Automated angular and translational tomographic alignment and application to phase-contrast imaging

X-ray computerized tomography (CT) is a 3D imaging technique that makes use of x-ray illumination and image reconstruction techniques to reproduce the internal cross-sections of a sample. Tomographic projection data usually require an initial relative alignment or knowledge of the exact object position and orientation with respect to the detector. As tomographic imaging reaches increasingly better resolution, thermal drifts, mechanical instabilities, and equipment limitations are becoming the main dominant factors contributing to sample positioning uncertainties that will further introduce reconstruction artifacts and limit the attained resolution in the final tomographic reconstruction. Alignment algorithms that require manual interaction impede data analysis with ever-increasing data acquisition rates, supplied by more brilliant sources. We present in this paper an iterative reconstruction algorithm for wrapped phase projection data and an alignment algorithm that automatically takes 5 degrees of freedom, including the possible linear and angular motion errors, into consideration. The presented concepts are applied to simulated and real measured phase-contrast data, exhibiting a possible improvement in the reconstruction resolution. A MATLAB implementation is made publicly available and will allow robust analysis of large volumes of phase-contrast tomography data.

General information

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Organisations: Department of Applied Mathematics and Computer Science, Department of Energy Conversion and Storage, Imaging and Structural Analysis
Authors: Cunha Ramos, T. J. (Intern), Jørgensen, J. S. (Intern), Andreasen, J. W. (Intern)
Pages: 1830-1843
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Journal: Journal of the Optical Society of America A
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BFI (2017): BFI-level 2
BFI (2016): BFI-level 2
Reduction of variable-truncation artifacts from beam occlusion during in situ x-ray tomography: Paper

Many in situ x-ray tomography studies require experimental rigs which may partially occlude the beam and cause parts of the projection data to be missing. In a study of fluid flow in porous chalk using a percolation cell with four metal bars, drastic streak artifacts arise in the filtered backprojection (FBP) reconstruction at certain orientations. Projections with non-trivial variable truncation caused by the metal bars are the source of these variable-truncation artifacts. To understand the artifacts, a mathematical model of variable-truncation data as a function of metal bar radius and distance to sample is derived and verified numerically and with experimental data. The model accurately describes the arising variable-truncation artifacts across simulated variations of the experimental setup. Three variable-truncation artifact-reduction methods are proposed, all aimed at addressing sinogram discontinuities that are shown to be the source of the streaks. The ‘reduction to limited angle’ (RLA) method simply keeps only non-truncated projections; the ‘detector-directed smoothing’ (DDS) method smooths the discontinuities; while the ‘reflexive boundary condition’ (RBC) method enforces a zero derivative at the discontinuities. Experimental results using both simulated and real data show that the proposed methods effectively reduce variable-truncation artifacts. The RBC method is found to provide the best artifact reduction and preservation of image features using both visual and quantitative assessment. The analysis and artifact-reduction methods are designed in context of FBP reconstruction motivated by computational efficiency practical for large, real synchrotron data. While a specific variable-truncation case is considered, the proposed methods can be applied to general data cut-offs arising in different in situ x-ray tomography experiments.

General information

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Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, University of Copenhagen, Ostbayerische Technische Hochschule Regensburg
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Publication information
SparseBeads data: benchmarking sparsity-regularized computed tomography

