Iterative region-of-interest reconstruction in cone-beam tomography with multiple reference scans at increasing resolutions

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Summary: We present a generalisation of the subtraction method [1] for high-quality iterative reconstruction in region-of-interest (ROI) tomography. Our method allows the use of one or more ROI reference scans of increasing magnification in addition to the usual low-resolution full-field scan, which can improve quality for high-magnification ROI reconstruction while retaining the computational efficiency of the original method.

INTRODUCTION

Iterative methods for tomographic reconstruction generally require the object to be fully contained within the reconstructed field of view. Among the various strategies proposed to circumvent this problem, the subtraction method by Ziegler et al [1] yields good results while requiring comparatively little additional memory and computation time. Here a low-resolution reference scan of the full sample is obtained, reconstructed, the region corresponding to the ROI deleted, and the result re-projected with parameters matching the ROI scan to obtain a correction term that can be subtracted from the set of ROI projections.

We propose a generalization of this method for high-magnification ROI with several reference scans of increasing magnification, which provide a series of correction terms of increasing resolution with proximity to the ROI. We demonstrate how reconstruction quality is improved relative to the single-reference-scan version.

EXPERIMENTAL METHOD

Here we assume a lens-less fine-focus geometry where magnification is achieved through the expanding spherical wave-front of X-rays emitted from a micro(nano)-focus X-ray source (S) that is a distance R from the rotation axis, which we take to be vertical. A flat-panel detector (D) of width w is located a distance L from the rotation axis (in the opposite direction). A set of projections with magnification $m = (R + L)/R$ is obtained while varying the elevation z and the horizontal angle θ of the system S-D with respect to the sample. The radius of support for this configuration is given by $r = R \cdot d/\sqrt{R^2 + d^2}$, where $d = w/2m$. A full-field scan is one in which the sample is fully contained within the cylinder of support, i.e. the infinite vertical cylinder $C(r)$ with radius r centered at the rotation axis.

We now consider a sequence of n tomographic scans $(\mathbf{P}_i)_{i=1}^n$ with strictly decreasing radii of support r_i, exactly the first of which is full-field. We reconstruct the full-field scan normally, producing a volume $\mathbf{V}_1$. If the first i reconstructions $\mathbf{V}_1, \ldots, \mathbf{V}_i$, $i < n$, are available, we inductively construct $\mathbf{V}_{i+1}$ as follows:

For $k = 1, \ldots, i$, take the volume $\mathbf{V}_k$, and set all voxels inside $C(r_{k+1})$ to zero, with a smooth transition at the boundary to avoid artifacts. The resulting volume image represents the portion of the sample within an annular cylinder with inner radius r_{k+1} and outer radius r_k. Re-project this modified volume with parameters and trajectory matching $\mathbf{P}_{i+1}$, yielding a correction term $\mathbf{Q}_{i+1,k}$, which is then our best available estimate of the attenuation effected between the radii r_{k+1} and r_k relative to the rotation axis when taking the ROI scan.

Finally, reconstruct the residue $\mathbf{P}_{i+1} - \sum_{k=1}^{i} \mathbf{Q}_{i+1,k}$ normally to obtain $\mathbf{V}_{i+1}$. Intuitively, we can view this process as peeling off successive layers of data from $\mathbf{P}_{i+1}$ that correspond to the attenuation components outside the cylinders $C(r_1), \ldots, C(r_i)$, each time using the best available resolution for a given layer.

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RESULTS

We discuss some preliminary results from simulations, comparing the reconstruction quality achieved using a single versus multiple reference scans. We are expecting first results from physical experiments very soon.

