Report of the supervisor on the PhD thesis

Author: Marie Kubínová
Title: Numerical Methods in Discrete Inverse Problems

Background of the candidate:

Marie Kubínová is known to me from several courses I have been teaching at the Faculty of Mathematics and Physics, Charles University. I was the advisor of her Master's and PhD thesis (together with Prof. Zdeněk Strakoš), we also collaborated on several research projects. She has a particularly strong background in numerical analysis and computational methods (mainly in the area of numerical linear algebra and linear inverse problems), and is well skilled in related areas such as optimization.

Her international experience includes (besides regular active attendance on international conferences, workshops and schools) two long term stays at: ETH Zurich, Switzerland (1 year), and Emory University, USA (1 year, under the Fulbright Scholarship), where she worked together with Prof. James Nagy on the results included in Chapter 4 of the thesis. Marie Kubínová was also awarded several prizes (Karel Urbanek Foundation Award, and SIAM Student Chapter Certificate of Recognition for her great activity in the students community). She was a principal investigator of two student projects (one industrial and one standard), results of the second one (obtained in collaboration with another PhD student) are included in Chapter 3 of the thesis.

The scientific independence of Marie Kubínová is obvious from the number of researchers and students she collaborated with, as can be seen from the list of publications included in the thesis. I can confirm that her role on the work on each of the publications was clearly substantial.

Content and its novelty:

The thesis addresses several research directions in the area of solution of linear inverse problems. The core of the thesis is represented by two papers published in high-quality impacted journals (Linear Algebra and its Applications, Springer and Numerical Algorithms, Springer) complemented by two peer-reviewed proceedings contributions (one of them in Lecture Notes in Computer Science series). Additional results, discussions and experiments are included at the end of each chapter.

Chapter 2 considers three regularization methods (LSQR, CGLS, CRAIG) for the solution of inverse problems contaminated by unknown noise. While the limiting assumption of white noise is typically considered in the literature, here no particular properties of noise are assumed. The chapter presents a novel approach allowing to control the resemblance between the residuals of these methods and noise in each iteration, which can be used to design effective stopping criteria. Moreover, the results are than used to analyze regularization properties of the methods.

Chapter 3 studies applicability of noise level estimator proposed previously by Hnětynková, Plešinger, Strakoš (2009) for problems with white noise, in estimating amount of noise in blurred images for various blurring models and noise models. Moreover, it is shown how the accuracy of the estimator is limited in case of low number of available measurements in some problems.

Chapter 4 contributes to a very complex and challenging area of studying behavior of short-recurrence based Krylov subspace methods (to which the methods discussed in Chapter 2 and 3 belong) in finite precision computations. Here the rounding errors typically cause significant delay of convergence, which has been observed and analyzed during past 50 years, but many open questions are still present. This chapter concentrates on the entities whose size does not decay monotonically with the increasing number of iterations (such as residuals in CG). It is shown that it is possible to relate the (theoretical) exact entities with the finite precision ones, but the later ones have to be specifically aggregated over the intermediate results. Some early ideas on the relationship between exact and computed Ritz vectors are presented.

Chapter 5 considers inverse (in particular image deblurring) problems contaminated by mixed Poisson-Gaussian noise, where additional difficulties are caused by the presence of outliers in the measured data. While the two types of errors are typically addressed separately in the literature, this chapter presents an approach allowing to deal with both of them at the same time. The derived model leads to an optimization scheme that is solved by a variant of Newton's method with the inner preconditioned CG solver. Possibility of using Gauss-Newton method allowing to include more general loss-functions is discussed.

Conclusion:

Overall, the PhD thesis clearly contributes to the knowledge and understanding of the field of solution of discrete inverse problems, and follows all the requirements aimed for obtaining the PhD degree. Thus it is my great pleasure to recommend it for the defense.

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