



AFRL-OSR-VA-TR-2015-0178

Toward Overcoming the Local Minimum Trap in MFBD

**James Nagy
EMORY UNIVERSITY**

**07/14/2015
Final Report**

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REPORT DOCUMENTATION PAGE

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| 13. SUPPLEMENTARY NOTES |
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| 14. ABSTRACT Multi-frame blind deconvolution (MFBD) requires solving an optimization problem with an objective function that may have many local minima. Standard numerical optimization methods may become trapped in one of these local minimum points, resulting in poor image reconstructions. The aim of this proposed research is to develop new computational approaches that help to overcome the local minimum trap for iterative MFBD algorithms. Success in this research requires new approaches in several, interrelated areas, including: obtaining a good initial guess, improved regularization methods and approaches for choosing regularization parameters, mathematical analyses and efficient computational methods to reduce the parameter space, and development of efficient implicit filtering algorithms for large scale optimization problems. In the three years of this grant, we have developed software, investigated the use of implicit filtering methods to avoid local minima, considered Gaussian Markov random fields to improve regularization, and we have developed methods for sparsity constraints that can be used for large scale MFBD problems. The work done on this, and a previous AFOSR grant, initiated a very productive collaboration with Dr. Stuart Jefferies, IFA, |
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| 15. SUBJECT TERMS Multi-frame blind deconvolution, optimization, local minimum, regularization, filtering |
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AFOSR Final Project Report

Proposal Title: Toward Overcoming the Local Minimum Trap in MFBD

Proposal Number: FA9550-12-1-0084

PI: James Nagy
Professor
Mathematics and Computer Science
Emory University
Atlanta, GA

Program Manager: Dr. Julie Moses

Project Summary

Multi-frame blind deconvolution (MFBD) requires solving an optimization problem with an objective function that may have many local minima. Standard numerical optimization methods may become trapped in one of these local minimum points, resulting in poor image reconstructions. The aim of this proposed research is to develop new computational approaches that help to overcome the local minimum trap for iterative MFBD algorithms. Success in this research requires new approaches in several, interrelated areas, including: obtaining a good initial guess, improved regularization methods and approaches for choosing regularization parameters, mathematical analyses and efficient computational methods to reduce the parameter space, and development of efficient implicit filtering algorithms for large scale optimization problems.

In the three years of this grant, we have developed software, investigated the use of implicit filtering methods to avoid local minima, considered Gaussian Markov random fields to improve regularization, and we have developed methods for sparsity constraints that can be used for large scale MFBD problems. The work done on this, and a previous AFOSR grant, initiated a very productive collaboration with Dr. Stuart Jefferies, IFA, University of Hawaii, Dr. Douglas Hope, U.S. Air Force Academy, and Dr. Michael Hart, Physics and Astronomy, University of Arizona.

Accomplishments for Period: March 15, 2012 – March 14, 2015

Graduate Student Support. This grant was used to partially support three graduate students:

| Student | # years in PhD program | Months of support |
|-------------------|------------------------|-------------------|
| Qing Chu | 5 | 8 |
| Sebastian Berisha | 5 | 6.75 |
| Keith Kelly | 2 | 6 |
| Clarissa Garvey | 2 | 6 |

Qing Chu completed her PhD in summer 2013, and Sebastian Berisha completed his PhD in summer 2014. Keith Kelly, who worked with the PI as an undergraduate and a first year Masters student, is now a PhD student at the University of Texas, Austin. Clarissa is outstanding second year graduate student.

In addition, Qing Chu received Honorable Mention for her paper *Wavefront Reconstruction in Adaptive Optics Imaging* at the Copper Mountain Conference on Iterative Methods, March 25-29, 2012. Qing also gave an oral presentation at the conference.

Keith Kelly presented a poster at the 2013 AMOS Conference, September 10-13, 2013.

Clarissa Garvey and Sebastian Berisha participated in the Trilinos User Group Meeting at Sandia National Laboratory, Albuquerque, NM, November 4-5, 2014.

Publications.

The following papers were written in the first two years of this grant:

