MAYO CLINIC

# Anatomic Surface Reconstruction from Sampled Point Cloud Data and Prior Models

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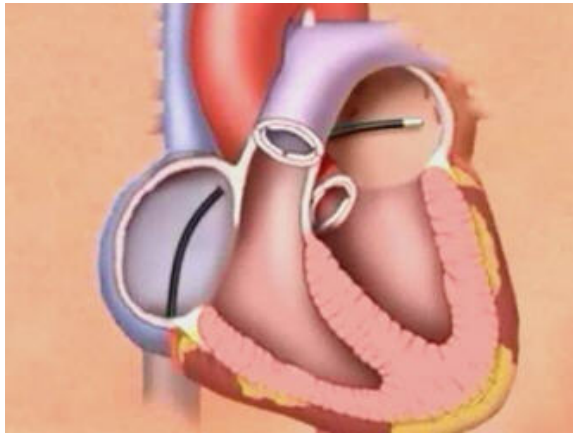
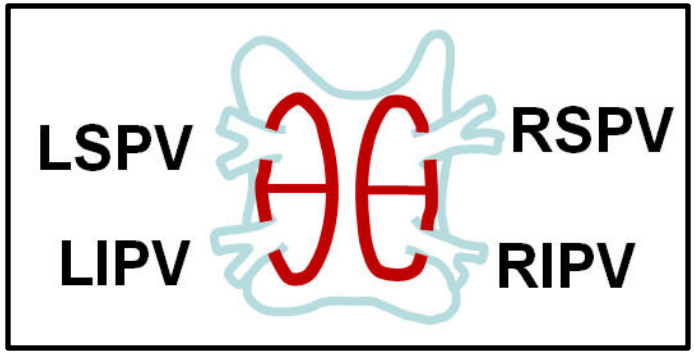
# Catheter-Based Cardiac Ablation

- Used to treat left atrial fibrillation
- Ectopic electrical foci often originate in pulmonary veins
- Typical treatment strategy electrical isolation of pulmonary veins
- Anatomical guidance and targeting is key component of procedure

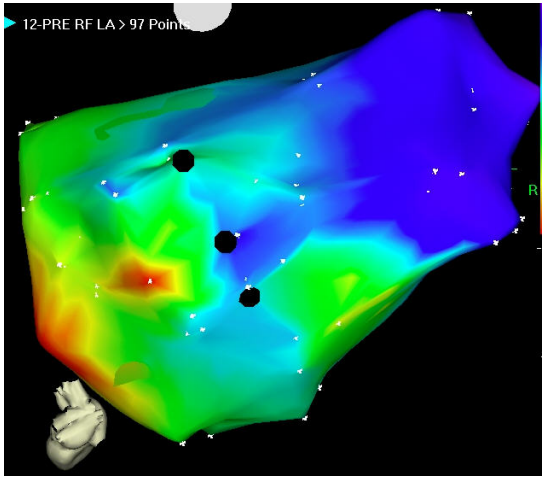




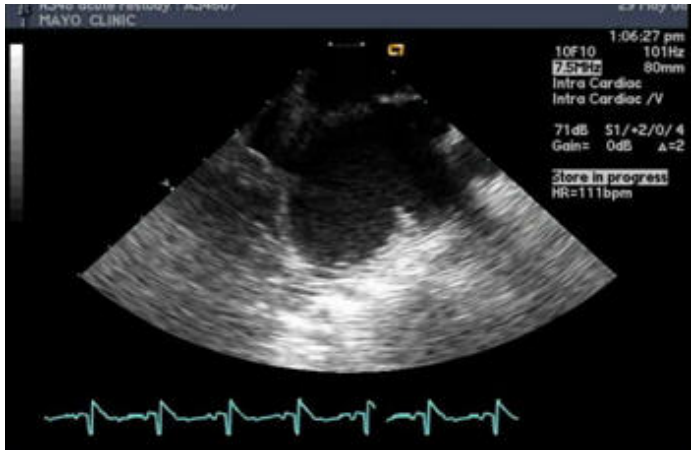
# Standard Visualizations

- Standard visualization tools include fluoroscopy, ultrasound, EAM
- Registration of preoperative surface models *(Dickfeld et. al. Circulation 2003, Reddy et. al. JACC 2004, Sun et. al. SPIE MI 2005)*

