TV-Regularization in Digital Breast Tomosynthesis: Regularization Parameters & Small Structures Segmentation

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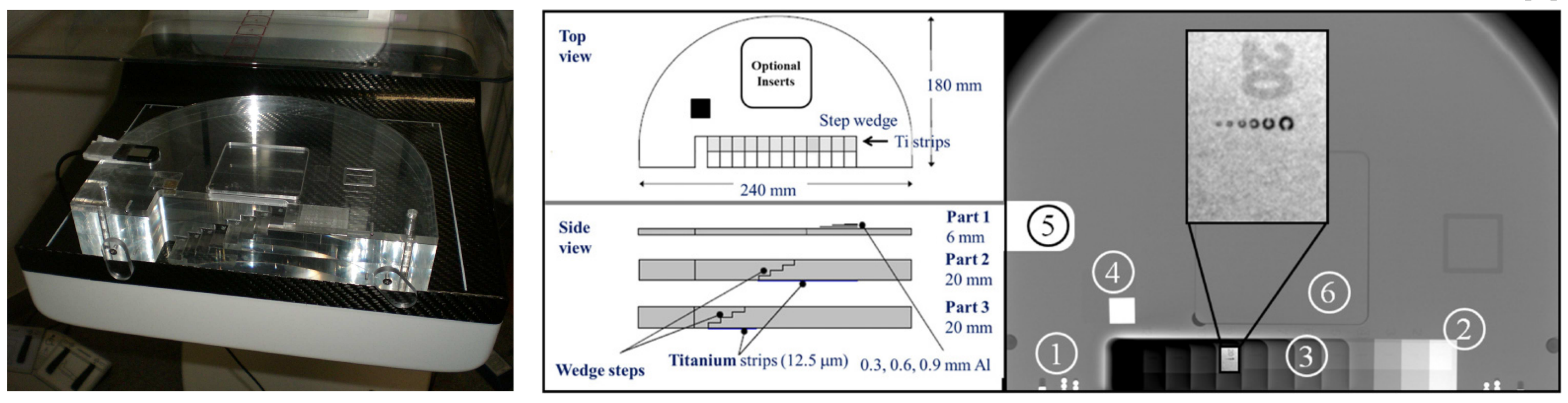
Motivation

Regularization approaches for the limited-angle reconstruction problem in digital breast tomosynthesis (DBT) are widely used. Though, their benefits depend largely upon a suitable regularization parameter estimation.
We aim to evaluate the reconstruction quality of precise small contrast features objectively with the help of the new Quart Mam/Digi phantom containing Landolt Rings (LR) combined with an automated LR detection process.

Materials and Methods

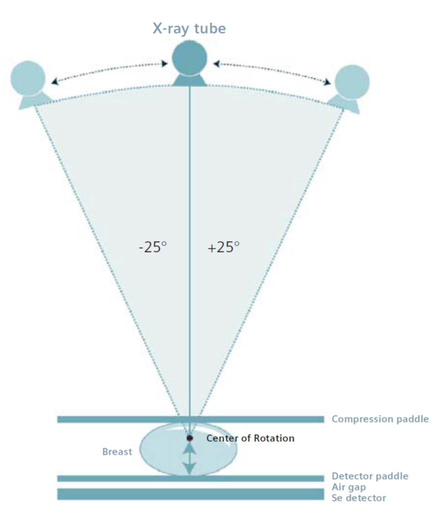
Landolt Rings - Quart Mam/Digi Phantom

The phantom for image quality evaluation of digital mammography systems contains Landolt rings (four alternatives: top, bottom, left or right) in a titanium background within a 12-step wedge. We can measure both aspects resolution and contrast-to-noise. [4]

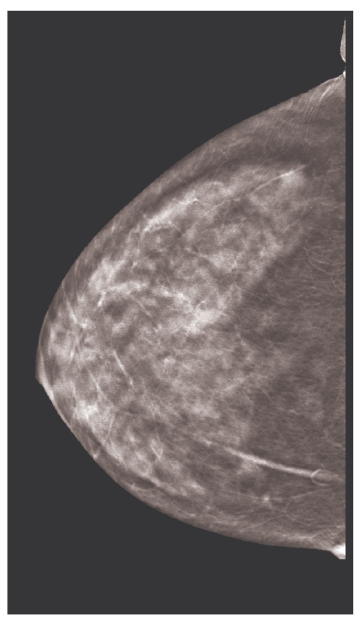


Breast Tomosynthesis System

Siemens Mammomat Inspiration [2]



