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Reconstruction of Coronary Artery Centrelines from X-ray Rotational Angiography using a Probabilistic Mixture Model

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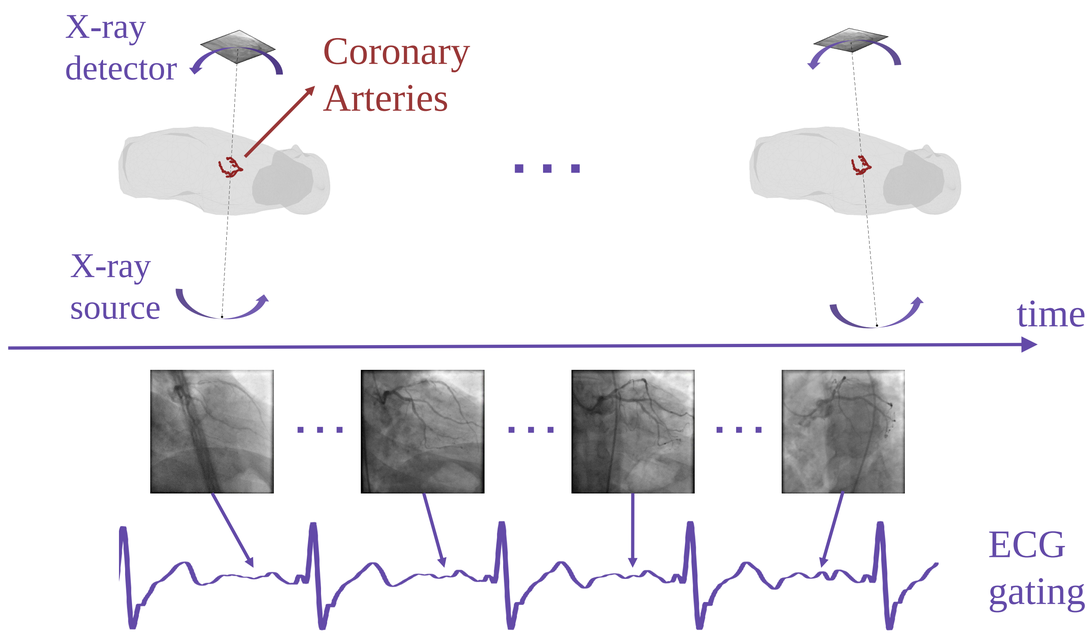
Introduction

- We propose a novel probabilistic formulation for reconstruction of coronary artery centrelines from Rotational Angiography (RA) based on a Mixture Model (MM) representation of point sets describing the coronary arteries.
- Most of the existing model-based reconstruction methods require clean and accurate segmentations of arteries from 2D X-ray angiography images, which is typically achieved using manual or semi-automatic algorithms.
- Our formulation offers robustness against possible errors in 2D centreline segmentations by employing an additional uniform MM component to model the erroneous parts of the segmentations.

