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Context-Sensitive Imaging for Single, Dual and Multi Energy Computed Tomography

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In clinical routine, a case-adapted CT examination is usually conducted for each medical indication in order to allow for a comprehensive high-quality diagnosis of a patient. Therefore, image reading requires the transition between various image stacks, since each medical question implicitly requires organ-dependent reconstructions, display settings, multi planar reformations and image analysis tools. In particular, if dual or multi energy CT data are available, various spectral evaluation methods yield material-specific or functional information. However, the interpretation of this large amount of data is a time-consuming and tedious task. Hence, the purpose of this thesis is to evaluate the potential benefit of the incorporation of patient-specific anatomical priors, which are gained from an automatic multi-organ segmentation, in order to discover novel opportunities to improve the clinical workflow.

In this thesis, a new paradigm is proposed which combines competing image properties resulting from different reconstruction algorithms and display settings into a context-sensitive CT imaging by means of anatomical prior information. With the incorporation of anatomical prior knowledge, which is obtained using an automatic multi-organ segmentation approach, various desired image characteristics are combined into a single context-sensitive CT image formation and presentation. The comparison with conventional CT images reveals an improved spatial resolution in highly attenuating materials as well as in air-filled body regions. Simultaneously, the compound image maintains a low noise level in soft tissue resulting in a superior soft tissue contrast compared to conventional images. Furthermore, the novel CT imaging framework allows for the combination of mutually exclusive display settings for the presentation of context-sensitive images to the radiologists. By exploiting anatomical prior information, numerous DECT applications can be integrated into one single DE analysis tool. Moreover, the tools can be chosen and applied to different organs simultaneously without any user interaction. The prior-based DE scheme performs all organ-specific feasible methods instantaneously without the need of a manual selection. Exploiting the anatomical priors, DECT analysis and evaluations are automated and standardized. The iodine quantification accuracy is significantly improved using patient-specific calibrations. The evaluation method and the presentation of the data to the radiologist can be realized via color overlays, pop up menus, volume rendering etc. Furthermore, the method can readily be generalized to the cases of multi energy CT data as it is not limited to the processing of DECT data.

The principle of incorporation anatomical prior knowledge is then extended to provide a novel pseudo material decomposition that decomposes dual energy data into more than three basis materials. The method consists of multiple three-material decompositions, where the basis materials are automatically adjusted to the organ of interest based on the automatic segmentation. Moreover, a patient-specific calibration is introduced to improve the volume fraction and material quantification accuracy. An organ-adapted basis material triplet is automatically assigned to each anatomical region resulting in overlapping triangles in the dual energy space. The basis materials are calibrated by evaluating ROIs to improve the volume fraction accuracy. Besides presenting evermore increasing material images to the radiologists, the volume fractions are rescaled to organ-dependent material scores and visualized via pie charts to be later correlated with different diagnoses. The prior-based pseudo multi material decomposition is evaluated using phantom and patient data. The materials are quantified according to the anatomical structure they belong to. Overall, the proposed method provides physically plausible volume fractions that bear the potential to improve the material quantification for diagnosis and e.g. tumor treatment monitoring.

In addition, the iodine quantification accuracy and the volume fraction accuracy are evaluated depending on different material calibration methods in conventional DECT applications as well as in the novel pseudo multi material decomposition. The accuracy using default parameters or simulation-based calibrations is compared against the accuracy obtained using patient-specific ROIs. All patient-specific calibrations can be performed directly from the patient data itself, such that almost no user interaction is required. It turns out that a patient-specific calibration is superior compared to a default or simulation based calibration.

The new paradigm offers the possibility to display evermore complex information in CT imaging in order to significantly improve the workflow of radiologists. In the clinical routine, e.g. during case presentations and discussions, the fast switching between different image stacks is time-consuming and can be avoided in the future since the CS images merge advantageous image properties resulting from various reconstructions and display settings. The results of the DE evaluation can be dynamically superimposed by color overlays. This superposition provides a comprehensive quantitative analysis of the patient data that can be interpreted as an additional image dimension. By means of the combined DECT evaluation scheme, the radiologists might be assisted in finding a precise diagnosis. In summary, diagnostic accuracy could be increased with the CS imaging by improving the sensitivity for incidental findings: e.g. small nodules can be diagnosed in the lung parenchyma, even if the radiologist is mainly focused on assessing soft tissue. The possibility to robustly decompose DECT data into more than three basis materials opens up for novel clinical evaluation to quantify e.g. fat content and iodine content in the liver simultaneously and to assess long term material scores using pie chart visualizations.