The system exposes 25 projections with 2400x3600 pixel and a pixel spacing of 0.085x0.085 mm.
The reconstructed volume is comprised of 2400x3600x47 voxels whereby each voxel has a size of 0.085x0.085x1.0mm^3.
Our evaluation series:
30 kVp, overall exposure of 200 mA(8mAs / projection), system's automatic mode: 105mAs for 30 kVp



Siemens reconstruction

Algebraic Reconstruction Framework

Linear system of equations: $\mathbf{Ax} = \mathbf{y}$ with $\mathbf{x} \in \mathbb{R}^n$, $\mathbf{y} \in \mathbb{R}^m$, $\mathbf{A} \in \mathbb{R}^{m\times n}$

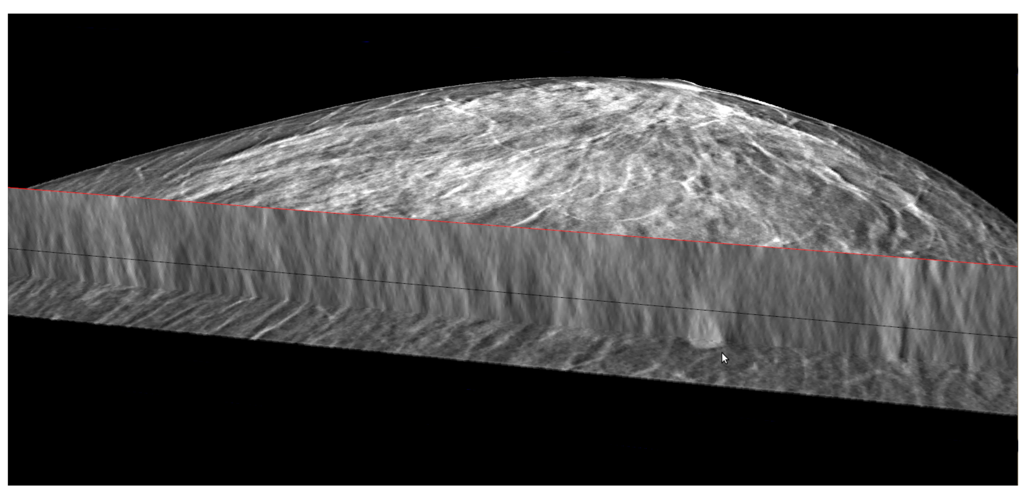
Minimization problem: $\|\mathbf{Ax} - \mathbf{y}\|^2 \rightarrow \min\limits_{x}$ and its normal equation: $\mathbf{A}^T\mathbf{Ax} = \mathbf{A}^T\mathbf{y}$

With TV-regularization the linear equation becomes a convex optimization problem of the form:

$$\min_{\mathbf{x}} f(\mathbf{x}) := \|\mathbf{Ax} - \mathbf{y}\|_2^2 + \lambda TV(\mathbf{x})$$

Iteration step of the Barzilai and Borwein (BB) method [3] (based on Quasi-Newton):