Sparsity regularization (SR) such as total variation (TV) minimization allows accurate image reconstruction in x-ray computed tomography (CT) from fewer projections than analytical methods. Exactly how few projections suffice and how this number may depend on the image remain poorly understood. Compressive sensing connects the critical number of projections to the image sparsity, but does not cover CT, however empirical results suggest a similar connection. The present work establishes for real CT data a connection between gradient sparsity and the sufficient number of projections for accurate TV-regularized reconstruction. A collection of 48 x-ray CT datasets called SparseBeads was designed for benchmarking SR reconstruction algorithms. Beadpacks comprising glass beads of five different sizes as well as mixtures were scanned in a micro-CT scanner to provide structured datasets with variable image sparsity levels, number of projections and noise levels to allow the systematic assessment of parameters affecting performance of SR reconstruction algorithms. Using the SparseBeads data, TV-regularized reconstruction quality was assessed as a function of numbers of projections and gradient sparsity. The critical number of projections for satisfactory TV-regularized reconstruction increased almost linearly with the gradient sparsity. This establishes a quantitative guideline from which one may predict how few projections to acquire based on expected sample sparsity level as an aid in planning of dose- or time-critical experiments. The results are expected to hold for samples of similar characteristics, i.e. consisting of few, distinct phases with relatively simple structure. Such cases are plentiful in porous media, composite materials, foams, as well as non-destructive testing and metrology. For samples of other characteristics the proposed methodology may be used to investigate similar relations.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, University of Manchester
Authors: Jørgensen, J. S. (Intern), Coban, S. B. (Ekstern), Lionheart, W. R. B. (Ekstern), McDonald, S. A. (Ekstern), Withers, P. J. (Ekstern)
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Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 1.75 SJR 0.668 SNIP 1.173
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 0.687 SNIP 1.303 CiteScore 1.71
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 0.657 SNIP 1.319 CiteScore 1.58
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 0.555 SNIP 1.244 CiteScore 1.53
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Towards characterizing and reducing artifacts caused by varying projection truncation

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Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, University of Copenhagen
Authors: Borg, L. (Ekstern), Jørgensen, J. S. (Intern), Sporring, J. (Ekstern)
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**Effect of sparsity and exposure on total variation regularized X-ray tomography from few projections**
We address effects of exposure and image gradient sparsity for total variation-regularized reconstruction: is it better to collect many low-quality or few high-quality projections, and can gradient sparsity predict how many projections are...
necessary? Preliminary results suggest collecting many low-quality projections is favorable, and that a link may exist between gradient sparsity level and successful reconstruction.

**Noise robustness of a combined phase retrieval and reconstruction method for phase-contrast tomography**

Classical reconstruction methods for phase-contrast tomography consist of two stages: phase retrieval and tomographic reconstruction. A novel algebraic method combining the two was suggested by Kostenko et al. [Opt. Express 21, 12185 (2013) [CrossRef], and preliminary results demonstrated improved reconstruction compared with a given two-stage method. Using simulated free-space propagation experiments with a single sample-detector distance, we thoroughly compare the novel method with the two-stage method to address limitations of the preliminary results. We demonstrate that the novel method is substantially more robust toward noise; our simulations point to a possible reduction in counting times by an order of magnitude.
Empirical average-case relation between undersampling and sparsity in X-ray CT

In X-ray computed tomography (CT) it is generally acknowledged that reconstruction methods exploiting image sparsity allow reconstruction from a significantly reduced number of projections. The use of such reconstruction methods is inspired by recent progress in compressed sensing (CS). However, the CS framework provides neither guarantees of accurate CT reconstruction, nor any relation between sparsity and a sufficient number of measurements for recovery, i.e., perfect reconstruction from noise-free data. We consider reconstruction through 1-norm minimization, as proposed in CS, from data obtained using a standard CT fan-beam sampling pattern. In empirical simulation studies we establish quantitatively a relation between the image sparsity and the sufficient number of measurements for recovery within image classes motivated by tomographic applications. We show empirically that the specific relation depends on the image class and in many cases exhibits a sharp phase transition as seen in CS, i.e., same-sparsity images require the same number of projections for recovery. Finally we demonstrate that the relation holds independently of image size and is robust to small amounts of additive Gaussian white noise.

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Authors: Jørgensen, J. S. (Intern), Sidky, E. Y. (Ekstern), Hansen, P. C. (Intern), Pan, X. (Ekstern)
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Scopus rating (2011): CiteScore 1.82
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Web of Science (2010): Indexed yes
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How little data is enough? Phase-diagram analysis of sparsity-regularized X-ray computed tomography

