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ECHOCARDIOGRAM SEGMENTATION USING ACTIVE CONTOURS WITH PREPROCESSING STEP

SEGMENTACIJA EHOKARDIOGRAMA KORIŠĆENJEM AKTIVNIH KONTURA SA PREDOBRADOM

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Ključne reči:
Ehokardiogram, segmentacija, CV model, Kuwahara filtar, aktivne konture.

Abstract

Segmentation of echocardiograms is difficult task since speckle noise embedded in ultrasound images. Standard techniques for image segmentation, such as thresholding, region growing or watershed method, give poor results in heart chambers segmentation. Active contours "without edges" proved to be robust to noise and applicable for ultrasound images segmentation. In this paper we use this model together with preprocessing step, Kuwahara filtering, which enables low-pass filtering in homogeneous regions while preserving edges (i.e. high frequency components) in image.

1. INTRODUCTION

Ultrasound image processing is highly conditioned by speckle noise. Many techniques for speckle noise reduction are developed thus far, some of them considering statistical model of speckles (multiplicative model of noise) while other techniques do not consider any particular characteristic of speckle noise, but attempt to be applicable to general noise model. In this paper we refer to former techniques, using Kuwahara filter as a preprocessing step for segmentation.

Speckle noise can affect ultrasound image segmentation by appearance of spurious curves in the segmentation contour. We use image denoising before segmentation in order to remove them.

Chan-Vese (CV) model [1] of segmentation is implemented in this paper. It is widely applicable model and is not dependable on gradient of the image (edge based), but is region based method of segmentation. Hence this method considers image globally and is less sensitive to placement of initial contour.

The paper is organized as follows. In the second chapter Kuwahara filter is described as a preprocessing step. Chapter three describes CV model for heart chambers segmentation. Results of the proposed technique are presented in chapter four, while conclusions and further work are explained in the last chapter.

2. KUWAHARA FILTER

In images degraded either by additive or multiplicative noise the standard approach toward noise reduction is low-pass filtering. There are many linear and nonlinear filters used in that purpose such as: Gauss, median, Wiener etc.; also, some adaptive filters have been developed thus far (e.g. Kuan, Foster). Although noise is substantially eliminated by those filters in homogeneous areas in the image, the most evident deficiency of those filters is edge smoothing. In other words, filtering is insensitive to high frequency components in image.

In order to prevail this problem there have been proposed filters for noise reduction with edge preservation. Here we used Kuwahara filter [2, 3] with filtering scheme shown in Fig.1. (there is 5x5 neighborhood; in general there is (4k+1)x(4k+1) neighborhood). Kuwahara filter considers for each pixel its four region neighborhood. Pixel intensity after filtering will be the mean of the region with the lowest variance. Since edges are areas with high variance, they will be preserved.

An example of Kuwahara filter implementation is shown in Fig. 2. for different neighborhoods. Noise reduction is evident from this figure, as filtered images do not contain granular pattern (noise). On the other hand, transitions between adjacent homogeneous regions in the image, i.e. edges, are clear.

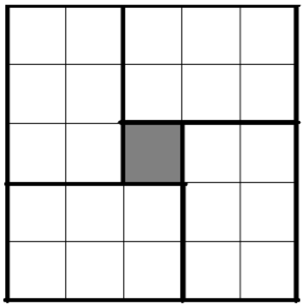
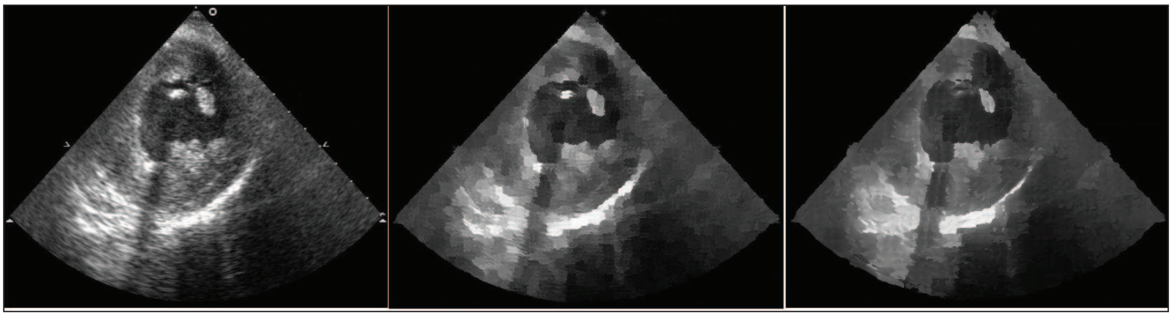


Fig.1. Kuwahara filtering mask: the central pixel surrounded by 5x5 neighborhood. Filtered pixel intensity is calculated as a mean of the region (four regions are bold lined) with the least variance [2].



a) b) c)

Fig.2. Kuwahara filtering: a) original echocardiogram; b) filtering 13x13 neighborhood; c) filtering 25x25 neighborhood. Higher order neighborhood guarantees better signal-to-noise ratio, i.e. stronger denoising.

