method (top row) in a coronal SOI view when compared to typical 2D PET visualisation of the same slices (bottom row). Note: the adaptive clipping depth computed for the different slice numbers and additional anatomical depictions relating to the PET SOI.

Figure 3 presents a further example of our automated depth clipping method when compared to embedding the 2D PET SOI with the 3D CT DVR in various viewing angles (MPR). This is the same patient study used for Figure 2. The depth of the volume clipping was automatically calculated according to the different view-points, and the resulting visualisation is able to depict the relevant CT structures for the PET SOI while minimising occlusion to the ROI; the bony skeleton and the lung tissue in (a) and (b), and the bowel and the lung tissue in (c) were cut away from the DVR to allow greater visualisation of the PET SOI while still retaining the important anatomy from the CT.

Figure 4 shows the resulting rendering from a user navigating through 2D slices (SOIs) from a PET volume from posterior to anterior. During the navigation, the amount of CT DVR information is dynamically calculated based on our opacity-driven clipping depth method, thus providing a non-obstructive view of the tumour (indicated by blue arrows) in the PET SOI as it also relates to anatomy.

Figure 5 is a plot of the computational performance evaluation, measured in milli-seconds (msec) for individual processing times for DVR and clipping calculation, and the total computing times. Frames per second (FPS) was also computed for the total computing time. All measures were applied during typical user volume manipulations / navigation, including rotation, panning, and TF controls. Four different rendering window sizes from 128 x 128 to 1024 x 1024 were used for the evaluation. Due to the GPU acceleration technique (parallel computation), even in the high resolution (1024 x 1024) window size, our implementation achieved an interactive rate of > 18 FPS.

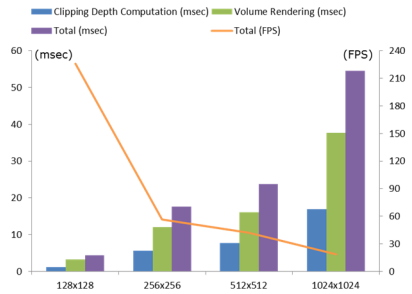

Figure 5. Averaged computation time for individual processes in our rendering algorithm.

IV. Conclusions and Future Works

We presents a new visualisation method that automatically calculates the depth clipping from a CT volume by an estimation of the occlusions from its voxels (structures) residing in front of its counterpart PET SOI. This method reduces the manual interactions that are required to define an appropriate depth. Our results with PET-CT studies demonstrated that our method is able to embed valuable 3D anatomical cues onto the functional PET SOI and at the same time, minimises the occlusion to the SOI. Although only PET-CT images were used in this paper, our visualisation method is not dependent on this specific imaging modality and there are no restrictions to the modalities where it can be applied.

Acknowledgment

We like to thank our collaborators at the Department of Molecular Imaging, Royal Prince Alfred Hospital, Sydney, Australia.

References

[1] M. Hutchings and S.F. Barrington, "PET/CT for therapy response assessment in lymphoma," J. Nucl. Med., 50(1), 21-30, 2009.

[2] A. Rosset et al., "Informatics in radiology (infoRAD): navigating the fifth dimension: innovative interface for multidimensional multimodality image navigation," Radiographics, 26(1), 299-308, 2006.

[3] B. Preim and D. Bartz, "Visualization in medicine: theory, algorithms, and applications," Elsevier, 2007.

[4] J. Kim et al., "Real-time volume rendering visualization of dual-modality PET/CT images with interactive fuzzy thresholding segmentation," IEEE Trans. Inf. Technol. Biomed., 11(2), 161–169 (2007).

[5] G. Kindlmann and J.W. Durkin, "Semi-automatic generation of transfer functions for direct volume rendering," Proc. IEEE Symp. Volume visualization, pp. 79-86, 1998.

[6] C. Correa and K-L. Ma, "Size-based transfer functions: a new volume exploration technique," IEEE Trans. Vis. Comput. Gr., 14(6), 1380-7, 2008.

[7] C. Correa and K-L. Ma, "The occlusion spectrum for volume classification and visualization," IEEE Trans. Vis. Comput. Gr., 15(6), 1465-72, 2009.

[8] J.J. Caban and P. Rheingans, "Texture-based transfer functions for direct volume rendering," IEEE Trans. Vis. Comput. Gr., 14(6), 1364-71, 2008.

[9] J. Kim et al., "Visualizing dual-modality rendered volumes using a dual-lookup table transfer function," Comput.Sci.Eng., 9(1), 20-5, 2007.

[10] Y. Jung et al., "Visibility-driven PET-CT visualisation with region of interest (ROI) segmentation", VISUAL COMPUT., 805-15, 29(6-8), 2013.

[11] C. Wei et al., "Real-time Ray Casting Rendering of Volume Clipping in Medical Visualization," J. Comput. Sci. & Technol., 804-14, 18(6), 2003.

[12] J. Kim et al., "A fully automatic bed/linen segmentation for fused PET/CT MIP rendering," J. Nucl. Med., 49(Suppl 1), 387P, 2008.

[13] Voreen: Volume Rendering Engine, http://www.voreen.org/.

[14] J. Kruger et al., "Acceleration Techniques for GPU-based Volume Rendering," *IEEE* Visualization 2003, 287-92, 2003.