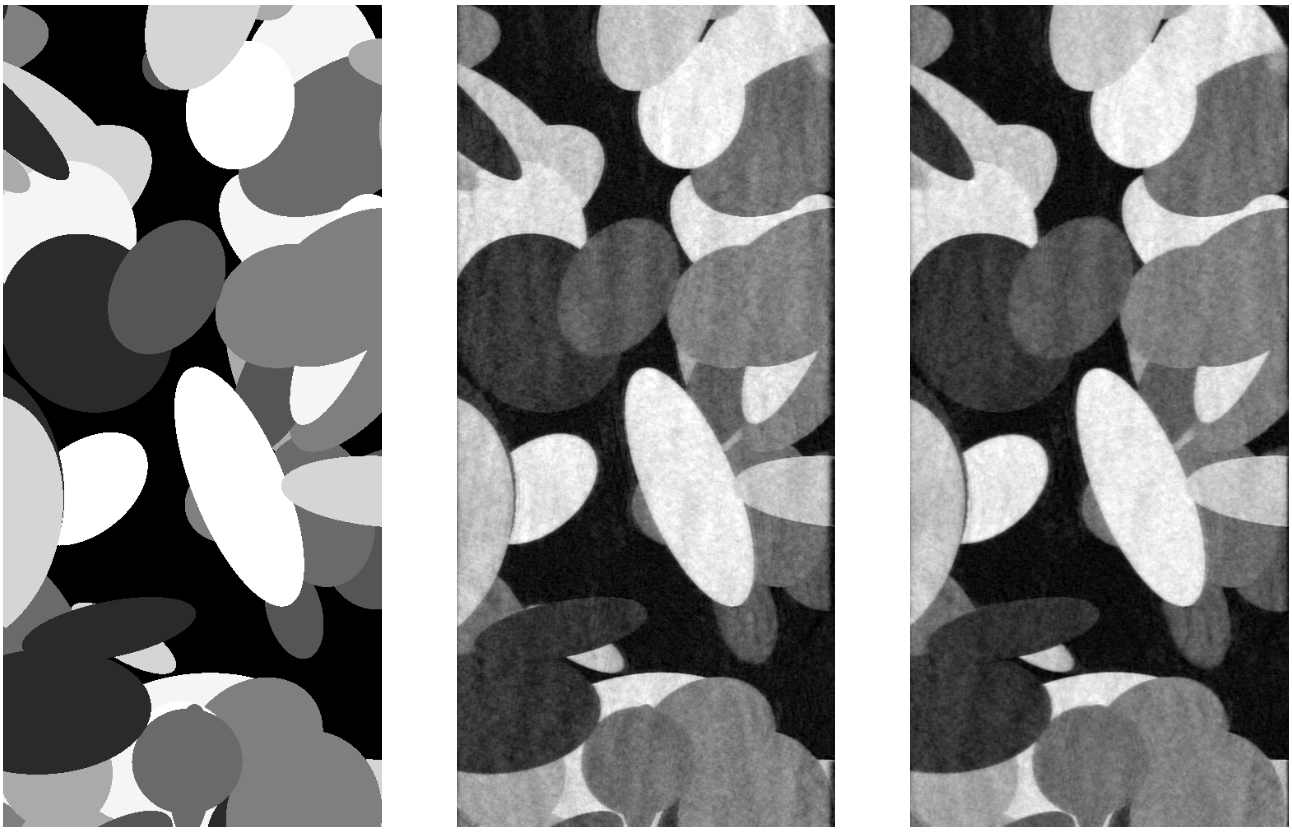
To test our method, we first created a phantom of 2048 x 2048 x 4096 voxels consisting of 8000 partially overlapping ellipsoids in a range of sizes, shades and orientations, within a hollow cylinder simulating a sample container. Part of a cross section of the phantom is shown in Figure 1a. From the phantom we created three projection sets using a space-filling trajectory, the first one full-field and the second and third one with magnifications 2x and 4x relative to the first. In each case, the results were sampled down to simulate a detector of 512 x 512 pixels. All reconstructions were obtained using an iterative multi-grid method.

A reconstructions of the 4x scan using only the 1x scan as a reference is shown in Figure 1b, and one using both the 1x and 2x scans in Figure 1c. We can see a clear reduction of low-frequency artifacts in the latter reconstruction.

Even though these simulations are quite limited in terms of available resolutions and magnifications, they show that the proposed method is sound and has the potential to yield improved results when applied to physical samples.

References

[1] A. Ziegler, T. Nielsen, & M. Grass. Iterative reconstruction of a region of interest for transmission tomography, *Med. Phys.*, 35(4), 1317–1327, 2008.



(a) (b) (c)

Figure 1: Digital phantom (a) with ROI reconstructions using one (b) and two (c) reference scans.