3. CV MODEL

CV [1] assumes an image, $u_o(x,y)$, as a piecewise-constant intensity regions. There are two such regions in basic CV model: object (to be segmented) and background. Let c_1 be mean pixel intensity of object and c_2 mean pixel intensity of background. Since object and background are not known in advance (neither are c_1 and c_2), it is needed to initialize boundaries (contour) between object and boundaries. Then segmentation process can be proposed as a minimization of mean-square error (MSE) of pixel intensities inside (outside) contour, C, and mean value of object (background):

$$\begin{aligned}\inf\{F(c_1, c_2, C)\} = inf\{&\lambda_1 F_{MSE}(inside\ (C), c_1)\\ &+ \lambda_2 F_{MSE}(outside\ (C), c_2)\\ &+ \lambda_3 Length(C)\}\end{aligned}$$

where $\lambda_1 \div \lambda_3$ are fixed weights. As it can be seen from the minimization equation, there is one more term to be minimized – contour length. First two terms can be calculated as they represent MSE:

$$F_{MSE}(region, c) = \int_{region} |u_0(x,y) - c|^2 dxdy.$$

Now it is obvious that the contour, after minimization process, will evolve from arbitrarily chosen contour to final contour. Thus final position of contour will separate object from background according to mean value criterion. As this is an optimization problem, this method is less sensitive to noise.

In order to represent contour and regions inside and outside the contour, CV model engages level set method [4, 5]. This method proposes level set function, $\phi(x,y)$, which acts as a mask in original image:

$$\begin{gathered}C = \{(x,y) \in \Omega : \phi(x,y) = 0\}\\ inside(C) = \{(x,y) \in \Omega : \phi(x,y) < 0\}\\ outside(C) = \{(x,y) \in \Omega : \phi(x,y) > 0\}.\end{gathered}$$

The most used such a function is: $\phi(x,y) = x^2 + y^2 - r^2$. It is clear from definition of level set function that it is positive for pixels outside the contour, negative for those inside contour and exactly zero on the contour. Thus every pixel has its value in this mask, labeling regions of object and background. Using level set formulation we can further describe functionals to be minimized:

$$F_{MSE}(\phi < 0, c_1) = \int_\Omega |u_0(x,y) - c_1|^2 (1 - H(\phi(x,y)))dxdy$$

$$F_{MSE}(\phi > 0, c_2) = \int_\Omega |u_0(x,y) - c_2|^2 H(\phi(x,y))dxdy$$

$$Length(C) = \int_\Omega \left|\nabla H\big(\phi(x,y)\big)\right| dxdy.$$

Here $H(w)$denotes Heaviside function. It is obvious from the last equation that functional F is of the form$F = \int F_0 dxdy$ Using Euler-Lagrange equation for minimization F of with respect to ϕ :

$$\frac{\partial F_0}{\partial \phi} - \frac{d}{dx}\left(\frac{\partial F_0}{\partial \phi_x}\right) - \frac{d}{dy}\left(\frac{\partial F_0}{\partial \phi_y}\right) = 0,$$

we arrive to solution:

$$\delta(\phi)\left[-\lambda_1(u_0 - c_1)^2 + \lambda_2(u_0 - c_2)^2 + \lambda_3 \nabla \cdot \left(\frac{\nabla\phi}{|\nabla\phi|}\right)\right] = 0$$

with $\delta(w)$ being Dirac function. When steepest (gradient) descent method applied to last equation, we finally have:

$$\frac{\partial \phi}{\partial t} = \delta(\phi)\left[-\lambda_1(u_0 - c_1)^2 + \lambda_2(u_0 - c_2)^2 + \lambda_3 \nabla \cdot \left(\frac{\nabla\phi}{|\nabla\phi|}\right)\right]$$

where $\phi(x,y,t)$ represents parameterization of level set function with respect to time (steepest descent iteration number), t .