Catheter in fluoroscopy image



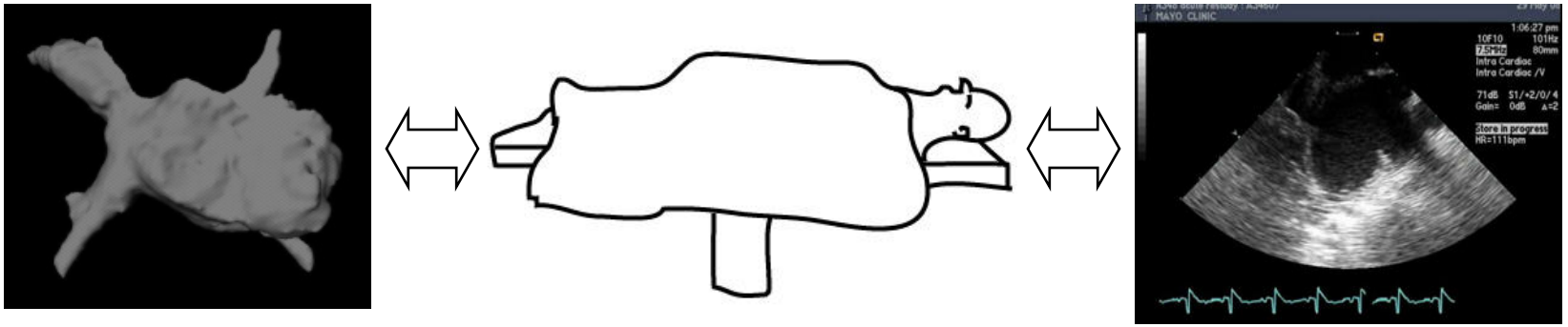

Electroanatomic map constructed from Biosense CARTO system




Real-time intracardiac echocardiography (ICE)

# Introduction

- Goals of study
  - Intra-operative surface reconstruction from tracked, ECG-gated ICE images and pre-op model built from CT scan



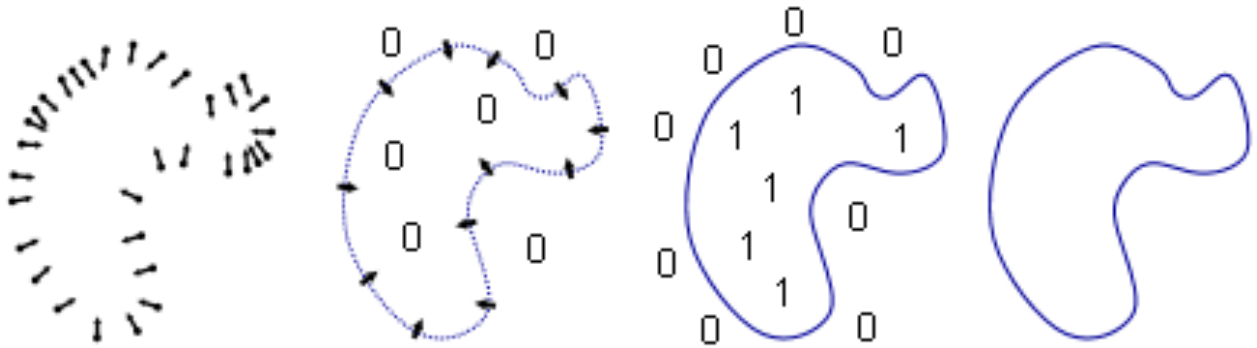

- Assumptions
  - ICE and pre-op model are acquired in the same ECG phase and have been registered to patient
  - Anatomy contour has been segmented from ICE images

# Introduction

- Challenges
  - Freehand ICE images are acquired in irregular positions and cannot be reconstructed by conventional methods such as marching algorithms
  - Point cloud generated from intra-operative scanning are sparse, thus difficult to be reconstructed by conventional methods developed in computer graphics area for dense laser scanning data

# Introduction

- Screened Poisson Surface Reconstruction
  - A high resolution and quality surface reconstruction method, robust to noise
  - In addition to point position information, also integrating normal direction, thus working for sparse point cloud

