Ultrasound segmentation based on statistical unit-root test of B-scan radial intensity profiles

Mehdi Moradi, Seyedeh Sara Mahdavi, Julian Guerrero, Robert Rohling, Septimiu E. Salcudean
Department of Electrical and Computer Engineering, University of British Columbia
moradi@ece.ubc.ca

Abstract: Delineation of the perimeter of hollow structures, such as veins and arteries, from ultrasound images is an important step in US-based medical interventions. A simple and efficient approach is proposed for edge detection in ultrasound images. The technique examines the radial edge profiles for unit root based on the Dickey-Fuller test. The existence of the unit root is a sign of a trend, and hence non-stationarity, in the statistics of the edge profile. The method is applied to simulated data and clinical images of human arteries and veins. The outcomes are validated based on the average of the Hausdorff distance between the automatically derived vessel contours and vessel contours marked by five experts. The proposed edge detection method provides accurate segmentations (average Hausdorff distance from expert segmentation of 1.5 mm in vessel images. and 0.4 mm in simulated data).

INTRODUCTION

Ultrasound provides a non-invasive, inexpensive and nonionizing medical imaging modality. However, in addition to occasional weak echo or echo drop-outs, ultrasound images suffer from the intrinsic abundance of speckle that is a result of the interactions of the high frequency mechanical waves with randomly distributed small scatterers. These shortcomings of ultrasound images pose a significant challenge for image processing algorithms. Specifically, derivative-based edge detection methods such as the standard Canny algorithm [3] are affected. These methods are designed to extract as many real edges as possible from images. In case of ultrasound, they produce numerous local edges caused by the speckle pattern. Nevertheless, segmentation of ultrasound images is a critical step in many diagnostic procedures (such as volume study of cancer tumors or detection of cardiovascular complications such as thrombosis) and surgical interventions (such as planning radiotherapy procedures). Therefore, researchers have worked on several methods based on texture operators [13], spectral clustering [2], active contours [8], [11], and model-based approaches [1], [5], [7] to segment ultrasound images.

Some of our previous research efforts have been dedicated to using *a priori* shapes to improve ultrasound segmentation [7], [12]. In the most basic form, these methodologies (1) assume an elliptical model (in the case of vessel segmentation [7]) or tapered ellipse (in the case of prostate segmentation [12]) for the object, (2) use an edge detector filter based on the derivative of the image intensity to select the organ boundary, and (3) refine the estimated organ boundary using *a priori* model in a Kalman filtering paradigm. While we continue to improve our methods, a fundamental improvement to our segmentation approach can be achieved by removing the need for derivative-based edge filters. This paper describes a new edge detection method that can potentially replace the conventional edge filters in step (2).

METHODS

The change in the statistical properties of the image intensity at the boundaries of an organ indicates that statistical methods can be used for edge detection. The proposed method relies on the Dickey-Fuller (DF) test [4,10]. The DF test, a very popular tool in econometric time series studies, examines the null hypothesis of non-stationarity which is equivalent to the existence of a unit root, against the hypothesis of stationarity for autoregressive processes. We apply this test along the radial intensity profiles starting from within the object of interest and look for points along the radii where the null hypothesis of unit root cannot be rejected. The change in the properties of the intensity profile from stationary to non-stationary can be due to the passage of the radial profile through an edge.

The assumption of the proposed approach is that in many ultrasound images, especially in the case of images of hollow structures such as vessels, the statistical properties of the intensity profile are altered at the edges. We treated the radial intensity profiles in ultrasound images as time series. We extended radii from a user selected seed point in the center of the vessel. Each radial intensity profile was considered as a time series.

A signal with a trend cannot be stationary, since its statistical moments depend on time, or in our model, on distance. If one traces the image in the radial direction, the intensity profile tends to become non-stationary upon passing through an edge.

This approach to edge detection is examined on simulated ultrasound images and also ultrasound images of human veins and arteries. In all cases, the outcome is compared with results of five expert segmentations using Hausdorff distance [6] as a measure of distance between contours.

Data and evaluation methods: The proposed edge detection method was first examined on simulated ultrasound images of vessels. Ultrasound images were simulated using Field II [9]. We used an elliptical model to describe the contour of a vessel. Second, For validation, the performance of the method was compared to the expert segmentation of four different vessels in two different ultrasound images. The images (720 × 480 pixels or 9 × 6 cm) included the cross sections of the human saphenous vein and artery. The segmentation algorithm was performed 10 times on each vessel, every time with a new seed point selection.

TABLE I: Hausdorff distance between the automatic and expert segmented contours in simulated and real data.

