Parametric LV Model Fitting to Coronary Arteries

Tobias Geimer1,2,3, Johannes Höhn1, Mathias Unberath1,2, Andreas Maier1,2

1 Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
2 Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
3 Department of Radiation Oncology, Universität Erlangen-Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

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 received increasing attention. We present an approach to fit a parametric ventricular heart model to the 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)

\[
  f_{a_x, a_y, a_z, e_x, e_y, e_z} (u, v) = \begin{bmatrix}
  \cos(t(u)) - \sin(t(u)) & 0 \\
  \sin(t(u)) & \cos(t(u)) & 0 \\
  0 & 0 & 1
  \end{bmatrix}
  \begin{bmatrix}
  a_x(u) \cos u \cos v & a_y(u) \cos u \sin v & a_z(u) \sin v \\
  a_y(u) \cos u \cos v & a_y(u) \cos u \sin v & a_z(u) \sin v \\
  0 & 0 & 1
  \end{bmatrix}
  \begin{bmatrix}
  e_x(u) \\
  e_y(u) \\
  e_z(u)
  \end{bmatrix}
\]

with \( u \in [-\frac{\pi}{2}, \frac{\pi}{2}] \) 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 \( p \in P \) on the coronary tree:

\[
  \hat{e}(p) = \arg\min_{\hat{e}_a, \hat{e}_b, \hat{e}_c} \sum_{p \in P} \left\| p - f_{a_x, a_y, a_z, e_x, e_y, e_z} (\hat{e}(p)) \right\|_2
\]

(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]:

\[
  \arg\min_{a_x, a_y, a_z, e_x, e_y, e_z} \sum_{p \in P} \left\| p - f_{a_x, a_y, a_z, e_x, e_y, e_z} (\hat{e}(p)) \right\|_2
\]

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