Directional Total Generalized Variation Regularization for Impulse Noise Removal

A recently suggested regularization method, which combines directional information with total generalized variation (TGV), has been shown to be successful for restoring Gaussian noise corrupted images. We extend the use of this regularizer to impulse noise removal and demonstrate that using this regularizer for directional images is highly advantageous. In order to estimate directions in impulse noise corrupted images, which is much more challenging compared to Gaussian noise corrupted images, we introduce a new Fourier transform-based method. Numerical experiments show that this method is more robust with respect to noise and also more efficient than other direction estimation methods.

Image fusion and denoising using fractional-order gradient information

Image fusion and denoising are significant in image processing because of the availability of multi-sensor and the presence of the noise. The first-order and second-order gradient information have been effectively applied to deal with fusing the noiseless source images. In this paper, due to the advantage of the fraction-order derivative, we first integrate the fractional order gradients of noisy source images as the target fraction-order feature, and make it fit with the fractional-order gradient of the fused image. Then we introduce the total variation (TV) regularization for removing the noise. By adding the data fitting term between the fused image and a preprocessed image, a new convex variational model is proposed for fusing the noisy source images. Furthermore, an alternating direction method of multiplier (ADMM) is developed for solving the proposed variational model. Numerical experiments show that the proposed method outperforms the conventional total variation in methods for simultaneously fusing and denoising.
Image reconstruction under non-Gaussian noise

During acquisition and transmission, images are often blurred and corrupted by noise. One of the fundamental tasks of image processing is to reconstruct the clean image from a degraded version. The process of recovering the original image from the data is an example of inverse problem. Due to the ill-posedness of the problem, the simple inversion of the degradation model does not give any good reconstructions. Therefore, to deal with the ill-posedness it is necessary to use some prior information on the solution or the model and the Bayesian approach.

Additive Gaussian noise has been extensively studied since it produces simple and tractable mathematical models. However, in the real applications, the noise is much more complicated and it cannot be well simulated by additive Gaussian noise, for instance, it may be signal dependent, very impulsive, multiplicative, mixed, etc. This PhD thesis intends to solve some of the many open questions for image restoration under non-Gaussian noise. The two main kinds of noise studied in this PhD project are the impulse noise and the Cauchy noise.

Impulse noise is due to for instance the malfunctioning pixel elements in the camera sensors, errors in analogue-to-digital conversion, faulty memory locations in hardware. Cauchy noise is characterized by a very impulsive behaviour and it is mainly used to simulate atmospheric and underwater acoustic noise, in radar and sonar applications, biomedical images and synthetic aperture radar images. For both noise models we introduce new variational models to recover the clean and sharp images from degraded images. Both methods are verified by using some simulated test problems. The experiments clearly show that the new methods outperform the former ones.

Furthermore, we have carried out a theoretical study on the two most known estimates: maximum a posteriori (MAP) estimate and conditional mean (CM) estimate for non-Gaussian noise. With only the convexity assumption on the data fidelity term, we introduce some cost functions for which the CM and MAP estimates are proper Bayes estimators and we also prove that the CM estimate outperforms the MAP estimate, when the error depends on Bregman distances.

This PhD project can have many applications in the modern society, in fact the reconstruction of high quality images with less noise and more details enhances the image processing operations, such as edge detection, segmentation, etc.
Segmentation-Driven Tomographic Reconstruction.

The tomographic reconstruction problem is concerned with creating a model of the interior of an object from some measured data, typically projections of the object. After reconstructing an object it is often desired to segment it, either automatically or manually. For computed tomography (CT), the classical reconstruction methods suffer from their inability to handle limited and/or corrupted data. Form any analysis tasks computationally demanding segmentation methods are used to automatically segment an object, after using a simple reconstruction method as a first step. In the literature, methods that completely combine reconstruction and segmentation have been suggested, but these are often non-convex and have very high computational demand. We propose to move the computational effort from the segmentation process to the reconstruction process, and instead design reconstruction methods such that the segmentation subsequently can be carried out by use of a simple segmentation method, for instance just a thresholding method. We tested the advantages of going from a two-stage reconstruction method to a one stage segmentation-driven reconstruction method for the phase contrast tomography reconstruction problem. The tests showed a clear improvement for realistic materials simulations and that the one-stage method was clearly more robust toward noise. The noise-robustness result could be a step toward making this method more applicable for lab-scale experiments. We have introduced a segmentation-driven reconstruction method which incorporates information about the main texture direction in an object. We proved that this method has mathematically desirable properties such as being convex and lower semicontinuous. We have also demonstrated the practical applicability of the method.

