A MORPHING TECHNIQUE TO ESTIMATE LUNG CANCER DEFORMATION DUE TO BREATHING IN RADIOTHERAPIC TREATMENT

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Keywords: Medical Image Detection, Acquisition, Analysis and Processing.

Abstract: A morphing technique aimed to correlate lung cancer patient's chest cross circumference variations with tumor morphology during quiet respiration is here described. Two CT slices corresponding to the same tumor section are acquired at forced inspiration and forced expiration and correlated with chest circumference values. An image sequence has been obtained by applying a linear morphing transformation. Each image of the sequence has been associated with a chest circumferential value and a sequence subset images corresponding to subject's tidal volume has then been selected and compared with a CT slice acquired at tidal volume. Images showing the minimum pixel differences with slice at tidal volume were identified and associated with chest circumference values, allowing to estimate in which phase of the breathing period the CT scan was carried out. CT exams in free-breathing and breath-hold conditions have been conducted on a lung cancer patient in order to correlate the acquired slices with the variations of patient's chest circumference measured with a pneumatic strain gauge. The here described methodology could allow to define the area to be irradiated during a particular phase of the breathing period, considering the cancer area in the morphing simulation frame corresponding to this phase as target.

1 INTRODUCTION

Tumour motion due to respiration is an important key issue for the development of accurate radiation treatment of neoplasms located in lungs and abdominal sites since, as it is well known, the movement and deformation of tumors during the breathing cycle affect not only the accuracy of CT imaging but also the possibility of a successful focused radiation treatment (Webb, 2006). Thus, organ deformation during radiation delivery is a geometric uncertainty that must be taken into account in order to improve the quality and the accuracy of radiotherapic treatment. The traditional approach, according to ICRU (International Commission on Radiation Units and Measurements) Report 50 (ICRU Report 50, 1993), considers safety margins around Gross Tumour Volume (GTV) defined from a free-breathing CT scan: this method estimates the extent of setup uncertainty and organ motion and adds margins around a Clinical Tumour Volume (CTV) to form a Planning Target Volume (PTV). Several studies of the internal motion of the tumour have been conducted based on the hypothesis of rigid motion (Lujian et al, 1999, Wu et al, 2004, Report 91 del AAPM Task Group 76, 2006) and different models of organ motion due to respiration interpolating experimental data have been proposed; moreover, it was observed that abdominal organs motion due to respiration is well correlated with diaphragm motion and it is predominant in the craniocaudal direction. Some authors (Lujian et al, 1999) have evaluated dose delivered to the moving organ undergoing radiation treatment as a function of the dose value predicted in static case, considering an unidirectional movement of the organ.The aim of focusing the dose within the

Maria Pia Masselli G., Battista L., Silvestri S., Ramella S. and Trodella L. (2010).
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In *Proceedings of the Third International Conference on Bio-inspired Systems and Signal Processing*, pages 363-366
DOI: 10.5220/0002591203630366

region of interest minimizing the irradiation of surrounding tissues, can be accomplished with various methods such as, among others: 1) continuous tracking systems, that allow the irradiation of tumors while patient is breathing normally –still in a research phase– (Murphy, 2007) ; 2) breath-hold techniques (Mageras and Yorke, 2004); 3) respiratory gated radiotherapy (Keall et al, 2006). Visual biofeedback techniques have also been developed in order to reduce respiratory amplitude (Masselli et al, 2009) and enhance respiration reproducibility (Masselli et al, 2009, George et al, 2006) and, in a preliminary way, for predicting organ motion due to respiration during radiation treatment (Briere et al, 2006, Venkat et al, 2008). Recently, "morphing" techniques have been used in a radiotherapy scenario (Deurloo et al, 2005), in order to develop a method for the quantification of tumor form variations in complex organs with respect to the mean GTV obtained from elaboration of CT slices acquired during free-breathing.