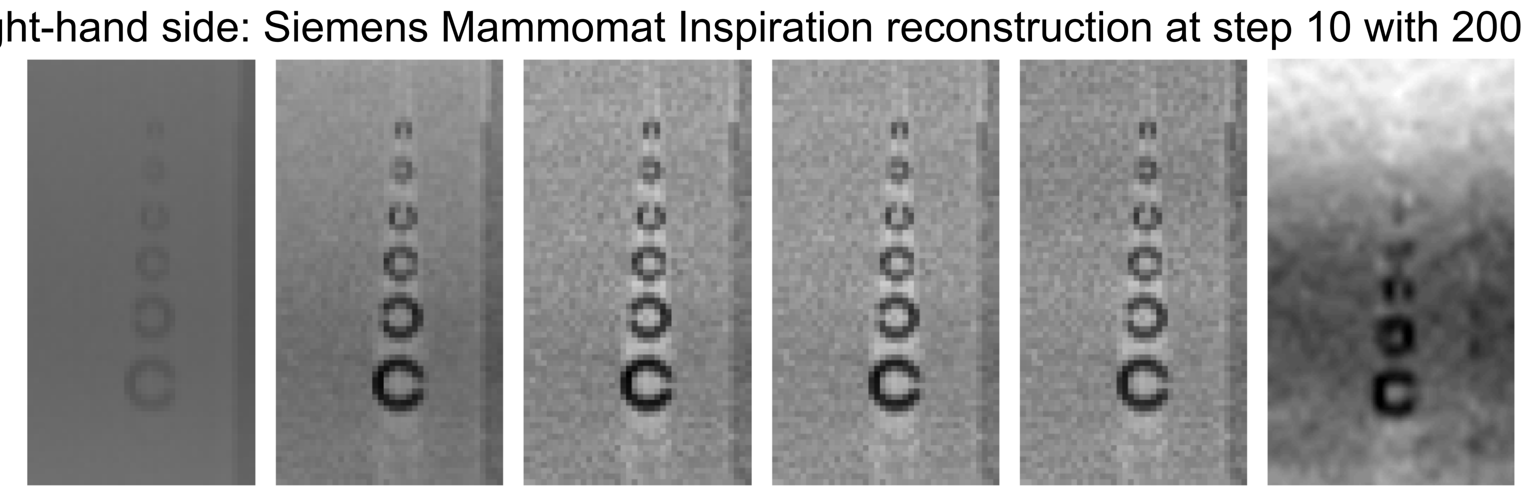
$$\mathbf{x}_{n+1} = \mathbf{x}_n - \alpha_n\left(2\,\mathbf{A}^T(\mathbf{Ax} - \mathbf{y}) + \lambda\nabla(TV(\mathbf{x}))\right)$$



sliced view of a reconstructed breast dataset

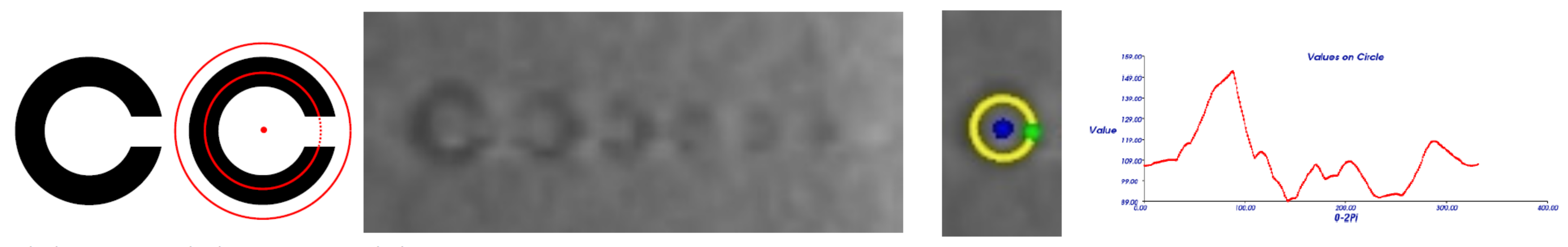
our reconstruction

Reconstructed Landolt ring sequence at one step of the Quart Mam/Digi phantom
6 LRs at step 10, 200 mAs, 30 kVp, BB reconstruction,TV λ = 0.2, iterations 1 up to 20
Right-hand side: Siemens Mammomat Inspiration reconstruction at step 10 with 200 mAs



0 5 10 15 20 Siemens

Automated Landolt Ring Detection



(a) (b) (c) (d) (e)

