Estimating the Motion of the LAD: A Simulation-Based Study

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Abstract. In this paper, we present a simulation-based study of a motion analysis technique designed to intra-operatively estimate the motion parameters of the LAD coronary artery from endoscopic images.

1 Introduction

The epicardial coronary arteries exhibit substantial phasic motion during the cardiac cycle. Our goal is to explore the feasibility of intra-operatively tracking the motion of the Left Anterior Descending (LAD) coronary artery using IR endoscopic images and patient-specific pre-operative data. Reconstruction of the three-dimensional geometry of the coronary arteries (e.g., from biplane projection data [1]) has received extensive attention. However, no parametric model of the arterial lumen that captures both the global and local shape characteristics has been presented. Similarly, although there is a substantial body of work on vessel tracking [2,5], most of the methods are limited to two-dimensional tracking in an image and there is no parametric model of the motion of the LAD during the cardiac cycle.

2 Methods

Modeling the arterial lumen: In our simulation-based study, we start with a triangular mesh of the inner lumen of the LDA. Our first objective is to obtain a parametric model of this mesh. To that end we employ the deformable model framework [4,3] to fit the model to the data. As a geometric model of the LAD we use a deformable model $\mathbf{s}(u,v)$ with a curved axis $\mathbf{e}(u) = (e_1(u), e_2, (u), e_3(u))^\top$ as follows: $\mathbf{s}(u,v) = \begin{pmatrix} s_1(u,v) \\ s_2(u,v) \\ s_3(u,v) \end{pmatrix} = \begin{pmatrix} e_1(u) + a_1(u)\ cos(v) \\ e_2(u) + a_2(u)\ sin(v) \\ e_3(u) \end{pmatrix}$, where $-\frac{\pi}{2} \leq u \leq \frac{\pi}{2}$, $-\pi \leq v \leq \pi$, and $a_1, a_2 \geq 0$ are the parameters that define the superquadric size in the x and y directions, respectively. To capture local deformations we use the finite element method and we represent the deformable model

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in the form of weighted sums of local polynomial basis functions [4]. Once fitting is accomplished, the estimated values are the parameters of a (pre-operatively obtained) parametric deformable model of the LAD.

Modeling LAD's motion: Our second objective is to describe parametrically the movement of the LAD during the cardiac cycle. For this purpose we obtained, from our colleagues at the Texas Heart Institute, surface meshes of the LAD during five steps of the cardiac cycle. We model the movement of the LAD (due to the heart movement) as a systole/diastole and twist around the major axis of the heart (in this paper, we will not consider the respiratory motion). Let $\mathbf{m}(u, v, t) = (m_1, m_2, m_3)^\top$ be the position of the LAD over time obtained by applying a systole/diastole transformation along with a twist transformation to the initial LAD shape, as described below. Also, let the initial shape $\mathbf{m}(u, v, 0) = \mathbf{s}(u, v)$. The systole/diastole deformation can be parameterized as follows: $\mathbf{o}(u, v, t) = \begin{pmatrix} d^1(u,t) \\ d^2(u,t) \\ d^3(u,t) \end{pmatrix} \mathbf{s}(u, v)$. Given the above primitive $\mathbf{o} = (o_1, o_2, o_3)^\top$, the parameterized twisting results in a new position for the LAD given by:
$\mathbf{m}(u, v, t) = \begin{pmatrix} o_1 cos(w(u,t)) - o_2 sin(w(u,t)) \\ o_1 sin(w(u,t)) + o_2 cos(w(u,t)) \\ o_3 \end{pmatrix}$, where $w(u, t)$ is the time-varying twisting parameter function along the axis of the heart model.

Model-Based Tracking: Our third objective is to track the motion of the LAD using IR endoscopic images. In this paper, we employ simulated IR endoscopic images. We have developed a model-based tracking technique to estimate the motion of the LAD from IR endoscopic images. The central idea of a model-based tracking approach is the following [3]: Using a previously acquired model of the object that you want to track, for each timestep find the position and orientation of the object such that it produces data like the ones acquired. We use as input the 2D coordinates of the silhouette of the LAD as computed by segmenting the IR images. The output is the functions: $d^1(u, t)$, $d^2(u, t)$, $d^3(u, t)$, and $w(u, t)$.

