Reduction of respiratory blurring in small-animal CT scans based on a fast retrospective gating method

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Purpose

Computed tomography (CT) has been widely applied in the diagnosis and treatment planning of numerous diseases because of the precise non-invasive morphological information that provides. However, when imaging the thorax and abdomen in in-vivo studies, respiratory motion causes blurring and artifacts in the CT projections and the reconstructed tomographic images.

Different methods have been proposed in the literature to compensate this motion. In prospective techniques, the acquisition is synchronized with the patient breath, obtaining all the projections at the same respiratory phase, which implies the tracking of a respiratory signal in order to generate a trigger. On the other hand, retrospective algorithms do not require any trigger signal during the acquisition. The acquisition protocol obtains multiple frames from every projection angle, each frame corresponding to a different breathing instant, and classifies them according to their phase to allow for separate respiratory phase reconstruction. To assign the different CT projections to the appropriate bin off-line, some authors made use of an external signal obtained during

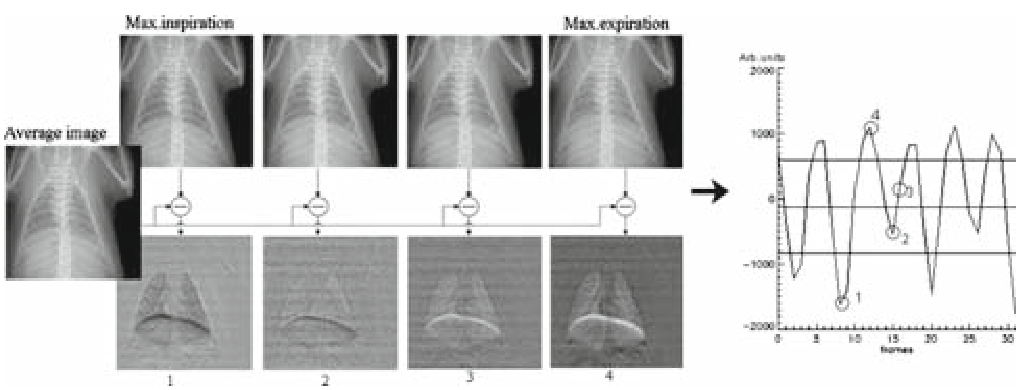

Fig. 1 Moving areas highlighted by subtracting the average image.

Zero value pixels are represented in grey, positive and negative values are brighter and darker, respectively. On the left, four examples of difference images: frame 8 at maximum inspiration, frame 15 and 16 corresponding to mid-stages and frame 12 corresponding to maximum expiration. On the right, the respiratory signal obtained by adding all the pixel values in each image

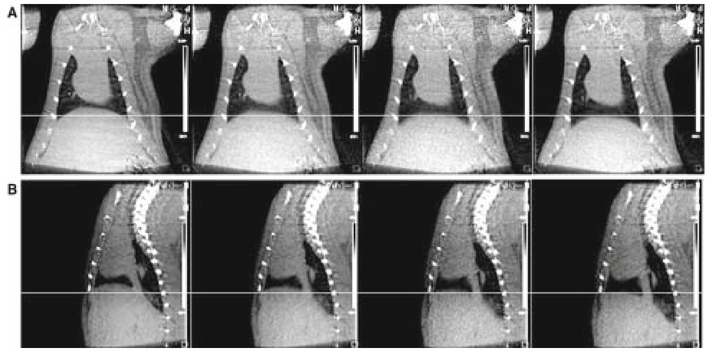

Fig. 2 Dynamic study. Horizontal axis represents time. A) shows coronal slices and B) sagittal ones. The white lines have been drawn over the slices as a spatial reference

the acquisition, whereas others preferred to extract the gating reference directly from the projections by means of image processing techniques. Extensive research has been conducted to automatically extract the signal from the projection images.

Both prospective and retrospective gating techniques have been applied to image small animals with dedicated CT scanners. Although it is also possible to mechanically ventilate the animals for a freebreathing triggered acquisition or an apnea-inducted one, the acquisition process becomes more cumbersome as special intubation techniques and animal breathing training are required for atelectasis avoidance.

The purpose of the present work was to develop a fast retrospective method to extract the respiratory signal from the CT projections in cone beam geometry and to obtain dynamic breathing studies in small animal scans. The whole process had to be software-based and automatic, avoiding the use of any additional respiratory gating instruments.

Materials and methods

In cone-beam micro-CT scanners equipped with flat panel detectors, the rotating gantry, to which the source and detector are attached, keeps still while multiple frames are acquired for each projection.

Then it rotates to obtain the remaining sets of frames until completing the desired number of angular positions. From every set of frames acquired at a particular angle we obtain the average image, which is subtracted from each individual frame, obtaining a set of difference images. These difference images contain pixels with almost zero values (gray) in the static areas and positive (white) or negative (black) values in the moving areas according to the respiratory phase. By calculating the total intensity of these difference images we obtain a curve that closely follows the desired respiratory signal (Fig. 1).

To generate a dynamic study we divided the amplitude of the breathing cycle into four different bins, each corresponding to a different respiratory phase. Averaging the frames of each bin resulted in a set of 4 representative projections per angle. Afterwards, we reconstructed each bin independently, obtaining a final dynamic study of the subject composed of 4 image volumes, one at end expiration, another at end inspiration, and two intermediate phases.

The scanner used was the CT subsystem of an eXplore PET/CT system (General Electric Healthcare), with cone-beam geometry.

Acquisition was based on a 1_ step-and-shoot protocol covering 360_, with multi-frame setup to obtain 32 frames per gantry position at a speed of 8 frames/second. All of the acquisitions were obtained at pixel binning 4 and the resulting image size was 512 x 512 pixels.

Finally, 3D reconstruction was performed following a Feldkamp algorithm. The studied specimens were 5 randomly chosen adult Wistar rats of 10 weeks and 300 grams of weight in average. Three of them were anesthetized with an intra-peritoneal injection of ketamine and the other two with inhaled isofluorane to ensure the robustness of our method regarding anesthesia effects.

To validate our 4D-CT retrospective gating protocol we measured the sharpness of the diaphragm-lung transition in the reconstructed non-gated volume and in the image volume corresponding to bin 1 (end-expiration). We calculated the slope of 5 adjacent vertical profiles taken at the diaphragm dome in coronal slices from 10% to 90% height. The five slope measurements were averaged and the result was compared to the respective dome slope obtained in the non-gated image.

Results

After assembling the resulting 4 volumes into a temporal sequence it is possible to distinguish the different positions of the diaphragm in each of the four cycle phases. Coronal and sagittal views are shown in Figure 2, with a white line drawn as a spatial reference through the different phases.

We quantified the blurring reduction achieved in the 5 studies by measuring the improvement in slope on vertical profiles drawn across the diaphragm dome as described in II, obtaining an average slope improvement of 54.8%.

Conclusion

In summary, we have successfully developed an automatic and fast respiratory gating technique from a retrospective approach to provide both dynamic studies throughout the respiratory cycle and image blurring reduction, demonstrated by the quality of the diaphragm-lung transition. Moreover, direct extraction of the respiratory signal from the cone-beam projections entails an important advantage over the use of external devices, since it not only avoids implementing the extra instrumentation, but it also makes the acquisition process much simpler and averts skin contact artifacts.