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A Novel Method of Image Segmentation in Intravascular Ultrasound

M. Sajewicz[1], E. Rokita[1,2], K. Żmudka[3], J. Kunz[4]

[1]Instituite of Physics, Jagiellonian University, Cracow, Poland
[2]Department of Biophysics, Cracow, Poland,
[3]Department of Hemodynamics and Angiocardiography,
[4]Department of Forensic Medicine, Jagiellonian University Medical College, Cracow, Poland

Abstract

The aim of this study is to present a novel segmentation method of the intravascular ultrasound (IVUS) images. The clinical IVUS system was used to acquire in vitro images of the renal arteries taken from autopsy. The laboratory system was constructed to mimic blood pressure variation ex-vivo. A modified threshold method was developed for automatic determination of inner and outer contours the vessel wall. Additional correction was introduced to account for catheter movement during image acquisition. The Langewouster's model was applied to verify vessel geometry determination. The usefulness of the proposed method in the clinical practice is demonstrated using clinical cases.

Keywords: intravascular ultrasound, image segmentation, artery, elasticity

Introduction

Usefulness of the intravascular ultrasound (IVUS) system has been proofed since 1990s when it has become important clinical tool [1]. The technique is used to determine geometry of the vessel (radius, lumen area), the vessel tissue characterization and to verify correctness of the stent placement. Additionally, IVUS images are used to evaluate mechanical properties of the arteries [2]. In principles IVUS examination could be also applied to determine the deformation of the heart arteries induced by the periodic blood pressure changes. To fulfill this task the artery borders have to be precisely detected. Unfortunately the delineation of the vessel boundary still represents a challenge for commercial IVUS systems [1]. Additional problem is caused by permanent movement of the catheter due to heart beating. Therefore realization of good contour detection algorithm encounters difficulties and still need to be developed.

Experimental procedures

To test the method 12 human renal arteries were collected at autopsy. Moreover, clinical usefulness of the method was verified by IVUS examinations of 8 patients with diagnosed arteriosclerosis disease aged from 46 to 73 years. Inform consent was obtained for all subject prior to examination.

Experimental setup consists of the IVUS System (Endosonics-Volcano, Rancho Cordova, CA, USA) with 64 elements solid state catheter, pressure measurement unit and tank filled with saline. The pressure inside artery was changed with the rate of 8 mmHg/s in the range 0÷200 mmHg. The vessel geometry changes observed and stored by the IVUS unit and synchronized with the pressure measurements. For the clinical studies ~1 minute examination at fixed position of the catheter was performed.

IVUS images were analyzed off-line using the dedicated software developed in our laboratories. The contour detection algorithm is based on the following assumptions: (1) the center of the vessel (S_A) and the position of the catheter (S_0) do not overlap, (2) inner radius of the vessel belongs to the range $R_{min}\div R_{max}$. (R_{min} and R_{max} determination is based on the visual image inspection), (3) outer radius of the vessel equals to the inner radius plus the wall thickens, which ranged from D_{min} to D_{max} and (4) the grayscale minimum value (M_{pix}) is calculated on the basis of a region within the lumen of the vessel. The minimum threshold value TR is selected as greater than M_{pix}. All constants are determined during the test run of the program for the vessel.

The calculation of the artery boundary starts with the determination of the S_A position. It is calculated step by step as the mass center in two perpendicular directions for whole image. S_A is determined independently for each image. The boundary detection algorithm is based on the threshold method. A vector $V(R,\varphi)$ is arbitrary selected and for different $R\in[R_{min},R_{max}]$ the distinction between the grayscale values and the threshold TR is checked. The first positive value of the difference is treated as a boundary position. In case of negative detection the procedure is repeated for R_{min} value in the range $(0.9*R_{min}, 1.1*R_{max})$. If the detection is still negative TR value is decreased by 10% steps and calculations are repeated. Non positive boundary detection for given φ results in case of $TR<M_{pix}$. The calculations are automated for the next angle $\varphi_{n+1}=\varphi_n+\Delta\varphi$ $(\Delta\varphi=1^0)$. Outer vessel border detection is based on the same rules but the vector $V(R_{out},\varphi)$ is changing in range $R_{out}\in[R_d+D_{min}, R_d+D_{max}]$ and additionally relies on earlier found inner border points R_d with assumption of vessel thickness limits D_{min} and D_{max} . Finally if necessary the missing segment of the vessel wall is replaced using a part from previously recognized images by interpolation. A result of calculations contains inner and outer boundary point's collection $I(\varphi)$ and $O(\varphi)$. The vessel lumen area A_{in} and whole vessel area A_{out} were computed from $I(\varphi)$ and $O(\varphi)$ by pixel summation.