"Morphing" stands for "metamorphosing" and indicates one of the first special digital effects used in motion pictures and animations that allows to transform a source image into a target image through a seamless, fluid and gradual transition (Gomes et al, 1999). A morphing technique aimed to estimate lung tumor deformation due to a lung cancer patient's breathing, in order to correlate patient's chest circumference variations with tumor morphology is here proposed. The methodology allows to define the area to be irradiated during a particular phase of the breathing period, considering the cancer area in the morphing simulation frame corresponding to this phase as target.

2 METHODOLOGY DESCRIPTION

A morphologic transformation is here used for creating transitions between two morphological configurations. Beyond the acquisition of a 2D CT slice during patient freely breathing at tidal volume (CT_{TV}), in which lung tumour border line has motion shadings because of breathing, CT images have been acquired in breath-hold condition, i.e. forced inspiration and forced expiration in order to obtain static images of the lung tumour. These two slices, approximately corresponding to the same tumour section and referred to the two different tumour configurations, called CT_{MaxExp} and $CT_{MaxInsp}$ in the following, have been considered as the source image and the target image for morphing sequence.

A pneumatic strain gauge (PSG) (Masselli et al, 2009) has been used in order to measure the variations of patient's chest cross section circumference ΔC during the above reported CT exams carried out in breath-hold and free-breathing conditions. Values ΔC_{MaxExp} and $\Delta C_{MaxInsp}$ have been measured in breath-hold conditions. During quiet respiration the $\Delta C(t)$ has been measured, according to patient's respiratory pattern, obtaining an interval of ΔC values comprised between ΔC_{TVmin} and ΔC_{TVmax}, which are the tidal volume chest circumference at quiet expiration and inspiration end respectively. The images $CT_{MaxInsp}$ and CT_{MaxExp} have been loaded on a 2D morphing program (http://www.stoik.com/) in order to generate a simulation of the lung tumour deformation from forced expiration to forced inspiration. After control point allocation, the number of frames of the morphing simulation has been set. Thus, the program allowed to transform the markers on source image in markers on target image. Marker movement was regulated by a distortion curve: we have considered a linear transformation. The quality of simulation depends on the number and position of chosen markers. In order to correlate ΔC values with lung tumour morphology, the correspondence between the number of each frame of morphing simulation and ΔC values has been found considering a n+2 frames sequence, where n is the number of simulation frames generated by the program and 2 are the source image $CT_{MaxInsp}$ (frame 0) and the target image CT_{MaxExp} (frame n+1) of the morphing transformation, that in turn refer to ΔC_{MaxExp} and $\Delta C_{MaxInsp}$ measured values.The interval between ΔC_{MaxExp} and $\Delta C_{MaxInsp}$ has been divided in n+1 intervals having the same amplitude, in order to associate a set of ΔC values with the corresponding frame of morphing sequence. Thus, it has been possible to calculate $\Delta C_{MaxInsp}$ with the following equation:

$$\Delta C_{MaxInsp} = \Delta C_{n+1} = \Delta C_{MaxExp} + (n+1) \cdot u \quad (1)$$

and, similarly, a generic value of chest circumference ΔC_m corresponding to the frame m of morphing sequence:

$$\Delta C_m = \Delta C_{MaxExp} + m \cdot u \quad (2)$$

It has been possible to associate the number of each frame of morphing sequence with ΔC values measured during CT scans. The sequence was between the minimal and the maximal tumour extension, so there were some frames of morphing

sequence describing lung tumour deformation during free-breathing: by substituting the corresponding set of ΔC values measured during CT exam in equation (2), it has been possible to individuate the interval of consecutive frames which described tumor motion and deformation during tidal volume respiration.

Among these frames, there was the "best frame", which was the most similar to the tumour configuration described by free-breathing CT slice (CT_{TV}) related to the same tumour section as CT slices used for morphing simulation. This frame has been found through the calculation of mean grey levels of the difference image between each simulation frame and the slice CT_{TV} related to the tumour configuration during free-breathing acquisition: the frame whose difference image had the smaller mean grey levels has been the most similar to CT_{TV}. By Eq. (2), ΔC value corresponding to this best frame was calculated and compared with the interval of ΔC_{TV} values: in this way it was possible to know in which phase of the breathing period CT exam at tidal volume was carried out and to define the target volume to be irradiated corresponding to this phase.

