Improved Semi-Automatic Basket Catheter Reconstruction from Two X-Ray Views

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Introduction

Atrial fibrillation

- Most common heart arrhythmia: rapid and irregular heart beat
- Four categories in classification system
- Firstline procedure: pulmonary veins isolation (PVI)
- New treatment option FIRM-guided ablation

Fig. 1. Heart with Atrial Fibrillation (left) [1], PVI procedure (middle) [2], FIRM-guided ablation (right) [3]

[1] J. Heuser: *Skizze Erregungsleitung im Herzen bei Vorhofflimmern,* 2005 https://commons.wikimedia.org/wiki/File:Heart_conduct_atrialfib.gif
[2] Biotronik: *Katheterablation gegen Herzfilmmern,* 2012 http://i.onmeda.de/gesund/Ablation-OP-Vorhofflimmern_0.jpg
[3] Abbott: *The Topera® 3D Rotor Mapping Animation,* 2015 http://www.abbottep.com/doctors-healthcare-providers/resources/topera-animation/

Objective

- 3-D reconstruction of the basket catheter based on two X-ray views

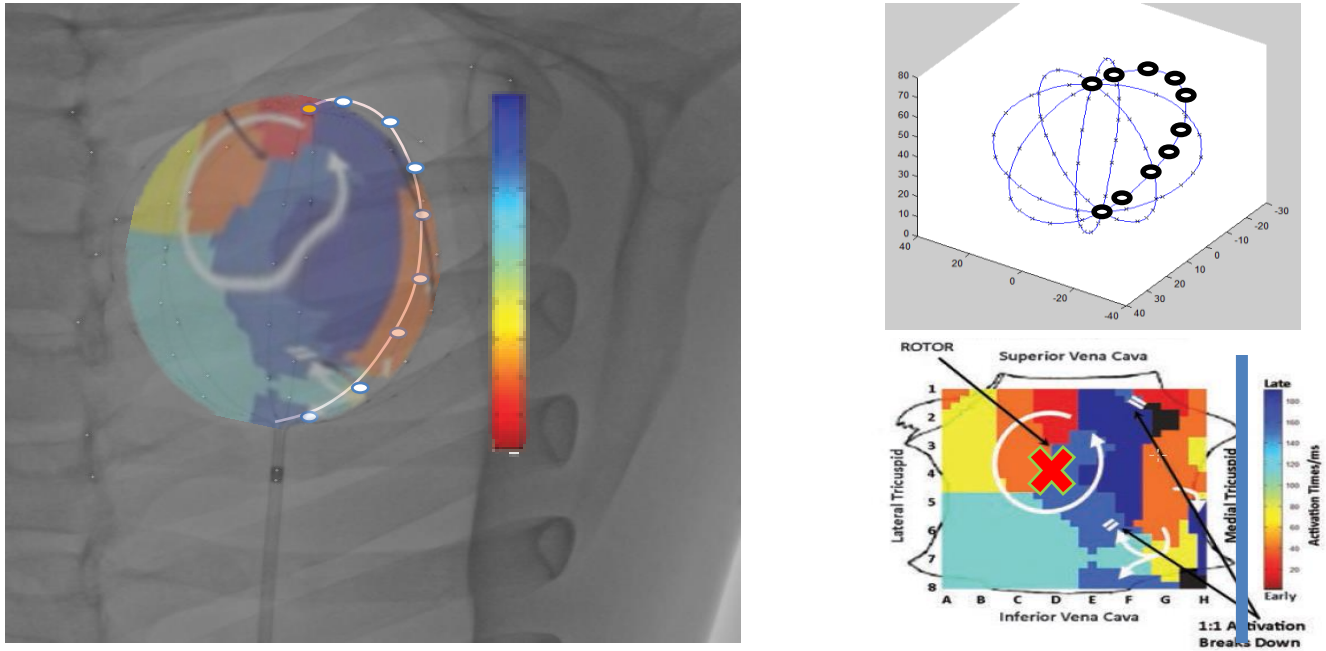


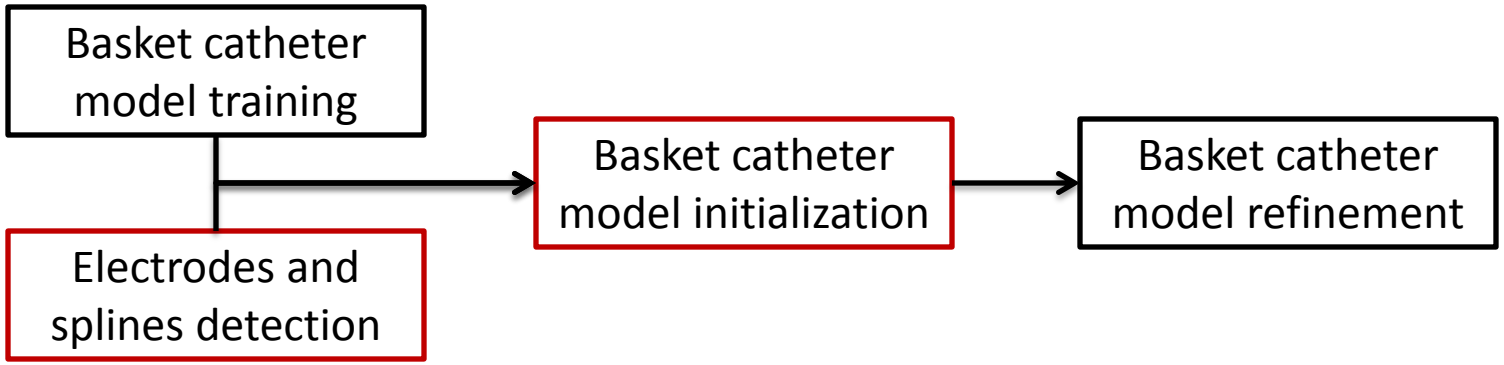
Fig. 2. Basket Catheter under X-ray with Rotor map overlay (left) [1], Right atrial rotor in AF (bottom right) [2], and reconstructed basket catheter (top right)

[1] A. Kirally (Siemens Corporate Research) and N. Strobel (Siemens Healthcare GmbH)
[2] A. Schricker and J. Zaman, Figure 2. *Process for Focal Impulse and Rotor Modulation-guided Mapping and Ablation, 2015, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4711496/figure/fig2/*