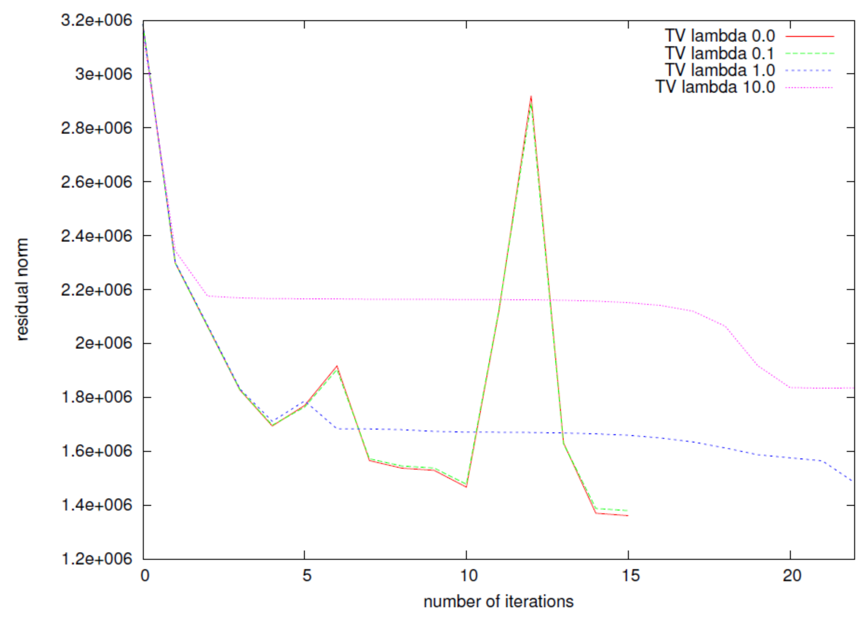
(a) LR with gap on the right side
(b) Marked features: center of ring (dot), path inside the ring (line), path in the gap (dotted line) and circle-path outside (line)
(c) LRs on Step 7, Exposure 99 mAs, Barzilai Borwein reconstruction, TV λ = 0.5
(d) Automatic LR detection for the first Ring in (c): center, ring and gap
(e) Profile on the circle-path inside the ring and the gap

Results

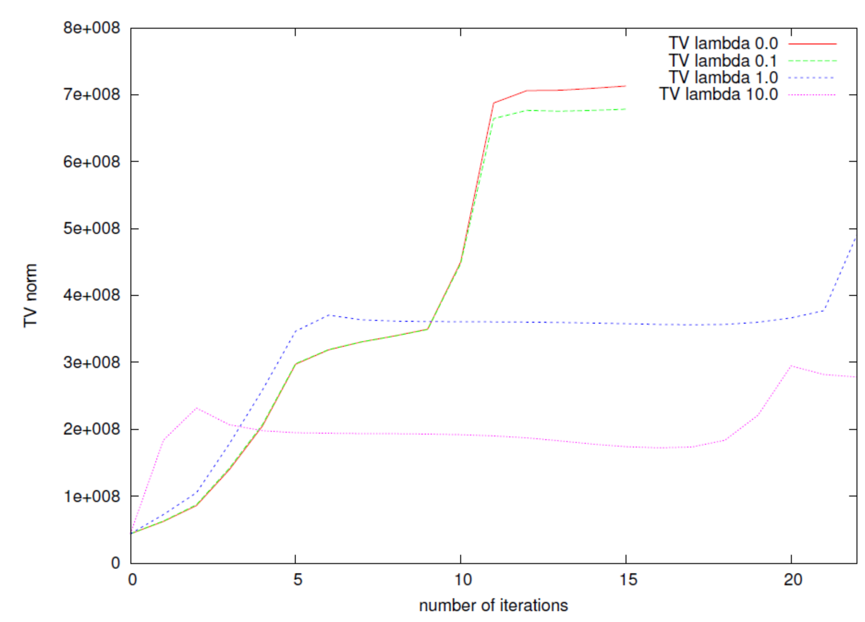
We assign 0.0, 0.1, 0.2, 0.3, 1.0 and 10.0 to the TV regularization constant λ and compare the reconstructions using up to 22 iteration steps. The Landolt ring detection threshold is varied to control its influence on the detection rates.

