Chapter 3

Forward Projection for Use with Iterative Reconstruction

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ABSTRACT

Modelling the forward projection or reprojection, that is defined as the operation that transforms a 3D volume into series of 2D set of line integrals, is of interest in several medical imaging applications as iterative tomographic reconstruction (X-ray, Computed Tomography [CT], Positron Emission Tomography [PET], Single Photon Emission Computed Tomography [SPECT]), dose-calculation in radiotherapy and 3D-display volume-rendering. As forward projection is becoming widely used, iterative reconstruction algorithms and their characteristics may affect the reconstruction quality; its accuracy and performance needs more attention. The aim of this chapter is to show the importance of the modelling of the forward projection in the accuracy of medical tomographic data (CT, SPECT and PET) reconstructed with iterative algorithms. Therefore, we first present a brief overview on the iterative algorithms used in tomographic reconstruction in medical imaging. Second, we focus on the projection operators. Concepts and implementation of the most popular projection operators are discussed in detail. Performance of the computer implementations is shown using the well-known Shepp_Logan phantom. In order to avoid possibly confounding perspective effects implied by fan or cone-beam, this study is performed in parallel acquisition geometry.

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INTRODUCTION

Tomographic reconstruction is the technique underlying nearly all of the key diagnostic imaging modalities, including X-ray, CT, PET, SPECT, some acquisition methods for Magnetic Resonance Imaging (MRI), and newly emerging techniques such as electrical impedance tomography (EIT) and optical tomography. During the last decades, various algorithms have been developed for both 2D and 3D tomographic reconstruction such as the analytical and the iterative methods. The analytical algorithms, the most used, have advantage to be fast, but they are not able to model the characteristics of the data acquisition process. While the iterative algorithms are able to precisely model the physical and statistical characteristics of the data acquisition process, independent of the dimensionality of the image. The ability to perform accurate iterative reconstruction relies fundamentally on the modelling of the forward projection. Some examples where modelling the forward projections have been found worthwhile to explore include: Redundant data, better noise models, incomplete data, resolution recovery, beam hardening correction and metal artifact reduction.

In general, more detailed models result in higher image quality but also in higher computational load, which can become especially cumbersome in 3D problems. Some of numerical methods for implementing forward and backprojections reduce total processing time by simplifying the process used in determining the actual value to be backprojected or reprojected but they result in varying degrees of approximation errors. These simplifications and approximations limit the absolute accuracy of the reconstruction, contribute to image reconstruction errors and may negate the advantages of an iterative reconstruction. Conversely, more accurate interpolation techniques tend to impose added requirements of the reconstruction algorithms, and thus longer processing times. As the projection is becoming widely used with iterative reconstruction algorithms and their characteristics may affect the reconstruction quality, its accuracy and performance needs more attention for better understanding. In this context, this chapter aims to detail the implementing of forward projection using the most models that are frequently used in medical tomography reconstruction with focus on errors generated by the geometrical models. It is structured as follows. After this introduction, a brief overview on the iterative algorithms used in tomographic reconstruction in medical imaging is first presented. Second, the concepts and implementation of the most popular projection operators will be detailed. Their performances have been shown using the well-known Shepp_Logan phantom (Shepp & logan, 1994).

ITERATIVE RECONSTRUCTION TECHNIQUES

During the last decades, various algorithms have been proposed for both 2D and 3D tomographic reconstruction such as the analytical and the iterative methods. The analytical algorithms, the most used, have advantage to be fast, but they are not able to model the characteristics of the data acquisition process. Iterative tomographic reconstruction which is the process of recovering 3D image data from a set of integrals of that data over 2D subspaces, provide an attractive solution for tomographic imaging modalities over analytic techniques and they have been successfully used in medical imaging (Ziegler, 2008; Suetens, 2002), including computed tomography (CT), single photon emission computed tomography (SPECT), positron emission tomography (PET), tomosynthesis and projection mode 2D magnetic resonance imaging (MRI). The iterative methods aim to minimize or maximize a cost function between reconstructed slices $\boldsymbol{T}$ and measured projection $\boldsymbol{P}$ and have the advantage to incorporate imaging geometry and physics effects into

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