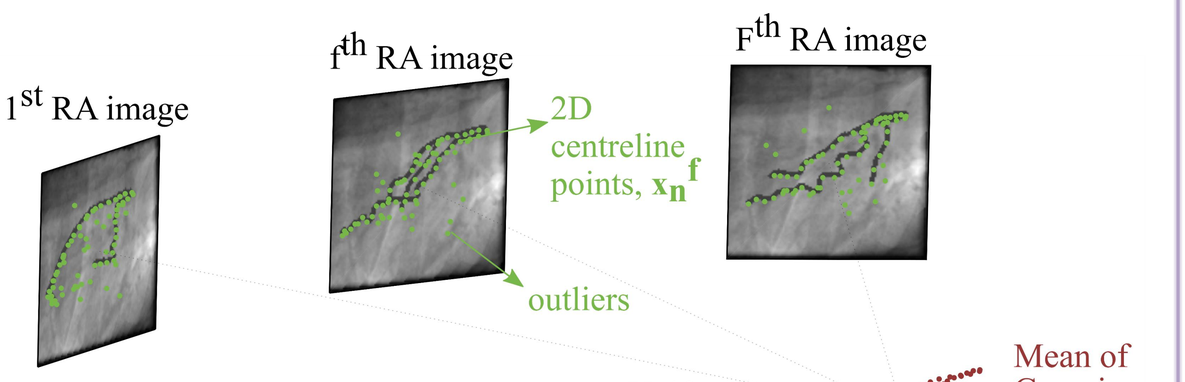
Methods

X-ray image acquisition and retrospective image gating



- Our method assumes that X-ray angiography images are collected using a properly calibrated system, thus the projection matrices are available.
- With the help of ECG, we select a subset (8-9 out of approximately 120 images) of images at the end-diastole, since it is one of the phases with least cardiac motion.

A probabilistic mixture model based reconstruction algorithm



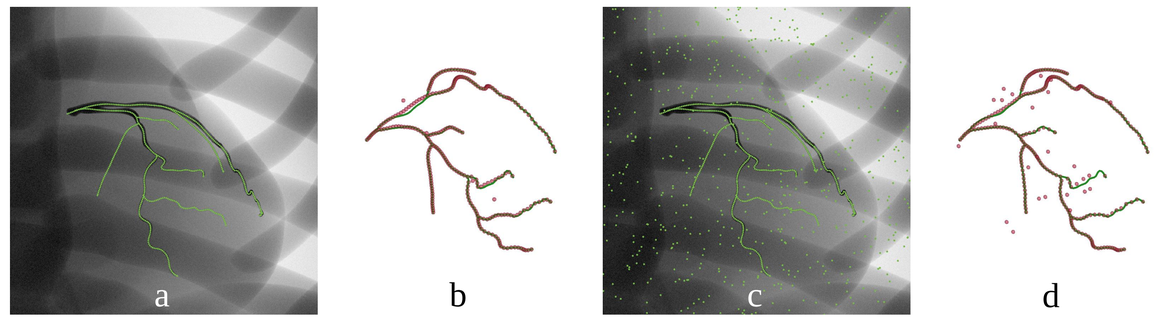
$$P(\mathbb{X},\mathbb{Z}|\boldsymbol{\theta}) = \prod_{f=1}^{F}\prod_{n=1}^{N_f}\prod_{m=1}^{M+1}\left[\Pi_m \tilde{P}\right]^{z_{nm}^f}.$$

- The main idea of our reconstruction method is to represent 3D coronary artery centrelines as a probabilistic mixture model (MM), which is composed of Gaussian distribution components and an additional uniform distribution.
- We hypothesize that the segmented 2D coronary artery points are generated by sampling from one of these Gaussian distributions and projecting them onto the 2D X-ray images. Similarly, we assume that an additional uniform distribution is responsible for generating the segmented 2D outlier points.
- We formulate the reconstruction as the problem of maximum-likelihood (ML) estimation of mixture model parameters given data. The ML solution is computed using Expectation-Maximization (EM) algorithm [1].

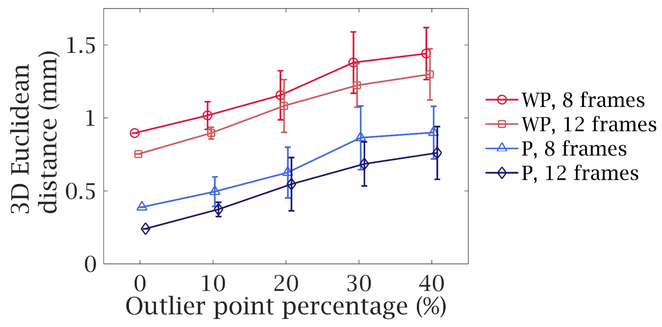
Results

Results on synthetic angiography data

- To quantitatively assess our method, synthetic angiography data and centreline segmentations at end-diastole were generated using left coronary artery geometry of 4D XCAT phantom [2].



