Final Report for NSF(2009)-PFUND-133: Narrative

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1 Abstract
The goals for the project include the study of the fundamental geometric problem Harmonic Volumetric Parameterization, and development of its applications in finite element mesh generation, scientific design/simulation, and others. The PI should train graduate students through this project. Accomplishments from this project include research and education results. During the period of this project, the PI has submitted or co-submitted 5 external proposals (4 to NSF, 1 to LA-Board of Regents); the PI has published 1 book, 6 international journal and conference papers; and there are 2 journals papers under revision, 5 conference papers under review. The PI’s group made 2 international presentations. 2 first-year PhD students supported by this project have started their research.

Specific contributions of this project to Louisiana’s economic development and diversification include

• a robust volumetric data analysis and processing software (developed by the PI’s group, and will be published online when submitted papers are accepted);

  – The proposed framework for volumetric data representation will contribute to effective mesh generation for Finite Element simulation and benefit computer aided design/analysis industry in Louisiana.

  – The proposed framework will have big potential contribution to forensic facial reconstruction on the LA missing & unidentified remains, by providing a computer-aided modeling and data processing environment for anthropologists and law enforcement agencies.

• a female PhD student and a male PhD student training.

  – The female graduate student training helps diversification of the LSU graduate program.
2 Specific Accomplishments

2.1 Project Goals

- To study parameterization for solid shapes with an emphasis on mathematical rigor, accuracy, efficiency and robustness.
- Bridge novel geometric modeling knowledge with computer aided design, finite element analysis and scientific simulations/computations in CAGD, virtual reality, and etc.

2.2 Activities Conducted

- Study the theoretic foundation for volumetric harmonic parameterization and its computation, develop the efficient domain decomposition method for volumetric data so that non-degenerated mapping can be guaranteed [1];
  - It remains an open problem that how to parameterize general volumetric data, guaranteeing the bijectiveness. This work studies the existence of bijective harmonic volumetric parameterization on shape-shape subregions, and provides a constructive proof using Methods of Fundamental Solutions (MFS).
  - We develop an efficient domain decomposition framework to partition the given solid domain into star-shaped sub-domains.
  - Bijective volumetric parameterization has been computed through our divide-and-conquer framework effectively.
  - We submitted this work [1] to ACM/SIAM Symposium of Solid and Physical Modeling 2010.

- Develop the volumetric mapping [2] that (1) can handle heterogenous data, (2) can enforce semantics feature alignment, and (3) have better computation accuracy and efficiency than the preliminary work [3];
  - Our preliminary work [3] on volumetric parameterization focuses on homogenous data, without taking in to account any non-geometry issue. In real scenarios, volumetric data processing needs to handle heterogenous data and should consider feature alignment. This work focuses on designing mapping framework accommodating heterogeneity and feature-alignment.
  - We use Multiple MFS to solve a set of harmonic functions to compose the harmonic map. This new paradigm has been demonstrated to be more efficient, and more accurate than the current mapping scheme [3].
  - The new framework can handle large heterogenous data, with enforced feature alignment. This makes the mapping algorithm practical for processing real solid data.
  - We submitted this work [2] to International Conference on Shape Modeling and Application, and the special issue of Computer & Graphics, and got very good comments in the first round review. It is now under revision.
• Study the application of harmonic volumetric mapping in meshing. Regular mesh structure has been constructed ([2, 4]) that is suitable for FEM analysis ([5, 6]);

  – We develop geometry-aware decomposition framework that segment boundary surface of 3D shapes into subregions, and generate adaptive regular boundary quad-meshes, allowing adaptive T-junctions. The representation is effective and compact. The work has been published/presented in International Conference on Shape Modeling and Application 2009, and the enhanced version [4] has been published in Computer & Graphics 2009.

  – We generate high-quality hexahedral meshes for input solid object using our harmonic volumetric parameterization, the work [2] is under revision for Computer & Graphics 2010.

  – We construct polycuboid trivariate splines using our harmonic parameterization, and use it for generating adaptive hex meshes with T-junctions. This work [6] has been submitted to Fourth International Symposium on 3D Data Processing, Visualization and Transmission (3DPVT2010).

  – We use our low-distorted parameterization to design parametric T-splines, and conduct iso-geometry deformation analysis based on it. This work [5] has been submitted to International Conference on Shape Modeling and Application (SMI) 2010.

• Explore the novel applications of volumetric parameterization, including solid texture synthesis and mapping (for virtual reality applications) [7, 8], Spline construction (for CAGD design and simulation) [4–6, 9, 10]), and forensic craniofacial reconstruction.

  – We used our harmonic volumetric parameterization [3] to synthesize the interior texture from the image of its boundary texture. This work [7] has been published in International Conference on Computer Science and Education (ICCSE) 2009.