3 RESULTS AND DISCUSSION

CT scans during free-breathing and in breath-hold conditions have been conducted on a lung cancer patient undergoing radiotherapic treatment. During CT exams, patient's chest circumference variations have been measured with the PSG, obtaining ΔC_{TVmin}=0 mm at the end of quiet expiration and ΔC_{TVmax}=10 mm at the end of quiet inspiration on average. $\Delta C_{MaxInsp}$=14 mm and ΔC_{MaxExp}=-5 mm during maximal inspiration and expiration, respectively. We have considered ΔC_{TVmin} as zero-reference for ΔC measurements. Slices CT_{MaxExp} and $CT_{MaxInsp}$ acquired during CT carried out in forced expiration and in forced inspiration respectively, were associated with the measured ΔC_{MaxExp} and $\Delta C_{MaxInsp}$ values and have been loaded on the morphing program for creating the interpolation sequence. 56 markers have been placed on the border line of the tumour (Fig. 1), a frame number equal to 100 and a linear transformation have been chosen for morphing sequence generation. By substituting the above reported measured ΔC_{TVmin} and ΔC_{TVmax} in equation (2), the numbers of the simulation frames corresponding to tumor configuration during tidal volume breathing have been calculated. Thus, the frames between 25 and 78 of the morphing simulation represented the minimal and the maximal tumor extension during free-breathing (Fig. 2). In order to verify the accuracy of the method, the differences between simulation frames and the image CT_{TV} acquired during free-breathing, after converting this slice from DICOM format in 8 bit bitmap format with 256 grey levels were calculated. In table 1 the numbers of simulation frames, along with the corresponding mean grey levels of the difference image are reported. From an exam of table 1, it emerges that the frames more similar to CT slice acquired during free breathing are frames 25-60, because the corresponding difference images have the smaller means of grey levels. ΔC values corresponding to these frames and calculated by equation (2) were equal to 0-7 mm. By comparing these values with the ΔC_{TV} values measured in the CT exam carried out during quiet respiration, it emerges that the slice CT_{TV} was acquired approximately at the end of expiration/beginning of inspiration, excluding the inspiratory peak. Thus, in order to define the area to be irradiated during each phase of tidal volume respiration, the frames corresponding to the ΔC interval between ΔC_{TVmin} and ΔC_{TVmax} have to be considered. Target tumor can be delimited on these frames, adding only a set up margin as safety margin, since it allows for the uncertainties on treatment reproducibility.

Figure 1: Markers placement on source image (forced expiration) and on target image (forced inspiration).

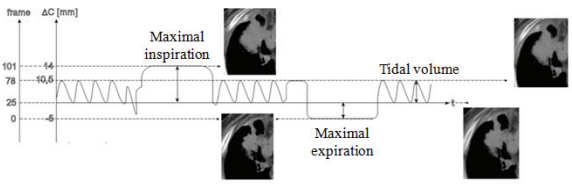

Figure 2: Correspondence between simulation frames and ΔC values.

Table 1: Results of comparison between simulation frames and CT slice acquired during free breathing.

Frame number	Mean of grey levels
0-5	17
10-20	16
25-60	15
65-70	16
75-80	17
85-90	18
95-101	19

4 CONCLUSIONS

The here proposed technique allows to estimate the lung tumor morphology during patient's free-breathing by acquiring CT slice at forced expiration and forced inspiration. The technique could give an important contribution for the improvement of radiation treatment planning, always considering the set up margin, which allows for the uncertainties on treatment reproducibility. In order to define the area to be irradiated during a particular phase of the breathing period, the cancer area in the simulation frame corresponding to this phase has to be considered as target: this allows the absence of motion shadings. The present work represents only a first stage study which could allow to deliver a high dose to the tumour while minimizing the dose delivered to the surrounding healthy tissue, though further researches with more subjects are still needed in order to test the accuracy of the presented methodology.

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