Method

Method

- Proposed method for basket catheter detection and reconstruction

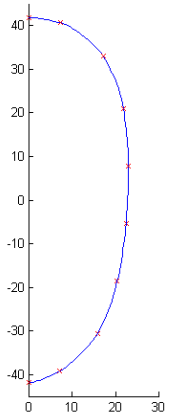


Basket catheter model

- Statistical shape basket catheter model
  - marker electrodes for every spline

$$\boldsymbol{x}(\boldsymbol{b}) = \bar{\boldsymbol{x}} + \boldsymbol{V}\boldsymbol{b}$$

$$\boldsymbol{x}'_k = \boldsymbol{x}'_k(\alpha_k, \boldsymbol{b}_k) = \boldsymbol{R}\boldsymbol{R}_{\mathrm{Y}}(\alpha_k)\boldsymbol{x}(\boldsymbol{b}_k) + \boldsymbol{t}$$



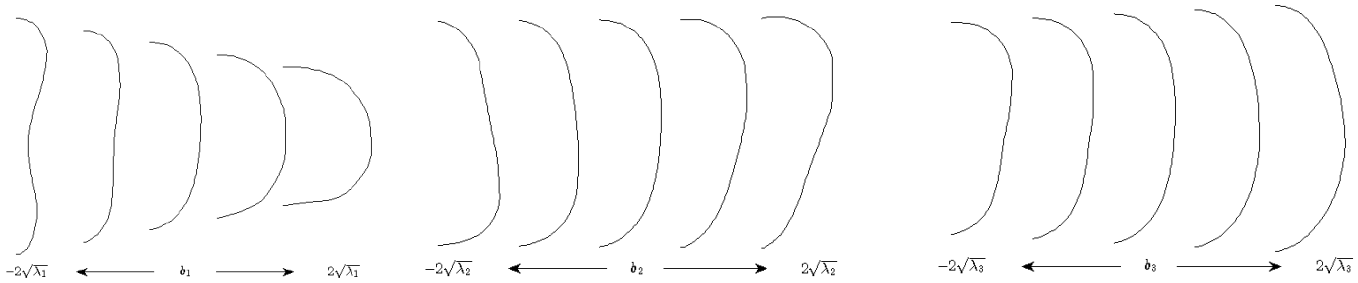
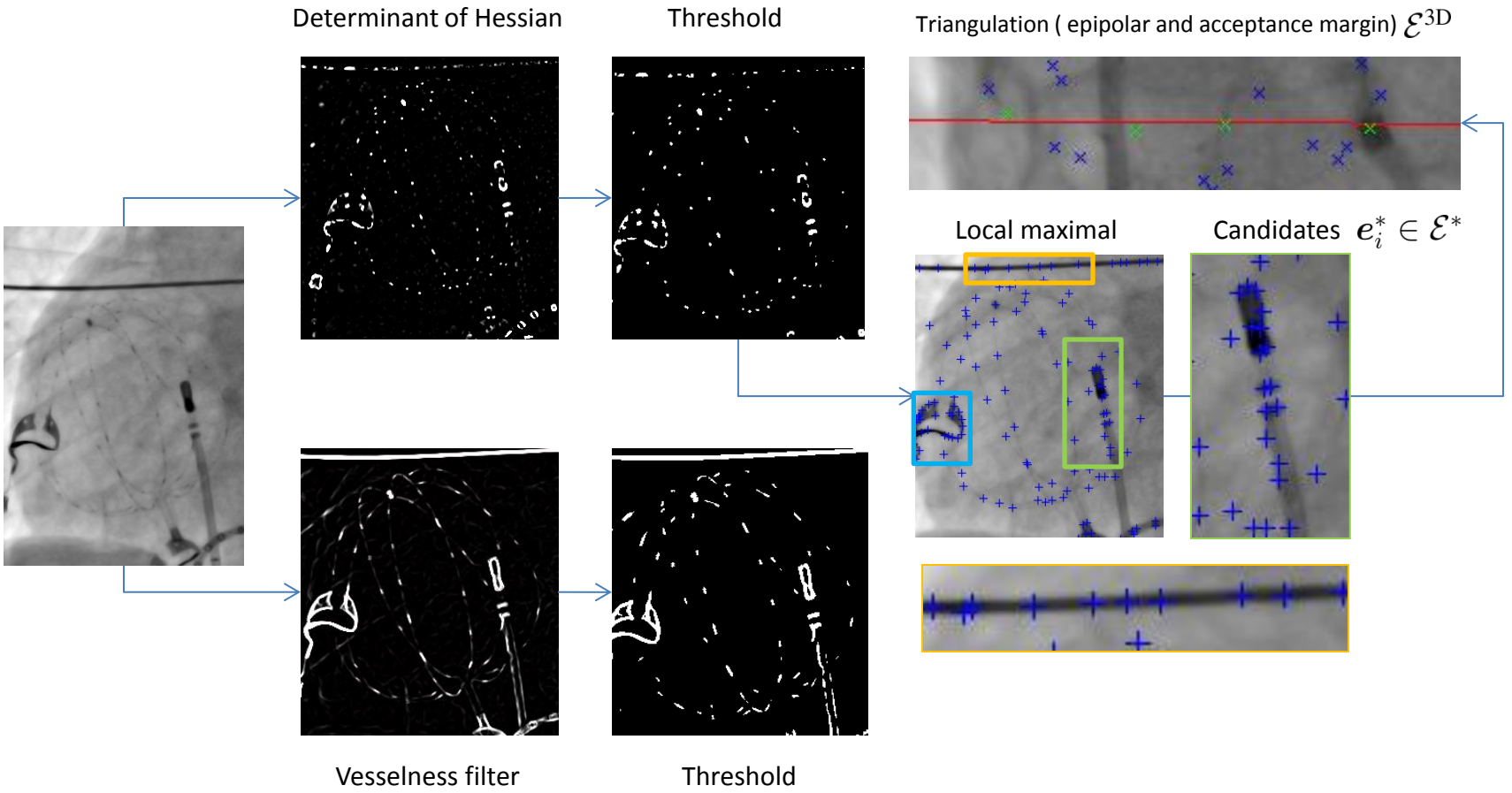
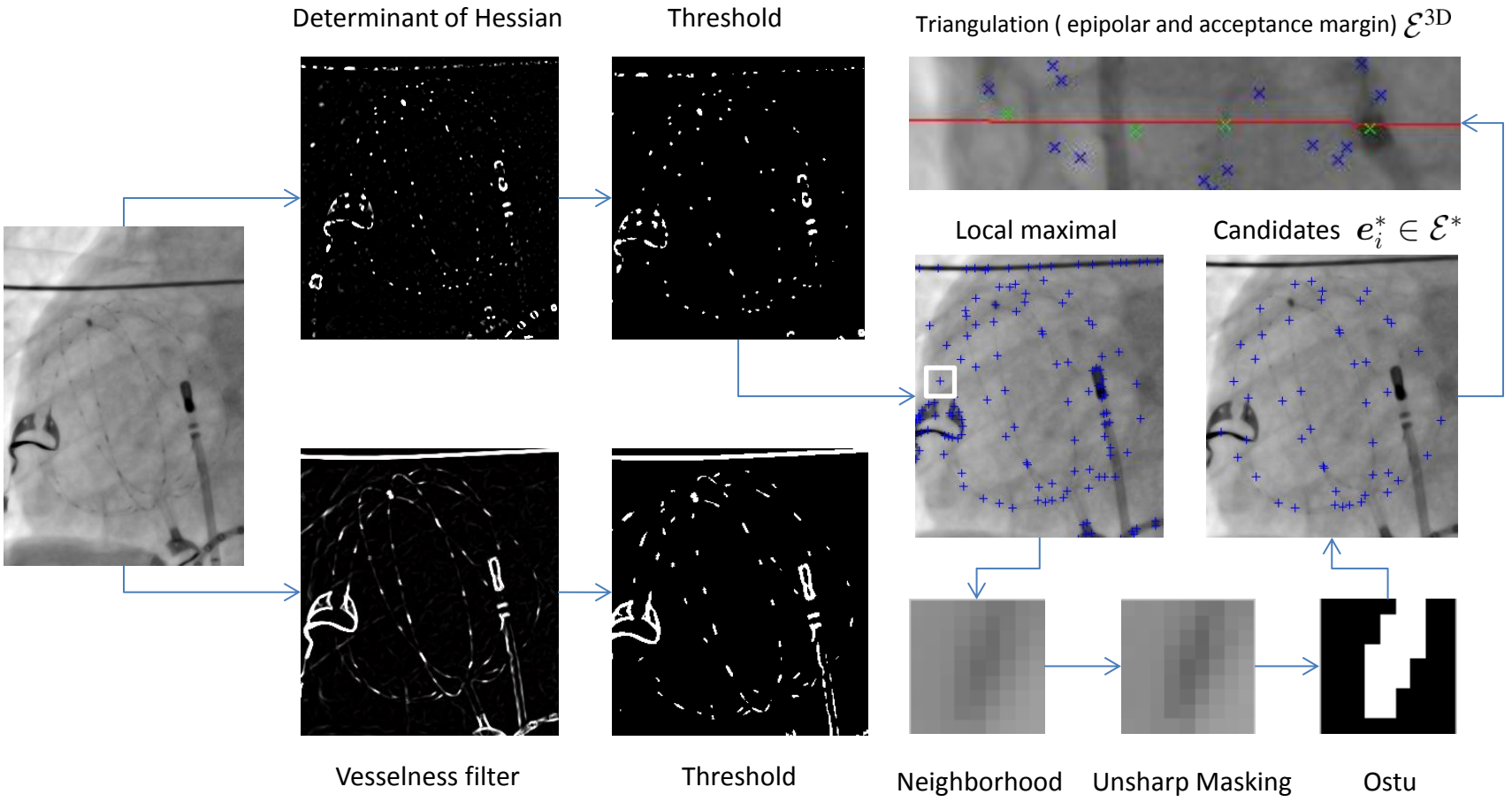