Simulation 1	$0.36 \pm 0.1mm$	Human Vessel 1	$1.1 \pm 0.4mm$
Simulation 2	$0.32 \pm 0.2mm$	Human Vessel 2	$2 \pm 0.5mm$
Simulation 3	$0.35 \pm 0.2mm$	Human Vessel 3	$1.5 \pm 0.4mm$
Simulation 4	$0.38 \pm 0.2mm$	Human Vessel 4	$1.4 \pm 0.4mm$

RESULTS

Table I provides the distance values (D) between the automatic and expert segmentations. The typical segmentation results are depicted in Figure 1 for simulated data and in Figure 2 for vessel data. It should be noted that the Hausdorff distance is a sensitive measure and results in high error values due to outliers. In many applications, such outliers can be fixed with minimal user interaction. A less sensitive measure is the area between the two contours. The ratio of this non-overlapping area to the area within the automatic contour was found to be 4.5%, 3.9%, 6.1%, 3.3% for the studied vessel images.

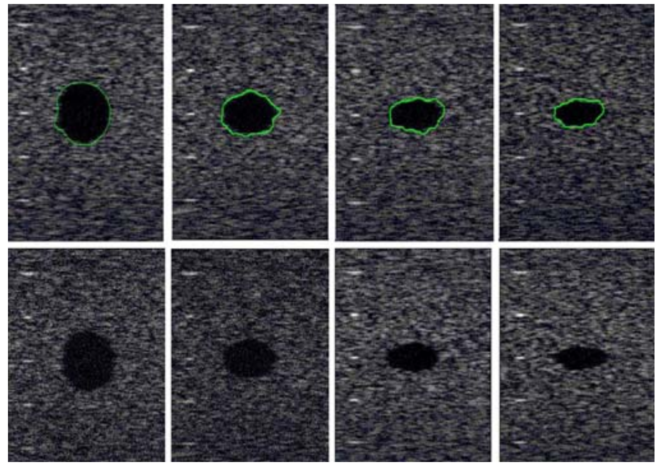

Fig. 1. Four simulated vessel images and their extracted contours.

CONCLUSIONS

In this paper we proposed an edge detection algorithm that can be used for semi-automatic segmentation of medical ultrasound images. The algorithm takes advantage of the Dickey-Fuller test, a popular statistical test in econometric studies, which examines the null hypothesis of existence of a unit root for an autoregressive time series. The algorithm treats the radial intensity profiles as time series and uses the Dickey-Fuller statistical test along the radii to find the pixel at which the profile becomes non-stationary. This simple test, combined with an assumption of continuity of the edge, resulted in very accurate delineations of the borders of the vessels in clinical ultrasound images and also Field II simulated data.

The method is fast and accurate as validated by comparison with expert delineation of the segmented structures. The main advantage of the method is its low sensitivity to local changes and speckle related local maxima in the edge profile difference function. However, without the assumption of *a priori* shape model, the method is vulnerable to weak echo artifacts that are common in clinical images. As part of our future work, we plan to employ this method within the framework of model based methods such as [1] to replace the derivative-based edge filters. This augmented version of the proposed method will be employed to segment more complex structures and organs, such as prostate boundary, from ultrasound images.

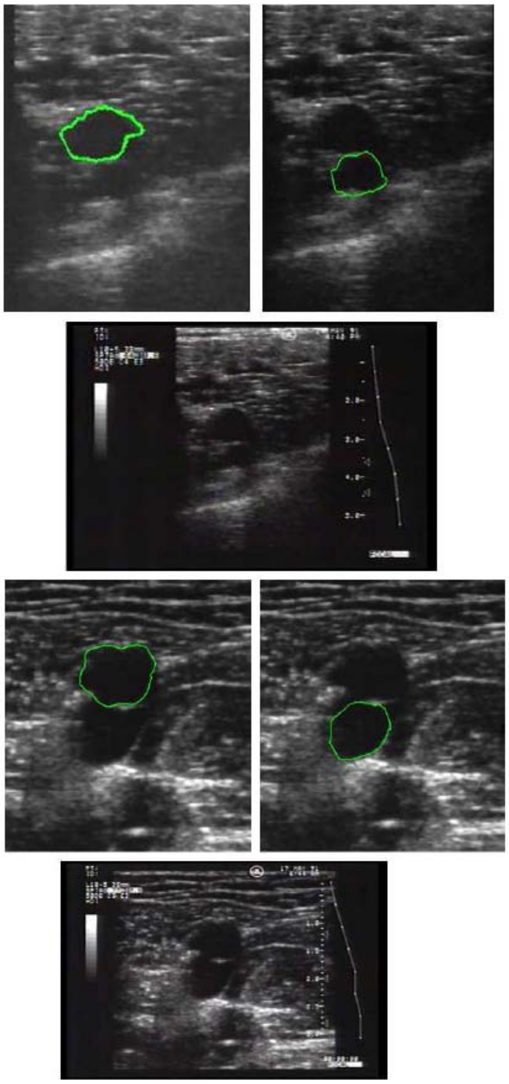

Fig. 2. Segmentation of the human superficial vein and artery in two different images. The vessels are successfully distinguished from each other.

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