Optical flow and principal components analysis combination for tumor motion analysis during X-ray radiotherapy

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During lung cancer treatment 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 combination of optical flow and Principal Components Analysis (PCA) on a clinical video enables to decompose the motion of the patient's lungs into main trajectories, which can be used to reconstruct the initial image sequence.

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

1. Introduction

Tracking a tumor located in the lung during radiation therapy using kilovolt (kV) fluoroscopic imaging is a challenge due to the motion caused by breathing. First, the present-day implemented markerless techniques enable to follow the general movement of the target, but they do not take into account its shape deformation. Secondly, the X-ray beam delivery should be stopped if the breathing becomes suddenly irregular. In both cases, the time lag of the treatment machine, of about 100ms, between the image acquisition and the beam delivery should be compensated. Indeed, during this time the tumor may move significantly, which leads to uncertainty in the knowledge of its position. We present here a method for analyzing the tumor motion by combining optical flow and PCA, which will be useful for visualizing the tumor in real-time and compensate the time delay of the treatment machine.

2. Materials and Method

The algorithm described below is used with $n = 10$ 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 $2(n-1)$ dimensional vector $\vec{T}(\vec{x}_0)$, containing the 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 a few 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. To recover the intensity of pixels with integer coordinates, an interpolation method which involves averaging intensities of pixels in the same neighborhood is used.

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

3. Results and Discussion

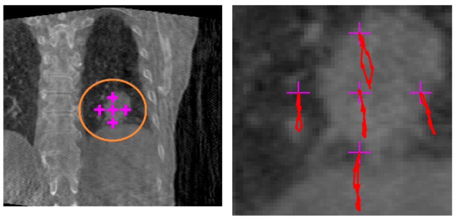

Fig. 1 Selection of 5 points $x_1, \ldots, x_5$ in the initial image (left) and display of their trajectories $T(x_1), \ldots, T(x_5)$ based on optical flow (right)

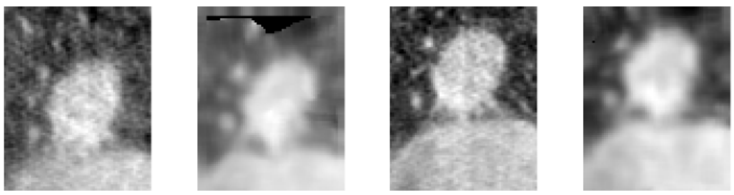

Fig. 2 Comparison between initial images and images reconstructed by computing the main trajectories from 9 pixels only

The trajectories of the selected pixels in Fig. 1 illustrate the up and down motion of the tumor. Fig. 2. shows part of the result of the reconstruction process, by comparing the original and the reconstructed images at different arbitrary times. The position of the tumor in the reconstructed images is quite similar to its position in the original images. The reconstructed images are less noisy but more blurred. Also, some pixels (black spots) are not calculated because of the basic interpolation method used.

3. Summary

We presented a new algorithm, consisting in the combination of optical flow and PCA, which successfully analyses the general up-and-down motion of the lung tumor, and we achieved fast reconstruction of the image sequence through calculation of the trajectories from a few initial pixels, which is a step towards real-time visualization during treatment.

References

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