Fig 3. Mean shape(up right) and first three modes of variation in trained shape model (down) projected in x-y plane

Electrode and spline detection (previous)



Electrode and spline detection (proposed)



Basket catheter model initialization

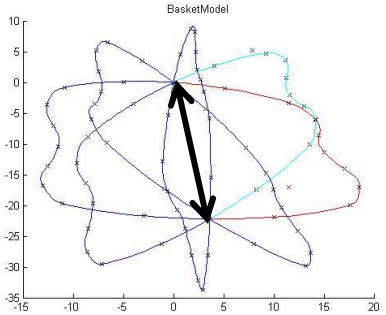
- Symmetric initializations (previous)
  - Assumption: all splines have the same shape

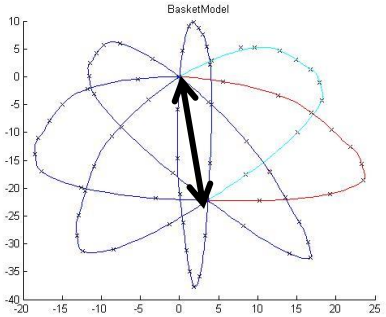
$$\boldsymbol{b}_{k=1,\ldots,8} = \boldsymbol{b}'_m = (b'_{m,1}, b'_{m,2}, b'_{m,3})^T$$

  - All initialization must have the same length as user entered

$$\|\tilde{\boldsymbol{p}}^{3D}_{start} - \tilde{\boldsymbol{p}}^{3D}_{end}\| = \|\hat{\boldsymbol{p}}^{3D}_{start}(\boldsymbol{b}'_m) - \hat{\boldsymbol{p}}^{3D}_{end}(\boldsymbol{b}'_m)\|$$

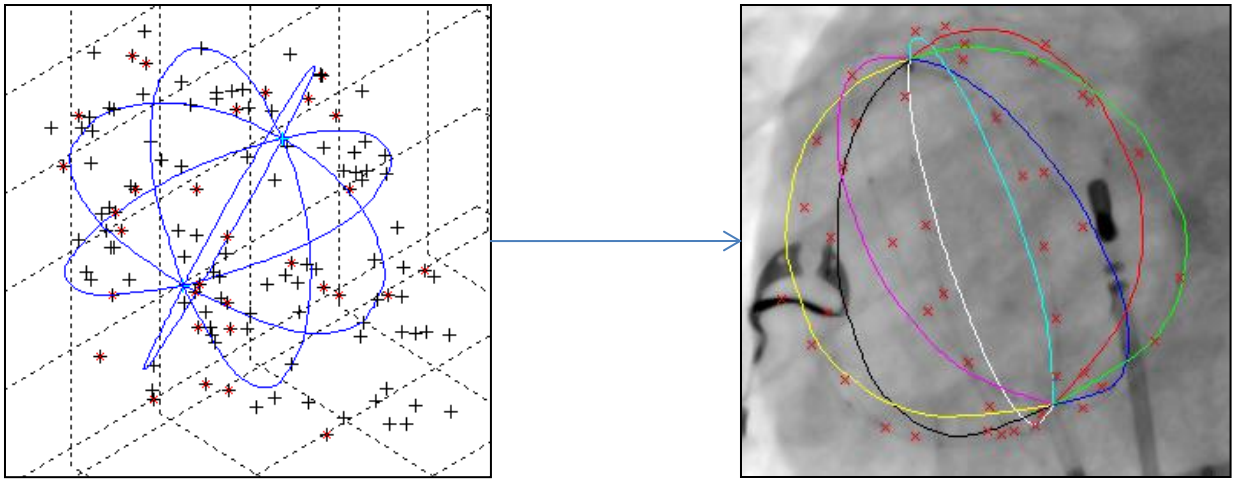
  - Results $\mathcal{B}_{\boldsymbol{b}} = \{\boldsymbol{b}'_1, \ldots, \boldsymbol{b}'_m, \ldots, \boldsymbol{b}'_M\}\ M = 70$