within image denoising, image deblurring and CT reconstruction. In order to use the proposed method we also proposed efficient and robust methods for estimating the main direction in either corrupted images or from limited and corrupted CT projection data. For directional object we also proposed two different reconstruction methods that separates the directional parts in the object from the non-directional parts. These method could for example be used for objects consisting of fibres and cracks. The results can be categorized as either completely combined reconstruction and segmentation of the object, or as highly supporting for the following segmentation process. Computed tomography is used within medical diagnosis, food science, materials science, production inspection, quality assessment, etc. Segmentation-driven reconstruction methods can help to improve both manual and automated segmentation processes that are used to analyze an object after the scanning. The results in this thesis are both of theoretical interest within regularization theory and directly applicable for image denoising, image deblurring and surely within tomographic reconstruction

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Segmentation-Driven Tomographic Reconstruction.

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Tomographic Reconstruction Methods for Decomposing Directional Components
X-ray computed tomography technique has many different practical applications. In this paper, we propose two new reconstruction methods that can decompose objects at the same time. By incorporating direction information, the proposed methods can decompose objects into various directional components. Furthermore we propose a method to obtain the direction information in the objects directly from the measured sinogram data. We demonstrate the proposed methods on simulated and real samples to show their practical applicability. The numerical results show the differences between the two methods and effectiveness as dealing with fibre-crack decomposition problem
Total Variation Based Parameter-Free Model for Impulse Noise Removal

We propose a new two-phase method for reconstruction of blurred images corrupted by impulse noise. In the first phase, we use a noise detector to identify the pixels that are contaminated by noise, and then, in the second phase, we reconstruct the noisy pixels by solving an equality constrained total variation minimization problem that preserves the exact values of the noise-free pixels. For images that are only corrupted by impulse noise (i.e., not blurred) we apply the semismooth Newton's method to a reduced problem, and if the images are also blurred, we solve the equality constrained reconstruction problem using a first-order primal-dual algorithm. The proposed model improves the computational efficiency (in the denoising case) and has the advantage of being regularization parameter-free. Our numerical results suggest that the method is competitive in terms of its restoration capabilities with respect to the other two-phase methods.

User-friendly simultaneous tomographic reconstruction and segmentation with class priors

Simultaneous Reconstruction and Segmentation (SRS) strategies for computed tomography (CT) present a way to combine the two tasks, which in many applications traditionally are performed as two successive and separate steps. A combined model has a potentially positive effect by allowing the two tasks to influence one another, at the expense of a more complicated algorithm. The combined model increases in complexity due to additional parameters and settings requiring tuning, thus complicating the practical usability. This paper takes it outset in a recently published variational algorithm for SRS. We propose a simplification that reduces the number of required parameters, and we perform numerical experiments investigating the effect and the conditions under which this approach is feasible.
Bregman Cost for Non-Gaussian Noise

One of the tasks of the Bayesian inverse problem is to find a good estimate based on the posterior probability density. The most common point estimators are the conditional mean (CM) and maximum a posteriori (MAP) estimates, which correspond to the mean and the mode of the posterior, respectively. From a theoretical point of view it has been argued that the MAP estimate is only in an asymptotic sense a Bayes estimator for the uniform cost function, while the CM estimate is a Bayes estimator for the means squared cost function. Recently, it has been proven that the MAP estimate is a proper Bayes estimator for the Bregman cost if the image is corrupted by Gaussian noise. In this work we extend this result to other noise models with log-concave likelihood density, by introducing two related Bregman cost functions for which the CM and the MAP estimates are proper Bayes estimators. Moreover, we also prove that the CM estimate outperforms the MAP estimate, when the error is measured in a certain Bregman distance, a result previously unknown also in the case of additive Gaussian noise.

Cauchy Noise Removal by Nonconvex ADMM with Convergence Guarantees

Image restoration is one of the most important and essential issues in image processing. Cauchy noise in engineering application has the non-Gaussian and impulsive property. In order to preserve edges and details of images, the total variation (TV) based variational model has been studied for restoring images degraded by blur and Cauchy noise. Due to the nonconvexity and nonsmoothness, there exist computational and theoretical challenges. In this paper, adapting recent
results, we develop an alternating direction method of multiplier (ADMM) in spite of the challenges. The convergence to a stationary point is guaranteed theoretically under certain conditions. Experimental results demonstrate that the proposed method is competitive with other methods in terms of visual and quantitative measures. Especially, by comparing to the PSNR values, our method can improve about 0.5dB on average.