We introduce phase-diagram analysis, a standard tool in compressed sensing (CS), to the X-ray computed tomography (CT) community as a systematic method for determining how few projections suffice for accurate sparsity-regularized reconstruction. In CS, a phase diagram is a convenient way to study and express certain theoretical relations between sparsity and sufficient sampling. We adapt phase-diagram analysis for empirical use in X-ray CT for which the same theoretical results do not hold. We demonstrate in three case studies the potential of phase-diagram analysis for providing quantitative answers to questions of undersampling. First, we demonstrate that there are cases where X-ray CT empirically performs comparably with a near-optimal CS strategy, namely taking measurements with Gaussian sensing matrices. Second, we show that, in contrast to what might have been anticipated, taking randomized CT measurements does not lead to improved performance compared with standard structured sampling patterns. Finally, we show preliminary results of how well phase-diagram analysis can predict the sufficient number of projections for accurately reconstructing a large-scale image of a given sparsity by means of total-variation regularization.
Testable uniqueness conditions for empirical assessment of undersampling levels in total variation-regularized X-ray CT

We study recoverability in fan-beam computed tomography (CT) with sparsity and total variation priors: how many underdetermined linear measurements suffice for recovering images of given sparsity? Results from compressed sensing (CS) establish such conditions for example for random measurements, but not for CT. Recoverability is typically tested by checking whether a computed solution recovers the original. This approach cannot guarantee solution uniqueness and the recoverability decision therefore depends on the optimization algorithm. We propose new computational methods to test recoverability by verifying solution uniqueness conditions. Using both reconstruction and uniqueness testing, we empirically study the number of CT measurements sufficient for recovery on new classes of sparse test images. We demonstrate an average-case relation between sparsity and sufficient sampling and observe a sharp phase transition as
known from CS, but never established for CT. In addition to assessing recoverability more reliably, we show that uniqueness tests are often the faster option.

**General information**

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Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, Technische Universität Braunschweig
Authors: Jørgensen, J. S. (Intern), Kruschel, C. (Ekstern), Lorenz, D. A. (Ekstern)
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- BFI (2016): BFI-level 1
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- Web of Science (2016): Indexed yes
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- Scopus rating (2015): SJR 0.474 SNIP 0.865 CiteScore 0.83
- Web of Science (2015): Indexed yes
- BFI (2014): BFI-level 1
- Scopus rating (2014): SJR 0.557 SNIP 0.944 CiteScore 0.95
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- Scopus rating (2013): SJR 0.479 SNIP 1.065 CiteScore 0.98
- ISI indexed (2013): ISI indexed yes
- BFI (2012): BFI-level 1
- Scopus rating (2012): SJR 0.433 SNIP 0.836 CiteScore 0.77
- ISI indexed (2012): ISI indexed yes
- BFI (2011): BFI-level 1
- Scopus rating (2011): SJR 0.362 SNIP 0.746 CiteScore 0.81
- ISI indexed (2011): ISI indexed yes
- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 0.449 SNIP 0.818
- BFI (2009): BFI-level 1
- Scopus rating (2009): SJR 0.396 SNIP 0.759
- Web of Science (2009): Indexed yes
- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 0.26 SNIP 0.64
- Scopus rating (2007): SJR 0.353 SNIP 0.842
- Scopus rating (2006): SJR 0.427 SNIP 0.829
- Web of Science (2006): Indexed yes
- Scopus rating (2005): SJR 0.477 SNIP 0.5
- Scopus rating (2004): SJR 0.457 SNIP 1.002
- Scopus rating (2003): SJR 0.432 SNIP 0.957
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Connecting image sparsity and sampling in iterative reconstruction for limited angle X-ray CT

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Few-view single photon emission computed tomography (SPECT) reconstruction based on a blurred piecewise constant object model

A sparsity-exploiting algorithm intended for few-view Single Photon Emission Computed Tomography (SPECT) reconstruction is proposed and characterized. The algorithm models the object as piecewise constant subject to a blurring operation. To validate that the algorithm closely approximates the true object in the noiseless case, projection data were generated from an object assuming this model and using the system matrix. Monte Carlo simulations were performed to provide more realistic data of a phantom with varying smoothness across the field of view. Reconstructions were performed across a sweep of two primary design parameters. The results demonstrate that the algorithm recovers the object in a noiseless simulation case. While the algorithm assumes a specific blurring model, the results suggest that the algorithm may provide high reconstruction accuracy even when the object does not match the assumed blurring model. Generally, increased values of the blurring parameter and TV weighting parameters reduced noise and streaking artifacts, while decreasing spatial resolution. As the number of views decreased from 60 to 9 the accuracy of images reconstructed using the proposed algorithm varied by less than 3%. Overall, the results demonstrate preliminary feasibility of a sparsity-exploiting reconstruction algorithm which may be beneficial for few-view SPECT.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Marquette University, University of Chicago
Authors: Wolf, P. A. (Ekstern), Jørgensen, J. S. (Intern), Schmidt, T. G. (Ekstern), Sidky, E. Y. (Ekstern)
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Main Research Area: Technical/natural sciences