Basket catheter model initialization

- Symmetric initializations – rotation estimation (previous)
  - Rotation $\boldsymbol{\alpha}'_m = (\alpha'_{m,1}, \ldots, \alpha'_{m,8})$ corresponding to $\boldsymbol{b}'_m$
  - Results $\mathcal{B}_{\boldsymbol{\alpha}} = \{\boldsymbol{\alpha}_1, \ldots, \boldsymbol{\alpha}_m, \ldots, \boldsymbol{\alpha}_M\}$ $M = 70$



Rotation estimation using 3D point cloud $\mathcal{E}^{3D}$ Rotation estimation refinement detected electrode candidates

Basket catheter model initialization

- Asymmetric initialization (proposed)
  - Assuming the parameter of the basket model is a combination of $\mathcal{B}_{\boldsymbol{b}}$ $\mathcal{B}_{\boldsymbol{\alpha}}$

$$\boldsymbol{b}_{k=1,\ldots,8} \in \mathcal{B}_{\boldsymbol{b}} = \{\boldsymbol{b}'_1, \ldots, \boldsymbol{b}'_m, \ldots, \boldsymbol{b}'_M\}$$

$$\boldsymbol{\alpha}_{k=1,\ldots,8} \in \mathcal{B}_{\boldsymbol{\alpha}} = \{\boldsymbol{\alpha}'_1, \ldots, \boldsymbol{\alpha}'_m, \ldots, \boldsymbol{\alpha}_M\}$$

  - Greedy search for combination $\boldsymbol{c} = (c_1, \ldots, c_8)^T \; c_i \in [1, M]$

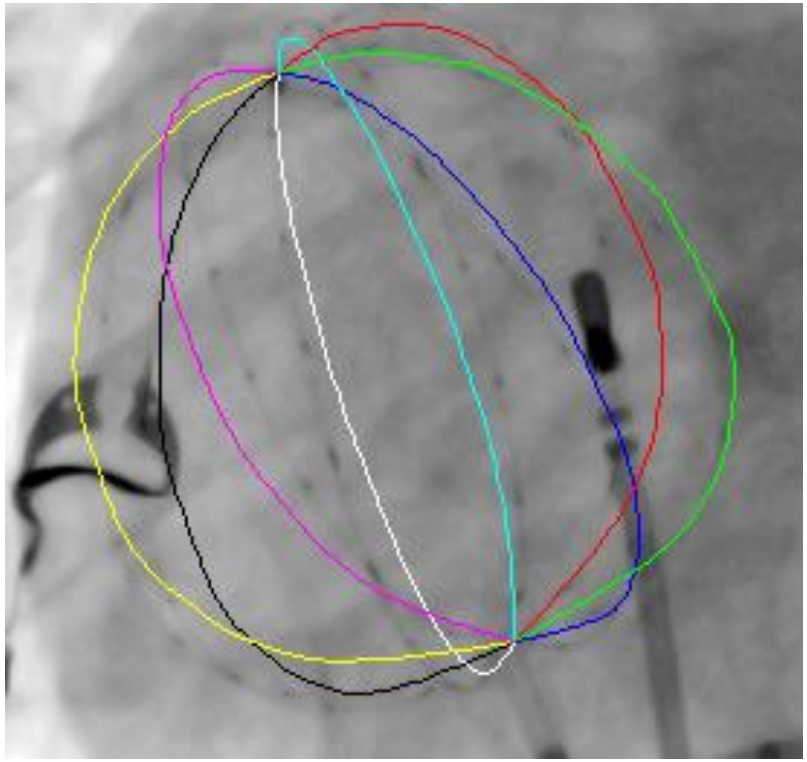
$$\mathcal{B}_{\boldsymbol{b}}(c_1, \ldots, c_8) = (\boldsymbol{b}'_{c_1}, \ldots, \boldsymbol{b}'_{c_8})^T$$

$$\mathcal{B}_{\boldsymbol{\alpha}}(c_1, \ldots, c_8) = (\boldsymbol{\alpha}_{c_1,1}, \ldots, \boldsymbol{\alpha}_{c_8,8})^T$$

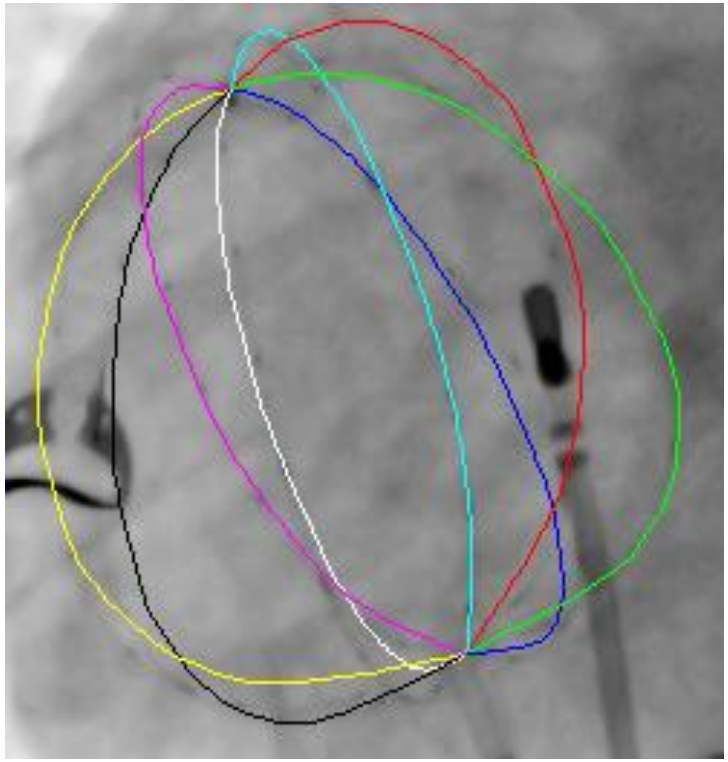
$$\boldsymbol{c} = \operatorname{argmin}_{c_1,\ldots,c_8} \mathcal{D}\left(\mathcal{B}_{\boldsymbol{b}}(c_1, \ldots, c_8), \mathcal{B}_{\boldsymbol{\alpha}}(c_1, \ldots, c_8)\right)$$