General information
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Contrast Invariant SNR
We design an image quality measure independent of local contrast changes, which constitute simple models of illumination changes. Given two images, the algorithm provides the image closest to the first one with the component tree of the second. This problem can be cast as a specific convex program called isotonic regression. We provide a few analytic properties of the solutions to this problem. We also design a tailored first order optimization procedure together with a full complexity analysis. The proposed method turns out to be practically more efficient and reliable than the best existing algorithms based on interior point methods. The algorithm has potential applications in change detection, color image processing or image fusion. A Matlab implementation is available at http://www.math.univ-toulouse.fr/_weiss/PageCodes.html.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Scientific Computing, Université de Toulouse
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Relaxed Simultaneous Tomographic Reconstruction and Segmentation with Class Priors for Poisson Noise
This work is a continuation of work on algorithms for simultaneous reconstruction and segmentation. In our previous work we developed an algorithm for data with Gaussian noise, and in that algorithm the coefficient matrix for the system is explicitly store. We improve this algorithm in two ways: our new algorithm can handle Poisson noise in the data, and it can solve much larger problems since it does not store the matrix. We formulate this algorithm and test it on artificial test
problems. Our results show that the algorithm performs well, and that we are able to produce reconstructions and segmentations with small errors.

Simultaneous tomographic reconstruction and segmentation with class priors
We consider tomographic imaging problems where the goal is to obtain both a reconstructed image and a corresponding segmentation. A classical approach is to first reconstruct and then segment the image; more recent approaches use a discrete tomography approach where reconstruction and segmentation are combined to produce a reconstruction that is identical to the segmentation. We consider instead a hybrid approach that simultaneously produces both a reconstructed image and segmentation. We incorporate priors about the desired classes of the segmentation through a Hidden Markov Measure Field Model, and we impose a regularization term for the spatial variation of the classes across neighbouring pixels. We also present an efficient implementation of our algorithm based on state-of-the-art numerical optimization algorithms. Simulation experiments with artificial and real data demonstrate that our combined approach can produce better results than the classical two-step approach.
Variational approach for restoring blurred images with cauchy noise

The restoration of images degraded by blurring and noise is one of the most important tasks in image processing. In this paper, based on the total variation (TV) we propose a new variational method for recovering images degraded by Cauchy noise and blurring. In order to obtain a strictly convex model, we add a quadratic penalty term, which guarantees the uniqueness of the solution. Due to the convexity of our model, the primal dual algorithm is employed to solve the minimization problem. Experimental results show the effectiveness of the proposed method for simultaneously deblurring and denoising images corrupted by Cauchy noise. Comparison with other existing and well-known methods is provided as well.
An algorithm for total variation regularized photoacoustic imaging

Recovery of image data from photoacoustic measurements asks for the inversion of the spherical mean value operator. In contrast to direct inversion methods for specific geometries, we consider a semismooth Newton scheme to solve a total variation regularized least squares problem. During the iteration, each matrix vector multiplication is realized in an efficient way using a recently proposed spectral discretization of the spherical mean value operator. All theoretical results are illustrated by numerical experiments.
R3GMRES: including prior information in GMRES-type methods for discrete inverse problems

Lothar Reichel and his collaborators proposed several iterative algorithms that augment the underlying Krylov subspace with an additional low-dimensional subspace in order to produce improved regularized solutions. We take a closer look at this approach and investigate a particular Regularized Range-Restricted GMRES method, R3GMRES, with a subspace that represents prior information about the solution. We discuss the implementation of this approach and demonstrate its advantage by means of several test problems.

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Authors: Dong, Y. (Intern), Garde, H. (Intern), Hansen, P. C. (Intern)
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Main Research Area: Technical/natural sciences
A Convex Variational Model for Restoring Blurred Images with Multiplicative Noise

In this paper, a new variational model for restoring blurred images with multiplicative noise is proposed. Based on the statistical property of the noise, a quadratic penalty function technique is utilized in order to obtain a strictly convex model under a mild condition, which guarantees the uniqueness of the solution and the stabilization of the algorithm. For solving the new convex variational model, a primal-dual algorithm is proposed, and its convergence is studied. The paper ends with a report on numerical tests for the simultaneous deblurring and denoising of images subject to multiplicative noise. A comparison with other methods is provided as well.

