Parameter Selection for Linear Iterative Image Reconstruction in Breast Tomosynthesis with the Non-prewhitening and Hotelling Observers

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Rationale

Iterative image reconstruction for digital breast tomosynthesis (DBT) involves a variety of parameter and implementation choices including voxel size, voxel aspect ratio, and regularization strength. Exploration of the corresponding parameter spaces is warranted for every algorithm, task, and system design under consideration. Efficiently computable simulation-based image quality metrics are needed to facilitate this task.

The purpose of this work is the development and comparison of two task-based image quality metrics for assessing the effect of regularization strength on microcalcification detectability in DBT reconstruction.

Methods

Two task-based image quality metrics are investigated: a region-of-interest (ROI) Hotelling observer for a signal-known-exactly/background-known-exactly (SKE/BKE) detection task and an ROI non-prewhitening (NPW) observer. The noise model is additive Gaussian in the sinogram domain with mean equal to variance, thus approximating a Poisson distribution. A simulation study is performed with the two metrics in which regularization strength is varied for Tikhonov penalized least-squares reconstruction (PLS), for which the reconstruction optimization problem is

$$\underset{x}{\operatorname{argmin}} \ \|Ax - b\|^2 + (\lambda\|A\|)^2\|x\|^2$$

where A is the linear forward model, b is the sinogram data, and x is an image estimate. The metrics are applied to the task of microcalcification detection, which is modeled using a 0.32mm diameter high-contrast Gaussian signal. The metrics are calculated in closed form, as opposed to with estimates using noise realizations, to facilitate efficient investigation of parameter spaces involved in reconstruction. Trends in the ROI-HO and ROI-NPW metrics are compared with 3D reconstructions from ACR mammography accreditation phantom data acquired with a Hologic Selenia Dimensions DBT system.

Results

The efficiencies — squared ratios of signal-to-noise ratio (SNR) in the image domain to SNR of the HO in the data domain — of the Hotelling and non-prewhitening observers are shown as a function of regularization strength in the top panel of Fig. 1. Real data ACR phantom reconstructions are shown in the bottom panel. A back projection reconstruction is included for reference. We note that the PLS solution limits to the back-projection image, up to scale, as $\lambda \to \infty$.

The efficiency of both observers tends to increase with increasing regularization strength until a point of saturation. The value of λ at which equal efficiency is achieved by the ROI-NPW can be up to 3 times larger than the corresponding value for the ROI-HO. The ROI-NPW and ROI-HO observer efficiencies both saturate at a value of 0.99 achieving close to the maximum attainable value of 1.0. In the real data reconstructions, the reconstructed specks appear more conspicuous as the noise level is reduced by increasing regularization strength.

Conclusions

The efficiency curves for both the ROI-HO and ROI-NPW observer suggest that information relevant to task performance is better preserved with increasing regularization but also suggest a point at which increasing regularization yields diminishing returns. The ROI-HO outperforms the ROI-NPW at all regularization strengths, suggesting prewhitening does impact performance of the investigated task in DBT. The trend of increasing conspicuity with increasing regularization in the ACR data reconstructions appears to coincide with the ROI-HO and NPW-HO efficiency trends.

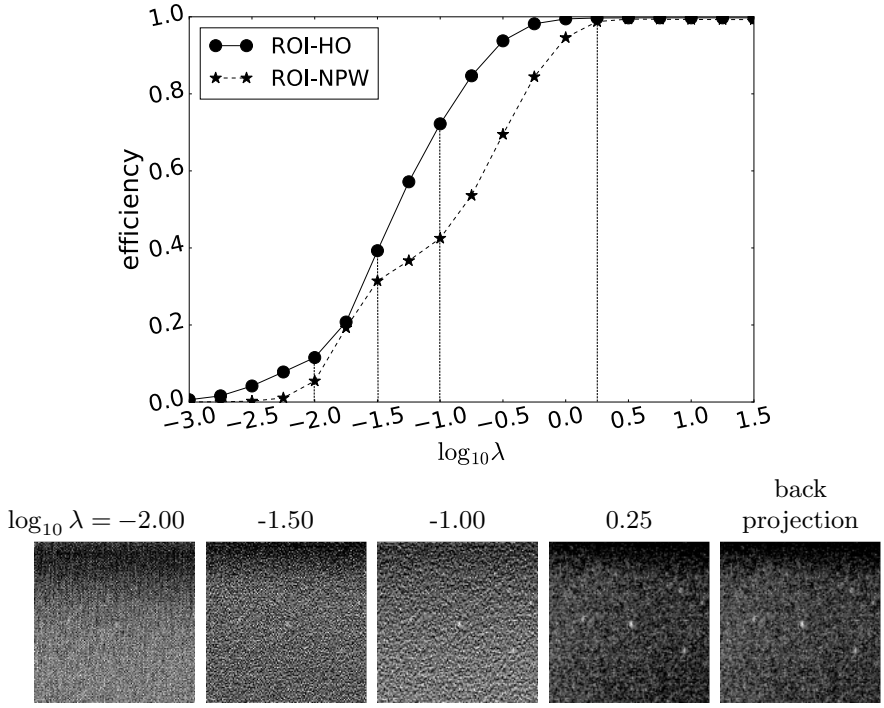

Fig. 1: Top: ROI-HO and ROI-NPW for detection of a 0.32mm calcification as a function of regularization strength in PLS reconstruction. Vertical lines mark regularization strengths used in phantom reconstructions. Bottom: PLS reconstructions of 0.32mm specks of ACR phantom at different regularization strengths. Display windows were chosen subjectively to maximize visibility of specks.