Parametric LV Model Fitting to Coronary Arteries

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Abstract

In the context of rotational coronary angiography, research focus is shifting towards 3D+t applications. Here, heart models allow for the extraction of functional parameters from the heart motion receive increasing attention. We present an approach to fit a parametric left ventricular heart model to centerlines of coronary arteries that accommodates the sparse point set conditional to the underlying angiography data. Using a coarse-to-fine optimization based on simulated annealing and ellipsoid pseudo-distances, we achieve a reprojection error of 0.794 mm compared to 0.422 mm of the 3D centerline ground truth.

Introduction

Rotational X-ray Angiography

- 3D+t reconstruction of arteries [1]
- Structure and movement of myocardium [2]

Left Ventricular (LV) Parametric Heart Model

- Originally developed for tagged MRI [3]
- Ellipsoid shape described by parameter functions

Adaption to Coronary Artery Centerlines

- No uniform distribution over the surface renders fitting complicated

Materials and Methods

Parameter Function Ellipsoid (PFE)

$$f_{t,a_x,a_y,a_z,e_x,e_y}(u,v) = \underbrace{\begin{pmatrix} \cos\tau(u) & -\sin\tau(u) & 0 \\ \sin\tau(u) & \cos\tau(u) & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{twisting}} \underbrace{\begin{pmatrix} a_x(u)\cos u \, \cos v \\ a_y(u)\cos u \, \sin v \\ a_z(u)\sin v \end{pmatrix}}_{\text{ellipsoid \& scaling}} + \underbrace{\begin{pmatrix} e_x(u) \\ e_y(u) \\ 0 \end{pmatrix}}_{\text{axis offset}}$$

with $u \in \left[-\frac{\pi}{2}, \frac{\pi}{4}\right]$ and $v \in [-\pi, \pi]$.

Equidistant piecewise linear functions (**Fig. 1**):

- $a_x(u), a_y(u)$: width of minor ellipsoid axes
- $e_x(u), e_y(u)$: offset from the principal axis
- $\tau(u)$: rotation around long axis (twist)

Pseudo-closest Point

For a segmented 3D point $\boldsymbol{p} \in P$ on the coronary tree:

$$\tilde{c}(\boldsymbol{p}) = \begin{pmatrix} \operatorname{atan2}\left(p'_z, a_z\sqrt{\left(\frac{p'_x}{a_x}\right)^2 + \left(\frac{p'_y}{a_y}\right)^2}\right) \\ \operatorname{atan2}(a_x p'_y, a_y p'_x) \end{pmatrix}$$

with $\boldsymbol{p}' = \boldsymbol{R}^{-1}(\boldsymbol{p} - \boldsymbol{c})$ in the ellipsoid's reference system

(a) Initial Post Estimation

- Semi-manual selection of LV base and apex in two views (supported by epipolar geometry)
- Triangulation yields center and orientation of cut-off ellipsoid
- Initial optimization of $a_x = a_y$ (further refined in **(b)**)

(b) Parameter Function Fitting

Coarse-to-fine optimization based on simulated annealing [4]:

$$\underset{a_x,a_y,e_x,e_y}{\arg\min} \sum_{\boldsymbol{p} \in P} \left\| \boldsymbol{p} - f_{t,a_x,a_y,e_x,e_y}(\tilde{c}(\boldsymbol{p})) \right\|_2$$

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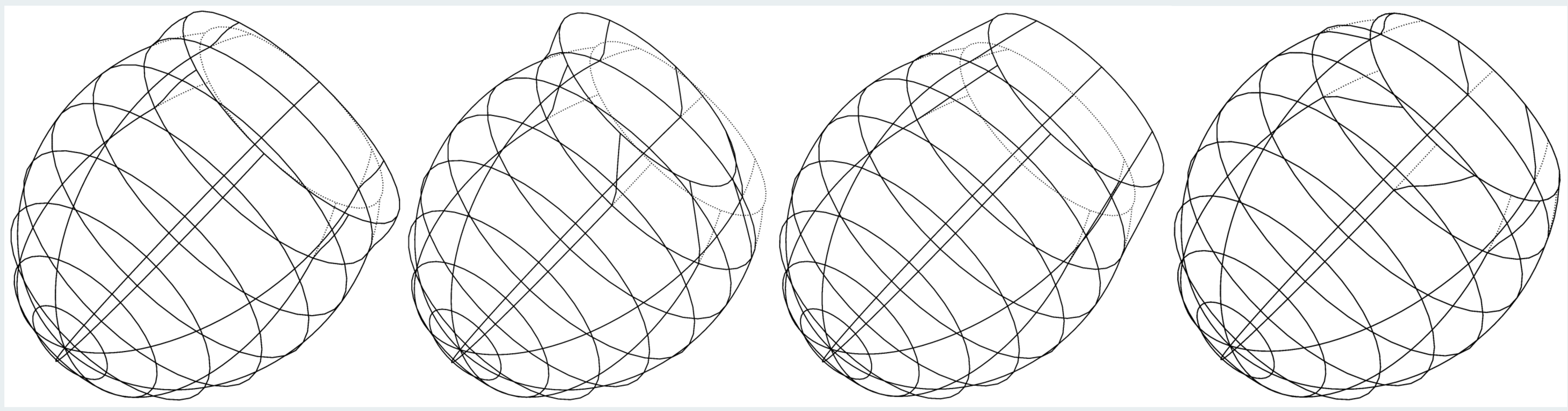

a) $a_x(u), a_y(u)$ **b)** $e_x(u), e_y(u)$ **c)** $a_z(u)$ **d)** $\tau(u)$

Figure 1: Effects of changing parameters in the ellipsoid.

