

Diaphragm border detection in coronary X-ray angiographies: New method and applications



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ABSTRACT

X-ray angiography is widely used in cardiac disease diagnosis during or prior to intravascular interventions. The diaphragm motion and the heart beating induce gray-level changes, which are one of the main obstacles in quantitative analysis of myocardial perfusion. In this paper we focus on detecting the diaphragm border in both single images or whole X-ray angiography sequences. We show that the proposed method outperforms state of the art approaches. We extend a previous publicly available data set, adding new ground truth data. We also compose another set of more challenging images, thus having two separate data sets of increasing difficulty. Finally, we show three applications of our method: (1) a strategy to reduce false positives in vessel enhanced images; (2) a digital diaphragm removal algorithm; (3) an improvement in Myocardial Blush Grade semi-automatic estimation.

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1. Introduction

In diseases related to heart malfunctioning, it is important to ensure proper blood supply to the heart and estimate the healthiness of the myocardial tissue. For this purpose, medical doctors insert a catheter into the affected coronary artery and inject a radio-opaque liquid through it. The liquid flows through the arteries and perfuses the myocardium. This process is recorded as an angiography video sequence using X-ray technology. Fig. 1 shows an exemplar angiographic image. The arteries are clearly visible as they are filled with the contrast liquid. The diaphragm is also visible as a darkened area due to the fact that it is a thick muscle. Usually, other structures like bones or gas are visible as bright or dark areas with varying gray level intensity and strength of the contours that delineate them. When contrast liquid perfuses myocardium, it is seen as a gray staining, which is brighter than arteries and diaphragm. The motion of the diaphragm follows the patient's breathing pattern; since the diaphragm often overlaps with the myocardium, it complicates both visual and automatic inspection of the myocardial perfusion.

1.1. Motivation

Digital removal of the diaphragm could help medical doctors when visually estimating myocardium healthiness. Additionally, several automatic or semi-automatic methods for myocardial perfusion estimation have been proposed in the last seven years and all of them are negatively affected by the diaphragm motion. The method in [1] use pre-processing to compensate for the diaphragm movement and the ones in [2–8] explicitly require that the diaphragm is not present or moving while image acquisition is performed. It has to be noted that not all patients can hold breath for the time required to record a complete sequence for myocardial perfusion analysis, i.e. at least 7 s. In [9], which is based on Digital Subtraction Angiography (DSA), authors have the same requirement that patient breathing is avoided for the time of recording. Moreover, in the context of vessels segmentation in X-ray images, the diaphragm border is often misclassified as a vessel [10–13].

1.2. State of the art

To the best of our knowledge, two methods for automatic diaphragm detection in cardiac X-ray angiographies have been proposed so far in [14,15]. In [14], authors model the diaphragm as an arc of a circle. A pre-processing step removes narrow contrast objects like arteries and the catheter by means of morphological closing operator. Then, a Canny edge detector defines an edgeness

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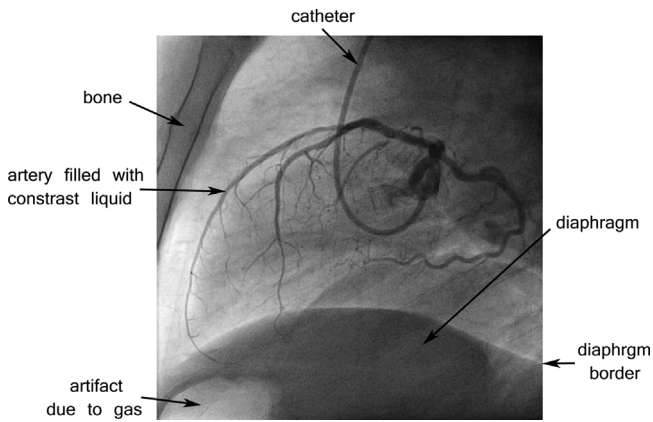


Fig. 1. An exemplar frame from a coronary angiography sequence.

map for the pre-processed image. For any arc in the image plane, authors assign a score – the sum of the edgeness values of the pixels composing the arc. The circle that maximizes that score is the optimal prediction. The initial result is refined with active contours (a.k.a. snakes) if a confidence measure indicates that it is not good enough. In [15], authors adopt a similar approach as in [14] to remove arteries and highlight edges. Then, a set of paths is constructed by tracking edges from one frame to the next. K-means clustering divides the paths in three clusters. The method keeps only the paths that follow the breathing pattern by selecting the cluster of highest quality paths as defined in [15], Section 2.4. The geometric model for the diaphragm border in [15] is a parabola; the final step of the method is to find the optimal parabola for each frame by removing outlying paths.