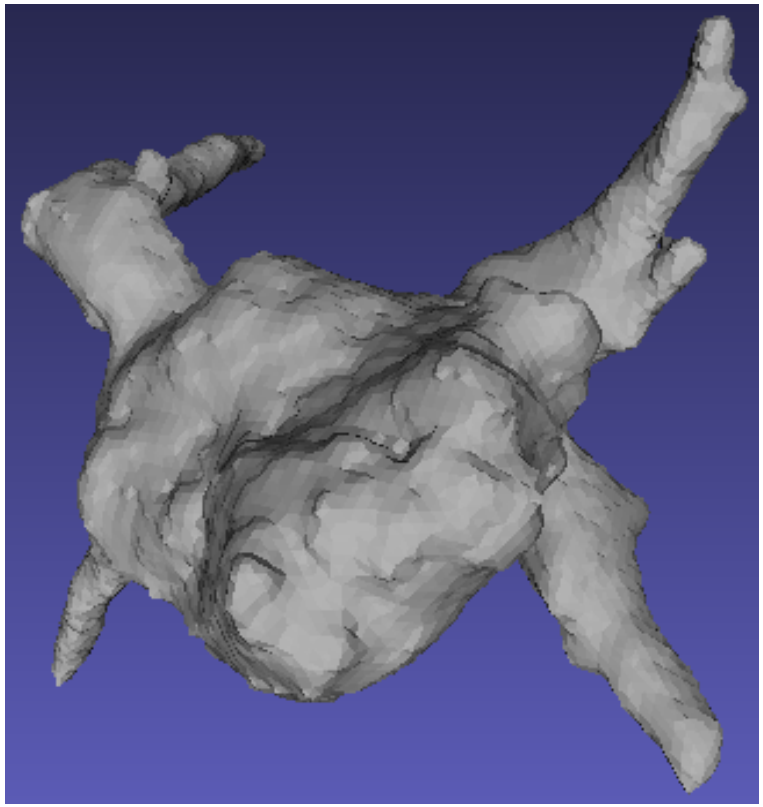



$$\Delta\chi \equiv \nabla\cdot\nabla\chi = \nabla\cdot\vec{V}.$$

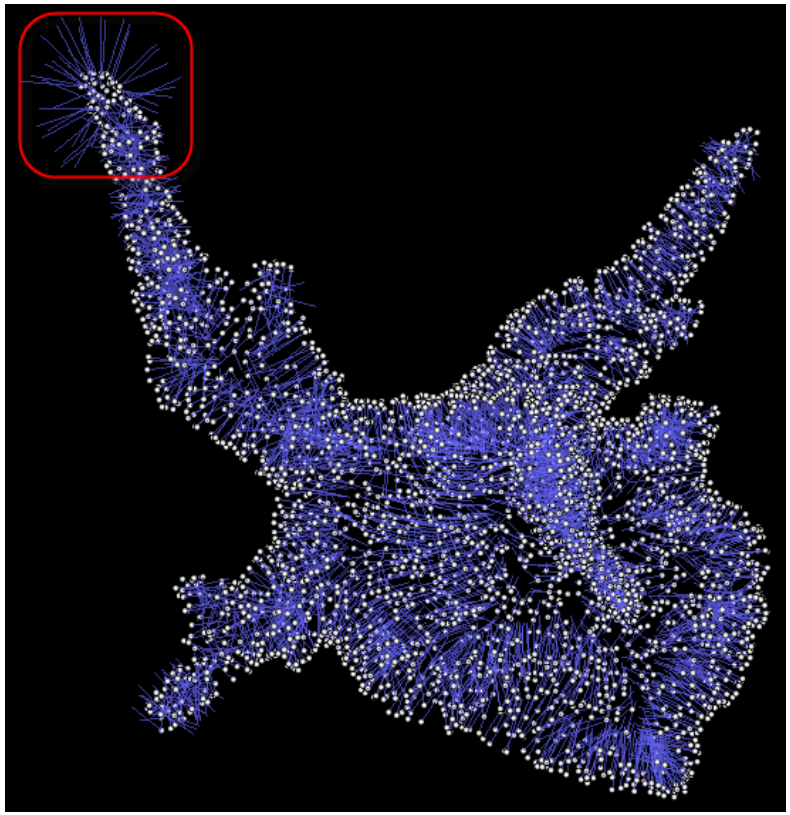
M. Kazhdan, M. Bolitho, H. Hoppe, Poisson Surface Reconstruction, *Eurographics Symposium on Geometry Processing*, (2006), 61-70.

# Introduction

- Challenge
  - Consistent estimation of normal vector for complex structure from sparse point cloud



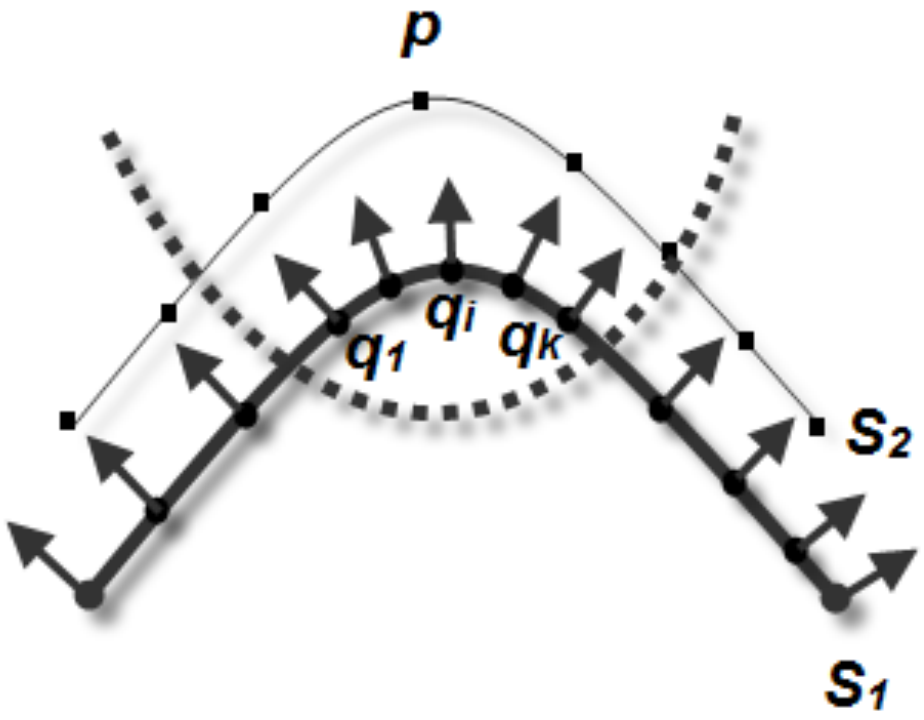
Pre-op model of left atrium



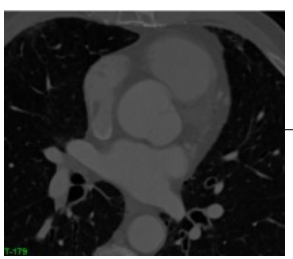
Normal estimation by Hoppe et al.' method

# Proposed Normal Vector Estimation Method

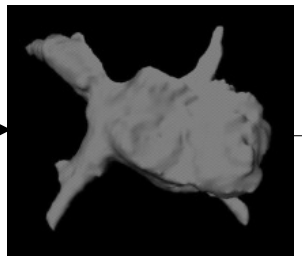
- K-NN based consistent estimation of normal vector
  - Using the average normal vectors of k nearest neighbor vertices in the pre-op model as an estimation for each point of the point cloud