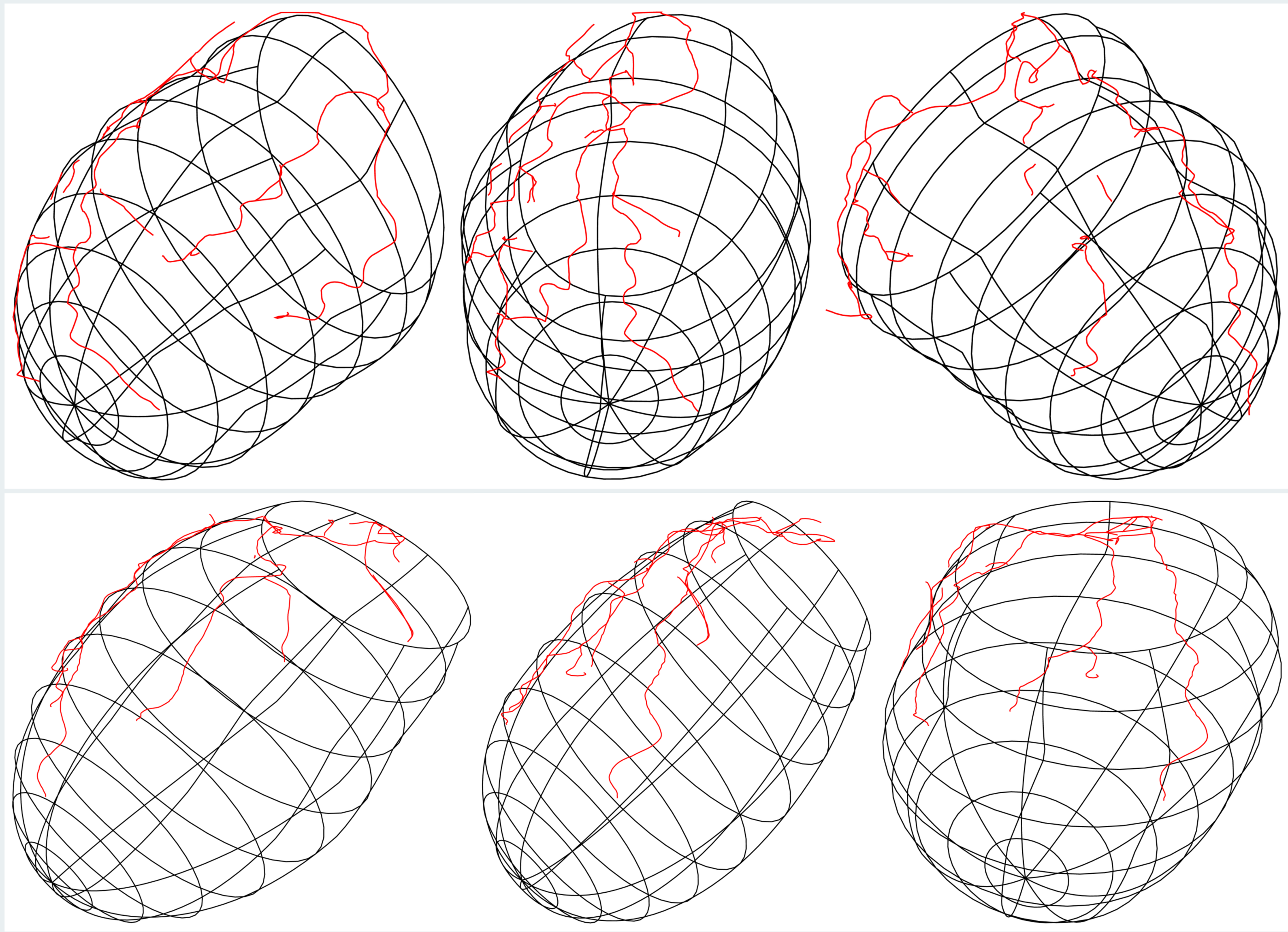

Figure 2: 3D PFE for patient 1 (top) and patient 2 (bottom).

Table 1: Average fitting and reprojection error in mm for points on the LV model surface and the centerline reconstruction.

	patient 1	patient 2
3D fitting error	1.020	0.810
reconstruction reprojection error	0.532	0.422
model surface reprojection error	0.815	0.794

Results and Discussion

Data & Evaluation

- X-ray angiography, two patients, 133 projections
- 3D left artery tree reconstruction [5], at cardiac time $t = 0.1$

Results

- Qualitative fitting results in **Fig. 2**
- 3D fitting error, 2D reprojection error in **Table 1**

Discussion

- Initial 3D reconstruction: lower bound on the reprojection error
- Further compromised by erroneous segmentation
- Comparably small error increase for surface points

Conclusions

- Approach to fitting a parametric LV model to coronary artery centerlines
- Direct involvement of functional heart parameters

Future Work

- Extension to 3D+t
- Extraction of twist from the cardiac cycle

References

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