In algorithm there are implemented regularized Heaviside function, $H_\varepsilon(w) = \frac{1}{2}\left[1 + \frac{2}{\pi}\arctan\left(\frac{w}{\varepsilon}\right)\right]$

and regularized Dirac function, $\delta_\varepsilon(w) = \frac{1}{\pi}\frac{w}{\varepsilon^2+w^2}$

4. RESULTS

In the preprocessing step we used Kuwahara filter with 9x9 neighborhood. Higher order neighborhoods are shown to be unacceptable because of loosing high frequency components of contour. This can be presupposed even by inspection Fig. 2., where boundary of the heart chamber becomes more flat as the neighborhood increases. It further results by imprecision in segmentation of the chambers.

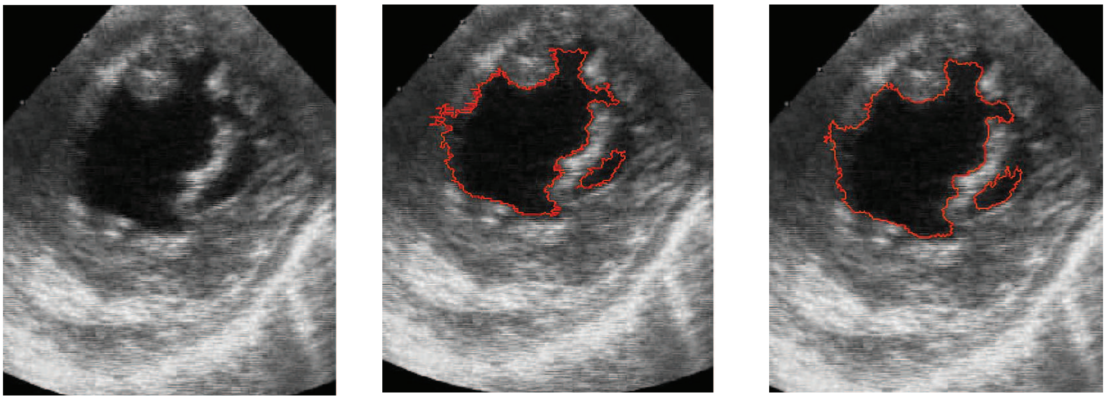

a) b) c)

Fig.3. Segmentation results with smoother boundaries comparing to non preprocessing segmentation: a) original SAX image [6] b) segmentation without preprocessing; c) segmentation after preprocessing with Kuwahara filter (9x9).

Considering active contour model, for initialization it was used level set function: $\phi(x, y, t=0) = x^2+y^2-r^2$ with $r=10$. Values of other parameters are empirically determined: $\lambda_1=\lambda_2= 1$, $\lambda_3 = 0{,}001 \cdot 255^2$, $\varepsilon = 1$. Time step of iteration is 0.1

Result of echocardiogram segmentation (short axis view, SAX) is presented in Fig.3. Comparing segmentation results with and without preprocessing it is evident that preprocessing have an effect on smoothing the final contour. As a result there is significantly smaller number of points describing contour when preprocessing step is applied (in our experiments it is more than 3 times). The smoothness of contour is controlled by the order of the Kuwahara filter. However tradeoff must be made between reduction of speckle induced contour points, on one hand, and over-smoothing, on the other.

One of the advantages of pursuing preprocessing step is decreasing of segmented components. It can be again ascribed to noise reduction since speckle artefacts in the original ultrasound image.

5. CONCLUSION

Applying preprocessing step in active contour model showed to be promising in elimination of additional curves due to speckle noise. Elimination can be obtained only by preprocessing of echocardiograms although some other filtering techniques can be applied. However chosen denoising technique must retain essential characteristics in the image such as edges.

As a next step toward echocardiogram segmentation, we are planning to improve CV model by implementing new term in functional which will absorb preprocessing step in active contour model. Actually, basic CV model regards only mean values of object and background while some more sophisticated statistical model should be included further.

Apstrakt

Segmentacija ehokardiograma predstavlja težak zadatak s obzirom na granularni šum koji je karakterističan za ultrazvučne snimke. Standardni postupci segmentacije slike, kao što su *thresholding, region growing* ili *watershed* tehnike, daju nezadovoljavajuće rezultate za segmentaciju srčanih komora. Aktivne konture "bez ivica" pokazale su se robusnima na šum i primenljive su za segmentaciju ultrazvučne slike. U ovom radu koristimo navedeni model zajedno sa korakom predobrade, Kuwahara filtrom, koji omogućava niskofrekventno filtriranje u homogenim regionima uz zadržavanje oštrine ivica (tj. visokofrekventnih komponenti) u slici.

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