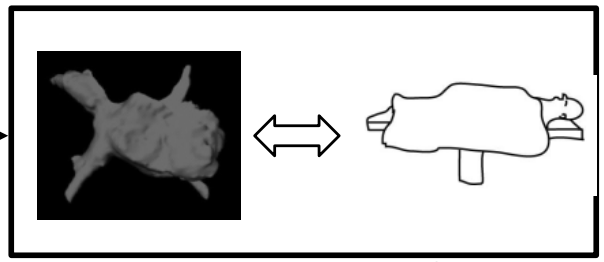
# Workflow



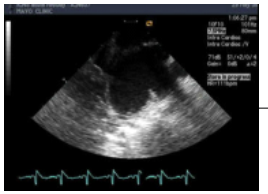
CT/MR scan



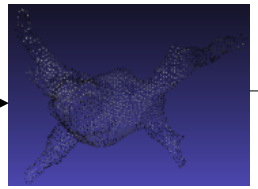
Pre-op model



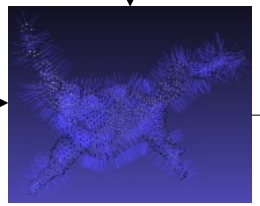
Pre-op model registered to patient



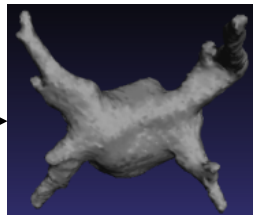
Inter-op images



Point cloud



Point cloud with estimated normals

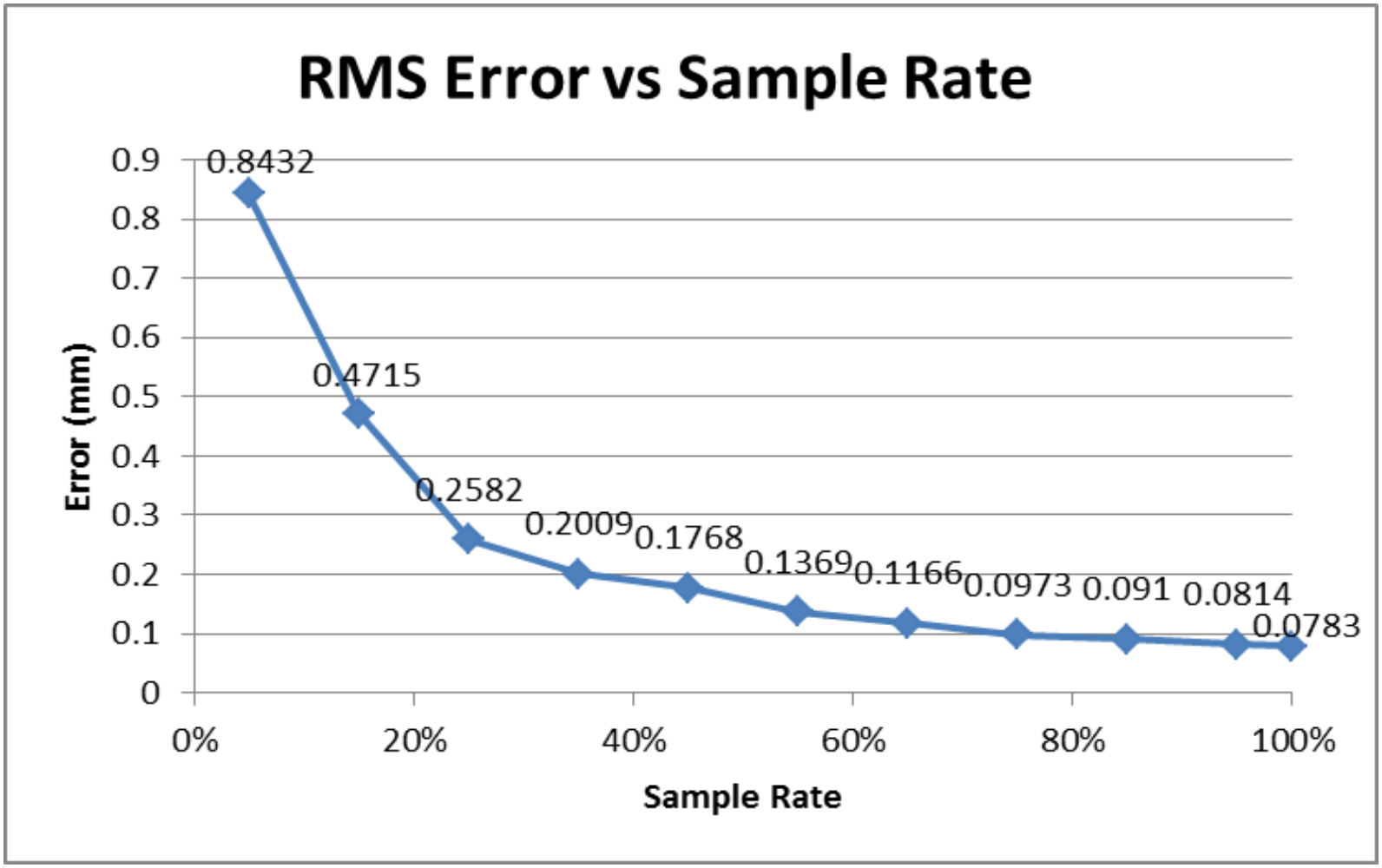


Reconstructed model

# Simulation Experiment

- Goal
  - Estimate reconstruction error (RMS error) due to different factors
- Single factor simulation experiment
  - Possible factors: point cloud density, ICE image noise, registration error, k value in k-NN normal vector estimation
- Combined factors simulation experiment
  - Combine all factors together and evaluate reconstruction error