- A. Cornelio, E. Loli-Piccolomini, and J. G. Nagy. *Constrained Variable Projection Method for Blind Deconvolution*, Journal of Physics: Conference Series, volume 386, issue 1, pages 012005, 2012.
- S. Berisha and J. G. Nagy. *Iterative Methods for Image Restoration*, Academic Press Library in Signal Processing: Image Video Processing and Analysis, Hardware, Audio, Acoustic and Speech Processing, Academic Press, editor S. Theodoridis, September 2013.
- Q. Chu, S. M. Jefferies, and J. G. Nagy. *Iterative Wavefront Reconstruction for Astronomical Imaging*, SIAM J. Sci. Comput., volume 35, issue 5, pages S84-S103, 2013.
- J. M. Bardsley, M. Howard, and J. G. Nagy. *Image Deblurring, Gaussian Markov Random Fields, and Neumann Boundary Conditions*, Elect. Trans. Numer. Anal., volume 40, pages 476–488, 2013.
- S. M. Jefferies, D. A. Hope, M. Hart and J. G. Nagy, *High-resolution imaging through strong atmospheric turbulence*. Proceedings of the SPIE, volume 8890, doi:10.1117/12.2028193, October 25, 2013.
- K. W. Kelly and J. G. Nagy. *Parallel Implementation of a Frozen Flow Based Wave-Front Reconstructor*, AMOS Technical Conference, Kihei, HI, 2013.
- A. Cornelio, E. Loli-Piccolomini, and J. G. Nagy. *Constrained Numerical Optimization Methods for Blind Deconvolution*, Numerical Algorithms, volume 65, issue 1, pages 23–42, 2014.
- P. C. Hansen, J. G. Nagy and K. Tigkos. *Rotational Image Deblurring with Sparse Matrices*, BIT Numerical Mathematics, 54, pages 649–671, 2014.
- S. Gazzola and J. G. Nagy. *Generalized Arnoldi-Tikonov Method for Sparse Reconstruction*, SIAM J. Sci. Comput., volume 36, issue 2, pages B225-B247, 2014.
- J. G. Nagy, S. M. Jefferies, M. Hart, and D. A. Hope. *Fast Tomographic Reconstruction of Atmospheric Turbulence from Micro-lens Imagery* Proceedings of the Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, September 9–12, 2014.
- S. Berisha, J. G. Nagy and R. J. Plemmons. *Estimation of Atmospheric PSF Parameters for Hyperspectral Imaging*. Numer. Lin. Alg. Appl., to appear, 2015.
- S. Berisha, J. G. Nagy and R. J. Plemmons. *Deblurring and Sparse Unmixing of Hyperspectral Images using Multiple Point Spread Functions*. SIAM J. Sci. Comput., to appear, 2015.

Conference, Colloquia, and Seminar Activities.

The following talks/lectures were given by PI Nagy:

- *Separable Nonlinear Inverse Problems and the Local Minimum Trap*. Copper Mountain Conference on Iterative Methods.
Copper Mountain, CO, March 25–29, 2012. Contributed Talk.
- *Implicit Filtering Methods for Inverse Problems*. SIAM Conference on Applied Linear Algebra. Valencia, Spain, June 16–23, 2012.
Invited Minisymposium Talk.
- *Large Scale Inverse Problems in Image Reconstruction*. SAMSI Opening Workshop on Massive Datasets Program. Research Triangle Park, Durham, NC, September 9–12, 2012.
Invited Plenary Talk.
- *Wavefront Reconstruction in Adaptive Optics Imaging*. VA Tech Department of Mathematics Colloquium. Blacksburg, VA, November 30, 2012.
Invited Talk.
- *Hybrid Krylov Subspace Methods for Inverse Problems*. New Frontiers in Numerical Analysis and Scientific Computing Conference, Kent State University, April 18–21, 2013.
Invited Talk.
- *Iterative Krylov Subspace Methods for Sparse Reconstruction*. International Workshop on Numerical Linear Algebra with Applications, Hong Kong, November 14–19, 2013.
Invited Talk.
- *Parallel Implementation of a Frozen Flow Based Wave-Front Reconstructor*, Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, Kihei HI, 2013.
Poster Presentation (given by student co-author K. W. Kelly).
- *Iterative Methods for Image Restoration*. 4th Workshop on Mathematical Analysis on Inverse Problems and Imaging, National Astronomical Observatory of Japan, Tokyo, Japan, January 8, 2014.
Invited Talk.
- *Wavefront Phase Reconstruction using a Frozen Flow Model*. 4th Workshop on Mathematical Analysis on Inverse Problems and Imaging, National Astronomical Observatory of Japan, Tokyo, Japan, January 8, 2014.
Invited Talk.
- *Imaging Through Strong Turbulence*. SIAM Conference on Imaging Science, Hong Kong, China, May 12–14, 2014.
Organized Minisymposium jointly with S. M. Jefferies.
- *Computational Methods for Inverse Problems with Applications in Image Processing*. University of Padova, Padova, Italy, February 17–25, 2014.
Invited Short Course for PhD Students.
- *Structured Computations in Multi-Frame Blind Deconvolution*. Structured Matrices and Tensors: Analysis, Algorithms and Applications, National Taiwan University, Taipei, Taiwan, December 8–11, 2014.
Invited Talk.

- *Tomographic Reconstruction of Atmospheric Turbulence from Microlens Imagery*. Optical Society of America topical meeting on Signal Recovery and Synthesis, Seattle, WA, July 13–17, 2014.
Invited Talk.
- *Tomographic Reconstruction of Atmospheric Turbulence from Microlens Imagery*. SIAM Conference on Imaging Science, Hong Kong, May 12–14, 2014.
Invited Talk.
- *Fast Tomographic Reconstruction of Atmospheric Turbulence from Micro-lens Imagery* Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, September 9–12, 2014.
Poster Presentation.
- *Numerical Linear Algebra and Blind Deconvolution*. Householder Symposium XIV, Spa, Belgium, June 9–13, 2014.
Poster Presentation.
- *Hybrid Constrained Iterative Methods for Inverse Problems*. SIAM-SEAS Conference, University of Alabama at Birmingham, March 20–22, 2015.
Invited Plenary Talk.

Future research activities resulting from this project. This project has produced several important research publications, and has initiated avenues of further research. In particular, because of this project, we have been inspired to continue work in the following areas:

- We have an ongoing MATLAB software project, called *RestoreTools*, that uses an object oriented approach to implement iterative image deblurring methods. Graduate student Sebastian Berisha has recently worked on updating the package, and has translated some of these codes into C++/MPI implementations for high performance computers. Two other students, Clarissa Garvey and James Herring, are being trained to make further contributions to this aspect of our work.
- The work we have done on using implicit filtering to avoid the local minimum trap in blind deconvolution problems has only scratched the surface of what may be possible. These methods are expensive to implement for complicated blurs, especially for cases where the blur is spatially variant. It is therefore important to focus on spatially variant blind deconvolution problems.
- An area of great interest and activity in the research community is sparse reconstructions. The algorithms for sparse reconstructions are expensive for large scale problems, such as those that arise in multi-frame blind deconvolution. The idea of using sparsity constraints, though, can be helpful in reducing some of the problems associated with local minima, and thus we have been putting a substantial amount of effort into this problem. We have already developed two different approaches for this problem: the first one is based on the idea of the Iteratively Reweighted Least Squares method and can be efficiently implemented in the context of Flexible Krylov Subspaces; the second one is based on restarting the iterative Arnoldi algorithm. A paper on this work has already been published, and we intend to continue working in this important area.

- Related to the previous item is iteratively reweighted least squares methods that account for outliers in data. Our interest in this area is motivated in part by some recent work by Dr. Brandoch Calef (Boeing) on iteratively reweighted MFBD methods. Calef's work shows great promise, and we are interested in developing this further, especially focusing on the efficient computational aspects.

1.

1. Report Type

Final Report

Primary Contact E-mail**Contact email if there is a problem with the report.**

nagy@mathcs.emory.edu

Primary Contact Phone Number**Contact phone number if there is a problem with the report**

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Organization / Institution name

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Grant/Contract Title**The full title of the funded effort.**

Toward Overcoming the Local Minimum Trap in MFBD

Grant/Contract Number**AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".**

FA9550-12-1-0084

Principal Investigator Name**The full name of the principal investigator on the grant or contract.**

James G. Nagy

Program Manager**The AFOSR Program Manager currently assigned to the award**

Julie Moses

Reporting Period Start Date

03/15/2012

Reporting Period End Date

03/14/2015

Abstract

Multi-frame blind deconvolution (MFBD) requires solving an optimization problem with an objective function that may have many local minima. Standard numerical optimization methods may become trapped in one of these local minimum points, resulting in poor image reconstructions. The aim of this proposed research is to develop new computational approaches that help to overcome the local minimum trap for iterative MFBD algorithms. Success in this research requires new approaches in several, interrelated areas, including: obtaining a good initial guess, improved regularization methods and approaches for choosing regularization parameters, mathematical analyses and efficient computational methods to reduce the parameter space, and development of efficient implicit filtering algorithms for large scale optimization problems.

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Archival Publications (published) during reporting period:

A. Cornelio, E. Loli Piccolomini, and J. G. Nagy.

Constrained Variable Projection Method for Blind Deconvolution,

Journal of Physics: Conference Series, volume 386, issue 1, pages 012005, 2012.

S. Berisha and J. G. Nagy.

Iterative Methods for Image Restoration,

book chapter in Academic Press Library in Signal Processing: Image Video Processing and Analysis,

Hardware, Audio, Acoustic and Speech Processing,

Academic Press, editor S.~Theodoridis, September 2013.

Q. Chu, S. M. Jefferies, and J. G. Nagy.

Iterative Wavefront Reconstruction for Astronomical Imaging,

SIAM J. Sci. Comput., volume 35, issue 5, pages S84-S103, 2013.

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High-resolution imaging through strong atmospheric turbulence.

Proceedings of the SPIE, volume 8890, doi:10.1117/12.2028193,

October 25, 2013.

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Parallel Implementation of a Frozen Flow Based Wave-Front Reconstructor,

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Deblurring and Sparse Unmixing of Hyperspectral Images using Multiple Point Spread Functions,
SIAM J. Sci. Comput., to appear, 2015.

Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, \$K)

| | Starting FY | FY+1 | FY+2 |
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| Supplies | | | |
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