To verify A_{in} and A_{out} data the Langewouster's arcentanges model [4] was utilized which is commonly used to describe area-pressure relation for human arteries:

$$A(p)=a\left(\frac{1}{2}+\frac{1}{\pi}\cdot\arctan\left(\frac{p-b}{c}\right)\right),$$

where A is area of the vessel, p is transmural pressure, a, b,c are free fitting parameters.

Results

The representative examples of lumen and vessel areas of the artery calculated from IVUS images are shown in Fig. 1A. Additionally results of the fit using the Langewouter's model are presented. Good correlation was observed between experimental and fitted data (correlation >0.991).

A movement of the coronary artery during examination caused by heart cycle is presented in Fig. 1 B. Correction of the movement allows better estimation of radius values for different angles. In fig. 1C the radius values in one direction with and without correction of central point position are presented. Usefulness of this correction appears in better determination of vessel wall in polar coordinates and additionally makes possible to estimate relative radius changes in different directions. In fig. 1 D two examples of angular distributions of the strain are presented without and with correction of the central point position.

Discussion

Presented method of vessel border determination was used for ex-vivo human arteries with good accuracy. High correlation (>.991) for Langewouter's fit indicates proper artery boundary determination by proposed method and agree very well with the presented in literature relation [4]. The geometric assumptions used in the detection algorithm allow precise demarcation of the artery border and could be simply adopted for in vivo studies. Results for in vivo studies shows that consideration of vessel – catheter movement may produce adulteration of the radius value for given angle. It may be appeared in over or under estimation of the radius (fig. 1C). Correction of the central point position allows reduction of errors in determining angular strain distribution and improves outer boundary detection accuracy. Disabling central point correction brings unacceptable adulterations and reduces effect of real distortions (fig. 1D). Assumptions done to the geometry of the vessels ($R_{min,}$, R_{max}, D_{min} and D_{max}) allow exacting determination of the boundaries and improve compute time by reducing the region of interest and especially allow better detection of the outer artery wall. Use of self adopting threshold value TR results in better determination of weak contrasted regions in IVUS images.

Presented method allows very good automated segmentation of IVUS artery images and prefaces our prospective goal – developing artery elastographic measurements based on standard IVUS images. The method could be used to determine angular distribution of strain (fig. 1C) and allows risk stratification of the arteriosclerotic alteration. Calculation of artery elastic properties is limited by physiological pressures range but elastography based on relative changes permit to estimate angular differences. It is known that many researches have been done IVUS elastography but there is still need to improve the technique. Additionally, presented uncomplicated threshold method utilizes IVUS images and could be used in present ultrasound devices opposite to methods depend on ultrasound signal processing.

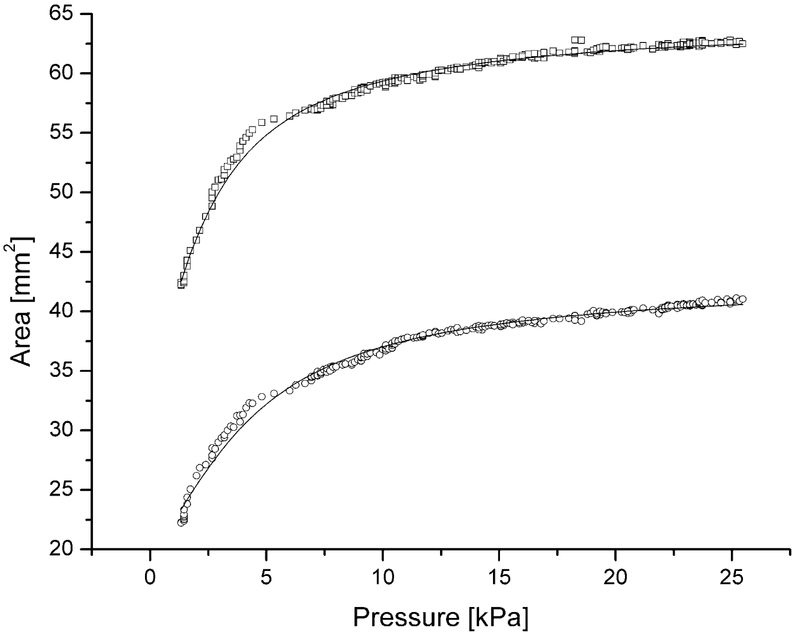

Fig. 1A Vessel and lumen areas of the renal artery vs. pressure: □ - outer vessel border, ○ - inner vessel border, — Langewouter's model