Basket catheter model initialization

- Symmetric vs. asymmetric initialization



Symmetric initialization

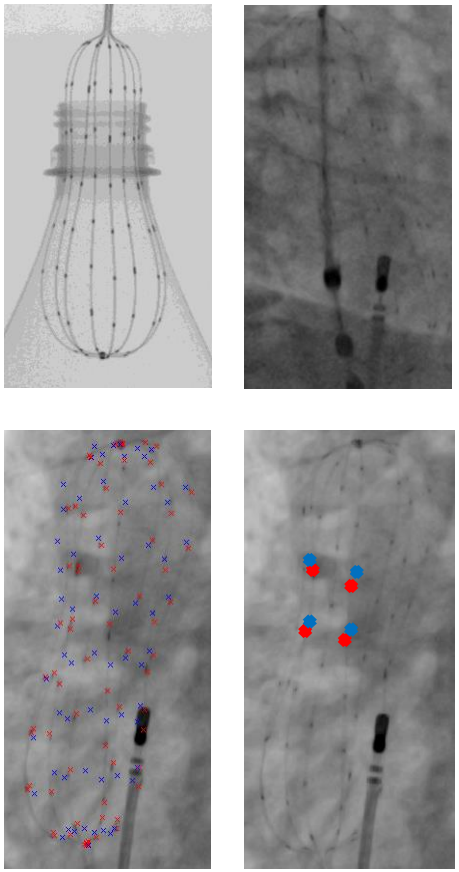


Asymmetric initialization

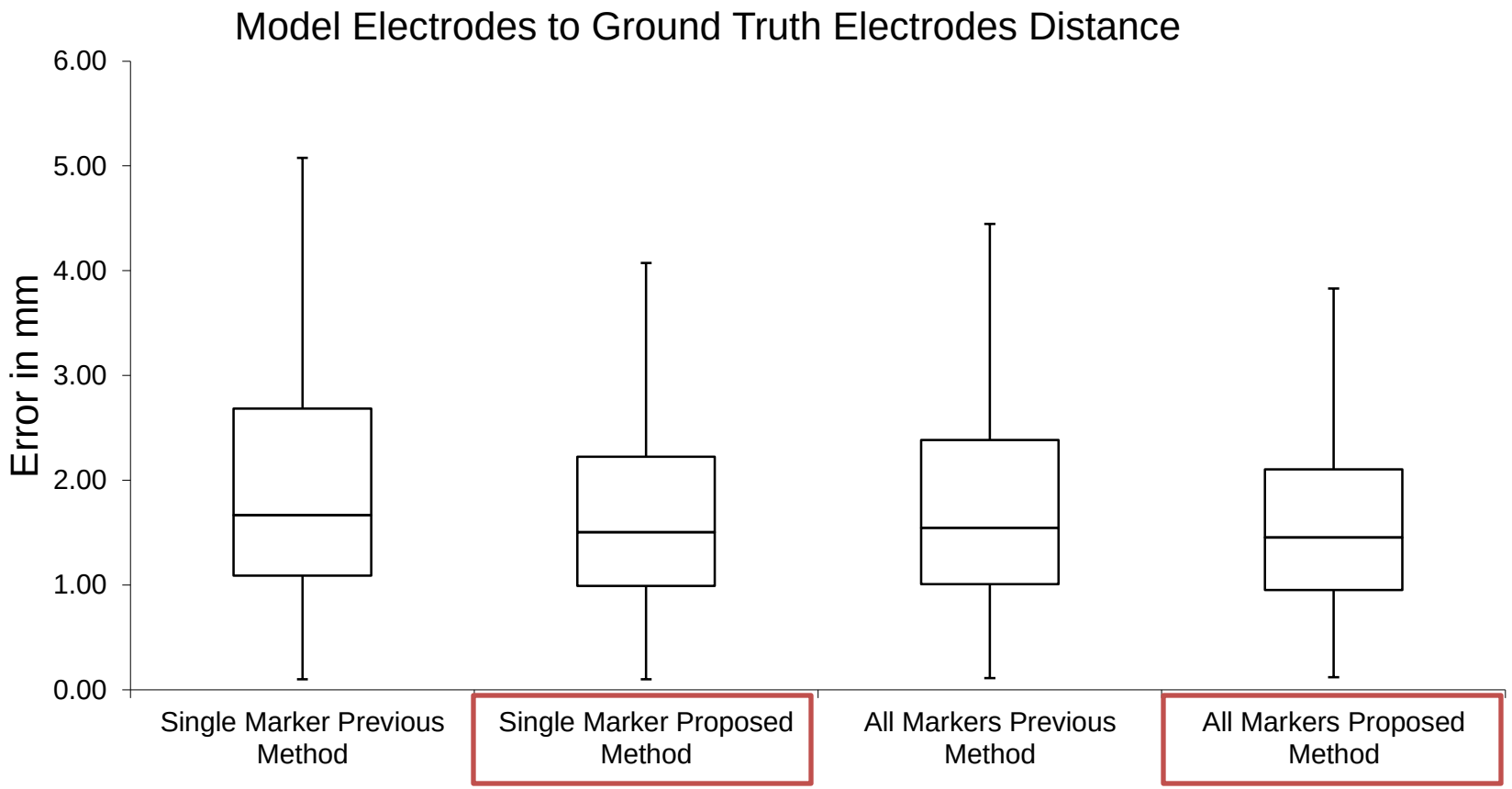
Evaluation

Evaluation

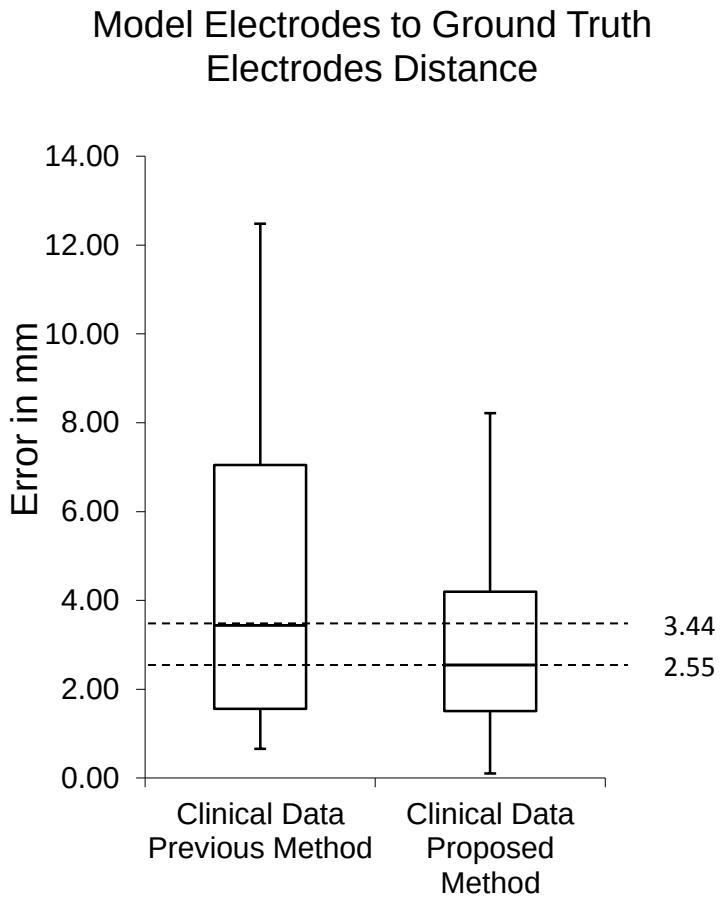
- Data description
  - 18 C-arm CT data
  - 8 clinical data (mono-plane)
- Error metric
  - Model electrodes to ground truth electrodes distance

