Utility of the optical flow method for motion tracking in the lung

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Introduction: MRI spirometry is technique that has been demonstrated to non-invasively measure pulmonary function on a regional basis [1]. Using real-time imaging of the lung during forced breathing maneuvers, this method is able to calculate regional physiologic measures, such as FVC, FEV1, and the time constant τ. Relevant for assessing heterogeneous pulmonary disorders, this technique has shown the ability to examine lung function with a resolution currently unavailable from commonly used non-invasive procedures.

MRI spirometry utilizes the ability to track the motion of the lung parenchyma using the pulmonary vasculature as fiduciary markers. Overall, this method performs well, however its accuracy has been shown to degrade in certain regions of the lung. In particular, the spatial resolution and accuracy is limited by level of structure visible within the vasculature tree, which varies widely throughout the lungs. During large displacements, accuracy is found to suffer in regions of containing large velocity gradients, for example near the posterior of the thorax where the lung effectively "slips" past the rib cage and spine. In this situation, discontinuities in the velocity field would systematically manifest as lower than expected displacement.

To overcome these deficiencies, this work introduces a new algorithm for tracking lung motion. The algorithm employs a multi-step optical flow method that improves spatial resolution more than two-fold, down to ±3 pixels in all directions. As a byproduct, the increased resolution shows improved results in large slip regions, improving the overall accuracy of the spirometry calculations. Also introduced is a performance index, which serves as a metric for assessing the confidence of regional pulmonary function calculations.

Methods: A gradient echo MRI sequence with very short TR/TE (1.6ms/0.7ms) was developed for real-time imaging of the lungs during forced breathing maneuvers. All studies were conducted on a 3.0T Siemens Tim Trio scanner with maximal gradient strength of 45mT/m and maximal slew rate of 200mT/m/s. The sequence was implemented with the following parameters: TR/TE = 1.6ms/0.7ms, FA = 5°, matrix size = 192x128-192, with partial Fourier and rectangular field of view, BW = 965 Hz/pixel, 16mm slice thickness, 420-450 filed of view. Measurements were acquired in both sagittal and coronal imaging planes, in real-time at rates up to 10 frames per second (fps) during forced breathing maneuvers.

The optical flow method (OFM) was used to calculate regional deformation maps from the dynamic image series. OFM is a coarse-to-fine model-based motion estimation technique that is based on the methods developed by Bergen [2], and Kumar [3] and has been used previously for displacement estimation in MR tagged cardiac imaging [4]. A multi-step procedure is used which first estimates a global parametric transformation for translation, rotation and then, using the global transformation as an initialization, estimates the local flow velocity vector for each point between the two images. The motion parameters (i.e. velocity) are computed which minimize the sum of the square differences (SSD) over three pyramid levels. The operation is performed sequentially, in coarse to fine order, through each level of the pyramid; the results at each level are used as the initial motion estimate for the subsequent level.

Results: Ten normal controls and ten subjects with known pulmonary disease were given pulmonary function tests in the MRI scanner during real-time acquisition. Data was processed using OFM using a fine square interrogation window ranging from ±3 to ±7 pixels wide. Confidence maps using the performance index were generated and evaluated to optimize the OFM processing parameters, ultimately to select the size of the fine pyramid level.

Discussion and Conclusions: Using the OFM method, regional assessment of lung motion during respiration was found to exhibit a distribution largely heterogeneous behavior. Motion fields from the OFM method, compared to the previous two-step cross-correlation tracking technique, showed more subtle, fine-scale structure (Fig 1). In addition, local displacement fields and dilatation were found to be influenced by cardiac motion, as translated along the pulmonary vasculature. Such observations must be further examined over larger normal and patient populations. Furthermore, the performance index implemented to evaluate the confidence of the pulmonary function calculations.

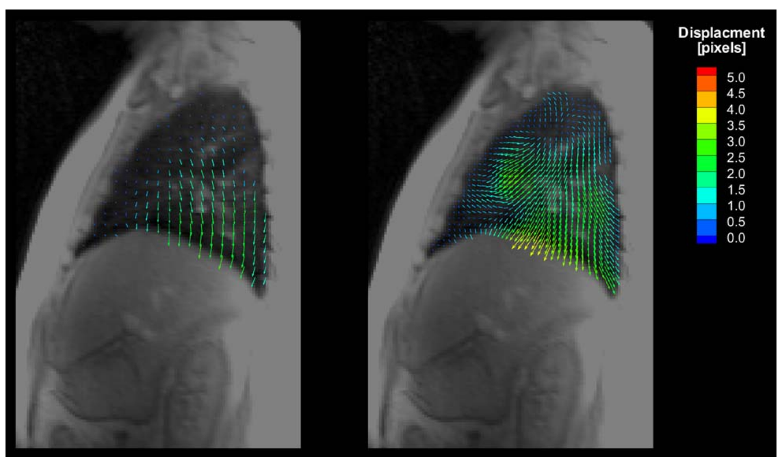

Fig 1. Comparison of motion-tracking techniques demonstrating improved resolution with OFM (left – cross-correlation based; right – OFM)

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