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Purpose: Iterative image reconstruction (IIR) algorithms in computed tomography (CT) are based on algorithms for solving a particular optimization problem. Design of the IIR algorithm, therefore, is aided by knowledge of the solution to the optimization problem on which it is based. Often times, however, it is impractical to achieve accurate solution to the optimization of interest, which complicates design of IIR algorithms. This issue is particularly acute for CT with a limited angular-range scan, which leads to poorly conditioned system matrices and difficult to solve optimization problems. In this paper, we develop IIR algorithms which solve a certain type of optimization called convex feasibility. The convex feasibility approach can provide alternatives to unconstrained optimization approaches and at the same time allow for rapidly convergent algorithms for their solution—thereby facilitating the IIR algorithm design process.
Methods: An accelerated version of the Chambolle–Pock (CP) algorithm is adapted to various convex feasibility problems of potential interest to IIR in CT. One of the proposed problems is seen to be equivalent to least-squares minimization, and two other problems provide alternatives to penalized, least-squares minimization.

Results: The accelerated CP algorithms are demonstrated on a simulation of circular fan-beam CT with a limited scanning arc of 144°. The CP algorithms are seen in the empirical results to converge to the solution of their respective convex feasibility problems.

Conclusions: Formulation of convex feasibility problems can provide a useful alternative to unconstrained optimization when designing IIR algorithms for CT. The approach is amenable to recent methods for accelerating first-order algorithms which may be particularly useful for CT with limited angular-range scanning. The present paper demonstrates the methodology, and future work will illustrate its utility in actual CT application.

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Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, University of Chicago
Authors: Sidky, E. Y. (Ekstern), Jørgensen, J. H. (Intern), Pan, X. (Ekstern)
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BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.227 SNIP 1.299 CiteScore 2.46
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.307 SNIP 1.553 CiteScore 2.63
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.523 SNIP 1.631 CiteScore 2.79
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.766 SNIP 1.767 CiteScore 3.17
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.42 SNIP 1.669 CiteScore 3.08
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.353 SNIP 1.627 CiteScore 3.03
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.617 SNIP 1.744
Web of Science (2010): Indexed yes
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Scopus rating (2009): SJR 1.534 SNIP 2.046
Web of Science (2009): Indexed yes
Quantifying Admissible Undersampling for Sparsity-Exploiting Iterative Image Reconstruction in X-Ray CT

Iterative image reconstruction with sparsity-exploiting methods, such as total variation (TV) minimization, investigated in compressive sensing claim potentially large reductions in sampling requirements. Quantifying this claim for computed tomography (CT) is nontrivial, because both full sampling in the discrete-to-discrete imaging model and the reduction in sampling admitted by sparsity-exploiting methods are ill-defined. The present article proposes definitions of full sampling by introducing four sufficient-sampling conditions (SSCs). The SSCs are based on the condition number of the system matrix of a linear imaging model and address invertibility and stability. In the example application of breast CT, the SSCs are used as reference points of full sampling for quantifying the undersampling admitted by reconstruction through TV-minimization. In numerical simulations, factors affecting admissible undersampling are studied. Differences between few-view and few-detector bin reconstruction as well as a relation between object sparsity and admitted undersampling are quantified.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, University of Chicago
Sparse Image Reconstruction in Computed Tomography

In recent years, increased focus on the potentially harmful effects of x-ray computed tomography (CT) scans, such as radiation-induced cancer, has motivated research on new low-dose imaging techniques. Sparse image reconstruction methods, as studied for instance in the field of compressed sensing (CS), have shown significant empirical potential for this purpose. For example, total variation regularized image reconstruction has been shown in some cases to allow reducing x-ray exposure by a factor of 10 or more, while maintaining or even improving image quality compared to conventional reconstruction methods.

