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.
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.

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.
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.
Projects:

**Image Reconstruction under Non-Gaussian Noise**

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Period: 01/09/2013 → 26/10/2016  
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