# Single Factor Experiment Results



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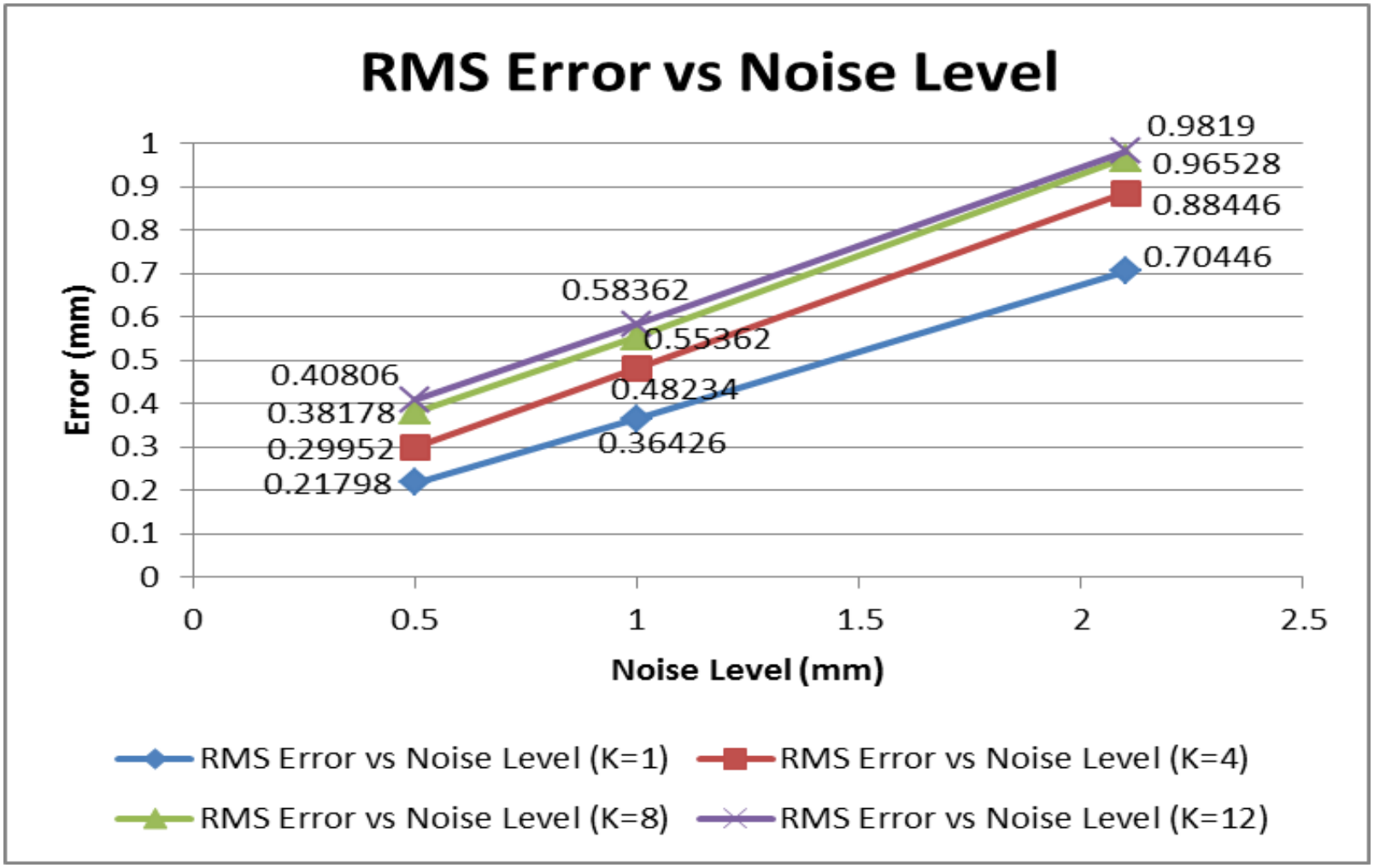

