Intima-Media Complex Segmentation

Haoxian Chen
School of Data Science
Fudan University
18307110276@fudan.edu.cn

1 Introduction

Clinically, the intima-media thickness is examined in ultrasound images. The boundary of the intima-media complex can be seen as two almost parallel lines. In this project, I segmented the intima-media complex in the ultrasound images and measured the thickness.

2 Method

The method can be divided into 5 parts: select ROI, generate edge map, get the rough boundary, refine the two curve and measure the thickness of the detected boundary.

2.1 Select ROI

I select a rectangle region manually using the function manual_rectangle.m.

2.2 Generate Edge Map

Edge map is to show the information of the edges. To generate the edge map, I use Gaussian smoothing on the image and calculate the gradient of the blurred image. The edge map is then calculated as the norm of image's gradient, which is normalized with infinite norm 1. In the implement, I calculate the gradient of the Gaussian function firstly, and do the convolution with the image.

Since we want to segment a boundary with two curve, it's necessary to generate two edge maps. The first one has a larger σ of Gaussian smoothing, which is used to detect the whole intima-media complex, while the second one has a smaller σ, which is used to detect the two sides of the boundary. In practice, I set the two σ as 7 and 0.5 respectively.

2.3 Get the Rough Boundary by Dynamic Programming

Once the edge map is generated, dynamic programming can be used to detect the edge. The dynamic programming I used here is the same as the original one, which is to minimize

$$E(y_1, y_2, \ldots, y_N) = \lambda \sum_{i=1}^{N} |y_i - y_{i-1}| - \sum_{i=1}^{N} \epsilon(i, y_i)$$

where M, N is the size of the image, ϵ is the edge map, $i = 2, \ldots, N$ and $y_i = y_i^{\min}, \ldots, y_i^{\max}$. λ is parameter and I set it 0.1 here. To detect the edge of the complex, just use the edge map with larger σ and set the $y_i^{\min} = 1$ and $y_i^{\min} = M$ and get the edge e_0. To detect two sides of the boundary, use the edge map with smaller σ and set the $y_i^{\min}$ and $y_i^{\max}$ based on e_0. For example, to detect the upper side, the search region should be above e_0. Therefore, set $y_i^{\min} = 1$ and $y_i^{\max} = e_0 - 1$ and can get the upper boundary. To detect the below boundary, set $y_i^{\min} = e_0 + 1$ and $y_i^{\max} = M$.

2.4 Refine the Two Curve Using Snake Model

The segmentation result of dynamic programming is a rough result and I use snake model to refine it. From the result of DP, I found that some information is missed in the image, resulting in the upper and below boundary is not so parallel. The relationship between the two curve should be considered.

Therefore, I use a function considering the smoothness of the two curve and their difference, as well as the edge map. Compared with the snake model introduced in the class, it adds a term represented the smoothness of difference of the two curve. And to simplify it, I ignore the term of second derivative.

Denote y_1, y_2 the two curve, the function is formulated as

$$E(y_1, y_2) = \int \frac{1}{2}\alpha \left[\left(\frac{\partial y_1}{\partial x} \right)^2 + \left(\frac{\partial y_2}{\partial x} \right)^2 \right] + \frac{\mu}{2} \left[\frac{\partial (y_1 - y_2)}{\partial x} \right] - f(x, y_1) - f(x, y_2) \mathrm{d}x$$

I set $\alpha = 0.1$ and $\mu = 1.5$ here. Using calculus of variations, we have

$$\frac{\partial y_1}{\partial t} = (\alpha + \mu) \frac{\partial^2 y_1}{\partial x^2} - \mu \frac{\partial^2 y_2}{\partial x^2} + \frac{\partial f(x, y_1)}{\partial y}$$

$$\frac{\partial y_2}{\partial t} = (\alpha + \mu)\frac{\partial^2 y_2}{\partial x^2} - \mu\frac{\partial^2 y_1}{\partial x^2} + \frac{\partial f(x, y_2)}{\partial y}$$

I use a semi-implicit difference scheme to update the discretized curve. The update procedure is

$$\begin{bmatrix} y_1^n \\ y_2^n \end{bmatrix} = \begin{bmatrix} I - \Delta t A & \Delta t B \\ \Delta t B & I - \Delta t A \end{bmatrix}^{-1} \begin{bmatrix} y_1^{n-1} + D\epsilon(y_1^{n-1}) \\ y_2^{n-1} + D\epsilon(y_2^{n-1}) \end{bmatrix}$$

where

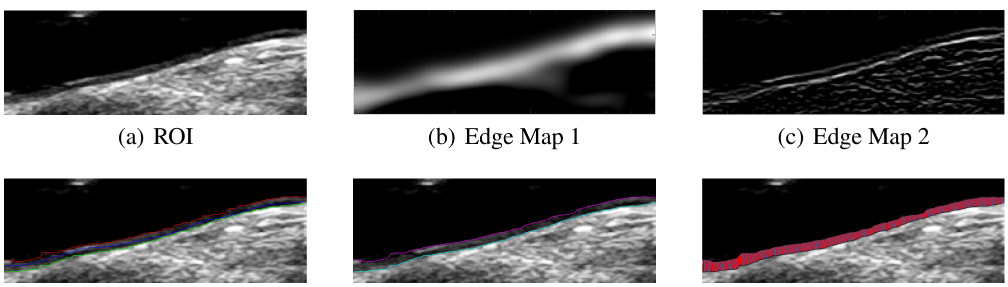
$$A = (\alpha + \mu)\begin{bmatrix} -1 & 1 & & & \\ 1 & -2 & 1 & & \\ & \ddots & \ddots & \ddots & \\ & & 1 & -2 & 1 \\ & & & 1 & -1 \end{bmatrix}, \quad B = \mu\begin{bmatrix} -1 & 1 & & & \\ 1 & -2 & 1 & & \\ & \ddots & \ddots & \ddots & \\ & & 1 & -2 & 1 \\ & & & 1 & -1 \end{bmatrix}$$

2.5 Measure the Thickness

To measure the thickness, I calculate the mean of the two curves, which lies in the middle and represents the whole complex. Then, calculate the normal of every discretized point and measure the distance from it to the two curves in the normal direction. Once the thickness of every point is calculated, the mean, standard deviation, minimum, maximum of its thickness can be calculated directly.

3 Result

The results of every step on image 2 are shown in fig 1. The mean, standard deviation, minimum, maximum of image 2 is 6.4221, 1.0709, 3.8029, 9.6270, of image 1 is 6.4155, 0.6330, 5.6612, 9.6433.



(a) ROI (b) Edge Map 1 (c) Edge Map 2

(d) Dynamic Programming (e) Snake (f) Thickness

Figure 1: Results

4 Discussion

The snake model I considered here can detect the boundary well. As we can see in the result of DP, some information is missed in the original image and edge map can not get it. But with a extra term in snake model, the two side of boundary can use the gradient information of the two and get a better boundary. This can be also considered in DP.

Besides, the update procedure of snake model can be written in another form,

$$y_1^n = (I - \Delta t A)^{-1}(y_1^{n-1} - \Delta t B y_2^{n-1} + D\epsilon(y_1^{n-1}))$$
$$y_2^n = (I - \Delta t A)^{-1}(y_2^{n-1} - \Delta t B y_1^{n-1} + D\epsilon(y_2^{n-1}))$$

which has a better numerical stability and less accuracy, since the matrix is diagonally-dominant. And it has less computation also since the matrix is smaller.

Moreover, the measurement of thickness may not be the best, since the point with same abscissa may not correspond. A better approach is to find the corresponding point and measure the thickness based on them.