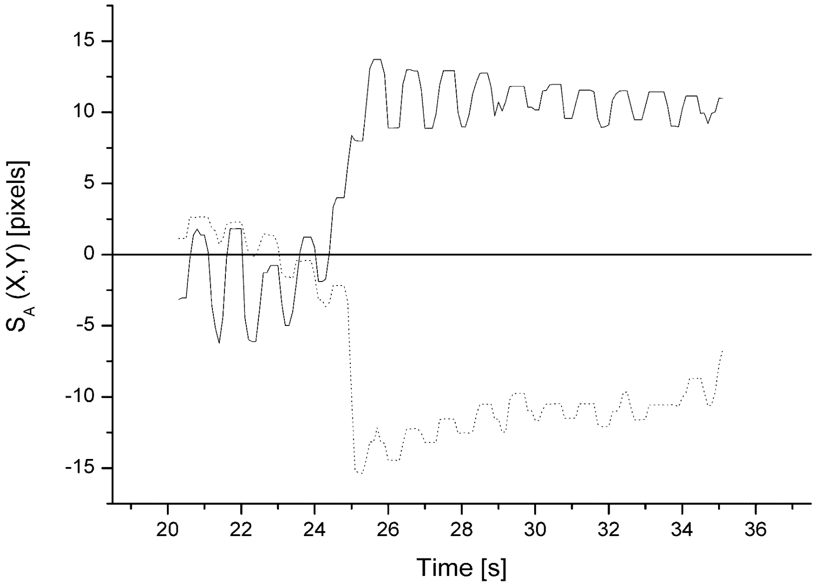

Fig. 1B The distance between the center of the vessel $S_A(X,Y)$ and the position of the catheter S_0 in the human coronary artery during routine examination in horizontal — and vertical ····· direction

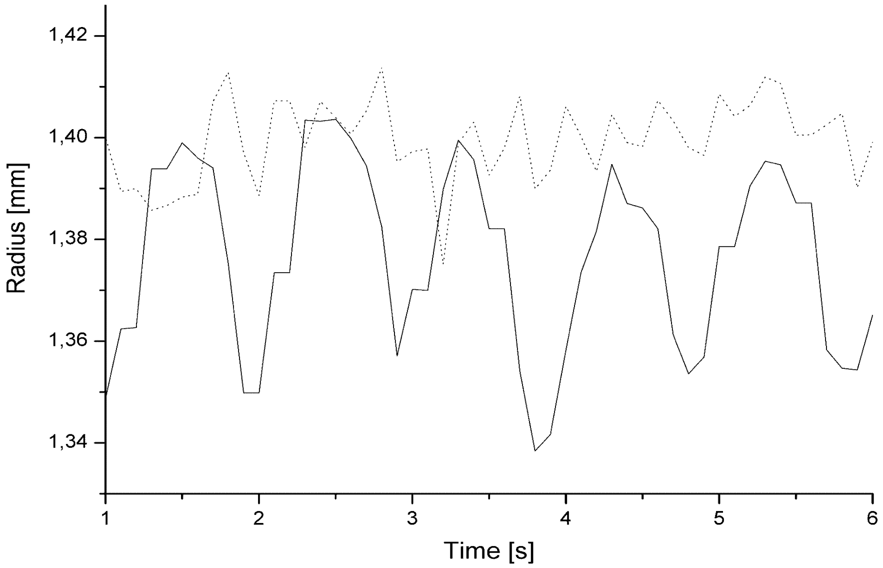

Fig. 1C Radius in one direction with —— and without ······ the central point correction

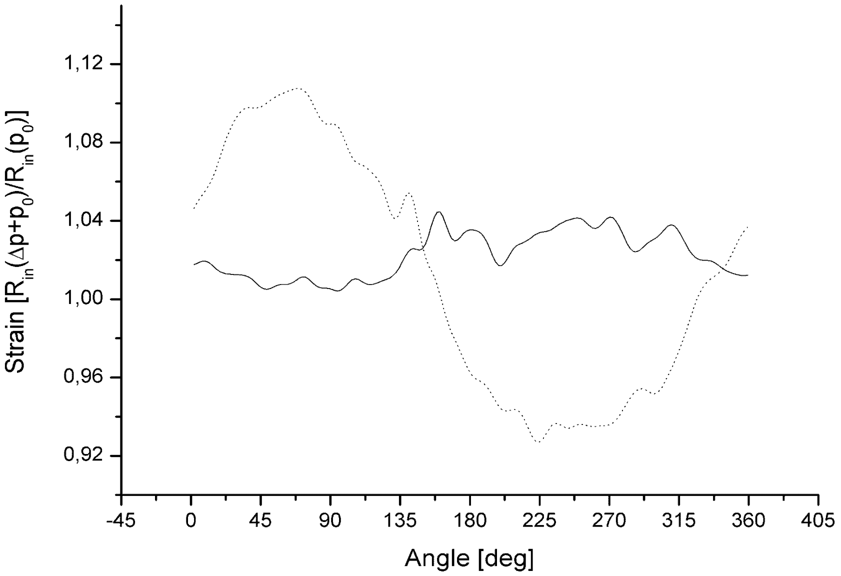

Fig. 1D Angular distribution of strain for Δp=40 mmHg, with —— and without ······ the central point correction

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