  – The new harmonic volumetric parameterization [2] is used for generating dynamic texture (e.g. video) mapping. This work demonstrates an efficient automatic texture mapping paradigm using our framework. The work [8] has been submitted to Computer Graphics International (CGI) 2010.

  – We also used harmonic parameterization to construct splines for the reverse engineering applications: reconstructing data points into CAD representations. Besides the aforementioned [5, 6], we design a novel Delaunay Configuration B-spline fitting scheme on parametric sub-domains, and use it to reconstruct 3D geometric scan data. The work has been published/presented in International Conference on Shape Modeling and Applications (SMI) 2009, and its enhanced version has been published in Computer & Graphics 2009 [9].

  – More recently, we improve the framework of [9] by using spherical harmonic parameterization and adaptive knots insertion, the work [10] has been submitted to Computer Graphics International (CGI) 2010.
2.3 The Results Obtained

- One book, Five International journal papers and Eight conference papers published or submitted.

- This project has greatly benefited the training as researchers of Huanhuan Xu and Shenghua Wan. These two PhD students supported by this project will use their work as part of their thesis.

2.4 Significance of Enhancement

- The discovery of the bijectiveness of harmonic volumetric parameterization over specific sub-shape domains, and the development of an efficient domain decomposition algorithm to conduct the parameterization via a divide-and-conquer paradigm. The non-degenerate volumetric mapping remained to be an open problem and now has a piecewise solution in our framework We plan to further explore in this problem to seek for a globally smooth solution.

- The volumetric star-shape decomposition is proved to be NP-complete, while we proposed an hybrid framework with both sub-optimal and greedy components that can generate a hierarchical result efficiently and robustly.

- The development of practical harmonic volumetric parameterization algorithms that can handle (1) large heterogenous data in real complex scenarios, (2) semantics features for integrating domain expertise, and can solve the harmonic volumetric parameterization with better efficiency and accuracy.

- The exploration of harmonic volumetric mapping in hexahedral regular mesh generation for efficient physics-based FEM analysis and CAGD design.

- 4 NSF proposals based on volumetric parameterization and its applications submitted.

- Working on exploring the application of harmonic volumetric parameterization in forensic science research. We collaborate with the FACES (Forensic Anthropology and Computer Enhancement Services Laboratory) lab at LSU in their craniofacial reconstruction from skeletal remains (skulls). A proposal (using harmonic volumetric parameterization to do facial reconstruction) has been submitted to NSF.

- Two new courses developed in LSU: (1) an undergraduate special topic course on computer graphics, “Geometric Modeling and Computer Graphics” (developed and taught in Fall 2009); (2) a graduate course on advanced computer graphics, “Graphics and Visual Computing”, (developed and taught in Spring 2009).

- We have begun to write a survey paper [11] on 3D shape registration techniques using geometric modeling and inter-shape parameterization methods. We will submit it to ACM Computing Surveys, and serve as an introduction to this field for a general scientific audience.
3 Nuggets

- Two papers on applying mapping in computer aided design and data reconstruction were presented in IEEE International Conference on Shape Modeling and Application 2009, which is a top conference in the area of geometric modeling. Enhanced versions of these papers have been invited and published in Computer & Graphics 2009.

- The two PhD students, Huanhuan Xu and Shenghua Wan \(^1\), supported by this project are both first year graduate students in LSU Electrical and Computer Engineering department. This is definitely an important part to the program and Louisiana economy.

- When all 12 international publications from this project are published, it will contribute to the LSU academic program.

- The explored applications, generated from this project, will contribute to the computer aided design, physics-based data simulation/analysis, and forensic research and law enforcement in Louisiana.

- We are wrapping up our developed programs and software for volumetric parameterization/processing, and will post them on our website after these submitted papers are published.

4 Variance from Original Work Plan

Not applied.

5 Problems Encountered

None.

6 Other Comments

None.

7 Reporting Period

Not applied.

\(^1\)Huanhuan Xu has been working on harmonic volumetric mapping computation using fundamental solution methods (MFS); the result in the paper will form part of her thesis. Shenghua Wan has been working on regular grids generation based on solid mapping; the result in the paper will form part of his thesis.
8 Publications

8.1 Referred Journal Publications

Published:


Under Revision:


8.2 Books


8.3 Referred Conference Publications

Published

7) H. Wang, Y. He, **X. Li**, X. Gu, and H. Qin,“Geometry-Aware Domain Decomposition for T-Spline-based Manifold Modeling”, presented in International Conference on Shape Modeling and Application 2009 (enhanced version published in the special issue of Computer & Graphics, see the above 2)).

8) J. Cao, **X. Li**, G. Wang, and H. Qin, “Surface Reconstruction using Bivariate Simplex Splines on Delaunay Configurations”, presented in International Conference on Shape Modeling and Application 2009 (enhanced version published in the special issue of Computer & Graphics, see the above 3)).


Submitted:

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References


