Stochastic Backprojection for Accelerated Model-based Iterative 3D Image Reconstruction

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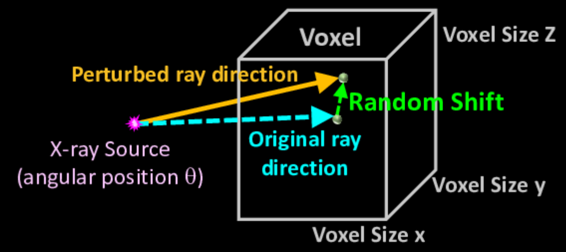
INTRODUCTION

Model-based iterative reconstruction (MBIR) yields improved image quality in CBCT compared to analytical methods in terms of noise-resolution tradeoff, truncation, sparse sampling, and/or cone-beam artifacts [1]. MBIR can also accommodate non-circular source-detector trajectories, which are beneficial in certain scenarios (e.g., in presence of metal [2]). However, MBIR requires accurate models of the imaging chain implemented through matched forward and backprojection operators, which pose significant computational burden [3]. Furthermore, assumptions made by common forward- and backprojection models with moderate computational burden, such as separable footprints [4] can break for highly non-circular orbits. Simple, mismatched, forward- and backprojection pairs (e.g, Siddon [5] forward- and Peters [6] backprojector) can reduce the computational burden and accommodate complex trajectories, but they result in artifacts from deterministic inconsistencies between the sampling patterns for the forward- and backprojection.

This work proposes a novel sampling approach for the Peters backprojector that breaks the deterministic structure of sampling inconsistencies by means of a random perturbation of the ray position inside each voxel.

METHODS

The stochastic backprojection consists of a modification of the Peters backprojection operator [6] by introducing a random perturbation of the ray position within each voxel, computed independently for every ray traced in the reconstruction (i. e. for every ray traced in the backprojection and for every iteration in the reconstruction).



Application to MBIR with penalized weighted least squares (PWLS)

Investigation of the SBP operator was exercised in MBIR using a penalized weighted least squares (PWLS) method. PWLS reconstructions were obtained minimizing a cost function of the form:

$$\hat{\mu} = \arg_{\mu} \min \|\mathbf{A}\mu - l\|_{\mathbf{W}}^{2} + \beta R(\mu)$$

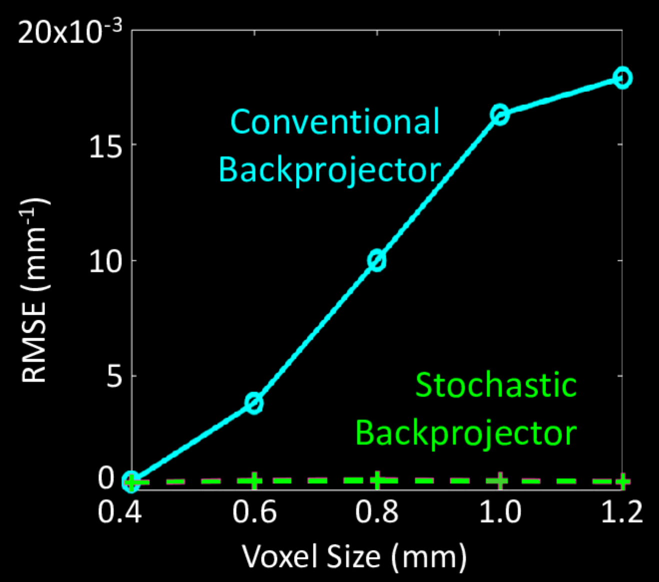
where μ is the image estimate, $\boldsymbol{A}$ is the operator for linear projection, l are the measured line integrals, and $\boldsymbol{W}$ is the matrix of data weighting terms, set to the raw measurements. The regularization term $R(\mu)$ penalizes image roughness weighted by the scalar β.