3 Results

Concerning modeling the shape of the LAD, Fig. 1(a) depicts the estimated deformable model, Fig. 1(b) depicts the estimated axis $\mathbf{e}(u)$, and Fig. 1(c) depicts the variation of the radius of the arterial lumen $a_1(u)$. Concerning our tracking technique, the input to our algorithm was the two-dimensional data of the silhouette of the LAD during a cardiac cycle obtained from simulated IR endoscopic images. Figs. 1(d,e) depict five samples of the estimated position of the LAD over time. The view chosen for Fig. 1(d) clearly shows the systole/diastole of the heart and the view chosen for Fig. 1(e) demonstrates the recovered twisting motion. Figs. 1(f-h) depict the values of the estimated motion parameters.

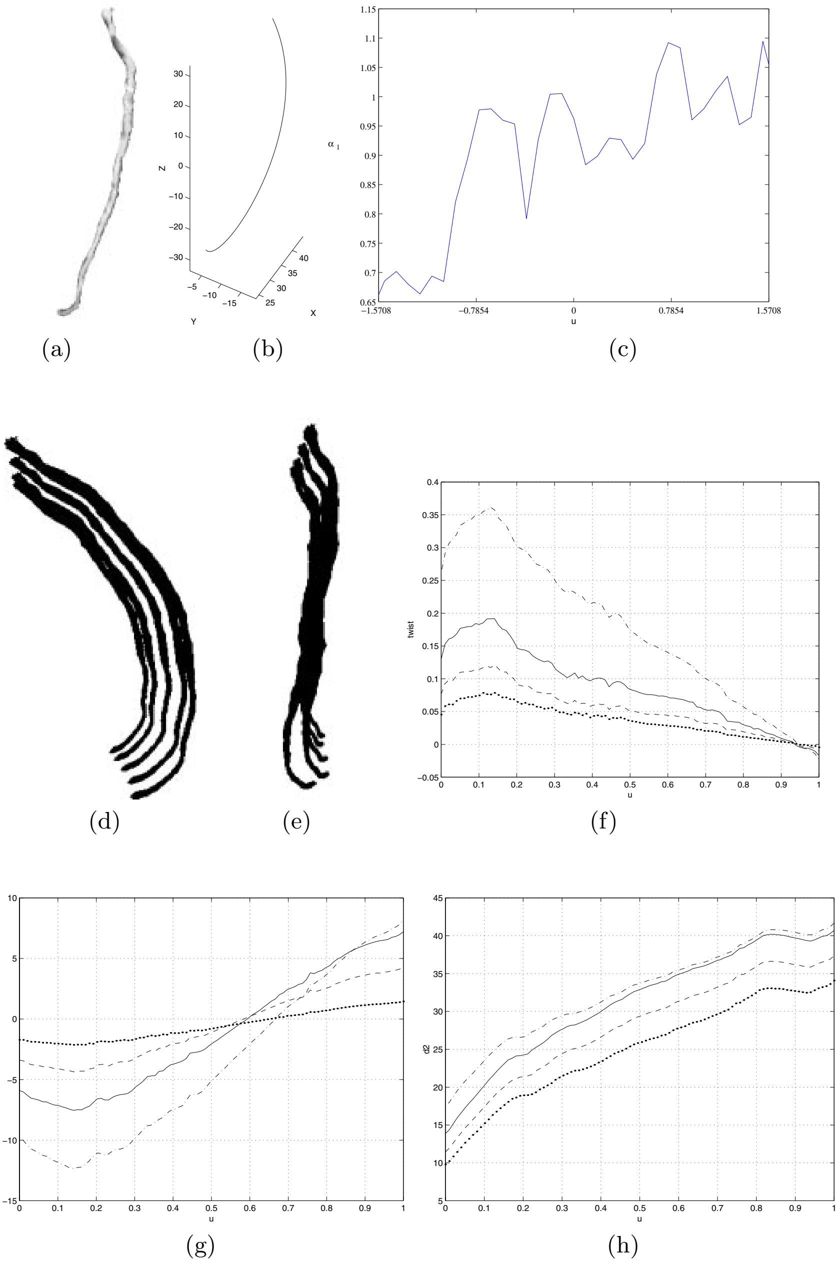

Fig. 1. (a) Deformable model of the LAD, (b) estimated axis, and (c) estimated radius $a_1(u)$. (d,e) Views of the estimated position of the LAD over time, (f-h) Estimated motion parameters $w(u,t)$, $d^1(u,t)$ and $d^2(u,t)$.

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