Generalized Filtered Back-Projection Reconstruction in Breast Tomosynthesis

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Abstract. Tomosynthesis reconstruction that produces high-quality images is a difficult problem, due mainly to the highly incomplete data. In this work we present a motivation for the generalized filtered backprojection (GFBP) approach to tomosynthesis reconstruction. This approach is fast (since non-iterative), flexible, and results in reconstructions with an image quality that is similar or superior to reconstructions that are mathematically optimal. Results based on synthetic data and patient data are presented.

1 Tomosynthesis Reconstruction – Background

Tomosynthesis focuses on one of the most important problems in mammography, namely superimposed normal tissue being interpreted as suspicious or hiding a lesion. The goal of advanced tomosynthesis reconstruction approaches is to overcome the following problems:

1. Reduced contrast of structures (the contrast of a structure in a projection image is a function of its attenuation and its thickness – ideally, however, only the attenuation should be reflected in the reconstructed gray scale values, while the thickness is reflected in the spatial distribution of the data);
2. Artifacts and so-called “structured noise” (due to out-of-plane structures);
3. Image noise (“statistical noise” - quantum and detector noise).

Until recently, simple backprojection (BP), which is also referred to as “shift-and-add” reconstruction, has been considered the standard reconstruction approach in tomosynthesis. However, it addresses only the image noise problem. Improvements due to other, more advanced reconstruction approaches are generally limited, and may have significant drawbacks. For example, the high-pass filtering in a filtered back-projection (FBP) type approach [1,2] (although differently motivated) addresses the contrast enhancement requirement. However, it also increases the contrast of artifacts, and creates potentially “noisy” reconstructions, unless the filter is suitably optimized. Artifact management is addressed in order-statistics based backprojection (OSBP) approaches [3,4], but these techniques do not result in any contrast enhancement. Other advanced reconstruction approaches (e.g., ML-maximum likelihood [5,6], algebraic reconstruction technique (ART) [7], matrix inversion tomosynthesis (MITS)

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[8]) are more involved, and a straightforward interpretation and evaluation of their effects on image quality and their effectiveness in addressing the problems above, becomes difficult. These approaches generally aim at maximizing the agreement (in some mathematical sense) of the reconstructed 3D volume with the acquired projection data.

The number of alternative reconstruction algorithm families, and the different choices within each family make a fair comparison of algorithms difficult. In one comparison study [1], ML was found to represent a good compromise in image quality (when compared to BP and FBP), while another comparison study [2] found generalized filtered backprojection (GFBP) superior, followed by ART (compared against OSBP and FBP). Some other comparisons [4,5] found tomosynthesis image quality superior to standard projection images, with varying results for the comparison among reconstruction algorithms. However, the scope of all of these studies has been too limited to even hint at a definitive answer as to what reconstruction algorithm may be "best", although they help illustrate some of the desirable properties of a "good" reconstruction algorithm. An additional problem in the comparison of reconstruction algorithms is that, unlike in CT reconstruction where complete or nearly complete data exist, in tomosynthesis the data are highly incomplete, and consequently most mathematical optimality criteria (which are used in many reconstruction algorithms) may not be appropriate as a measure for image quality.

2 Superior Reconstructions That Are "Non-optimal"

As an example of a mathematically optimal reconstruction we consider the so-called "minimum-norm solution", which is achieved (theoretically) by several different reconstruction algorithms (e.g., MITS and additive ART). Although generated in a different manner, this solution can be represented as a simple backprojection of "suitably modified" projection images; this is obvious from the fact that the basis functions that span the vector space containing the minimum-norm solution is spanned by the intersection of individual rays with the imaged volume.

From this basic observation it follows that the minimum-norm solution, although optimal in a mathematical sense, is not very effective in managing the artifact problem (since the backprojection operator, by its very definition, creates "streaks"). Furthermore, the minimum-norm solution can be seen to have a high-pass filtering characteristic, but only in the scanning direction of the x-ray tube. That is, it enhances the contrast, but favors one orientation over another. Both properties are illustrated in Figure 1, which shows reconstructions (BP, ART, GFBP) from simulated projections of identical wires of 1cm length and 1mm diameter, in two different orientations. The images are normalized such that the brightest point and the background assume the same gray level in all images. Note the out-of-plane artifacts from the wires, as well as the different in-plane appearance of the two wires, for the ART reconstruction (center column).