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Report on the PhD thesis

,,Image Restoration in the Presence of Poisson-Gaussian Noise"

by Anna Jezierska

The practical background for the main part of this thesis is the processing of images arising from confocal microscopy which are typically blurred images corrupted by Poisson-Gaussian noise. This is an interesting highly nontrivial task which A. Jezierska tackles by stochastical methods and techniques from optimization theory.

In the following I briefly comment on the specific chapters:

Chapter 1 gives a general overview over the applied techniques which includes in particular stochastic approaches (MLE, Bayesian estimators) and tools from discrete and continuous optimization. I am wondering about Example 1.1.1. If the matrix H is invertible we have no problem with condition 1 and 2 in Hadamard's definition, but condition three is not fulfilled since blurr matrices are usually ill-conditioned.

Chapter 2 addresses vector-quantization which is closely related to segmentation and clustering problems. For minimizing the proposed regularity constrained biconvex functional A. Jezierska uses an alternating optimization algorithm, also known as Gauss-Seidel approach: the novelties in contrast to the LGB algorithm consist in the penalizer which has additionally to be considered when minimizing over the 'label field' (first step) and in the constraint for the 'codebook' (second step). For solving the first problem she suggests two (standard) methods from combinatorial optimization. In the concluding discussion A. Jezierska mentions some other methods, e.g., convex relaxation methods to (approximately) solve the first problem. For finding the codebook which becomes more complicated than, e.g., with a pure quadratic approach due to the constraint, the PPXA+ algorithm introduced by Pesquet and Pustelnik (2012) is the method of choice. A. Jezierska demonstrates the good performance of the novel algorithm for low resolution quantization and quantization in the presence of noise.

Chapter 3 deals with the classical, challenging topic of estimating the parameters of a probability distribution from observations, where the considered distribution is a mixed one consisting of the weighted sum of a non-stationary Poisson process which exhibits an exponential decay in time and stationary Gaussian white noise with arbitrary mean. A. Jezierska provides a new framework for estimating the parameters for such mixed Poisson-Gaussian noise distribution from multidimensional time series. For the solution she proceeds with an EM algorithm, where several specific implementation issues have to be announced. For the initialization of the EM algorithm A. Jezierska suggests optimizing a moment-based estimate of the unknown parameters. The optimization of this non-convex functional is done by Douglas-Rachford splitting. An alternative way with observed slower convergence was developed in [Jezierska et al., 2012]. Moreover, performance bounds by computing Cramer-Rao bounds on the estimated variables are derived and the performance of the algorithm is demonstrated by numerical examples both for synthetic and real confocal image sequences.

In **Chapter 4** a simultaneous segmentation(denoising) and noise parameter estimation for single images corrupted by Poisson-Gaussian noise is handled. The proposed model consists of a negative log-likelihood and a gradient sparsity promoting regularizer (which include non-convex and non-local ones). The optimization is done by alternating the minimization of the label field and of the noise parameters. This is related to the functional considered in Chapter 2, in particular the first step can be handled as those in in Chapter 2. To solve numerically the non-convex problem stated in the second step A. Jezierska proposes as in the previous chapter an EM algorithm. Since the approach is again sensitive to the initial values it is accomplished with a patch-based initialization step. Numerical examples demonstrate the performance of the algorithm (with the anisotropic TV regularizer).

Chapter 5 establishes a convex model for the restoration of images degraded by a linear operator and corrupted by Poisson-Gaussian noise (MAP estimator with convex prior). A. Jezierska proves that the data term of the functional is μ-Lipschitz differentiable with a certain parameter μ and strictly convex. In particular the latter is an interesting result. For minimizing the functional primal-dual splitting methods were applied. The approach is validated on blurred and noisy images where the restoration with three penalization strategies (TV , NLTL, hybrid TV-Hessian prior) is addressed.

The following two chapters are not directly related with the main topic of the PhD (the treatment of Poisson-Gaussian noise) but deal with the minimization of certain special energies.

Chapter 6 considers the the minimization of multilabel energies with truncated convex priors. A. Jezierska proposes two novel binary graph-cut moves called convex move (= modified α-expansion move) and quantized move (= graph cut representation of the Murota algorithm). Finally, she introduces a quantized-convex split moves algorithm which alternates between both moves. The performance of this fast solver for labeling problems with a high number of labels and convex data terms is illustrated on denoising problems.

Chapter 7 deals with very interesting functionals involving ℓ_2-ℓ_0 regularizers (plus a quadratic term), i.e., asymptotically constant functions with quadratic behavior near zero. Such functionals are useful models in many applications. The author is in particular interested in image restoration since ℓ_2-ℓ_0 models are recognized for their ability to preserve edges between homogeneous regions. A. Jezierska establishes conditions such that F_δ epi-converges (Γ-converges) to an ℓ_0-penalized objective function, proposes a subspace algorithm with Majorize-Minimize stepsize choice which extends an approach of [Chouzenoux et al, 2011] and provides a convergence proof for functionals F_δ satisfying the Kurdyka-Lojasiewicz inequality. The chapter is completed by simulation results.

Chapter 8 summarizes the contributions of the thesis and gives an rather involved outlook to future research topics.

Each chapter of the thesis is accomplished by an extensive review of the existing literature together with a discussion of related work and concluding remarks pointing to future research topics.

A. Jezierska has co-authored three papers which were published in highly ranked journals and seven conference papers. She has presented her results at various international conferences.

In summary, this Ph.D. thesis is a successful work which contains interesting new and mathematically sound results. The thesis is well-written and it was a pleasure to read it. Anna Jezierska has provided high quality work in image processing both from the theoretical, practical (implementation) and interdisciplinary point of view. She has demonstrated herself to be an independent researcher who deserves the grade of Doctor from the University Paris-Est. I strongly recommend the acceptance of her PhD thesis .

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