Automatic and efficient tomographic reconstruction algorithms

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Chapter 6

Conclusion

One of the main goals of the research presented in this thesis is to bridge the gap between theoretical research and practical use of CT reconstruction methods. Throughout this research the focus is on using mathematical insights from various fields to tackle practical problems encountered when using CT reconstruction methods: making state-of-the-art reconstruction methods more accessible to users without the need to fully understand the underlying mathematical theory, and improving already accessible reconstruction methods such that these methods are more widely applicable.

In **Chapter 2** we presented a framework in which one can efficiently explore different parameter choices for a reconstruction method. The framework was developed for a class of reconstruction methods: variational methods. These reconstruction methods are very effective in computing accurate reconstructions if the correct regularization parameter is chosen. Picking the optimal regularization parameter is not a straightforward process and often requires experience and understanding of the reconstruction method. The proposed method requires only a rough guess of the range of the regularization parameter from which approximate reconstructions can be computed using pixel-wise interpolation. The approximations can be computed efficiently and the choice of optimal regularization parameter is reduced to picking the optimal reconstruction from these approximations.

Filtered-backprojection methods are the among the easiest-to-use reconstruction methods due to their easy to choose parameters and the efficiency with which a reconstruction can be computed. However, the challenge for these methods is that they require measured projection data with a large number of projection images and low noise levels to produce accurate results. **Chapters 3**, **4** and **5** aim to improve FBP-type methods using various strategies, while maintaining the ease of use.

The reconstruction accuracy of FBP-type methods, such as the FDK algorithm, can be improved by adapting the filter used in the algorithm. The process of determining the optimal filter is often a trial-and-error process. Therefore, we formulate in **Chapter 3** an optimization problem from which we can automatically compute the optimal filter for the measured projection data or similar projection data.

Due to the efficiency of FBP-type methods they are an excellent candidate for real-time tomography, *i.e.*, reconstructing the measured projection data as it is acquired. However, data acquired in a real-time scanning protocol often has a low number of projection images and high noise levels. In **Chapter 4** we have shown that the Neural Network Filtered-backprojection (NN-FBP) algorithm — an algorithm shown to be fast and accurate for parallel beam — can be extended to general FBP-type methods and specifically to the FDK algorithm.

The challenge with the NN-FBP and NN-FDK algorithm is that they contain a machine learning component trained using supervised learning. This limits the applicability of these methods to cases where high quality reference data is available. In **Chapter 5** we have shown that this problem can be circumvented by using the Noise2Inverse training to train the NN-FBP network, which only uses noisy measured projection data to train the network. Moreover, we have shown that this training process is very fast — *i.e.*, sub-minute — and that the NN-FBP algorithm can be applied in the RECAST3D real time quasi 3D reconstruction framework. The resulting method is dubbed the Noise2Filter (N2F) method and can be used to reconstruct arbitrarily oriented 2D slices of a 3D reconstruction volume in real-time. And although the N2F method combines several state-of-the-art concepts, the number of reconstruction parameters that have to be set is limited. Moreover, the choice of the reconstruction parameters is straightforward.

The effects of the regularization in NN-FBP and NN-FDK can mainly be observed in the x, y-plane, whereas the effects in the z-direction are less pronounced. Therefore, I believe that adapting these methods to 2D filters could lead to even better results. This could be achieved by using the proposed multilayer perceptron framework and moving to full 2D filters or slab filters, *i.e.*, a stack of several 1D filters. Alternatively, the multilayer perceptron framework could be replaced by a CNN framework. Ideally when developing such methods, the locality, pointwise, and two-step properties — as described in **Chapter 5** — are maintained such that the method could be applied in the RECAST3D framework.

To automate a reconstruction method one should know what the reconstruction parameters are that lead to an optimal reconstruction. However, as we have seen in this thesis, there are many different metrics and conditions for what an "optimal" reconstruction is. Even with a ground truth or high quality reference reconstruction it is not agreed upon which metric indicates the best reconstructions. Therefore, instead of computing a reconstruction and then using that reconstruction to answer an application specific question, one could combine the two steps in one method and directly answer the question. This could be achieved by combining a classifier network architecture with reconstruction method and considering the reconstruction parameters as trainable parameters. This way the classifier network automatically determines which reconstructions are best to use to answer the posed question.

We have considered several machine learning methods throughout this thesis and there are many more being applied and developed. Although the training procedure for these methods rely roughly on the same mechanism, almost every network architecture has a different best practice to train the networks. Understanding why these differences work best and standardizing training procedures will greatly improve the ease of use of a machine learning method.

To conclude, with the rise in popularity of machine learning methods, the commercial availability of CT scanners, and the development of high-resolution detectors the field of CT imaging is still generating many interesting research questions from both an application and a theoretical point of view.