Fully Automatic Intrinsic Respiratory and Cardiac Gating of Cone-Beam CT Scans of the Thorax Region

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Introduction

Cone-beam CTs (CBCTs) are widely used in image-guided radiation therapy. With their limited acquisition times of about 30 s for one rotation, the reconstructed volume shows motion blurring caused by respiration and cardiac motion. Accurate information of the motion phase for each projection is required if one wants to correct these artifacts. If no external signal is recorded e.g. using a respiratory belt or an ECG, a surrogate signal has to be extracted from the raw data. While several methods are able to retrieve a respiratory surrogate, there are only two methods for the cardiac surrogate for CBCT scans. While the first one requires multiple rotations and was developed for small animals, the second one showed promising results for a patient [1] and will be called M1 in the following. In this work we present a method M2 that overcomes an issue that can occur with M1 and is therefore more robust.

Materials and Methods

The goal of the proposed method is a fully automatic extraction of the cardiac and the respiratory signal in CBCT scans of the thorax region. It consists of a preprocession step, where a static background is subtracted from the raw data, and a signal acquisition step, in which a motion surrogate is acquired by tracking the ventricular wall in the raw data.

Preprocession

Since the method aims to identify regions in the raw data that show respiratory/cardiac motion, everything that is not subjected to motion is subtracted in the following way. A standard 3D FDK reconstruction X^{-1} gives a blurred volume due to the motion. Its forward projection X does, however, not give blurred raw data but still contains the motion due to the fact that X and X^{-1} are inverse operations. We break this relation by introducing a median filter M in the volume before forward projection. The new raw data p_{stat} show an average motion state. By subtracting them from the original rawdata, only regions that are subjected to motion remain, i.e. large dark or bright areas around the diaphragm depending on the respiratory state and small dark or bright areas at the ventricular wall depending on the heart phase. All further steps are carried out on these dynamic rawdata q_{dyn} (Fig. 1).

Signal Generation

Grid points are distributed regularly in the volume (Fig. 2). The goal is to identify a grid point that is at a place that is best suited to obtain a surrogate signal. In M1, all grid points are forward projected and tracked in the rawdata (Fig. 3). In an ROI around the projection of the grid point, the average gray value is calculated for every projection. A bandpass filter in the range of 10-30 rpm and 50-120 bpm is applied depending if one wants to get the respiratory or cardiac surrogate, respectively. Peaks are determined automatically and the signal is converted to a saw-tooth phase signal. While this works well for the respiratory signal, it can result in problems with the cardiac signal. If a grid point at the ventricular wall is identified and if it is also located at the ventricular wall in one projection, it can be in the middle of the heart a few projections later. In order to avoid this issue, each point represents the center of a circle with a fixed radius r and the tangential rays are tracked in the rawdata. To find the best radius, we interate over radii between 3 cm and 5 cm in steps of 2 mm. The grid point resulting in the most regular peaks is chosen as the final signal.

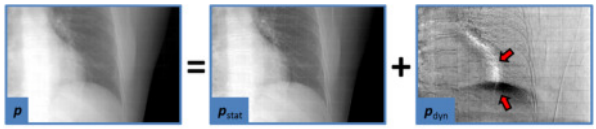

Figure 1: The original raw data are separated into a static and a dynamic part.

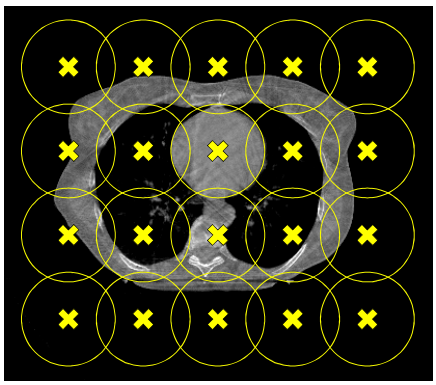

Figure 2: Grid points are spread regularly over the volume. For the cardiac signal acquisition, each grid point represents the center of a circle in an axial plane.

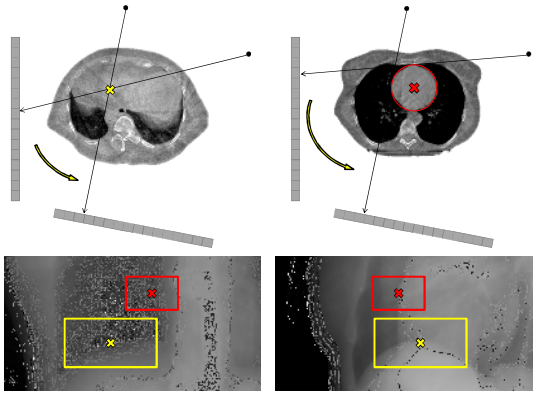

Figure 3: Grid points (left top) or the tangent of the circle around a grid point (right top) to acquire the respiratory or the cardiac signal, respectively. Around the projected centers rectangular ROIs are placed (bottom).

Patient	N_{GT}	N_{M1}	N_{M2}	ΔN_{M1}	ΔN_{M2}
1	80	81	80	1	0
2	65	85	65	20	0
3	70	70	70	0	0
4	78	81	78	3	0
5	78	101	78	23	0
6	86	89	85	3	-1
7	74	74	74	0	0

Table 1: Results cardiac gating. N_{GT} indicates the true number of heart beats during one rotation. N_{M1} and N_{M2} are the number of heart beats determined using M1 and the proposed algorithm M2, respectively. ΔN_{M1} and ΔN_{M2} are the differences to the ground truth. M2 outperformed M1 for all but two patients.

Patient Data

The algorithms were tested on 7 patient scans of the thorax region acquired with a Varian True Beam scanner in shifted detector mode (11 fps, 660 projections, 60 s). The patients had between 11 and 26 rpm and between 65 and86 bpm. As a ground truth for the respiratory phase, the signal from the Varian real-time position management (RPM) system was available for 2 patients. For the other patients, the points of max inhale were determined manually from the projections. For respiratory gating 10×10×10 grid points are used. The ROI size is set to [300 px, 300 px]=[116.4 mm, 116.4 mm]. Since no ECG was available for all patients, the number of heart beats was determined by carefully inspecting the projections manually. For the cardiac surrogate 50×50×50 grid points are distributed in the volume. The ROI size was set to [200 px, 100 px]=[77.6 mm, 38.8 mm]. The number of grid points and ROI sizes are empiric values.

Results

M2 and M1 were able to determine the correct number of heart beats for all projections. M2 significantly outperformed M1 in case of cardiac gating (Table 1).

Acknowledgements

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[1] A. Hahn, S. Sauppe, and M. Kachelrieß, „Automatic intrinsic cardiac and respiratory gating from cone-beam CT scans of the thorax region.“, *SPIE Medical Imaging Proc.*, pp 97 830S-97 830S, 2016