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A Spatial Binning Method for Improving the Quantitative Accuracy of Free-breathing PET/CT Images

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Introduction

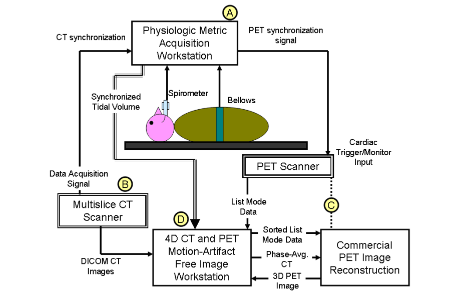
Breathing motion in imaging of the thorax and upper abdomen can yield significant artifacts in the images of tumors and normal organs. Positron Emission Tomography (PET) temporal resolution is approximately the average of several breathing cycles whereas helical Computed Tomography (CT) scan temporal resolution is less than 1 sec (equivalent to snap shot of a breathing cycle). The spatial and temporal misalignments between PET and CT lead to significant discrepancies in the estimated SUV values from corrected lung PET images. A spatial binning method that uses five-dimensional (5-D) breathing model is evaluated for its effectiveness to improve the quantitative accuracy of free-breathing PET/CT images.

Materials and Methods

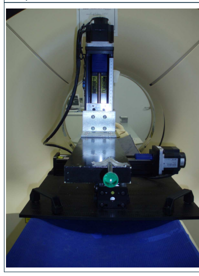
Our group has found that there is a good correlation between air content and tidal volume, due in part to the lack of detectable hysteresis in the air content [1]. As it has been shown, internal lung and tumor motion does exhibit hysteresis. Low, et al. [2], modeled lung motion including hysteresis using the three spatial dimensions, tidal volume and airflow (tidal volume phase space), or a 5-dimensional model. They therefore label CT and PET scans that monitor or use tidal-volume phase space information as "5D" rather than "4D" because the model is based on these five dimensions. This process can provide a prospective volumetric model of breathing motion. The model will be used here retrospectively, first to map the motion using "5D CT" and then to gate the PET data ("5D PET") for subsequent compensation of breathing motion. The breathing motion model developed using the 5D CT procedure will provide the relationship between the target motion and tidal volume phase space.

In this study, the process of subdividing (gating) of PET data throughout the breathing cycle is based on the spatial binning of target trajectory. The target trajectory is subdivided to different spatial bins (gating windows). Based on the relative position of the target, the PET events happened in that bin (window) will be grouped together to generate the corresponding PET image. To subdivide the PET events (list-mode data) as well as synchronization of tidal volume and PET acquisition data, a synchronization trigger was generated by the spirometry acquisition computer and sent to the PET scanner in preselected and uneven time increments using the existing PET cardiac gating software (normally used for cardiac applications) and hardware package. The status of this trigger is recorded as a part of the entire list mode data, to aid synchronization of the list-mode and physiological data. Once a series of spatially-gated PET images are reconstructed, we deformably map the PET voxels from each phase to a reference phase to generate a single image that has better statistics.

Materials and Methods



Proposed image and physiologic data acquisition and synchronization process. The CT (B) and PET scanner (C) components of the PET/CT system are shown separately for clarity. The arrows indicate information flow, while the dashed line connecting the PET scanner to the image reconstruction indicates that the image reconstruction can take place either on the PET scanner computer or offline on a separate commercial workstation.



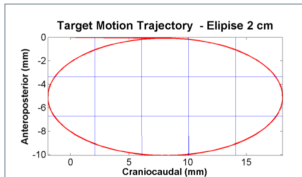
In-house built 4D phantom in a Philips PET/CT scanner. The 4D Phantom is capable of moving a radiological phantom and a respiratory surrogate device through custom trajectories. It can reproduce concurrent, patient-specific internal and external tissue motion.

In this investigation, a 2cm diameter sphere filled with FDG with an activity of 203 μCi per c.c. was used as a target. Three motion trajectories were chosen in this study, the first two were elliptical with amplitudes of 1 cm and 2 cm (mimicking periodic breathing) and the third one was a tumor motion trajectory modeled in a lung cancer patient. The phantoms were moved using an in-house built 4D phantom [3]. These scans were performed on a Philips Gemini TF PET/CT scanner using cardiac trigger mode.