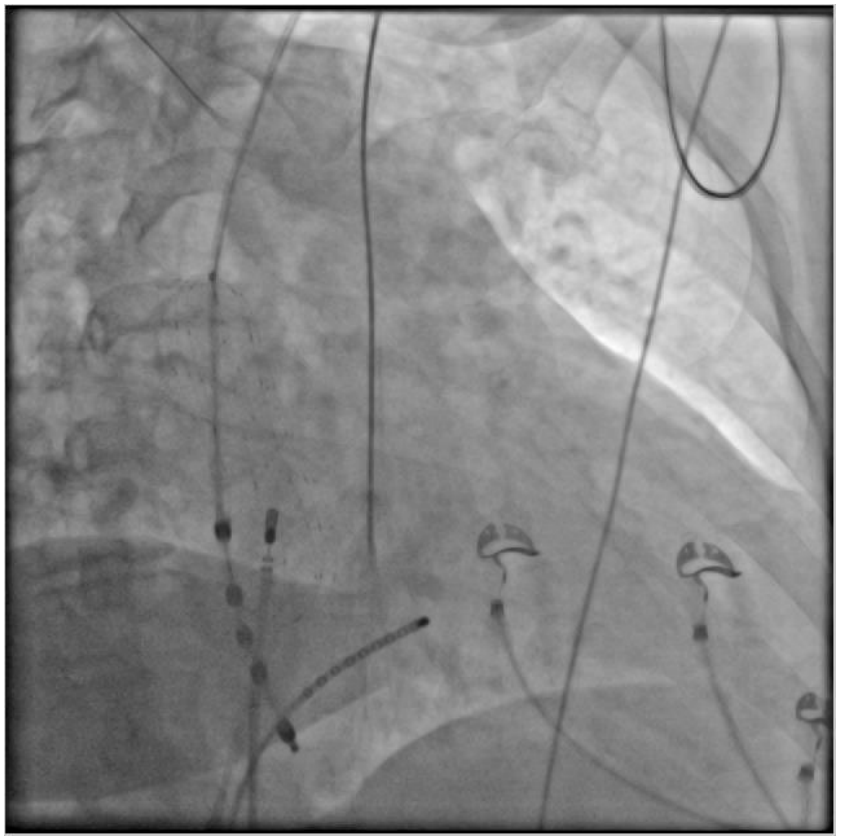


Evaluation – C-arm CT data

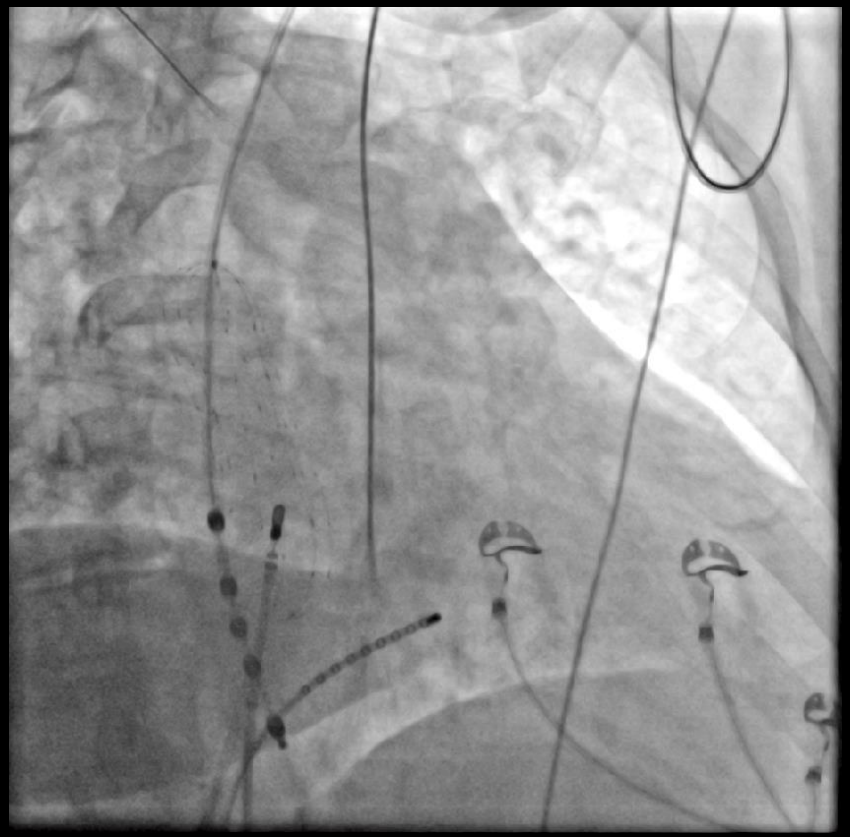


Evaluation – clinical data

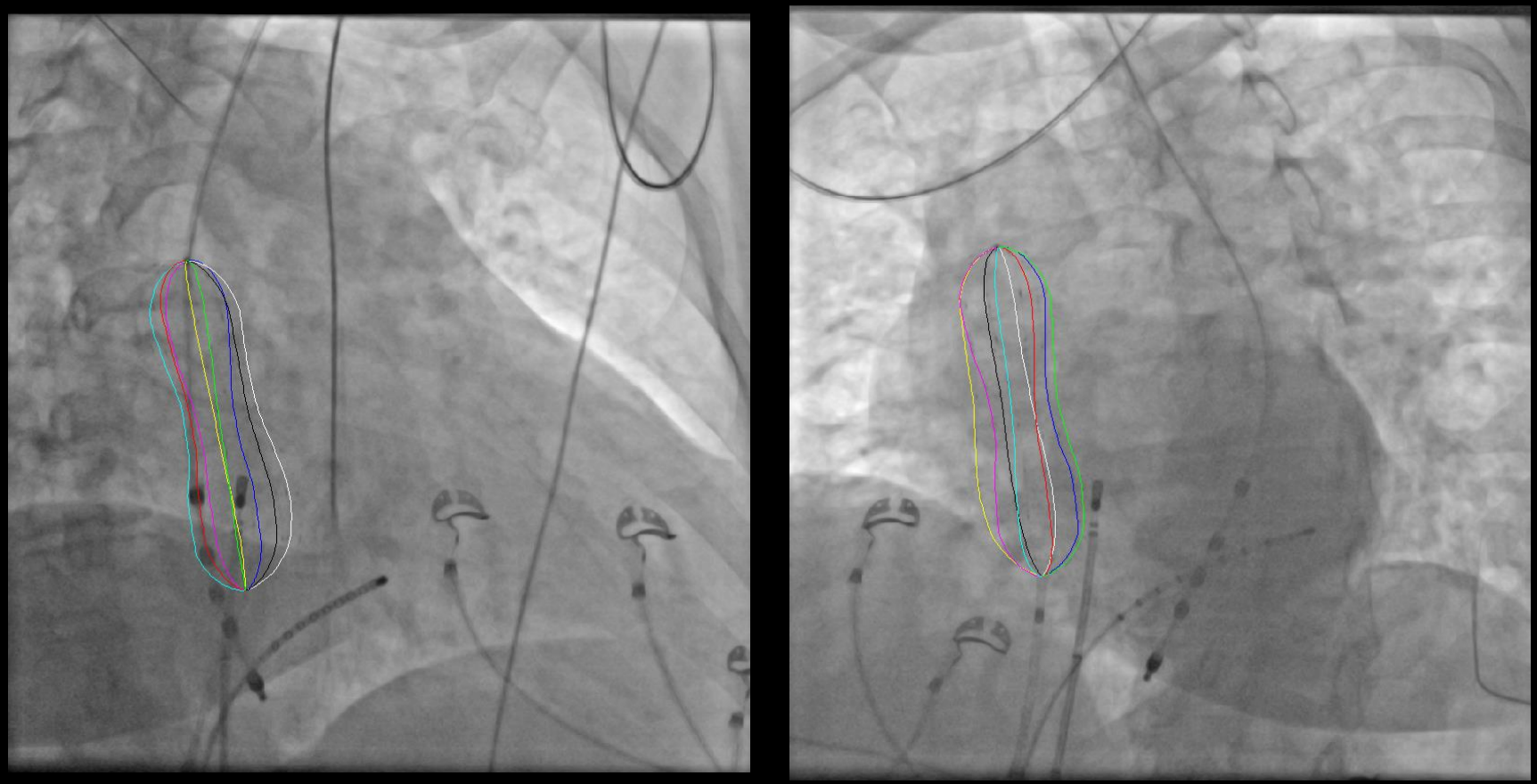




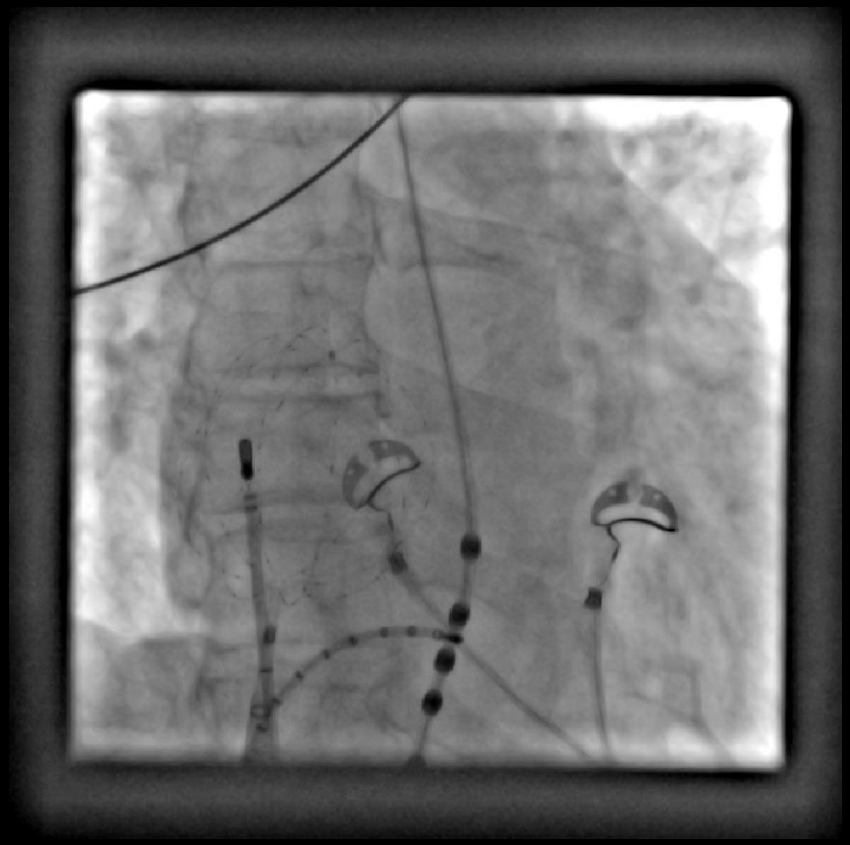
Evaluation – clinical data

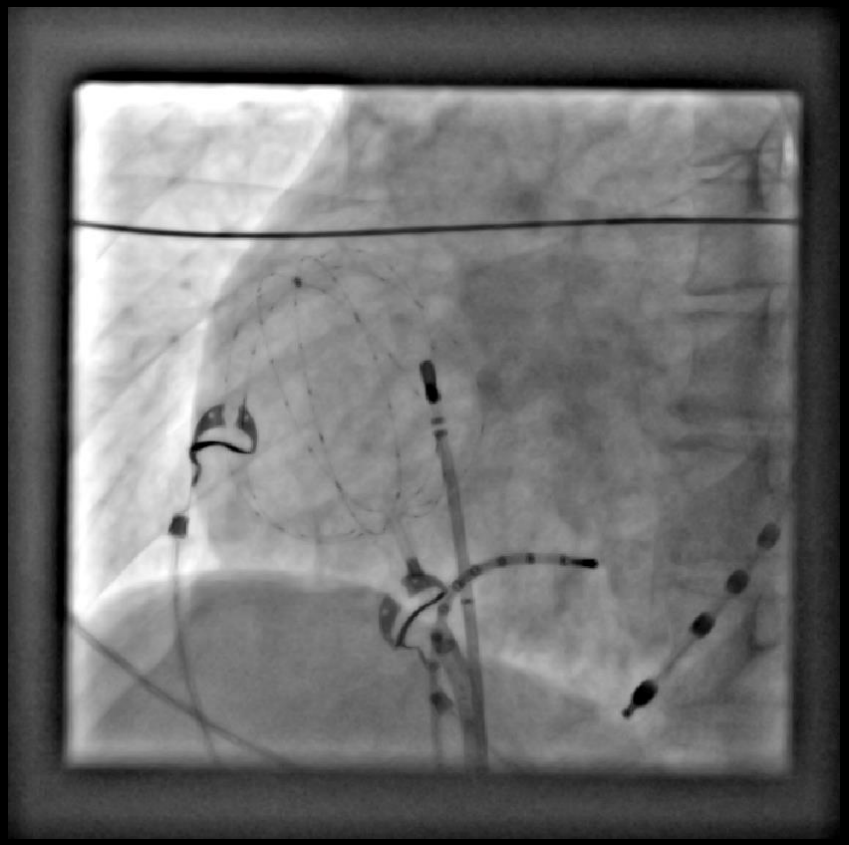


Evaluation – clinical data

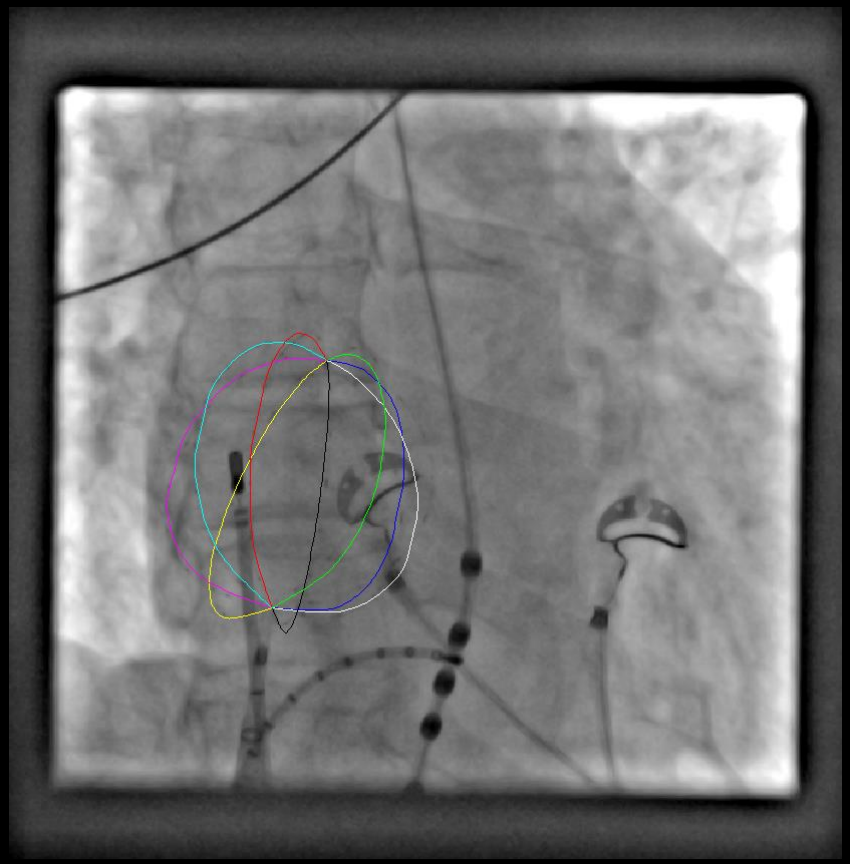