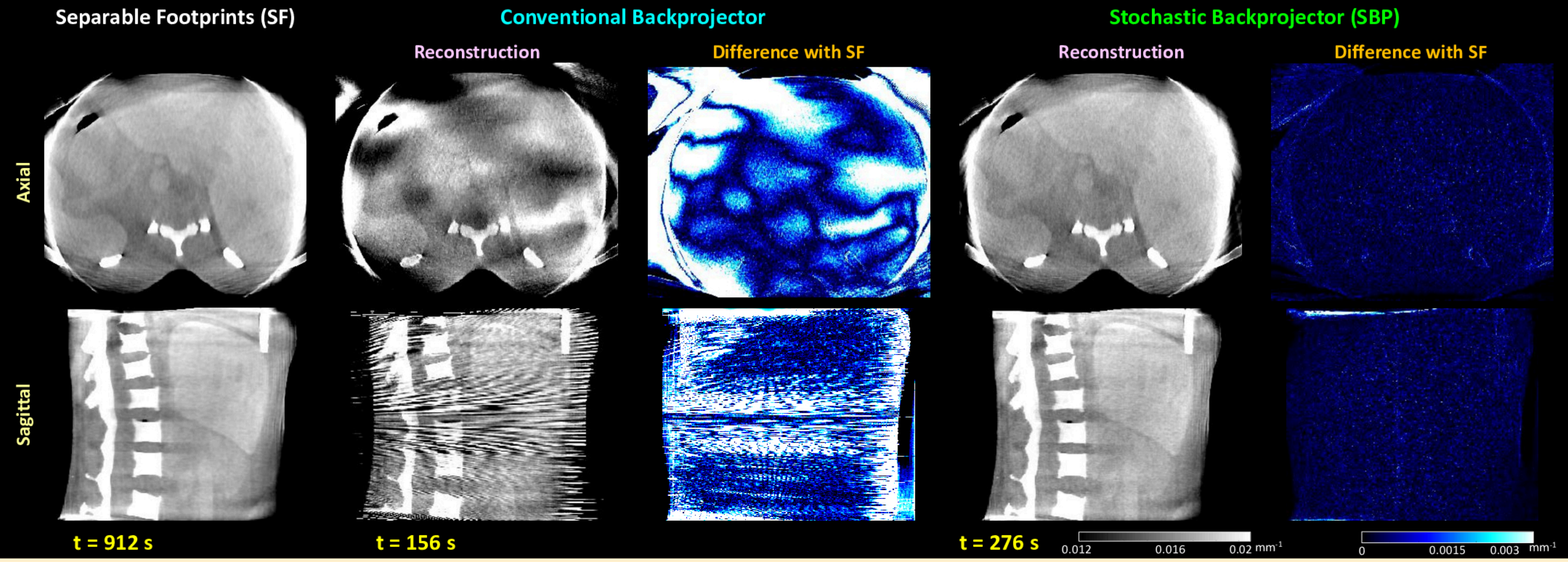
RESULTS

Single-resolution PWLS reconstruction

The approach was tested in CBCT on a robotic C-arm (Artis Zeego, Siemens) (496 projections, 100 kV, and 700 mAs) for an abdomen phantom with realistic anatomy (Kyoto Kagaku). PWLS reconstructions were obtained with matched SF operators and with the Siddon forward projector coupled to: i) Conventional (Peters); and, ii) stochastic backprojector. Volumes of 342x342x240 mm were reconstructed with voxel size ranging from 0.4 mm (matched to detector pixel size) to 1.2 mm. Reconstructions were obtained with 20 iterations and 8 subsets, with Nesterov momentum accumulation for further acceleration. A Huber penalty term was used for regularization. Performance was assessed in terms of root mean squared error (RMSE) with PWLS using SF.

Root mean squared error (see plot) increased steeply for PWLS with a conventional simple backprojector (Peters) as voxel size departed from the matched detector pixel size, while the error value remained low with increasing voxel size for the stochastic backprojector. Image results below show images reconstructed with PWLS with 0.6 mm voxels. Reconstructions were obtained with SF (912 s runtime), with a Siddon forward projector coupled to a conventional Peters backprojector, and to the stochastic backprojector. The Peters backprojector resulted in 0.17x runtime compared to SF, but it yielded severe sampling artifacts, quantified in the difference image. The stochastic backprojector resulted in improved image quality and reduced artifacts at 0.33x of SF runtime.





CONCLUSIONS

The use of conventional simple backprojectors (Peters) resulted in significantly reduced runtime compared to separable footprints but accompanied by conspicuous sampling artifacts and noticeable increase in RMSE (ranging 4x10-3 mm-1 and 1.8x10-2 mm-1 for 0.6 mm and 1.2 mm voxel size, respectively). The stochastic backprojector achieved a more modest reduction of runtime, but with significant reduction of sampling artifacts for all voxel sizes (maximum RMSE of 4.0x10-4 mm-1, for 1.2 mm voxels).

The stochastic backprojection method permits simplified, mismatched forward- and back-projectors in 3D image reconstruction for faster runtime without the image quality degradation suffered with conventional backprojectors.

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