Iterative reconstruction characteristics for different TV regularization values λ:

$\|y - Ax\|_2$ (residual norm)

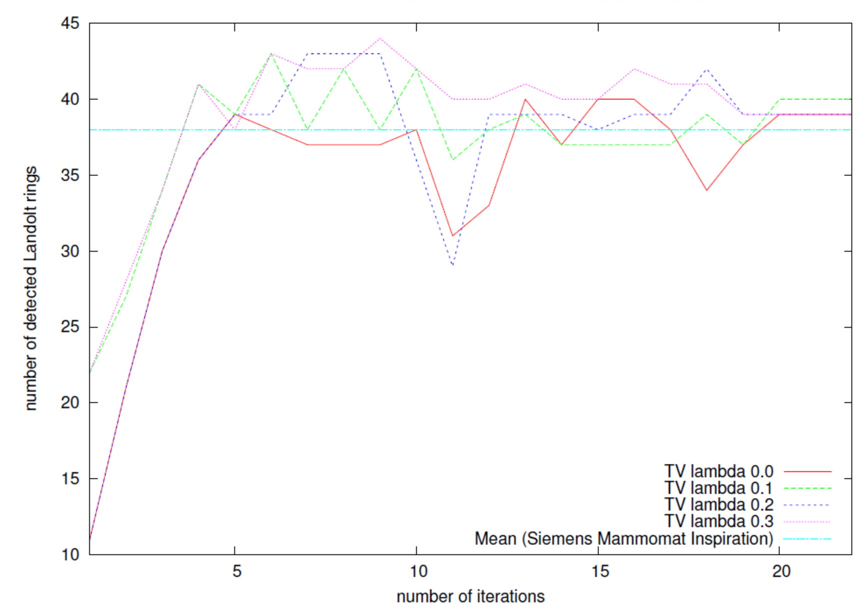


$\|x\|_{TV}$ (TV norm)

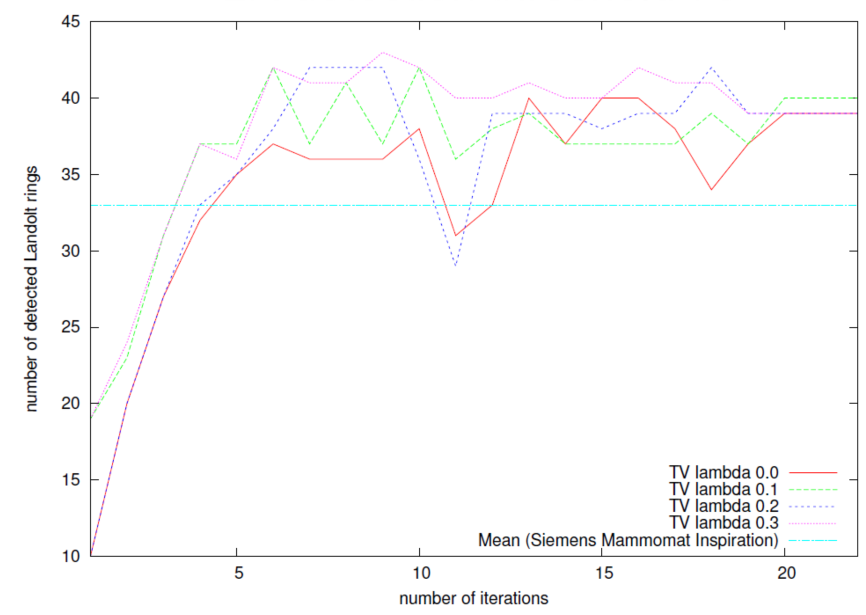


LR counts for TV reconstructions with different λ values

LR detection threshold 50



LR detection threshold 75



→ In comparision to the Siemens reconstruction λ = 0.1, 0.2, 0.3 values mostly deliver higher LR counts after 4 iterations.

Conclusion / Outlook

We showed in this work that the Landolt ring component of the specific phantom is an adequate tool for the evaluation of DBT algorithms with respect to the representation of small dense structures. TV regularization yielded better perceptibility of the LRs contained in the Quart Mam/Digi phantom, when the regularization parameter λ is adjusted carefully.
In a next step we will compare the results of the automatic LR detection with the reading of radiologists to evaluate reconstruction quality in a clinical context. Furthermore, we hope that our method can be applied in the context of limited angle breast tomography in order to improve the detection of clinical pathologies (e.g. microcalcifications).

References

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[2] T. Mertelmeier, J. Speitel, and C. Frumento, "3d breast tomosynthesis - intelligent technology for clear clinical benefits," Siemens, Henkestrasse 127, DE-91052 Erlangen, Germany, White Paper A91XP-30011-25C1-7600, 2012.
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