However, the potential in CT has mainly been demonstrated in individual proof-of-concept studies, from which it is hard to distill general conditions for when sparse reconstruction methods perform well. As a result, there is a fundamental lack of understanding of the effectiveness and limitations of sparse reconstruction methods in CT, in particular in a quantitative sense. For example, relations between image properties such as contrast, structure and sparsity, tolerable noise levels, sufficient sampling levels, the choice of sparse reconstruction formulation and the achievable image quality remain unclear. This is a problem of high practical concern, because the large scale of CT problems makes detailed exploration of the parameter space very time-consuming. Due to the limited quantitative understanding, sparse reconstruction has not yet become the method of choice in practical CT applications.

This thesis takes a systematic approach toward establishing quantitative understanding of conditions for sparse reconstruction to work well in CT. A general framework for analyzing sparse reconstruction methods in CT is introduced and two sets of computational tools are proposed:

1. An optimization algorithm framework enabling easy derivation of algorithms for sparse reconstruction problems, and
2. Tools for characterizing sparse reconstruction in CT, i.e., establishing relations between parameters governing reconstruction quality.

The flexibility of the optimization algorithm framework is demonstrated by constructing convergent optimization algorithms for a range of sparse reconstruction problems of interest to CT. The practical usefulness of the framework is shown through case studies of the effectiveness of specific sparse reconstruction problems in tomographic reconstruction.

The characterization methods proposed in the thesis focus on the role of image sparsity for the level of sampling required for accurate CT reconstruction. While a relation between sparsity and sampling is motivated by CS, no theoretical guarantees of accurate sparse reconstruction are known for CT. In simulation studies, a sparsity-sampling relation is established in CT. This enables quantification of the undersampling allowed by sparse reconstruction methods.

Both the prototyping framework and the characterization methods add to the understanding of sparse reconstruction methods in CT and serve as initial contributions to a general set of computational characterization tools. Thus, the thesis contributions help advance sparse reconstruction methods toward routine use in

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Authors: Jørgensen, J. S. (Intern), Hansen, P. C. (Intern), Schmidt, S. (Intern)
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A First-Order Primal-Dual Reconstruction Algorithm for Few-View SPECT

A sparsity-exploiting algorithm intended for few-view Single Photon Emission Computed Tomography (SPECT) reconstruction is proposed and characterized. The algorithm models the object as piecewise constant subject to a blurring operation. Monte Carlo simulations were performed to provide more projection data of a phantom with varying smoothness across the field of view. For all simulations, reconstructions were performed across a sweep of the two primary design parameters: the blurring parameter and the weighting of the total variation (TV) minimization term. Maximum-Likelihood Expectation Maximization (MLEM) reconstructions were performed to provide reference images. Spatial resolution, accuracy, and signal-to-noise ratio was calculated and compared for all reconstructions. In general, increased values of the blurring parameter and TV weighting parameters reduced noise and streaking artifacts, while decreasing spatial resolution. The reconstructed images demonstrate that the algorithm introduces low-frequency artifacts in some cases, but eliminates streak artifacts due to angular undersampling. Further, as the number of views was decreased from 60 to 9 the accuracy of images reconstructed using the proposed algorithm varied by less than 3%. Overall, the results demonstrate preliminary feasibility of a sparsity-exploiting reconstruction algorithm which may be beneficial for few-view SPECT.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Scientific Computing, Marquette University, University of Chicago
Authors: Wolf, P. (Ekstern), Jørgensen, J. H. (Intern), Gilat-Schmidt, T. (Ekstern), Sidky, E. Y. (Ekstern)
Pages: 2381-2385
Publication date: 2012

Characterizing a discrete-to-discrete X-ray transform for iterative image reconstruction with limited angular-range scanning in CT

Iterative image reconstruction in computed tomography often employs a discrete-to-discrete (DD) linear data model, and many of the aspects of the image recovery relate directly to the properties of this linear model. While much is known about the properties of the continuous X-ray, the corresponding DD version can be more difficult to characterize due to non-standardization and wide variation in model parameters in the image expansion set and the integration model. For this work, we analyze in detail the DD model for fan-beam CT with a limited scanning range, namely less than 180 degrees plus the fan-angle. The analysis is performed by specifying the class of system matrices considered and computing their condition number. A scaling is observed that aids in relating the condition number for large system matrices to that of more easily analyzed small matrices.