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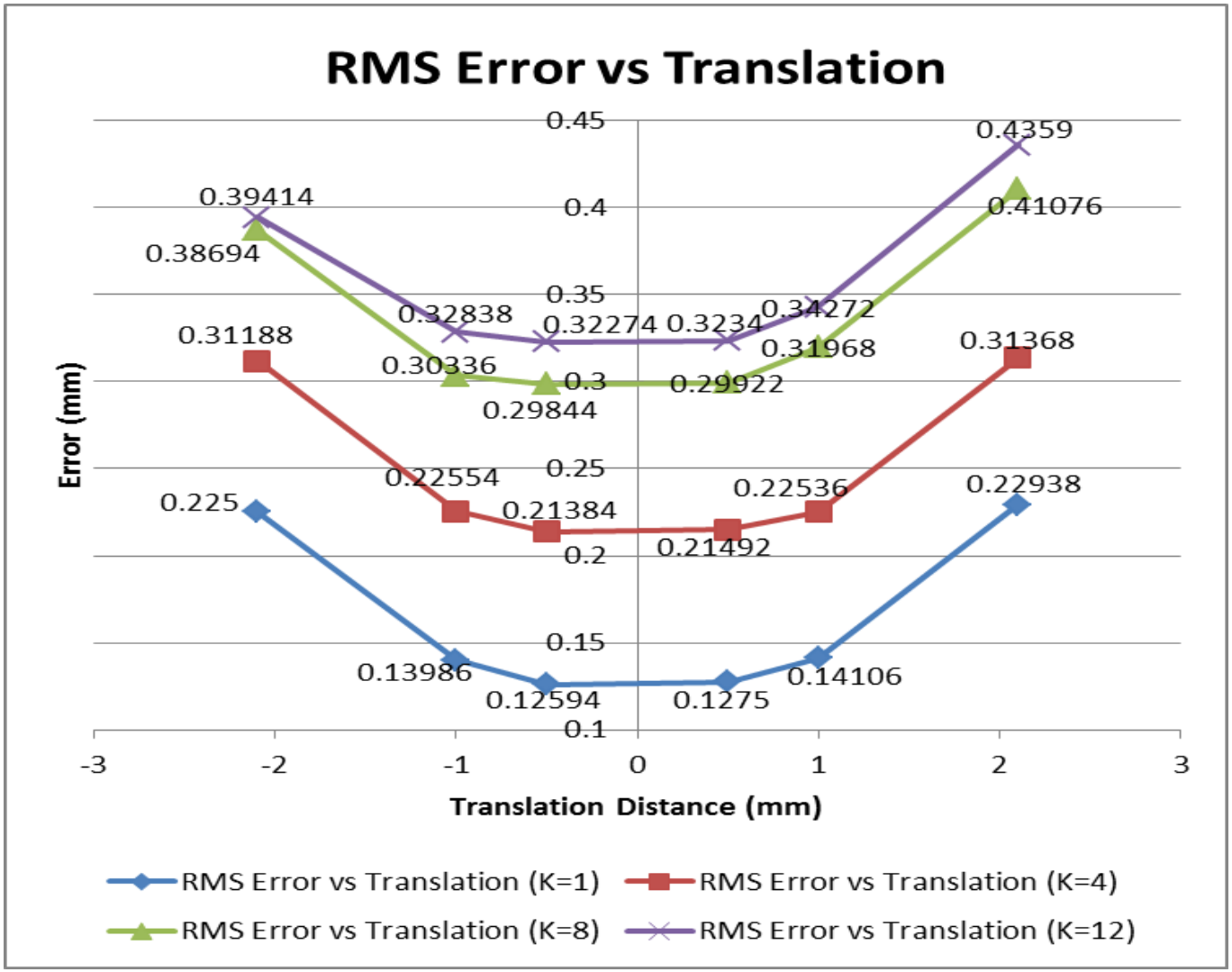

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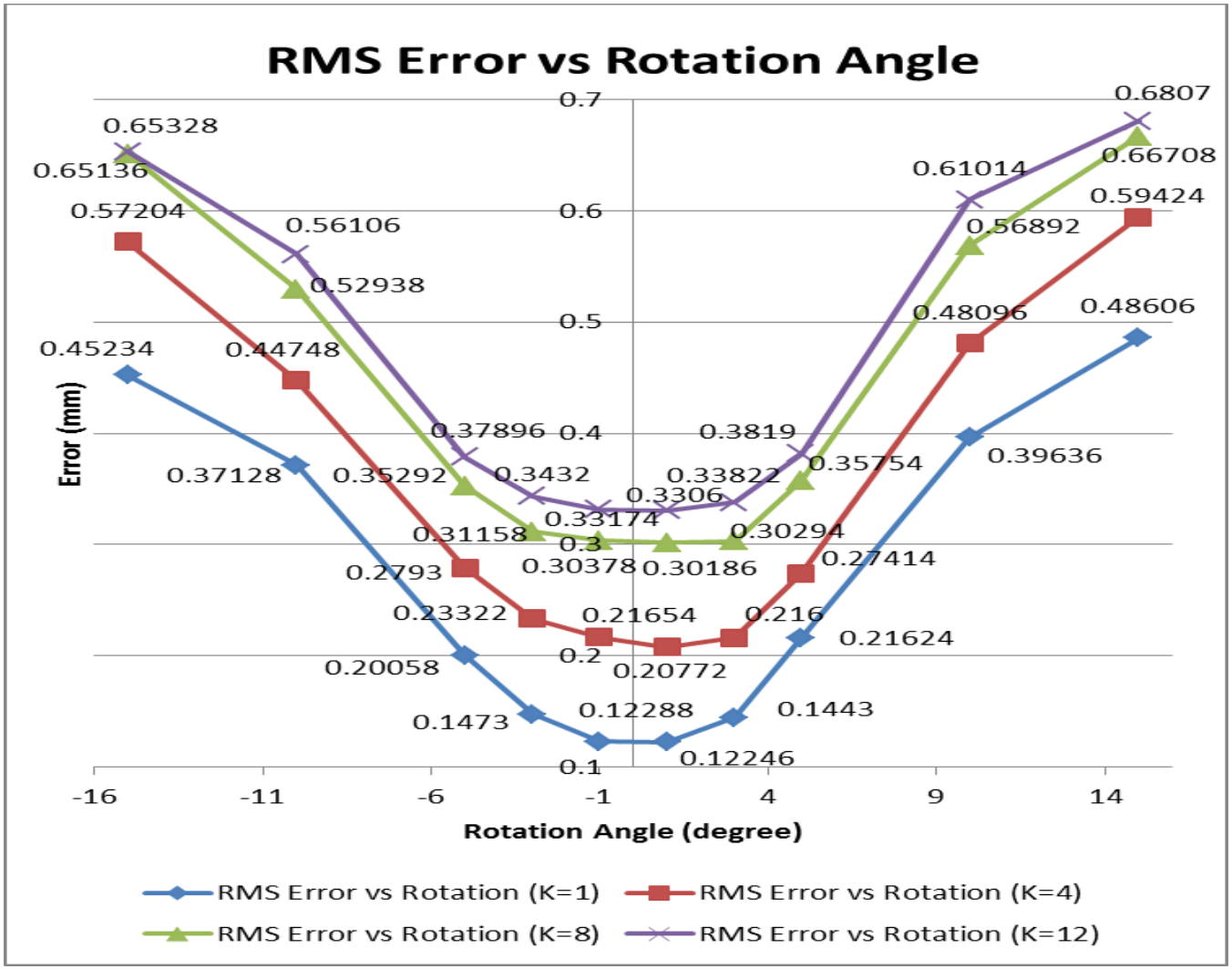


