Automatic Registration of Lung Nodules on 4D Dynamic Contrast Enhanced MR Images

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Introduction

Dynamic contrast enhanced MRI may prove to be a useful non-invasive method for assessing lung cancer. However, assessment of contrast enhancement is hindered by respiratory motion that limits analysis and interpretation. For example, in our current study, each examination yields at least 60 serial sets of 3D images containing a lung tumor(s), which makes manual registration prohibitively labor-intensive. Therefore, our purpose was to develop an automatic registration method for dynamic contrast-enhanced 3D ("4D") MR imaging of pulmonary nodules.

Methods

Dynamic contrast enhanced images were acquired on a Siemens Tim Trio 3T MR scanner. In-plane resolution is 2.34mm by 2.34mm. Slice thickness is 3mm. Time resolution was one second during the first 45 seconds except for breathing time interval; after 90 seconds, a larger time interval of 60seconds was used. Patients with known cancer were studied. Informed consent was obtained before each study.

Given a user prepared cropped volume of the MR lung data, registration algorithms run as a fully automated approach. A 3D anisotropic diffusion filter was next applied on each 3D volume over time to suppress noises in an anisotropic and edge preserving fashion. A level-set method [1] was then used to generate features which were used for registration. Since nodules prior to contrast administration are not easily distinguished from background lung tissue, it is difficult to segment them without assistance. The pre-segmentation method used in our current work does not need manual seed inputs or manual threshold values to initiate. A 4D phase-correlation based registration method was developed to correct translations from in-plane and out-of-plane motion. Because translation only appears in the phase domain on imaging k-space, a correlation coefficient peak value corresponds to a distinct translation vector. Therefore, a 3D translational motion was recovered easily by calculating phase-correlation between two different 3D volumes over time [2]. Two schemes were applied to 4D perfusion lung data: (1) Targeted 3D image fixed and (2) where the targeted 3D image was the previous time volume (t and t-1 are pairs). Optimal translational vectors were then selected from these two schemes at each time point. Therefore, each 3D volume was co-registered through this automatic framework. The computation time for processing a typical 4D data set (60 serial 3D images) including anisotropic diffusion, level-set segmentation, and registration was about 5min, 2min, and 2min, respectively.

Results

An oblique MR section through a right lower lobe tumor obtained 35 s after contrast enhancement is shown in Fig. 1. A 3D visualization of the original image (Fig. 1, center) and a binary mask used as features for registration (Fig. 1, right) are shown. Two regions of interest (ROI) are selected in the outer area of a tumor and the center area of the tumor. As shown in Fig. 2, before registration, signal intensity vs. time courses over a time index (image numbers) are very bumpy and true enhanced features across time could not be appreciated. However, after automatic registration, the motion has been significantly reduced. ROI 1 (Fig. 2) shows an enhancement around 20 seconds, while for ROI 2, which is in the center of the tumor, there is no enhancement at all because it is composed of necrotic cancer cells. In Fig. 3, sample images across time are shown in the first row without registration and the second row shows corresponding images after our method of 3D motion correction.

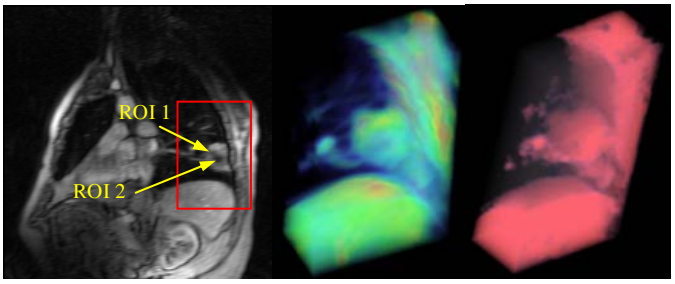

Figure 1. Left: an oblique section at 35sec of lung perfusion image; middle: 3D view of cropped volume; right: 3D view of level set segmentation binary mask.

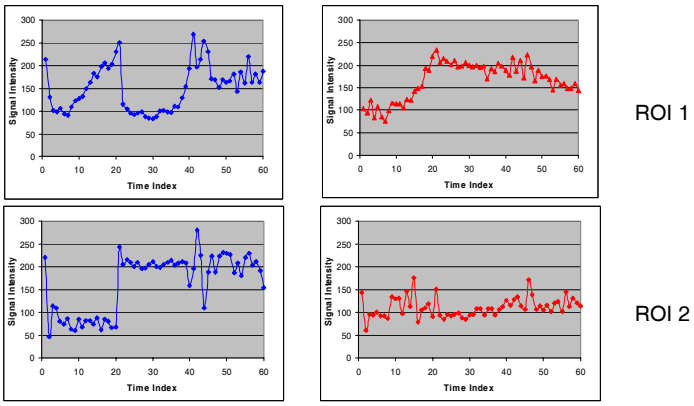

Figure 2. Time courses over time index on ROI 1 (top) and ROI 2 (bottom) before and after registration.

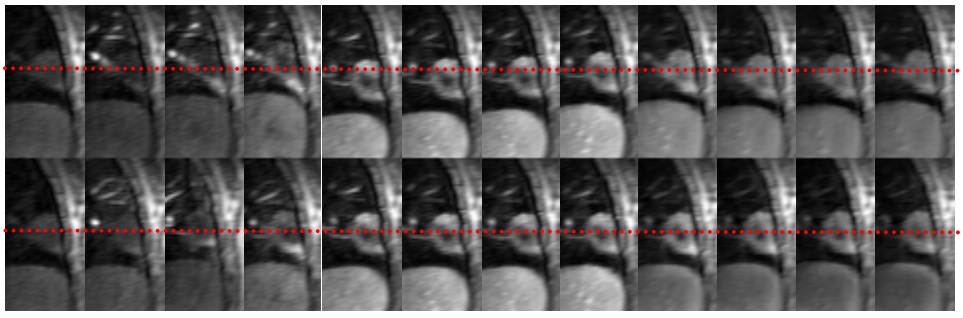

Fig. 3. First row are coronal cropped slices over time index 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60 (5, 10, 15, 20, 30, 35, 40, 45, 330, 630, 930, 1230 sec) before registration and the second row shows slices after auto-registration.

Conclusions

An automatic framework for dynamic 3D ("4D") MR pulmonary analysis has been put forward that alleviates manual labor and time-consuming image analysis that provides an enabling solution to practical clinical application. These preliminary results are promising in that they provide reliable enhancement curves which may be used in clinical diagnosis; screening and can enable quantitative biomarkers for lung cancer.

References [1] Chan and Vese, IEEE TMI, vol. 10(2), pp. 266-277, 2003. [2] T. Song et al., vol. 2, pp. 2205-213, MICCAI 2005.