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Authors: Sidky, E. (Ekstern), Jørgensen, J. H. (Intern), Pan, X. (Ekstern)
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Publication date: 2012
Convergence of iterative image reconstruction algorithms for Digital Breast Tomosynthesis

Most iterative image reconstruction algorithms are based on some form of optimization, such as minimization of a data-fidelity term plus an image regularizing penalty term. While achieving the solution of these optimization problems may not directly be clinically relevant, accurate optimization solutions can aid in iterative image reconstruction algorithm design. This issue is particularly acute for iterative image reconstruction in Digital Breast Tomosynthesis (DBT), where the corresponding data model is particularly poorly conditioned. The impact of this poor conditioning is that iterative algorithms applied to this system can be slow to converge. Recent developments in first-order algorithms are now beginning to allow for accurate solutions to optimization problems of interest to tomographic imaging in general. In particular, we investigate an algorithm developed by Chambolle and Pock (2011 J. Math. Imag. Vol. 40, pgs 120-145) and apply it to iterative image reconstruction in DBT.

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Conference: 2012 IEEE Nuclear Science Symposium and Medical Imaging Conference, Anaheim, CA, United States, 29/10/2012 - 29/10/2012
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Publication: Research - peer-review > Article in proceedings – Annual report year: 2012

Convex optimization problem prototyping for image reconstruction in computed tomography with the Chambolle–Pock algorithm

The primal–dual optimization algorithm developed in Chambolle and Pock (CP) (2011 J. Math. Imag. Vis. 40 1–26) is applied to various convex optimization problems of interest in computed tomography (CT) image reconstruction. This algorithm allows for rapid prototyping of optimization problems for the purpose of designing iterative image reconstruction algorithms for CT. The primal–dual algorithm is briefly summarized in this paper, and its potential for prototyping is demonstrated by explicitly deriving CP algorithm instances for many optimization problems relevant to CT. An example application modeling breast CT with low-intensity x-ray illumination is presented.

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Organisations: Scientific Computing, Department of Informatics and Mathematical Modeling, University of Chicago
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Convex optimization prototyping for iterative image reconstruction in X-ray CT

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Authors: Sidky, E. Y. (Ekstern), Jørgensen, J. H. (Intern), Pan, X. (Ekstern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2012
Implementation of an optimal first-order method for strongly convex total variation regularization

We present a practical implementation of an optimal first-order method, due to Nesterov, for large-scale total variation regularization in tomographic reconstruction, image deblurring, etc. The algorithm applies to \( \mu \)-strongly convex objective functions with \( L \)-Lipschitz continuous gradient. In the framework of Nesterov both \( \mu \) and \( L \) are assumed known—an assumption that is seldom satisfied in practice. We propose to incorporate mechanisms to estimate locally sufficient \( \mu \) and \( L \) during the iterations. The mechanisms also allow for the application to non-strongly convex functions. We discuss the convergence rate and iteration complexity of several first-order methods, including the proposed algorithm, and we use a 3D tomography problem to compare the performance of these methods. In numerical simulations we demonstrate the advantage in terms of faster convergence when estimating the strong convexity parameter \( \mu \) for solving ill-conditioned problems to high accuracy, in comparison with an optimal method for non-strongly convex problems and a first-order method with Barzilai-Borwein step size selection.