# Combined Factors Experiment Results

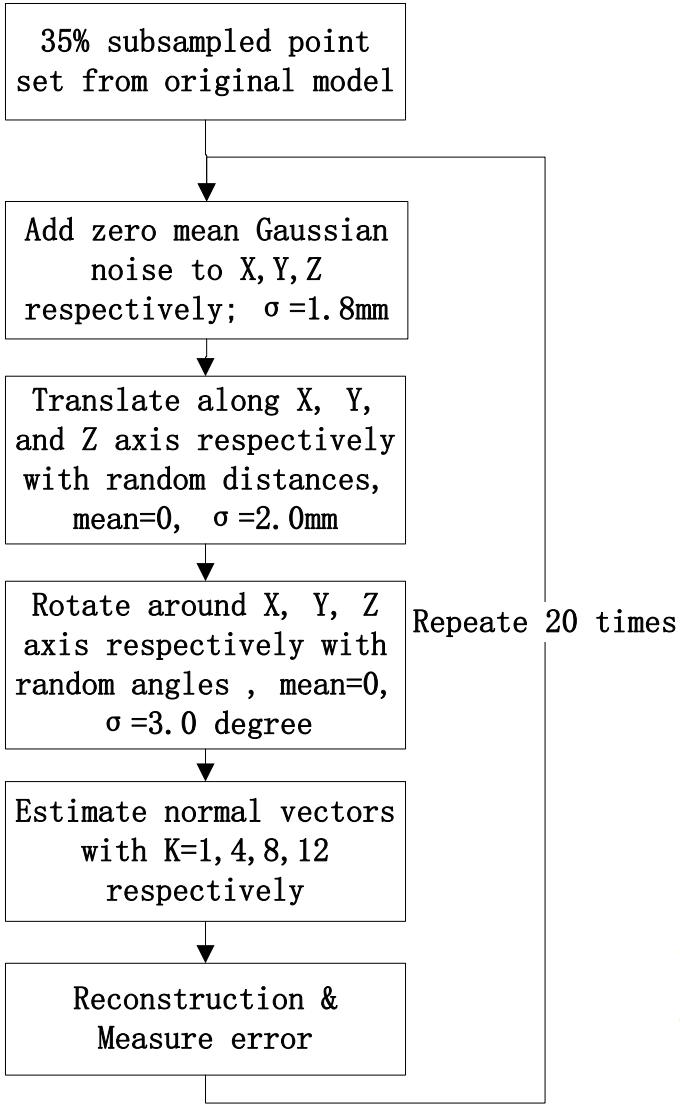
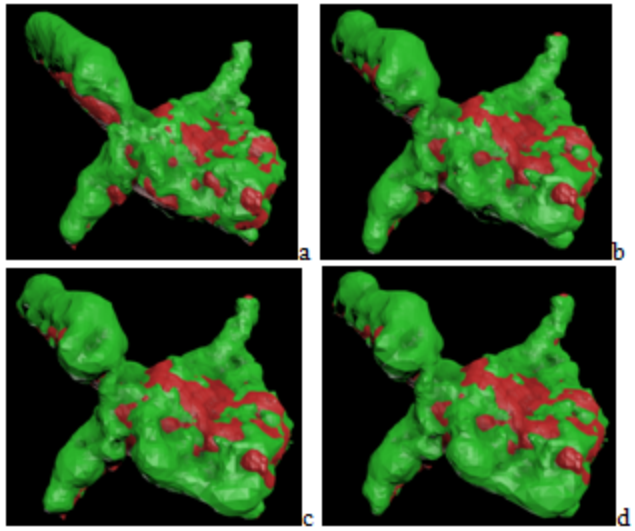