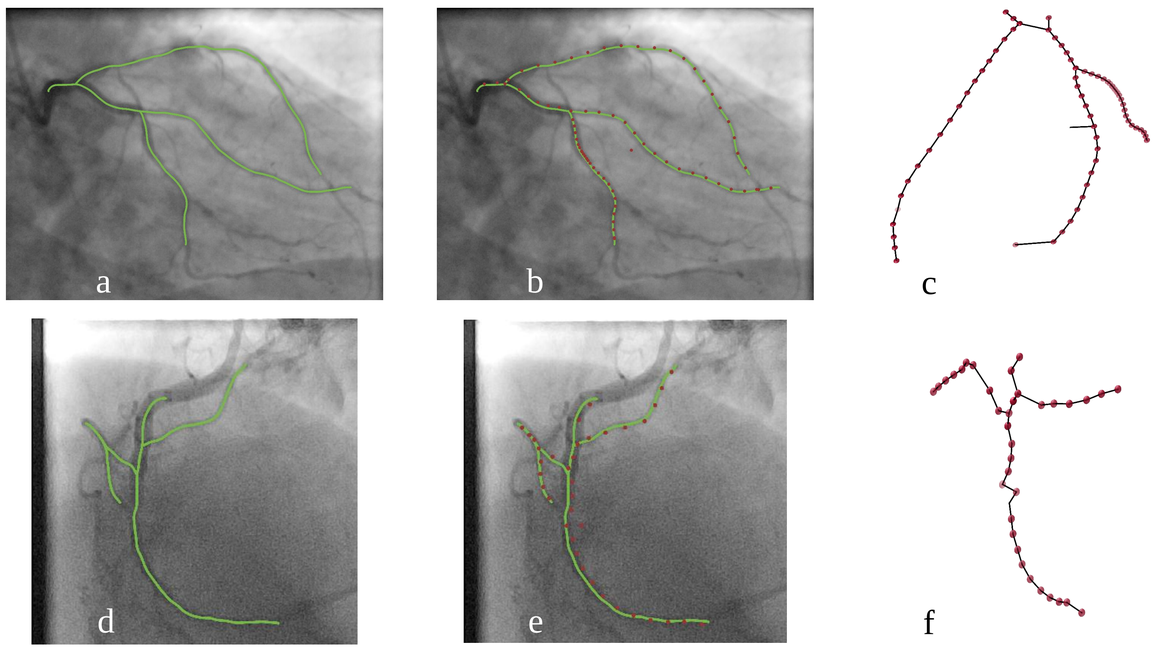
(a) An example of a single gated frame from the synthetic phantom, where the centrelines are shown in green. (b) The reconstruction result using clean segmentations. The red points correspond to the estimated means of the Gaussian components, whereas the ground truth centrelines are shown in green. (c) An example of a single gated frame from the synthetic phantom with outliers (cf. (a)). (d) The reconstruction result using segmentations with outliers (cf. (b)).



Results of the experiments averaged over 10 runs with different outlier levels (0% to 40%), camera models (weak-perspective, WP or perspective, P) and number of gated frames (8 or 12 frames). The averages of mean Euclidean distances from the reconstructed points to the closest ground truth centreline point were reported.

Results on real angiography data

- To assess the performance of the proposed method in real X-ray RA data, two reconstructions were computed from one LCA and one RCA study.
- As a post-processing step, reconstructed points are connected to each other by computing minimum spanning arborescence using Edmond's algorithm [3].



Results of the experiments with real RA data are shown for LCA (First row) and RCA (second row). (a)-(d) Segmented centreline points are shown in green. (b)-(e) Reconstruction result projected onto the RA image is shown by red points. (c)-(f) The reconstruction at convergence with perspective camera model. The opacity of the points reflect the importance of the component in MM.

Conclusions

- We propose a method for 3D reconstruction of coronary arteries from X-ray RA with a novel probabilistic perspective, and present our preliminary results.
- Because of its probabilistic formulation, our method provides a convenient framework to include prior information (such as sparsity, spatial smoothness etc.) about coronary arteries. This aspect will be investigated in future work.

References

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[2] *Segars, W. P., Sturgeon, G., Mendonca, S., Grimes, J., and Tsui, B. M. W., "4D XCAT phantom for multimodality imaging research.," Med. Phys. 37(9), 4902-15 (2010).*

[3] *Tarjan, R. E., "Finding optimum branchings," Networks 7(1), 25-35 (1977).*