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Abstract

TITLE:
Respiratory signal extraction for 4D CT imaging of the thorax from cone-beam CT projections

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ABSTRACT BODY:

Purpose/Objective: The purpose of this study was the four-dimensional (4D) imaging of a free-breathing thorax with the Elekta Synergy cone-beam (CB) for 4D radiotherapy. The first step consisted in facing the slowness of the acquisition by restrospectively sorting CB projections with a respiratory signal. We propose to extract the respiratory signal directly from thorax CBCT projections instead of using an external device (spirometer, infrared camera,...). We firstly simulated a set of CBCT images with a 4D CT model for the development and the validation of the method. From the simulation output, we secondly extracted, selected and integrated motion information to obtain the respiratory signal.

Materials/Methods: Cone-beam simulation Our simulation follows a temporal respiratory signal; at each instant *t*, the respiratory signal gives the position *f(t)* in the respiratory cycle and the 4D model gives the corresponding 3D volume. The 4D model had been obtained in a previous study by non-rigid registration between two 3D CT breath-hold images (at end-inhale and end-exhale). Digitally Reconstructed Radiographs (DRR) of the volume, i.e. CBCT projections, are then computed using a home made shearwarp algorithm.

Respiratory signal extraction The method includes three sequential parts:

- selection of points of interest, constituting a sub-sampling of pixels of CB projections (between 100000 and 200000 points in total);
- motion extraction using a block matching algorithm;
- processing of extracted 2D+t trajectories: projection in 1D+t signals and frequency filtering; selection based on the highest component in the Fourier domain; integration over the time of acquisition.

Results: We extracted from CB images a respiratory signal with 96.4% linear correlation with the reference signal. We sorted both the respiratory signal extracted from CB images (result bins) and the gold standard (reference bins), then measured the percentage of misplaced samples in the result bins compared to the reference ones. We also calculated *s*, the average of σ, the respiratory signal standard deviations from reference values in each bin, for both reference and result bins, and their ratio s_{ref} / s_{res}. The smaller *s* is, the more data in each bin were in phase with the respiratory cycle.

Conclusions: Our method extracted a signal strongly correlated to the reference. Trajectories were automatically selected in the lower part of the lungs, both around the lung walls and the diaphragmatic cupola; the direction of the trajectories is mostly cranio-caudal for the cupola and perpendicular to the walls elsewhere. Sorting the signal pointed out the decrease of s_{res} with the increase of the number of bins, which means that acquired data were more in phase in each bin; reported to a single bin (no sorting), this decrease was particularly significant and we expect 4D images much less blurred than 3D images. Meanwhile, when we increased too much the number of bins (from 8 to 10 bins for example), s_{res} decreased slightly, particularly when compared to the reference. Depending of the accuracy of the respiratory signal and the total number of projections, we will adjust the number of bins by a trade-off between the quantity of data and their phase in each bin. 3D images will be reconstructed in each bin to obtain the 4D image.

Number of bins	Misplaced samples	s_{ref}	s_{res}	s_{ref}/s_{res}
1	0	0.258	0.258	1
2	27 (4%)	0.125	0.127	0.98

5	123 (17%)	0.050	0.064	0.78
8	226 (31%)	0.033	0.053	0.62
10	268 (37%)	0.024	0.050	0.48

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