General information
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Organisations: Department of Informatics and Mathematical Modeling, Scientific Computing, Aalborg University
Authors: Jensen, T. L. (Ekstern), Jørgensen, J. H. (Intern), Hansen, P. C. (Intern), Jensen, S. H. (Ekstern)
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Scopus rating (2011): SJR 0.683 SNIP 1.171 CiteScore 0.79
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Scopus rating (2010): SJR 1.273 SNIP 1.093
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Scopus rating (2008): SJR 0.805 SNIP 1.273
Scopus rating (2007): SJR 0.99 SNIP 1.081
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Quantitative study of undersampled recoverability for sparse images in computed tomography

Image reconstruction methods based on exploiting image sparsity, motivated by compressed sensing (CS), allow reconstruction from a significantly reduced number of projections in X-ray computed tomography (CT). However, CS provides neither theoretical guarantees of accurate CT reconstruction, nor any relation between sparsity and a sufficient number of measurements for recovery. In this paper, we demonstrate empirically through computer simulations that minimization of the image 1-norm allows for recovery of sparse images from fewer measurements than unknown pixels, without relying on artificial random sampling patterns. We establish quantitatively an average-case relation between image sparsity and sufficient number of measurements for recovery, and we show that the transition from non-recovery to recovery is sharp within well-defined classes of simple and semi-realistic test images. The specific behavior depends on the type of image, but the same quantitative relation holds independently of image size.
Sampling conditions for gradient-magnitude sparsity based image reconstruction algorithms

We seek to characterize the sampling conditions for iterative image reconstruction exploiting gradient-magnitude sparsity. We seek the number of views necessary for accurate image reconstruction by constrained, total variation (TV) minimization, which is the optimization problem suggested in the compressive sensing (CS) community for this type of sparsity. The preliminary finding here, based on simulations using images of realistic sparsity levels, is that necessary sampling can go as low as N/4 views for an NxN pixel array. This work sets the stage for fixed-exposure studies where the number of projections is balanced against the X-ray intensity per projection.
The Matlab Syntax: Explore the syntax
Matlab (MATrix LABoratory) is one of the most widely used programming environments for numerical computations and simulations in the technical sciences. The reason is that Matlab makes it easy to get started as well as to construct advanced programs.

This book is a practical guide to understanding and using Matlab. It works as a quick reference for anyone who is starting to use Matlab for example while enrolled in university studies.

For this reason, the book is limited to covering what is typically used by a university student and is designed as a reference of the syntax including plenty of examples.

While the primary audience of the book is university students, it is well suited for anyone who wants to become acquainted with Matlab.

Toward quantifying admissible undersampling of sparsity-exploiting iterative image reconstruction for X-ray CT
Toward quantifying admissible undersampling of sparsity-exploiting iterative image reconstruction for X-ray CT

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Publication: Research - peer-review › Article in proceedings – Annual report year: 2012
Accelerated gradient methods for total-variation-based CT image reconstruction

Total-variation (TV)-based CT image reconstruction has shown experimentally to be capable of producing accurate reconstructions from sparse-view data. In particular TV-based reconstruction is very well suited for images with piecewise nearly constant regions. Computationally, however, TV-based reconstruction is much more demanding, especially for 3D imaging, and the reconstruction from clinical data sets is far from being close to real-time. This is undesirable from a clinical perspective, and thus there is an incentive to accelerate the solution of the underlying optimization problem. The TV reconstruction can in principle be found by any optimization method, but in practice the large scale of the systems arising in CT image reconstruction preclude the use of memory-demanding methods such as Newton’s method. The simple gradient method has much lower memory requirements, but exhibits slow convergence. In the present work we address the question of how to reduce the number of gradient method iterations needed to achieve a high-accuracy TV reconstruction. We consider the use of two accelerated gradient-based methods, GPBB and UPN, to solve the 3D-TV minimization problem in CT image reconstruction. The former incorporates several heuristics from the optimization literature such as Barzilai-Borwein (BB) step size selection and nonmonotone line search. The latter uses a cleverly chosen sequence of auxiliary points to achieve a better convergence rate. The methods are memory efficient and equipped with a stopping criterion to ensure that the TV reconstruction has indeed been found. An implementation of the methods (in C with interface to Matlab) is available for download from http://www2.imm.dtu.dk/pch/TVReg/. We compare the proposed methods with the standard gradient method, applied to a 3D test problem with synthetic few-view data. We find experimentally that for realistic parameters the proposed methods significantly outperform the gradient method.
Reliable Small-object Reconstruction from Sparse Views in X-ray Computed Tomography