*Table I. Reconstruction Errors of Combined factors (unit: mm)*

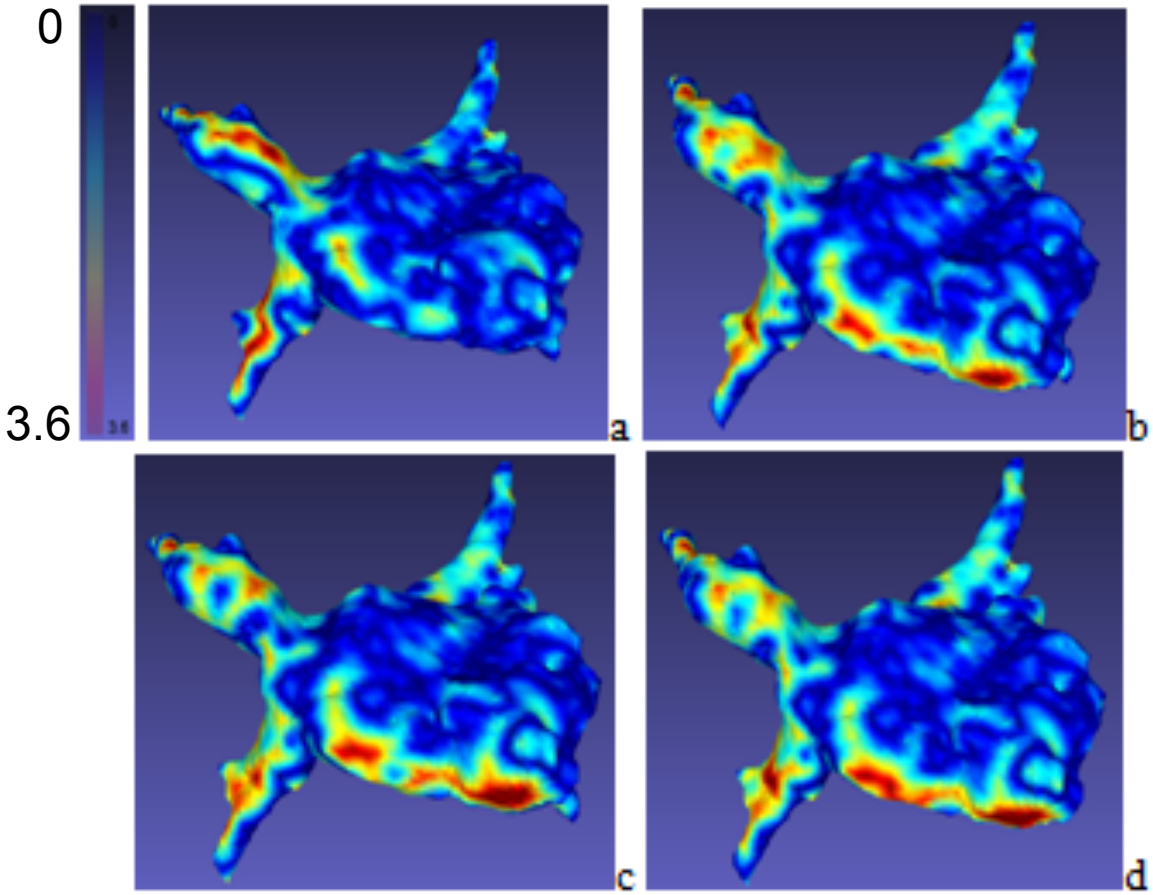
| | K=1 | K=4 | K=8 | K=12 |
|---|---|---|---|---|
| RMS | 0.88±0.03a | 0.98±0.02b | 1.04±0.02c | 1.05±0.02c |
| Max | 3.72±0.13a | 3.87±0.08a | 4.59±0.07b | 4.74±0.10b |

*Note: Values are mean ±standard error. Pairwise comparisons are within rows: means that do not share letters are significantly different ($p<0.05$).*




*#9.Comparison of reconstructed models of the 18th experiment and the prior model. The red surface is the prior model and the green surface is the reconstructed model. The reconstruction parameters for a~d are K=1& RMS=0.88mm, K=4& RMS=1.02mm, K=8& RMS=1.05mm, K=12 & RMS=1.06mm respectively.*

# Combined Factors Experiment Results




*#10 Visualization of reconstruction error of 18th experiment on the surface of the prior model. Different colors indicate different reconstruction errors; the color map was scaled from 0 to 3.6mm reconstruction error; if the error is larger than 3.6mm, then it was set to the same color as 3.6mm. The reconstructed models were reconstruction results of 18th experiment. The reconstruction parameters for a-d are K=1 & RMS=0.88mm, K=4 & RMS=1.02mm, K=8 & RMS=1.05mm, K=12 & RMS=1.06mm, respectively.*

# Conclusion & Future Development

- Summary
  - Proposed an approach to estimate consistent normal vectors which helps adapt SPSR in modeling left atrium from intra-op point cloud and prior models
  - Estimated reconstruction error caused by practical factors by simulation experiments
  - Setting factors to normal values, the surface reconstruction error is 0.88±0.03mm
- Future development
  - Further validation by collecting data via ICE transducer from real left atrium phantom and animals

# Acknowledgement


- Thanks to my partners from Biomedical Imaging Resource lab
- Thank you for your attention