3D image reconstruction for real-time monitoring and tumor tracking in radiotherapy through optical flow and principal components analysis

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During lung cancer treatment with radiotherapy, only 2D chest images can be provided in real time using conventional techniques. Using optical flow and principal components analysis, 3D chest images can be reconstructed fast and accurately from limited information, which is a step forward in monitoring and automatic tumor tracking.

Keywords : Lung cancer, Optical flow, Principal Components Analysis, Radiotherapy

1. Introduction

During the treatment of lung cancer with radiotherapy, positioning the X-ray beam correctly to minimize damage to healthy tissues is difficult because of the tumor motion due to breathing. The Elekta Synergy therapy machine in the University of Tokyo Hospital can only provide kV images from the diagnostic beam and MV images from the treatment beam (Fig. 1). However, these images do not have high quality and the MV image is small due to the obstruction of the ray by the multileaf-collimetor. Moreover, they are obtained by « projection », that is to say, the beam crosses human tissue in only one direction, which makes anatomic structures depth estimation difficult. Last but not least, the arms of the machine are rotating around the body during the treatment, in other words, the camera angle is constantly moving. However, monitoring the beam delivery during the treatment is necessary to ensure that the tumor is correctly targeted. Indeed, the X-ray beam delivery should be stopped if the breathing becomes suddenly irregular, for instance in the case of coughing. In this work, we present a method to provide 3D images from limited information, that is to say, an initial 3D image and the trajectory of a few points (which can be obtained using markers or computationally by optical flow).

2. Materials and Method

$$\vec{T}(\vec{x})=\sum_{i=1}^{m} a_i(\vec{x})\vec{T}_i \quad (1)$$

The algorithm described below is applied on the tumor region of $n = 10$ 4D-CBCT (cone beam computed tomography) images of a patient's moving chest with lung cancer, corresponding to different breathing phases, acquired by the Elekta Synergy therapy machine in The University of Tokyo Hospital. First, we calculate the optical flow between two successive images of the sequence, using the Lukas-Kanade technique [1]. Given a pixel $\vec{x}_0$ in the initial image, we can thus define the *3(n-1)* dimensional vector $\vec{T}(\vec{x}_0)$, containing the 3D position of the points in the trajectory of constant intensity originating from $\vec{x}_0$. We then use PCA [2] to decompose the trajectory of each initial pixel of the first image into a weighted sum of a few principal trajectories, according to Eq. (1). PCA is performed twice, the first time for calculating the coefficients a_i from the trajectories of all the pixels, and the second time to compute the principal trajectories $\vec{T}_i$ only from $m = 3$ arbitrary initial pixels. Images are reconstructed using only the latter principal trajectories $\vec{T}_i$, the pixel weights a_i, and the first image of the sequence, by forward-warping the recovered optical flow.

3. Results and Discussion

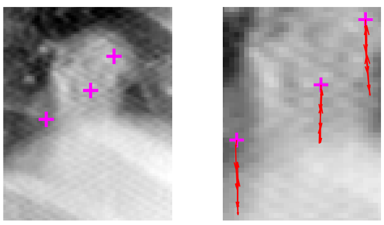
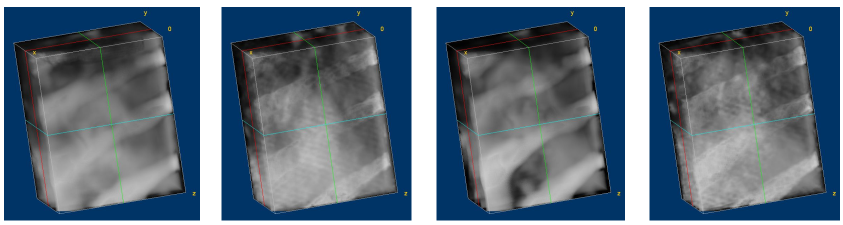


Fig. 1. Selection of three initial points around the tumor (left) and their trajectories $T(x_1)$, $T(x_2)$, $T(x_5)$



Reconsctructed t = 7 | Original t = 7 | Reconsctructed t = 10 | Original t = 10

Fig. 2 Comparison between initial images and images reconstructed using the 3 trajectories in Fig. 1.

The position of the tumor is quite similar to its position in the original images, and the original images are less noisy but more blurred. The high cross-correlation between the initial and reconstructed images binarized by Otsu's method, equal to 0.877 ± 0.029 indicates also a good similarity between the two sets of images. The reconstruction time with Matlab takes 16.00s on a computer with Intel Core i3 3.7 GHz with 12 Gb RAM.

3. Summary

We presented an algorithm which enables to reconstruct 3D images of a lung tumor in a breathing sequence using only limited information, that is to say, the first image of the sequence, the trajectories of a few points, obtained through optical flow, and information about statistical dependencies between the motion of each point, obtained through PCA.

References

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