Evaluation – clinical data

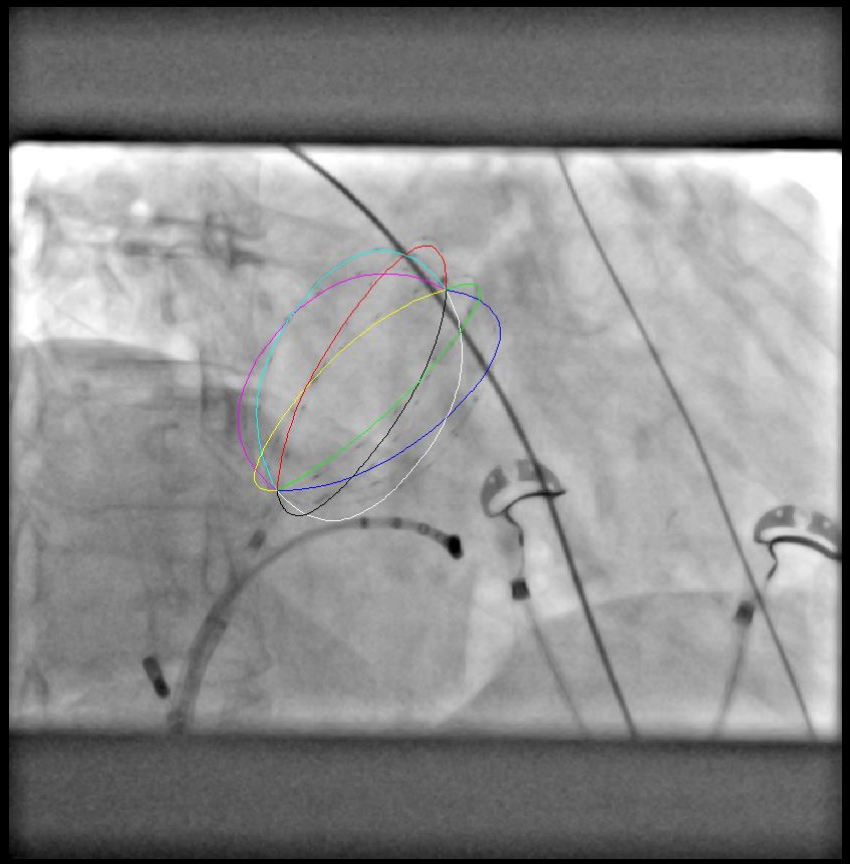




Evaluation – clinical data



Evaluation – clinical data



Summary

Summary

- Method
  - Better electrode candidates detection
  - Asymmetric model initialization
- Evaluation
  - Evaluated 18 C-arm CT and 8 clinical dataset
  - Evaluated with two different error metrics
- Result
  - Error between reconstructed and ground truth electrodes in both setups are below 3mm

Outlook

Outlook

- Method
  - More robust electrode detection by training classifier with more data
  - Minimize reconstruction error in region of interest

- Evaluation
  - Evaluate more clinical data, especially bi-plane data

Thank you for your attention