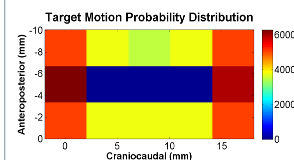
To assess the motion effect on SUV values, a static scan of the target was also performed, giving a total of 4 scans. Each data set was acquired for 10 minutes, including the static scan. To synchronize the PET list mode and the breathing metric acquisition, a synthetic cardiac trigger was generated using a predetermined and uneven time sequence. The PET list mode was interrogated to identify the triggers, and a spatial bin of 5mmx4mmx4mm was chosen which was approximately PET image resolution, to subdivide the list-mode data into the corresponding events when the target was in a spatial bin. These sub-divided list-mode data sets were reconstructed using a commercial reconstruction algorithm and the corresponding spatial-gated PET images were added and shifted according to bin spacing to obtain the gated PET image.

Results

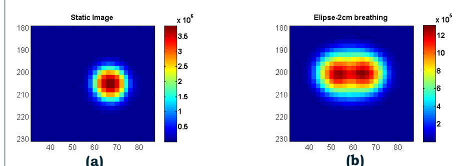
Results from 2 cm diameter spherical PET phantom following a periodic motion trajectory (elliptical with amplitude of 2 cm)

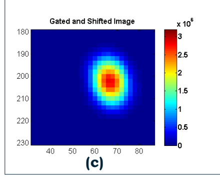


Plot of the trajectory used to move the two centimeter sphere (red line) along with the spatial bins/gating windows used to subdivide the list-mode data (blue lines)



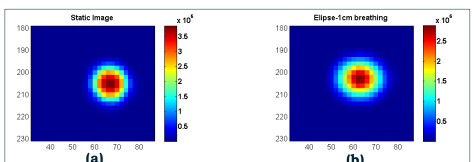
The probability distribution (in 20 ms time units) of the phantom motion distribution.

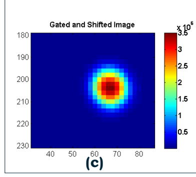




(a) The static image (without motion) of 2-cm spherical target. (b). The image reconstructed using all of the list-mode data (ungated) acquired in the Philips PET/CT scanner. The elongation of the spherical target due to the motion is evident. (c) The shifted and summed PET image showing the recovery of the spherical target shape due to the quantitative nature of the gating and shifting algorithm.

Results from another periodic (elliptical with an amplitude of 1 cm) motion trajectory

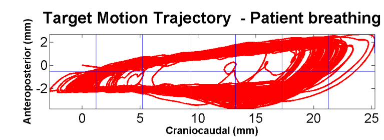


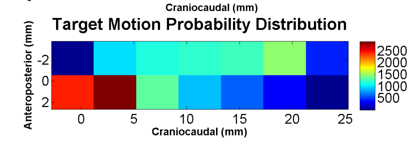


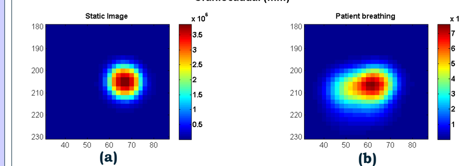
(a) The static image (without motion) of 2-cm spherical target. (b). The image reconstructed using all of the list-mode data (ungated) acquired in the Philips PET/CT scanner. The elongation of the spherical target due to the motion is evident. (c) The shifted and summed PET image showing the recovery of the spherical target shape due to the quantitative nature of the gating and shifting algorithm.

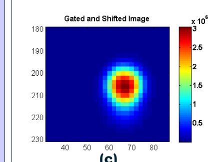
Results

Results from 2 cm diameter spherical PET phantom following a tumor motion trajectory obtained from a lung cancer patient









(a) The static image (without motion) of 2-cm spherical target. (b). The image reconstructed using all of the list-mode data (ungated) acquired in the Philips PET/CT scanner. The elongation of the spherical target due to the motion is evident. (c) The shifted and summed PET image showing the recovery of the spherical target shape due to the quantitative nature of the gating and shifting algorithm.

Conclusions

The ungated images showed the target shape was elongated along the motion trajectory and the standard uptake values (SUV) in the ungated PET images were underestimated by 22%, 65%, and 40% for cases of periodic motion (elliptical trajectories of amplitudes 1 and 2 cm) and patient tumor motion comparison to a static scan (used as a reference SUV). For the periodic motion patterns, as the motion amplitude increased, the ungated PET SUVs decreased linearly with increasing amplitude of motion, for 1 cm and 2 cm amplitude motion the SUVs were 78% and 35% of the reference SUV. The spatial-gated and shifted PET images reconstructed the target shape more accurately and SUVs were recovered within 20% of the expected values. These phantom studies showed the potential of using a spatially-based binning method for improving the quality and quantitation of free-breathing lung-cancer PET/CT images.

References

[1]. W. Lu et. al., Med. Phys. 32, 3295-304 (2005).
[2]. D. Low et. al., IJROBP 63, 921-929 (2005).
[3]. K. Malinowski et. al., Proc. SPIE 6510, 65100E (2007).

Acknowledgements

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