General information
New Hybrid Variational Recovery Model for Blurred Images with Multiplicative Noise

A new hybrid variational model for recovering blurred images in the presence of multiplicative noise is proposed. Inspired by previous work on multiplicative noise removal, an I-divergence technique is used to build a strictly convex model under a condition that ensures the uniqueness of the solution and the stability of the algorithm. A split-Bregman algorithm is adopted to solve the constrained minimisation problem in the new hybrid model efficiently. Numerical tests for simultaneous deblurring and denoising of the images subject to multiplicative noise are then reported. Comparison with other methods clearly demonstrates the good performance of our new approach.
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Projects:

Characterization and Reducing the Influence of Model Errors in Inverse Problems
Department of Applied Mathematics and Computer Science
Period: 01/09/2017 → 31/08/2020
Number of participants: 4
PhD Student:
Riis, Nicolai Andre Brogaard (Intern)
Supervisor:
Frikel, Jürgen (Intern)
Hansen, Per Christian (Intern)
Main Supervisor:
Dong, Yiqiu (Intern)
Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

X-ray phase contrast nano-tomography of 3rd generation solar cells
Department of Energy Conversion and Storage
Period: 01/09/2016 → 31/08/2019
Number of participants: 4
PhD Student:
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Supervisor:
Carbone, Gerardina (Ekstern)
Dong, Yiqiu (Intern)
Main Supervisor:
Andreasen, Jens Wenzel (Intern)
Financing sources
Source: Internal funding (public)
Prior-Driven Diffusion Regularization for Inverse Problems

Department of Applied Mathematics and Computer Science
Period: 01/12/2014 → 30/11/2017
Number of participants: 3
PhD Student:
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Supervisor:
Dong, Yiqiu (Intern)
Main Supervisor:
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Financing sources
Source: Internal funding (public)

PhD Project: Segmentation-Driven Tomographic Reconstruction
Computed tomography (CT) is a non-invasive technique for analyzing the interior of objects. The mathematical method of calculating the interior of an object is called reconstruction. A great variety of different reconstruction techniques exist. For this project the goal is to incorporate different forms of prior information into the reconstruction process to achieve results with desired features for a subsequent segmentation. The CT problem is an ill-posed problem, which is a motivation for incorporation prior information, in order to regularize and stabilize the reconstructions. Prior information is based on what we perceive as expected and typical behavior for specific problems, for example an often-used prior for CT reconstructions is piecewise constancy of the solutions, which is utilized by for example Total Variation regularization. Incorporation of prior information in reconstructions is also a part of the overall theme for the ERC project “High-Definition Tomography”, which this project is a part of.

CT is typically used for analyzing biological objects, for medical imaging purposes, though in the research field of material science this has also become a highly used technique. For materials science a typical CT-investigation pipeline consist of four major stages: scanning, reconstruction, segmentation and analysis. Often the reconstruction is carried out by a simple filtered back projection method, whereas the segmentation stage consists of more advanced and computationally expensive methods.

In my project we aim to move the computational effort from the segmentation stage to the reconstruction stage. The reconstruction methods that primarily investigate are related to the variational methods. Prior information about the object we are scanning is used to regularize the reconstruction in order aid the following segmentation stage. Some regularization keywords that I have been working with are: Total Variation, Directional Total Variation, Total Generalized Variation, Mumford-Shah and Euler's Elastica.

Scientific Computing
Period: 01/09/2014 → 31/08/2017
Number of participants: 3
Number of related Ph.D. students: 1
Project participant:
Kongskov, Rasmus Dalgas (Intern)
Dong, Yiqiu (Intern)
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Segmentation-Driven Tomographic Reconstruction
Department of Applied Mathematics and Computer Science
Period: 01/09/2014 → 31/08/2017
Number of participants: 6
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Main Supervisor:
Dong, Yiqiu (Intern)
Examiner:
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Pock, Thomas Georg (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering

**Relations**
Publications:
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Project: PhD

**Image Reconstruction under Non-Gaussian Noise**
Department of Applied Mathematics and Computer Science
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Number of participants: 6
Phd Student:
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Hansen, Per Christian (Intern)
Main Supervisor:
Dong, Yiqiu (Intern)
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Lauze, Francois Bernard (Ekstern)
Steidl, Gabriele (Ekstern)

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

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Publications:
Image reconstruction under non-Gaussian noise
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