Perfusion and ventilation filters for Fourier-decomposition MR lung imaging

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Abstract

MR imaging without the use of contrast agents has recently been used for creating perfusion and ventilation functional lung images. The technique incorporates frequency- or wavelet-domain filters to separate the MR signal components. This paper presents a new, subject-adaptive algorithm for perfusion and ventilation filters design. The proposed algorithm uses a lung signal model for separation of the signal components in the frequency domain. Non-stationary lung signals are handled by a short time Fourier transform. This method was applied to sets of 192 and 90 co-registered non-contrast MR lung images measured for five healthy subjects at the rate of 3,33 images per second, using different slice thicknesses. In each case, the resulted perfusion and ventilation images showed a smaller amount of mutual information, when compared to those obtained using the known lowpass/highpass filter approach.

Perfusions- und Ventilationsfilter für Fourier-zerlegte MR-Lungenbildgebung

Zusammenfassung

Magnetresonanztomographie ohne den Einsatz von Kontrastmitteln wurde unlängst zur Erzeugung funktioneller Perfusions- und Ventilationsaufnahmen des Lungengewebes verwendet. Die bereits publizierte Methode benutzte Frequenz- oder Waveletfilter um das MR-Signal in verschiedene Komponenten aufzuspalten. In diesem Artikel wird ein neuer Algorithmus zur Optimierung der verwendeten Filter beschrieben. Der vorgeschlagene Algorithmus verwendet ein bekanntes Lungenmodell um die gesuchten Komponenten des Signals im Frequenzband zu bestimmen und danach zu separieren. Nicht stationäre Signale, die beispielsweise durch unregelmäßige Atemzyklen der Versuchspersonen erzeugt wurden, werden dabei mit Hilfe einer Short-Time-Fourier-Transformation verarbeitet. Der neue Algorithmus wurde auf Datensätze bestehend aus entweder 192 oder 90 koregistrierten Bildern angewandt. Die verwendeten Aufnahmen stammen von fünf gesunden Probanden und wurden mit einer Rate von 3,33 Bildern pro Sekunde bei verschiedenen Schichtdicken aufgenommen. In allen betrachteten Fällen besaßen

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die neu errechneten Perfusions- und Ventilationsbilder einen geringeren Anteil an mutual information verglichen mit der konventionellen Methode. Diese Ergebnisse belegen klar die Vorteile der individuell errechneten Filter im Vergleich zu den klassischen Hoch-/Tiefpassfiltern.

Keywords: Perfusion imaging, ventilation imaging, non-contrast lung MRI, functional FD lung MRI

Schlüsselwörter: Perfusionsbildgebung, Ventilationsbildgebung, kontrastmittelfreie Lungen-MRT, funktionelle FD Lungen-MRT

1 Introduction

Lung imaging plays a critical role in the diagnosis and treatment of lung diseases. In radiotherapy, tumor motion caused by respiration processes is estimated, and for treatment planning an irradiation dose is computed [1]. This dose is computed in relation to the breathing phase [2]. Irradiation should be delivered only to the tumor and exposure to healthy tissues minimized, which requires an accurate tumor localization and its motion estimation, based on 4D data (free breathing imaging).

Lung functional images that are also derived from 4D data can be helpful in performing these tasks. In the case of pulmonary diseases, both blood flow or air flow in lungs may be affected. Inhaled air traverses up to pulmonary alveoli, where oxygen enters the blood, and carbon dioxide moves from blood to alveoli. Ventilation characterizes lungs regions, where the gas exchange takes place. Blood flow at capillary level, measured in $ml\ min^{-1}\ 100g^{-1}$ is also called perfusion [3]. In functional images of different modalities both perfusion and ventilation of the lungs can be visualized. The common approaches used for the visualization of lung ventilation and perfusion are CT (computed tomography), MRI (magnetic resonance imaging) and scintigraphy [4,5].

In CT, lesions in the lungs result in changes of X-ray attenuation, passed via the subject during examination. These defects are visible in CT scans as various brightness abnormalities [6]. Using dual energy CT scanners, lung ventilation can be visualized by means of enhanced xenon [7,8]. This technique requires inhalation of Xe before examination and makes it possible to directly measure the amount of Xe component inside the lungs. Dual CT scanners are also used for creating lung perfusion images [8].

Imaging of lung function with scintigraphy is used for diagnosis of pulmonary embolism and restrictive lung disease, as well as for evaluation of candidates for lung volume reduction surgery and as a predictor of outcome after surgery [9,10].

Lung perfusion and ventilation can also be visualized using MRI. This modality, in contrast to the ones mentioned above, does not suffer from the use of ionizing radiation, and thus can be applied for repeated measurements in any age group. However due to the low proton density of the lungs, the visualization is a challenge in MRI [3]. From the MRI point of view, lung diseases are divided into two groups: one that increases the proton density, and another that reduces it. Lung regions affected by diseases from the first group can be directly visualized with MRI, while those of the second group require MRI contrast agents [3]. The technique for creating angiograms using MRI is called MRA (MR Angiography). In MRA, a contrast agent, typically gadolinium, is injected in order to boost the signal of veins. A different technique for creating perfusion images is arterial spin labeling. Using this technique, no external contrast agent is necessary, since protons of the blood are used as an endogenous tracer [3]. When creating ventilation images, an inhalation of hyperpolarized gases like ^{129}Xe and ^{3}He is performed before examination [3].

Recently, a novel method for functional lung imaging has been developed i.e. Fourier decomposition lung MRI (FD MRI) [11]. With this technique, the patient is examined without any additional contrast agents. This method requires the acquisition of a time sequence of lung images. The lung volume changes in accordance with the respiratory cycle and thus