General information
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Organisations: Department of Informatics and Mathematical Modeling, University of Chicago
Authors: Jørgensen, J. H. (Intern), Sidky, E. Y. (Ekstern), Pan, X. (Ekstern)
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http://ecos.maths.ed.ac.uk/SPARS11/
Source: orbit
Source-ID: 279088
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Total Variation and Tomographic Imaging from Projections

Total Variation (TV) regularization is a powerful technique for image reconstruction tasks such as denoising, in-painting, and deblurring, because of its ability to produce sharp edges in the images. In this talk we discuss the use of TV regularization for tomographic imaging, where we compute a 2D or 3D reconstruction from noisy projections. We demonstrate that for a small signal-to-noise ratio, this new approach allows us to compute better (i.e., more reliable) reconstructions than those obtained by classical methods. This is possible due to the use of the TV reconstruction model, which incorporates our prior information about the solution and thus compensates for the loss of accuracy in the data. A consequence is that smaller data acquisition times can be used, thus reducing a patients exposure to X-rays in medical scanning and speeding up non-destructive measurements in materials science.

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http://wsc.project.cwi.nl/woudschoten/2011/conferentieE.php
Source: orbit
Source-ID: 286357
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011
Toward optimal X-ray flux utilization in breast CT
A realistic computer-simulation of a breast computed tomography (CT) system and subject is constructed. The model is used to investigate the optimal number of views for the scan given a fixed total X-ray fluence. The reconstruction algorithm is based on accurate solution to a constrained, TV minimization problem, which has received much interest recently for sparse-view CT data.

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Authors: Jørgensen, J. H. (Intern), Hansen, P. C. (Intern), Sidky, E. Y. (Ekstern), Reiser, I. S. (Ekstern), Pan, X. (Ekstern)
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Authors: Skajaa, A. (Intern), Jørgensen, J. H. (Intern)
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Main Research Area: Technical/natural sciences
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Source-ID: 279091
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tomobox
Tiny collection of tools that enables simple experiments with tomographic reconstruction of three-dimensional objects from two-dimensional projections using a parallel beam geometry.

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Authors: Jørgensen, J. H. (Intern)
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TVReg

“TVReg” is a software package for 3D tomography using Total Variation regularization. The work was carried out as part of the project CSI: Computational Science in Imaging, funded by the Danish Research Council for Technology and Production Sciences, and headed by Prof. Per Christian Hansen, DTU Informatics. The collaborators are DTU Informatics, Dept. of Electronic Systems at Aalborg University, and MOSEK ApS. The main algorithm (UPN) is our practical implementation of an optimal first-order method for strongly convex functions, due to Nesterov, tailored to large-scale total variation regularization. Nesterov’s algorithm requires knowledge of both the Lipschitz constant and the strong convexity parameter, both of which are usually unknown, and our implementation incorporates mechanisms to estimate these important parameters during the iterations - thus making the algorithm suited for practical use. The package also includes two other first-order methods: a method by Nesterov, Beck, and Teboulle (UPN_0) for the case of a zero strong convexity parameter, and the Barzilai-Borwein accelerated gradient projection method (GPBB).

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The use of deconvolution in the analysis of impedance spectroscopy data

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Authors: Jørgensen, J. H. (Intern)
Publication date: 2008

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Publisher: Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi
Original language: English
Series: BC-959
Main Research Area: Technical/natural sciences

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Publication: Research - peer-review › Report – Annual report year: 2008

Projects:

Nano-scale 3D reconstruction of phase contrast X-ray projections
Department of Energy Conversion and Storage
Period: 15/09/2015 → 14/09/2018
Number of participants: 3
Phd Student:
Cunha Ramos, Tiago Joao (Intern)
Supervisor:
Jørgensen, Jakob Sauer (Intern)
Main Supervisor:
Andreasen, Jens Wenzel (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Tomography with Prior Information
Department of Informatics and Mathematical Modeling
Period: 01/10/2009 → 17/06/2013
Number of participants: 7
Phd Student:
Jørgensen, Jakob Sauer (Intern)
Supervisor:
Schmidt, Søren (Intern)
Sidky, Emil (Ekstern)
Main Supervisor:
Hansen, Per Christian (Intern)
Examiner:
Larsen, Rasmus Werner (Intern)
Arridge, Simon R. (Ekstern)
Siltanen, Samuli (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD