



AFRL-OSR-VA-TR-2015-0039

High-Fidelity Geometric Modeling and Mesh Generation for Mechanics Characterization of Polycrystalline Materials

**Yongjie Zhang
CARNEGIE MELLON UNIVERSITY**

**01/07/2015
Final Report**

DISTRIBUTION A: Distribution approved for public release.

**Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTA
Arlington, Virginia 22203
Air Force Materiel Command**

REPORT DOCUMENTATION PAGE

*Form Approved
OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Service Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE (DD-MM-YYYY) 26-10-2014	2. REPORT TYPE Final Report	3. DATES COVERED (From - To) Oct 1, 2011-Sep 30, 2014
--	---------------------------------------	---

4. TITLE AND SUBTITLE High-Fidelity Geometric Modeling and Mesh Generation for Mechanics Characterization of Polycrystalline Materials	5a. CONTRACT NUMBER
	5b. GRANT NUMBER FA9550-11-1-0346
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S) Yongjie Zhang	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Mechanical Engineering Carnegie Mellon University Scaife Hall, 5000 Forbes Avenue Pittsburgh, PA 15213	8. PERFORMING ORGANIZATION REPORT NUMBER
--	---

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. Fariba Fahroo, Computational Mathematics, AFOSR/RSL, Tel: (703) 696-8429, Fax: (703) 696-8450, Email: fariba.fahroo@afosr.af.mil	10. SPONSOR/MONITOR'S ACRONYM(S)
Dr. David Stargel, Multi-Scale Structural Mechanics & Prognosis, AFOSR/RSA, Tel: (703) 696-6961, Fax: (703) 696-7320, Email: david.stargel@afosr.af.mil	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT None
--

13. SUPPLEMENTARY NOTES None
--

14. ABSTRACT During the Fiscal Year 2014 (from October 1, 2013 to September 30, 2014), the PI and her group worked on the following four problems. Based on our research, we have published three book/book chapters, 4 peer-reviewed journal papers and 2 peer-reviewed conference papers. 1. Image-Based Geometric Modeling and Mesh Generation. 2. Quality Improvement for Segmented Hexahedral Meshes Using Geometric Flows. 3. Adaptive and Anisotropic All-Hexahedral Mesh Generation Using a Hybrid Octree and Bubble Packing. 4. Octree-based Dual Contouring Method for Triangular and Tetrahedral Mesh Generation with Guaranteed Angle Range.
--

15. SUBJECT TERMS None

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)

Reset

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

To: technicalreports@afosr.af.mil
Subject: Final Progress Statement to Drs. Fariba Fahroo and David Stargel

Contract/Grant Title: High-Fidelity Geometric Modeling and Mesh Generation for Mechanics Characterization of Polycrystalline Materials

Contract/Grant #: FA9550-11-1-0346

Reporting Period: October 1, 2013 to September 30, 2014

Annual accomplishments (200 words max):

During the Fiscal Year 2014 (from October 1, 2013 to September 30, 2014), the PI and her group worked on the following three problems. Based on our research, we have published four book/book chapters [1-4], 7 peer-reviewed journal papers [5-11] and 2 peer-reviewed conference papers [12-13].

1. **Image Restoration of Phase Contrast Nano Scale X-ray CT Images.** Zernike phase contrast is a technique useful for nano-scale X-ray imaging of materials with a low absorption coefficient. It enhances the image contrast, but it also creates artifacts that hinder the use of traditional techniques for segmentation. We have developed an image restoration method [5] to remove artifacts in multiple phase contrast CT images and aid image segmentation.
2. **Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation.** We have developed an extended model [6] named harmonic edge-weighted centroidal Voronoi tessellation. This method can overcome the sensitivity to the seed point initialization and noise, and also improve the accuracy and stability of clustering results.
3. **Adaptive and Anisotropic Surface T-mesh Generation from Cross Field.** We have developed a cross field-based method [7, 12] to generate adaptive and anisotropic quadrilateral meshes, which can be used as the control mesh for high-order T-spline surface modeling.

Archival publications (published) during reporting period:

1. Computational Modeling of Objects Presented in Images: Fundamentals, Methods, and Applications. 4th International Conference, CompIMAGE 2014, Pittsburgh, PA, USA, September 3-5, 2014. Lecture Notes in Computer Science, Volume 8641. Springer Publisher. Editor: Yongjie Jessica Zhang and Joao Manuel R. S. Tavares. ISBN: 978-3-319-09993-4 (Print), 978-3-319-09994-1 (Online).
2. Image-Based Geometric Modeling and Mesh Generation. Lecture Notes in Computational Vision and Biomechanics, Volume 3. Springer Publisher. Editor: Yongjie (Jessica) Zhang. ISBN-10: 9400742541, ISBN-13: 978-9400742543. 2013.
3. Y. Zhang. Challenges and Advances in Image-Based Geometric Modeling and Mesh Generation. *Image-Based Geometric Modeling and Mesh Generation*. Springer Publisher. Editor: Yongjie (Jessica) Zhang, 2013. (Review Article)
4. J. Leng, G. Xu, Y. Zhang, J. Qian. Quality Improvement of Segmented Hexahedral Meshes using Geometric Flows. *Image-Based Geometric Modeling and Mesh Generation*. Springer Publisher. Editor: Yongjie (Jessica) Zhang, 2013.
5. A. Kumar, P. Mandal, Y. Zhang, S. Litster. Image Restoration of Phase Contrast Nano Scale X-ray CT Images. Lecture Notes in Computer Science, 8461:280-285, 2014.
6. K. Hu, Y. Zhang. Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation. Lecture Notes in Computer Science, 8461:164-175, 2014.
7. T. Liao, G. Xu, Y. Zhang. Structure-Aligned Guidance Estimation in Surface Parameterization Using Eigenfunction-based Cross Field. *Graphical Models*, 76(6):691-705, 2014
8. X. Liang, Y. Zhang. An Octree-based Dual Contouring Method for Triangular and Tetrahedral Mesh Generation with Guaranteed Angle Range. *Engineering with Computers*, 30(2):211-222, 2014.
9. J. Leng, Y. Zhang, G. Xu. A Novel Geometric Flow-Driven Approach for Quality Improvement of Segmented Tetrahedral Meshes. *Computer-Aided Design*, 45(10):1182-1197, 2013.
10. J. Qian, Y. Zhang, D. T. O'Connor, M. S. Greene, W. K. Liu. Intersection-free Tetrahedral Meshing from Volumetric Images. *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, 1(2):100-110, 2013.

11. Y. Zhang, X. Liang, G. Xu. A Robust 2-Refinement Algorithm in Octree and Rhombic Dodecahedral Tree Based All-Hexahedral Mesh Generation. *Computer Methods in Applied Mechanics and Engineering*, 256:88-100, 2013.
12. T. Liao, W. Wang, Y. Zhang. Adaptive and Anisotropic T-mesh Generation from Cross Field. Workshop on Structured Meshing: Theory, Application and Evaluation, the 27th Conference on Computer Animation and Social Agents (CASA 2014). Houston, TX. May 26-28, 2014.
13. K. Hu, J. Qian, Y. Zhang. Adaptive All-Hexahedral Mesh Generation Based on a Hybrid Octree and Bubble Packing. *22nd International Meshing Roundtable*. Orlando, FL. Oct. 13-16, 2013.

Changes in research objectives, if any: None

Change in AFOSR program manager, if any: None

Extensions granted or milestones slipped, if any: None

Include any new discoveries, inventions, or patent disclosures during this reporting period (if none, report none): None

Abstracts (250 words or more)

During the Fiscal Year 2014 (from October 1, 2013 to September 30, 2014), the PI and her group worked on the following three problems. Based on our research, we have published four book/book chapters [1-4], 7 peer-reviewed journal papers [5-11] and 2 peer-reviewed conference papers [12-13].

(1) Image Restoration of Phase Contrast Nano Scale X-ray CT Images

Zernike phase contrast is a useful technique for nanoscale X-ray computed tomography (CT) of materials with a low X-ray absorption coefficient. It enhances the image contrast using a phase ring. However, it also creates artifacts that hinder the use of traditional image segmentation techniques. We have developed an image restoration method [5] that models the X-ray phase contrast optics, computes a 3D kernel and minimizes an energy function. Though similar ideas have been used for visible light microscopy, this method employs an effective edge detection method and can be applied on various types of samples. Using this algorithm, we restore multiple phase contrast X-ray CT images and threshold them to produce segmented results. We quantitatively evaluate and compare our method to other segmentation techniques to demonstrate its high accuracy.

(2) Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation

We have extended the basic edge-weighted centroidal Voronoi tessellation (EWCVT) for image segmentation to a new advanced model [6], namely harmonic edge-weighted centroidal Voronoi tessellation (HEWCVT). This extended model introduces a harmonic form of clustering energy by combining the image intensity with cluster boundary information. Improving upon the classic CVT and EWCVT methods, the HEWCVT algorithm can not only overcome the sensitivity to the seed point initialization and noise, but also improve the accuracy and stability of clustering results, as verified in several types of images. We then present an adaptive superpixel generation algorithm based on HEWCVT. First, an innovative initial seed sampling method based on quadtree decomposition is introduced, and the image is divided into small adaptive segments according to a density function. Then, the local HEWCVT algorithm is applied to generate adaptive superpixels. The presented algorithm is capable of generating adaptive superpixels while preserving local image features efficiently.

(3) Adaptive and Anisotropic Surface T-mesh Generation from Cross Field

In this study, an extended cross field-based parameterization method [7, 12] is developed to adapt the parametric line spacings to different surface resolutions. Moreover, an anisotropy defined from an input scalar field can also be achieved. From the parameterization results, we extract adaptive and anisotropic T-meshes for the further T-spline surface construction. Finally, a gradient flow-based method is developed to improve the T-mesh quality, with the anisotropy preserved in the quadrilateral elements. The effectiveness of the presented algorithm has been verified using several complex models.

Research Progress

This section will describe the accomplishments in detail for Fiscal Year 2014 for the project. The PI and her group mainly worked on three specific problems.

1. Image Restoration of Phase Contrast Nano Scale X-ray CT Images

X-ray CT images can be very effective in differentiating materials by their density and absorption coefficient. However, many materials in engineering applications, such as polymers, carbon structures and soft tissues, often have a low atomic number and offer negligible contrast relative to their surroundings. In addition, many of these materials have sub-micron features of interest that require nanoscale resolution X-ray CT (nanoCT). The use of lens-based X-ray optics, that achieves resolutions as high as 30-50nm, makes Zernike phase contrast the most suitable technique for nanoCT. Unfortunately, this imaging technique produces an image with artifacts, which makes image segmentation a significant challenge. The two main artifacts are halos and shade-off. Halos are bright or dark thin regions around the boundary of the sample. These false edges around the object make many segmentation algorithms, such as level-set and region growing methods, less robust. Shade-off refers to the similar range of intensities the object and the background share away from edges. This reduces the efficiency of methods based on histogram analysis. Due to these artifacts, standard segmentation techniques produce inaccurate results despite structural boundaries being clearly visible to the human eye.

Efforts to automate the segmentation of phase contrast images have mostly been applied in visible light biological microscopy. It is still a developing area of research. There is no general optimal method and post hoc methods are often applied. Morphology tools and Laplace of Gaussian filters for edge detection are prone to errors due to shade-off. Level set methods tend to fail at halos and boundaries with large gradients. However, they can be improved using machine learning-based validations and intelligent contour initialization. Restoring artifact-free images based on a derived model of the microscope optics can also make segmentation more robust. Current trends show that the use of phase contrast imaging is becoming more prevalent in X-ray microscopy. The primary research focus has been on developing new reconstruction methods to improve the quality and increase the contrast of CT images. Previous work retrieved the phase shift of each radiograph by modelling the refractive index of the object. Other interesting methods include frequency harmonics, regularization techniques and optics modeling. However, a lot of these attempts verified their theoretical work using simulations and have not focused on segmenting acquired CT images.

Lastly and importantly, phase retrieval algorithms often perform poorly for Zernike phase contrast, leaving a dearth of previous work for this application. Fig. 1(a) shows the important components of a typical nanoCT instrument using Zernike phase contrast optics. The Fresnel zone plate (FZP) achieves the nanoCT's high resolution by means of diffraction. Upon transmission through the sample, the waveform from the X-ray source can be divided into two different components, the diffracted and undiffracted waves. As shown in Fig. 1(b), the phase difference between the diffracted wave and sample wave, which is the sum of all waves, is related to the change in refractive indices of the wave medium. However, the resulting amplitude difference is minimal and provides insufficient image contrast. The key component of Zernike phase contrast is the phase ring. It increases the image contrast by phase shifting the undiffracted wave by $-\pi/2$. However, a fraction of the diffracted wave leaks onto the phase ring and is also phase shifted by $-\pi/2$. As a result, bright artifacts appear where the magnitude of the sample wave is lower than that of the undiffracted wave. This is illustrated in Fig. 1(c).

Our work aims to deconvolve nanoCT images, eliminate the artifacts and generate accurate segmented results. To that end, we model the phase contrast optics of a nanoCT instrument, minimize an energy function and threshold the restored images. We present the modelling of the nanoCT components and the computational tools to derive the system's kernel. It also outlines our method of computing the 3D kernel,

which allows us to extend our method to CT images from radiographs. The set up of an inverse problem is a new technique for Zernike phase contrast in nanoCT. An energy function and the robust edge detection method are used to solve the inverse problem. This solution procedure is more flexible for samples with different geometries than that of previous restoration techniques in visible light microscopy. We use multiple CT images obtained from the nanoCT (UltraXRM-L200, Xradia Inc., Pleasanton, CA) for testing and show their restored images and segmentations. Despite ground truth segmentations not available, we qualitatively and quantitatively show the high accuracy of our results. Figure 2 shows an example.

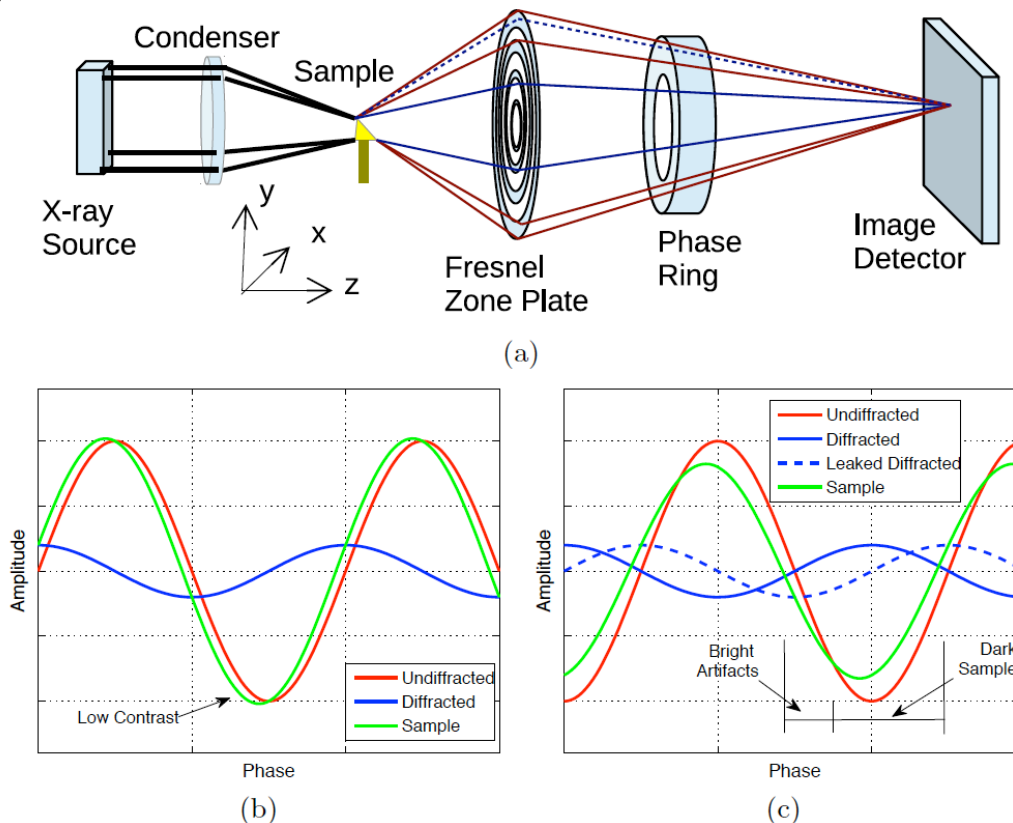


Figure 1. Illustration of the benefits and drawbacks of the phase ring. (a) Schematic of the diffracted and undiffracted waves through the important components of a CT machine; (b) low contrast without the phase ring; and (c) higher contrast and artifacts due to the negative shift of the undiffracted wave and a portion of the diffracted wave respectively.

2. Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation

Image segmentation has been one of the core topics in computer vision and image processing for decades. Its central task is to partition an image into subsets of pixels that share similar characteristics, such as color, brightness or texture. The success of most tasks requiring image analysis is often a direct consequence of the success of segmentation. Many methods have been developed for image segmentation, such as thresholding, edge detection, level set method and clustering techniques. Since each method has its own advantages and drawbacks, the appropriate method tends to depend on the nature of the particular application. As an over-segmentation of the image, superpixels have also become popular as they provide an efficient preprocessing tool for various computer vision applications. A superpixel is defined as a homogeneous image region that aligns well with object boundaries. It has been shown that using superpixels is advantageous because they can preserve natural image boundaries and reduce redundant information of the image data as well as enforce local consistency. Many algorithms have been developed to divide an image into superpixels, such as NCuts, TurboPixel and SLIC.

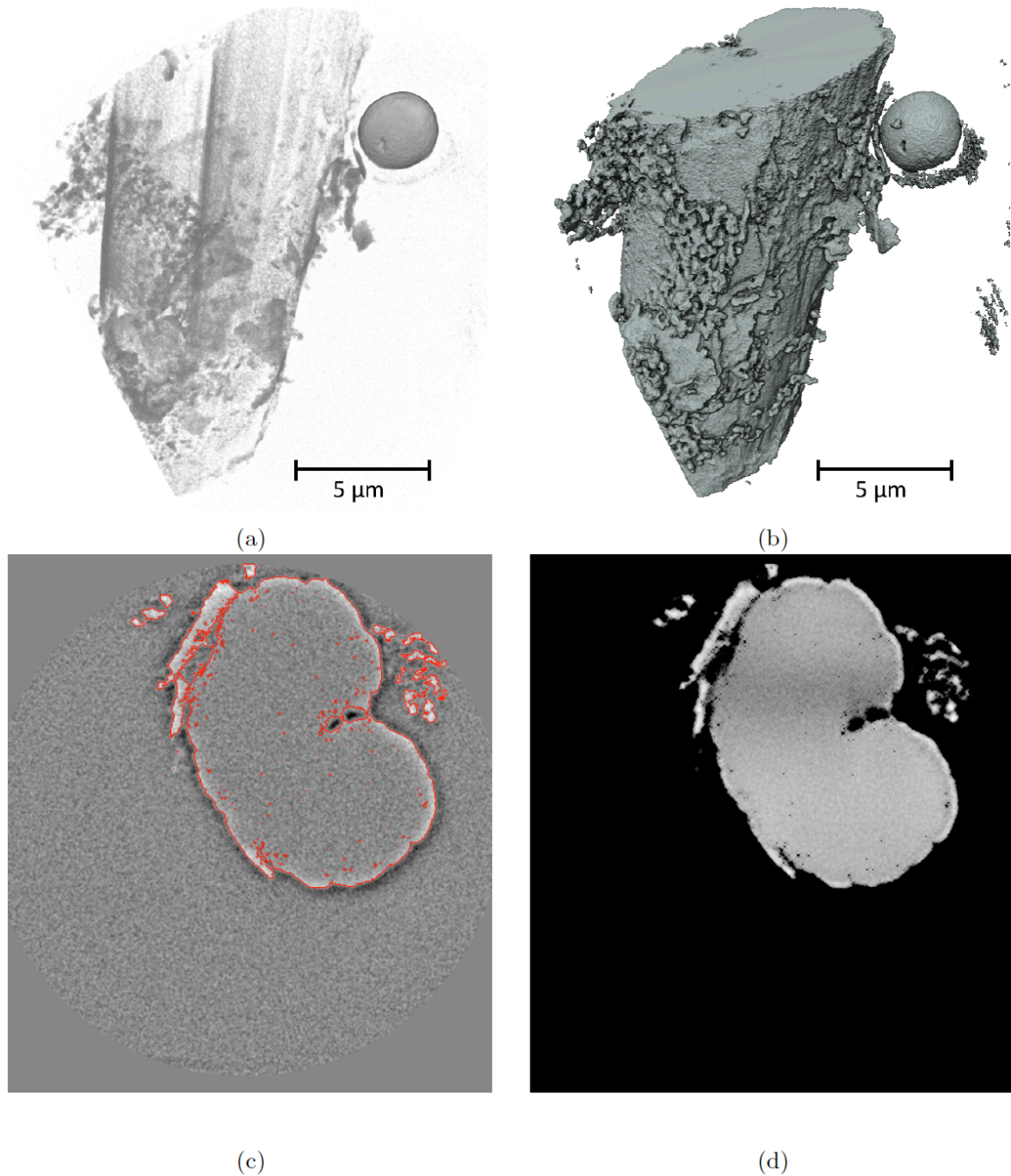


Figure 2. Volume rendering of the (a) high intensities and (b) segmentation of the fiber coated with PTFE. A slice of the (c) original image, whose segmentation is outlined by the red curve, and (d) corresponding slice of the original image.

In recent years, a lot of efforts have been put into the research of Centroidal Voronoi tessellation (CVT) based methods for both image segmentation and superpixel generation. The classic CVT method and edge-weighted centroidal Voronoi tessellation (EWCVT) methods are sensitive to seed point initialization, which may result in incorrect and unstable segmentation results. To extend the EWCVT method for both image segmentation and superpixel generation, we first develop an innovative model named harmonic

edge-weighted centroidal Voronoi tessellation (HEWCVT) for image segmentation. The proposed method extends and improves upon the EWCVT method by using the harmonic formulation in the clustering energy function. We then present an adaptive superpixel generation algorithm based on the local HEWCVT. Compared to the classic CVT and EWCVT methods, our proposed algorithms have three main advantages: (1) our HEWCVT-based segmentation scheme is much more stable and less sensitive to the initializations due to an imposition of a soft membership onto the data points; (2) the segmentation accuracy is also improved since the spatial information of local image features is integrated into the harmonic form energy function to compensate for the effect of noise; and (3) we propose an innovative adaptive superpixel generation algorithm using quadtree decomposition and density function, yielding high quality adaptive superpixels with image features preserved efficiently. Figures 3-4 show two examples.

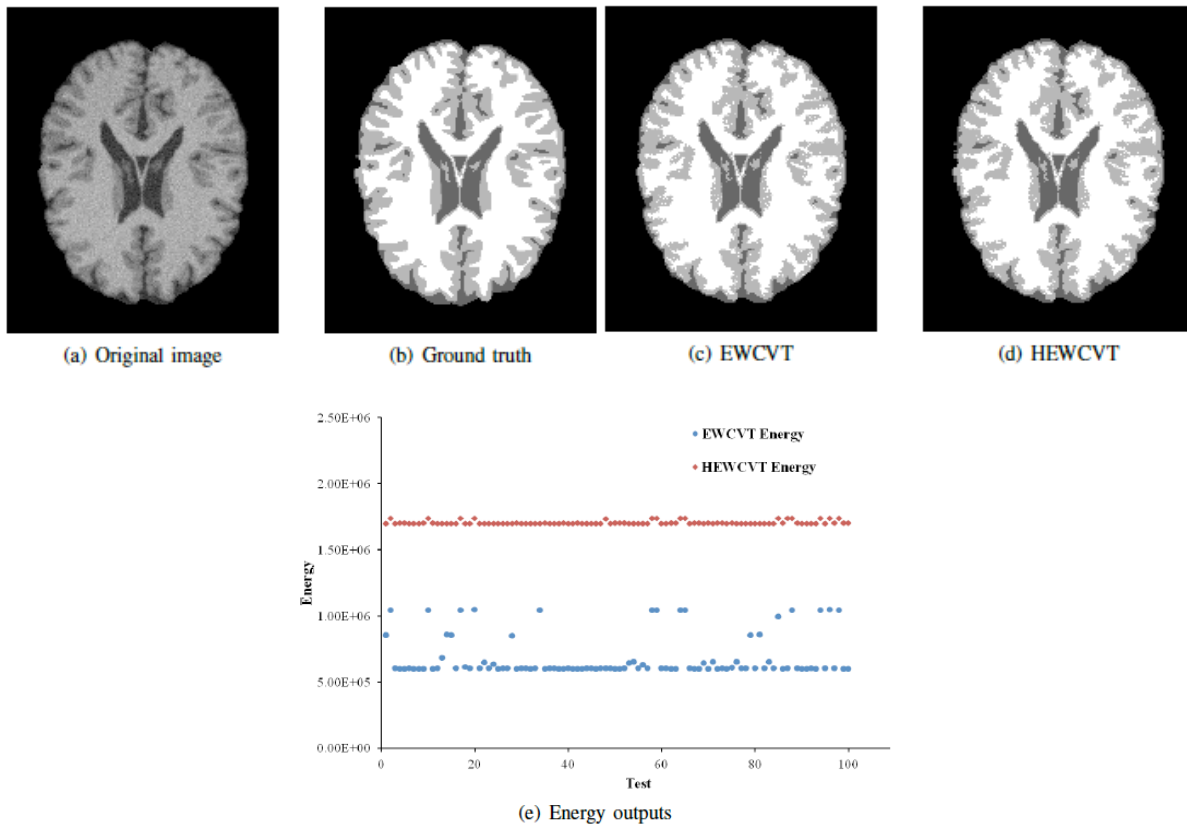


Figure 3. Segmentation results of a brain MRI-T1 image with 7% noise and 20% INU. (a) Original image; (b) ground truth result; (c) EWCVT; (d) HEWCVT; and (e) energy outputs.

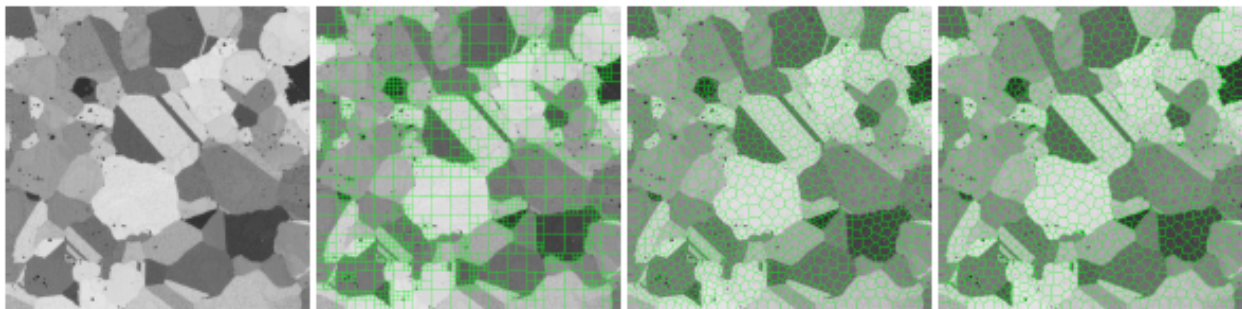


Figure 4. Adaptive superpixel generation results of Alloy. From left to right: original image, quadtree decomposition, CVT in physical space, and adaptive superpixels.

3. Adaptive and Anisotropic Surface T-mesh Generation from Cross Field

T-mesh is made up of quadrilateral elements with T-junctions on the edges. In recent years, global parameterization methods were introduced to generate quadrilateral meshes. Some of these methods capture surface features using a cross field, and align the quadrilateral elements to the feature directions. Most of the methods yield uniform quadrilateral elements. It remains a challenge to achieve the adaptation or anisotropy together with the orthogonality in the parametric lines due to the difficulty in the vector field optimization. In this study, we extended the cross field-based method for adaptive and anisotropic parameterization, which adapts the parametric line spacings to multi-resolution surface features; and also developed a new gradient flow-based method for T-mesh quality improvement, with the anisotropy in quadrilateral elements preserved. Figure 5 shows three results.

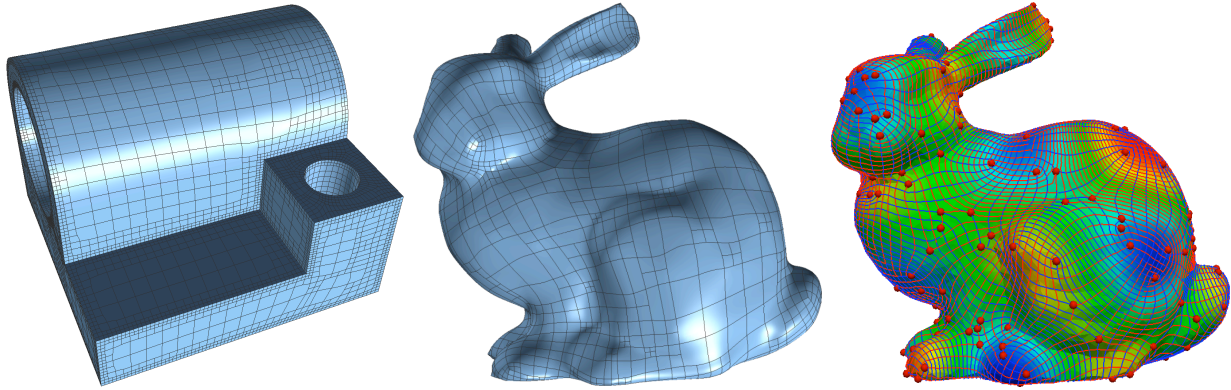


Figure 5. Isotropic (left and middle) and anisotropic (right) T-mesh results of a bunny model. For the right picture, one eigenfunction is used to build the cross field.

Conclusion

During FY 2014, the PI and her group worked on three specific research problems: (1) Image Restoration of Phase Contrast Nano Scale X-ray CT Images; (2) Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation; and (3) Adaptive and Anisotropic Surface T-mesh Generation from Cross Field. Based on our research, we have published four book/book chapters [1-4], 7 peer-reviewed journal papers [5-11] and 2 peer-reviewed conference papers [12-13].

References

1. Computational Modeling of Objects Presented in Images: Fundamentals, Methods, and Applications. 4th International Conference, CompIMAGE 2014, Pittsburgh, PA, USA, September 3-5, 2014. Lecture Notes in Computer Science, Volume 8641. Springer Publisher. Editor: Yongjie Jessica Zhang and Joao Manuel R. S. Tavares. ISBN: 978-3-319-09993-4 (Print), 978-3-319-09994-1 (Online).
2. Image-Based Geometric Modeling and Mesh Generation. Lecture Notes in Computational Vision and Biomechanics, Volume 3. Springer Publisher. Editor: Yongjie (Jessica) Zhang. ISBN-10: 9400742541, ISBN-13: 978-9400742543. 2013.
3. Y. Zhang. Challenges and Advances in Image-Based Geometric Modeling and Mesh Generation. *Image-Based Geometric Modeling and Mesh Generation*. Springer Publisher. Editor: Yongjie (Jessica) Zhang, 2013. (Review Article)
4. J. Leng, G. Xu, Y. Zhang, J. Qian. Quality Improvement of Segmented Hexahedral Meshes using Geometric Flows. *Image-Based Geometric Modeling and Mesh Generation*. Springer Publisher. Editor: Yongjie (Jessica) Zhang, 2013.

5. A. Kumar, P. Mandal, Y. Zhang, S. Litster. Image Restoration of Phase Contrast Nano Scale X-ray CT Images. *Lecture Notes in Computer Science*, 8461:280-285, 2014.
6. K. Hu, Y. Zhang. Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation. *Lecture Notes in Computer Science*, 8461:164-175, 2014.
7. T. Liao, G. Xu, Y. Zhang. Structure-Aligned Guidance Estimation in Surface Parameterization Using Eigenfunction-based Cross Field. *Graphical Models*, 76(6):691-705, 2014
8. X. Liang, Y. Zhang. An Octree-based Dual Contouring Method for Triangular and Tetrahedral Mesh Generation with Guaranteed Angle Range. *Engineering with Computers*, 30(2):211-222, 2014.
9. J. Leng, Y. Zhang, G. Xu. A Novel Geometric Flow-Driven Approach for Quality Improvement of Segmented Tetrahedral Meshes. *Computer-Aided Design*, 45(10):1182-1197, 2013.
10. J. Qian, Y. Zhang, D. T. O'Connor, M. S. Greene, W. K. Liu. Intersection-free Tetrahedral Meshing from Volumetric Images. *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, 1(2):100-110, 2013.
11. Y. Zhang, X. Liang, G. Xu. A Robust 2-Refinement Algorithm in Octree and Rhombic Dodecahedral Tree Based All-Hexahedral Mesh Generation. *Computer Methods in Applied Mechanics and Engineering*, 256:88-100, 2013.
12. T. Liao, W. Wang, Y. Zhang. Adaptive and Anisotropic T-mesh Generation from Cross Field. Workshop on Structured Meshing: Theory, Application and Evaluation, the 27th Conference on Computer Animation and Social Agents (CASA 2014). Houston, TX. May 26-28, 2014.
13. K. Hu, J. Qian, Y. Zhang. Adaptive All-Hexahedral Mesh Generation Based on a Hybrid Octree and Bubble Packing. 22nd *International Meshing Roundtable*. Orlando, FL. Oct. 13-16, 2013.

AFOSR Deliverables Submission Survey

Response ID:4116 Data

1.

1. Report Type

Final Report

Primary Contact E-mail

Contact email if there is a problem with the report.

jessicaz@andrew.cmu.edu

Primary Contact Phone Number

Contact phone number if there is a problem with the report

1-412-2685332

Organization / Institution name

Carnegie Mellon University

Grant/Contract Title

The full title of the funded effort.

High-Fidelity Geometric Modeling and Mesh Generation for Mechanics Characterization of Polycrystalline Materials

Grant/Contract Number

AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-11-1-0346

Principal Investigator Name

The full name of the principal investigator on the grant or contract.

Yongjie Zhang

Program Manager

The AFOSR Program Manager currently assigned to the award

Fariba Fahroo and David Stargel

Reporting Period Start Date

10/01/2011

Reporting Period End Date

09/30/2014

Abstract

During the Fiscal Year 2014 (from October 1, 2013 to September 30, 2014), the PI and her group worked on the following three problems. Based on our research, we have published four book/book chapters [1-4], 7 peer-reviewed journal papers [5-11] and 2 peer-reviewed conference papers [12-13].

(1) Image Restoration of Phase Contrast Nano Scale X-ray CT Images

Zernike phase contrast is a useful technique for nanoscale X-ray computed tomography (CT) of materials with a low X-ray absorption coefficient. It enhances the image contrast using a phase ring. However, it also creates artifacts that hinder the use of traditional image segmentation techniques. We have developed an image restoration method [5] that models the X-ray phase contrast optics, computes a 3D kernel and minimizes an energy function. Though similar ideas have been used for visible light

microscopy, this method employs an effective edge detection method and can be applied on various types of samples. Using this algorithm, we restore multiple phase contrast X-ray CT images and threshold them to produce segmented results. We quantitatively evaluate and compare our method to other segmentation techniques to demonstrate its high accuracy.

(2) Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation

We have extended the basic edge-weighted centroidal Voronoi tessellation (EWCVT) for image segmentation to a new advanced model [6], namely harmonic edge-weighted centroidal Voronoi tessellation (HEWCVT). This extended model introduces a harmonic form of clustering energy by combining the image intensity with cluster boundary information. Improving upon the classic CVT and EWCVT methods, the HEWCVT algorithm can not only overcome the sensitivity to the seed point initialization and noise, but also improve the accuracy and stability of clustering results, as verified in several types of images. We then present an adaptive superpixel generation algorithm based on HEWCVT. First, an innovative initial seed sampling method based on quadtree decomposition is introduced, and the image is divided into small adaptive segments according to a density function. Then, the local HEWCVT algorithm is applied to generate adaptive superpixels. The presented algorithm is capable of generating adaptive superpixels while preserving local image features efficiently.

(3) Adaptive and Anisotropic Surface T-mesh Generation from Cross Field

In this study, an extended cross field-based parameterization method [7, 12] is developed to adapt the parametric line spacings to different surface resolutions. Moreover, an anisotropy defined from an input scalar field can also be achieved. From the parameterization results, we extract adaptive and anisotropic T-meshes for the further T-spline surface construction. Finally, a gradient flow-based method is developed to improve the T-mesh quality, with the anisotropy preserved in the quadrilateral elements. The effectiveness of the presented algorithm has been verified using several complex models.

Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form

Please attach your SF298 form. A blank SF298 can be found [here](#). Please do not spend extra effort to password protect or secure the PDF, we want to read your SF298. The maximum file size for SF298's is 50MB.

[AFD-070820-035_2014.pdf](#)

Upload the Report Document. The maximum file size for the Report Document is 50MB.

[FA9550-11-1-0346_2014.pdf](#)

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

Archival Publications (published) during reporting period:

1. Computational Modeling of Objects Presented in Images: Fundamentals, Methods, and Applications. 4th International Conference, CompIMAGE 2014, Pittsburgh, PA, USA, September 3-5, 2014. Lecture Notes in Computer Science, Volume 8641. Springer Publisher. Editor: Yongjie Jessica Zhang and Joao Manuel R. S. Tavares. ISBN: 978-3-319-09993-4 (Print), 978-3-319-09994-1 (Online).
2. Image-Based Geometric Modeling and Mesh Generation. Lecture Notes in Computational Vision and Biomechanics, Volume 3. Springer Publisher. Editor: Yongjie (Jessica) Zhang. ISBN-10: 9400742541, ISBN-13: 978-9400742543. 2013.
3. Y. Zhang. Challenges and Advances in Image-Based Geometric Modeling and Mesh Generation. Image-Based Geometric Modeling and Mesh Generation. Springer Publisher. Editor: Yongjie (Jessica) Zhang, 2013. (Review Article)
4. J. Leng, G. Xu, Y. Zhang, J. Qian. Quality Improvement of Segmented Hexahedral Meshes using Geometric Flows. Image-Based Geometric Modeling and Mesh Generation. Springer Publisher. Editor: Yongjie (Jessica) Zhang, 2013.
5. A. Kumar, P. Mandal, Y. Zhang, S. Litster. Image Restoration of Phase Contrast Nano Scale X-ray CT Images. Lecture Notes in Computer Science, 8461:280-285, 2014.
6. K. Hu, Y. Zhang. Extended Edge-Weighted Centroidal Voronoi Tessellation for Image Segmentation. Lecture Notes in Computer

Science, 8461:164-175, 2014.

7. T. Liao, G. Xu, Y. Zhang. Structure-Aligned Guidance Estimation in Surface Parameterization Using Eigenfunction-based Cross Field. Graphical Models, 76(6):691-705, 2014

8. X. Liang, Y. Zhang. An Octree-based Dual Contouring Method for Triangular and Tetrahedral Mesh Generation with Guaranteed Angle Range. Engineering with Computers, 30(2):211-222, 2014.

9. J. Leng, Y. Zhang, G. Xu. A Novel Geometric Flow-Driven Approach for Quality Improvement of Segmented Tetrahedral Meshes. Computer-Aided Design, 45(10):1182-1197, 2013.

10. J. Qian, Y. Zhang, D. T. O'Connor, M. S. Greene, W. K. Liu. Intersection-free Tetrahedral Meshing from Volumetric Images. Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 1(2):100-110, 2013.

11. Y. Zhang, X. Liang, G. Xu. A Robust 2-Refinement Algorithm in Octree and Rhombic Dodecahedral Tree Based All-Hexahedral Mesh Generation. Computer Methods in Applied Mechanics and Engineering, 256:88-100, 2013.

12. T. Liao, W. Wang, Y. Zhang. Adaptive and Anisotropic T-mesh Generation from Cross Field. Workshop on Structured Meshing: Theory, Application and Evaluation, the 27th Conference on Computer Animation and Social Agents (CASA 2014). Houston, TX. May 26-28, 2014.

13. K. Hu, J. Qian, Y. Zhang. Adaptive All-Hexahedral Mesh Generation Based on a Hybrid Octree and Bubble Packing. 22nd International Meshing Roundtable. Orlando, FL. Oct. 13-16, 2013.

Changes in research objectives (if any):

None

Change in AFOSR Program Manager, if any:

None

Extensions granted or milestones slipped, if any:

None

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
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Appendix Documents

2. Thank You

E-mail user

Nov 12, 2014 11:49:37 Success: Email Sent to: jessicaz@andrew.cmu.edu