The method in [15] has one main drawback – it cannot make a prediction for a single frame before processing the whole sequence, while the method in [14] operates individually on each frame. The models used in the two methods show that none of them has the flexibility to represent the diversity of diaphragm borders. The circle is too simple and extensive search over circular arcs often leads to non-plausible detections. The parabola is not flexible enough to model diaphragm border curves, since it is symmetric along a single axis and this assumption is not verified for all diaphragm borders.

Although the following two papers do not present an automatic diaphragm detection method, they are worth mentioning. In [16], a method to track anatomical curves in X-ray sequences is presented. The method requires manual initialization of the curve to be tracked and clearly outperforms a classical optical flow technique. In [17], authors present a method that estimates the “background” layer of an X-ray angiography sequence. The goal is to perform a form of digital subtraction in angiographies, which highlights coronary arteries. The method is based on a Bayesian framework, which combines tracking and modeling of the background. Prior to

contrast liquid injection, it requires that a small number of images are acquired at different cardiac cycles and breathing phases to serve as static masks for the background estimation.

1.3. Contribution

Our paper contributes with a new diaphragm border detection method that outperforms previous ones (Section 4). The method we propose has two main novelties compared to previous methods. Firstly, we make use of a priori knowledge for the shape of the diaphragm border, which reduces the possibility of non-plausible predictions caused by edges that do not belong to the diaphragm border. Secondly, our method is based on increasing flexible polynomial model to improve the detection accuracy.

We also provide a quantitative evaluation of different models for the diaphragm border (Section 2.1). The methodology for digital diaphragm removal from X-ray angiographies (Section 5.2) is another contribution. In addition, we extended the publicly available data set adding new images that increase the diversity of cases.

2. Diaphragm border detection

Our method is composed by a training phase and three main steps, as depicted in Fig. 2. The trained model introduces a probability criterion for the diaphragm border shape. In the first step of the method, a morphological pre-processing removes the arteries and the catheter. The second step computes an edgeness map by means of first order vertical derivatives within a Gaussian pyramid [18]. The last step estimates the optimal diaphragm border, maximizing two criteria – (1) the diaphragm border shape probability and (2) the normalized edgeness value collected by the pixels that belong to the border. The proposed method has three parameters:

- The size of the structuring disk for the morphological operator – R_M .
- The standard deviation of the normal probability distribution expressing the diaphragm border positional uncertainty – σ_G .
- The regularization factor for the diaphragm shape probability – ξ .

Section 2.1 explains the rationale for using a polynomial curve to model the diaphragm border and following subsections explain in detail each of the method modules. Section 2.6 describes the validation we performed for tuning the three method parameters.

2.1. Evaluating different models for the diaphragm border

To compare different diaphragm border models, we fitted various choices to the annotated ground truth curves of data sets A and B (described in Section 3). We evaluated quantitatively a circular model $R^2 = (x - x_c)^2 + (y - y_c)^2$ and polynomial curves of the

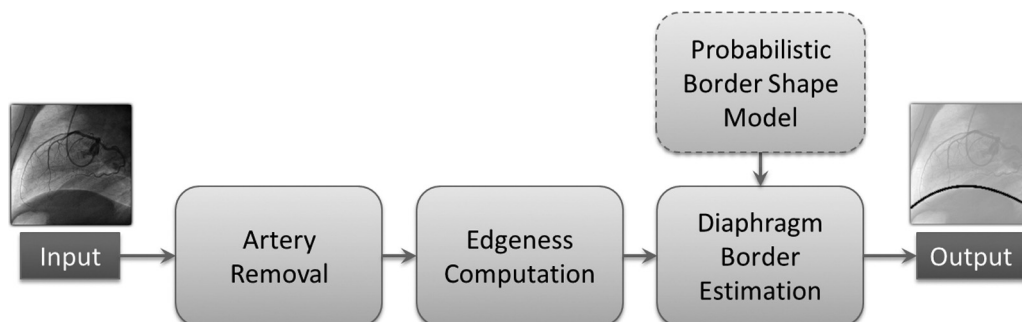


Fig. 2. Block scheme of our method.

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