Histograms should not be used to segment functional lung MRI

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Abstract

Magnetic resonance imaging using hyperpolarized gases, notably He-3 and Xe-129, has facilitated the novel visualization of airspaces, such as the human lung. The advent and refinement of these imaging techniques have furthered research avenues with respect to the growth, development, and pathologies of the pulmonary system. In conjunction with the improvements associated with image acquisition, multiple image analysis strategies have been proposed and developed for the quantification of hyperpolarized gas images with much research effort devoted to semantic segmentation, or voxelwise classification, into clinically-oriented categories based on ventilation levels. Given the functional nature of these images and the consequent complexity of the segmentation task, many of these algorithmic approaches reduce the complex spatial image intensity information to intensity-only considerations, specifically those associated with the intensity histogram. Although significantly simplifying computational processing, this transformation results in the loss of important spatial cues for identifying salient imaging features, such as ventilation defects, which have been identified as correlating with lung pathophysiology. In this work, we demonstrate the interrelatedness of the most common approaches for histogram-based, ventilation segmentation of hyperpolarized gas lung imaging for driving voxelwise classification. We evaluate the underlying assumptions associated with each approach and show how these assumptions lead to suboptimal performance. We then illustrate how a convolutional neural network can be constructed in a multi-scale, hierarchically feature-based (i.e., spatial) manner which circumvents the problematic issues associated with existing histogram-based approaches. Importantly, we provide the entire evaluation framework, including this newly reported deep learning functionality, as open-source through the well-known Advanced Normalization Tools (ANTs) library.

Introduction

Early hyperpolarized gas pulmonary imaging research reported findings in qualitative terms.

Descriptions:

- "^{3}He MRI depicts anatomical structures reliably" (1)
- "hypointense areas" (2)
- "signal intensity inhomogeneities" (2)
- "wedge-shaped areas with less signal intensity" (2)
- "patchy or wedge-shaped defects" (3)
- "ventilation defects" (4)
- "defects were pleural-based, frequently wedge-shaped, and varied in size from tiny to segmental" (4)

Subsequently, initial attempts at quantification were limited to ennumerating the number of "ventilation defects" or estimating ventilation defect percentage (as a percentage of total lung volume).

Additional sophistication:

- linear binning
- (semi-automated) k-means
- some percentage of the global mean intensity
- Gaussian mixture modeling with Markov Random Field prior-based smoothing

Methods

Results

Discussion

References

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