

Quantitative Analysis of Lung Morphology and Function in Computed Tomographic Images

In clinical lung radiology, primary cancer, metastatic disease, and parenchymal diseases such as emphysema or fibrosis play central roles. In the examination of these and other lung diseases, Computed Tomography (CT) is the reference imaging modality. In current clinical routine, the standard procedure for examining lung CT data is visual inspection. However, visual inspection not only requires a large amount of concentration and time, but is also limited to a solely qualitative and highly subjective image assessment. This thesis is concerned with research, development, and evaluation of new methods in digital image processing that assist the radiologist in performing a quantitative CT-based assessment of pulmonary morphology and function in patients with parenchymal or tumorous lung disease.

To support the regional analysis of the lung parenchyma in patients with parenchymal disease, fast robust methods for the automated segmentation of the lungs and their subsequent subdivision into lung lobes are developed. The lobe segmentation relies on an analysis of the vessel and airway anatomy rather than explicitly detecting the lobe-separating fissures. This makes it applicable to cases in which the fissures are concealed by pathology, incomplete, or missing. The new methods are extensively evaluated on a large heterogeneous set of pathological test cases to demonstrate their potential in the analysis of clinically relevant patient data. In the field of lung tumor analysis, previous research focused on supporting lung cancer screening by providing automatic segmentation methods for the volumetry of small pulmonary nodules. The algorithm presented in this thesis is designed to perform a fast, automated segmentation of small nodules and large lung metastases alike, and to be thereby equally suitable for application in the diagnosis of early stage lung cancer and monitoring of chemotherapy response. This flexibility is achieved by the introduction of an optimal opening procedure that, based on realistic model assumptions, permits a theoretically guaranteed separation of connected vasculature. Still, segmentation is merely the first step to volume measurement: The imaging variabilities caused by slight variations of the acquisition protocol are shown to severely impair clinical applicability of conventional segmentation-based volumetry approaches. This thesis proposes a volume quantification technique that compensates for these variabilities by exploiting the knowledge gained during segmentation and performing a selective volume averaging analysis at the tumor boundaries. Evaluation is performed on both in-vivo metastases and phantom nodules to demonstrate the robustness of the new segmentation method as well as the validity and significantly increased reproducibility of the developed volumetry technique.

While the technical soundness of the developed solutions is crucial, clinical impact can only be achieved if attention is also paid to practical applicability, i.e., the capability of running robustly under clinical conditions and of blending in smoothly with the demanding radiological workflow. Thus, the developed algorithms are integrated into a software prototype that can be conveniently used by clinicians. In addition to the technical evaluation, several evaluation studies are performed by clinical experts to verify applicability and clinical usefulness of the novel methods.