Border Extraction of Epidermises, Derma and Subcutaneous Fat in High-Frequency Ultrasonography

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Abstract

Skin image segmentation semi-automatic algorithm for high-frequency ultrasound probes with 75 MHz has been designed. The method includes a specific image filtering procedure followed by multiframe active contour algorithm to detect borders between the epidermis and the dermis and between the dermis and subcutaneous fat tissue.

Keywords: *Skin, Epidermis, Dermis, Border, High-frequency ultrasound, Snakes.*

1. INTRODUCTION

Last decade showed a rapid increase in the number of new treatments in the field of dermatology and aesthetic medicine. However, the number of objective skin diagnostical evaluation methods is not too big.

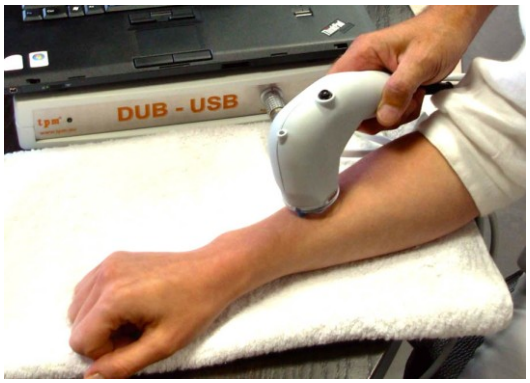


Figure 1: High-frequency ultrasonography study process.

High-frequency ultrasound probes with 22, 30, 50, 75 and 100 MHz is one of noninvasive evaluation methods of the skin [1] (see an example of the clinical procedure in Figure 1). The resolution of this method lies in the range 80-16 microns, which allows visualization of the skin and its layers. In addition to visualization, high-frequency ultrasound imaging allows to obtain quantitative data on the size of the observed objects, such as the thickness of the epidermis and dermis, as well as their acoustic density, which increases the reliability of clinical data. High-frequency ultrasound examination of the skin provides valuable diagnostic information when monitoring skin tumors, in assessing the development and regression of primary and secondary elements of skin lesions; also it has been successfully used for monitoring of the effects of different treatments – topical therapy, pharmacological therapy, physiotherapy and surgery. In the aesthetic medicine high-frequency ultrasound is used before and after fillers injections.

Recently, ultrasonography of the skin became quite widespread. It is used both in research and in clinical practice [2–4]. Application of high-frequency ultrasound under the existing time limits for the examination of the patient makes very actual the problem of automating the processing of ultrasound images. Particularly it is necessary to automate calculation of dermis thickness, as well as to detect borders between the epidermis and the dermis and between the dermis and subcutaneous fat tissue.

The structure of the article is as follows: The statement of the high-frequency ultrasound probes images analysis is given in Section 2; The necessary filtering procedure for the high-frequency ultrasound images is described in Section 3; Section 4 presents the use of the proposed multiframe active contour algorithm for experimental images segmentation; An example of the obtained processing results by our method is given in Section 5.

2. CLINICAL INVESTIGATION

We studied the skin of the forearm in healthy caucasian women 35-37 years old. The study was carried out on a high-frequency ultrasound skin imaging system DUB (tpm production, Germany).

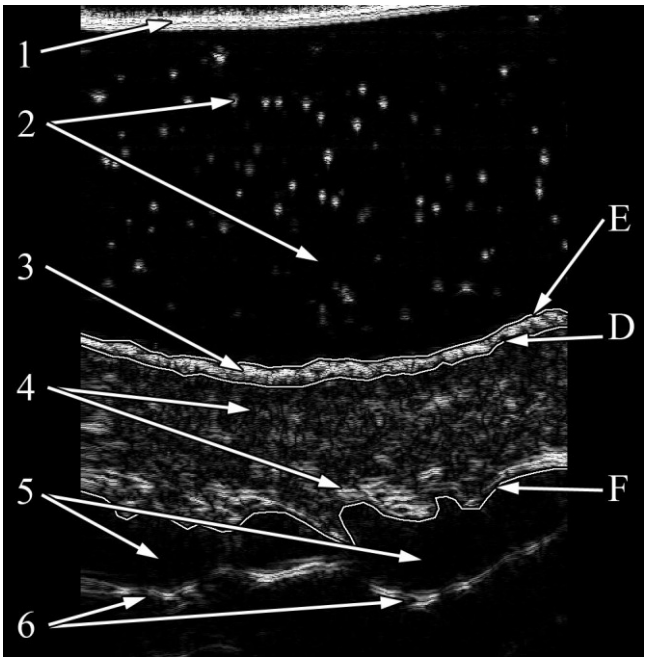


Figure 2: Skin structure visualization. 1) is a membrane delimited water chamber of the ultrasonic transducer, 2) is a contact gel between the membrane and the patient's skin, 3) is the epidermis (bright hyperechoic band), 4) is the derma (geteroechoic area, light and dark pixels), 5) is hypoechoic subcutaneous fat, 6) is superficial fascia. Lines: E is surface between epidermis and gel, D is surface between dermis and epidermis, F is surface between hypoechoic subcutaneous fat and dermis.

We used 75 MHz linear transducer for ultrasound with scanning depth 4 mm and the width of the scanned area of 12.9 mm/ Axial resolution was 21 microns. The epidermis, dermis and subcutaneous fat, were visualized (Figure 2) and the thickness of the epidermis and dermis were measured, and the level of echogenicity were determined.

3. SKIN IMAGE FILTERING

The input noisy data have a distinct anisotropic structure (see example of input data in Figure 3a). To suppress this artifact 1D-vertical Gaussian blurring and median filtering are used. Median filter preserve the brightness of image regions but small details (especially in dark areas) can be lost (Figure 3b). Gauss blurring with small radius (in our calculations we used value $\sigma = 2$) preserve small details in image. However, the entire image becomes blurred and the overall brightness of the image can be lost (especially for the bright areas) (see Figure 3c).

For image filtering a combination of median filter with 3x3 kernel and vertical Gauss blurring is used:

$$F(i_{x,y}) = \max\{\, M(G(i_{x,y})), G(M(i_{x,y}))\,\},$$

where i is the processed image, $M(i_{x,y})$ is the result of applying the median filter to the image i in $\{x, y\}$, $G(i_{x,y})$ is the result of the vertical Gauss blurring with $\sigma = 2$ to the image i in $\{x, y\}$.

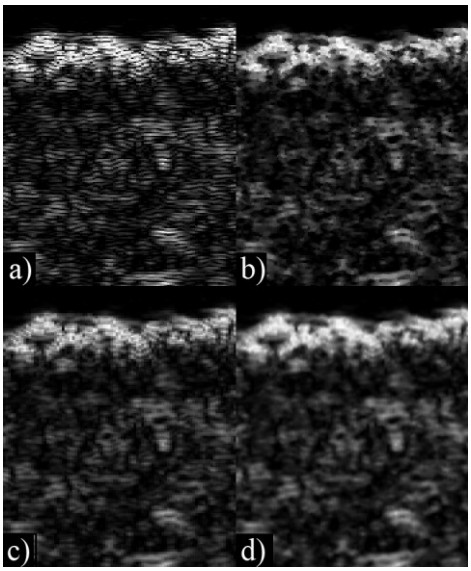


Figure 3: Results of filters application. a) input image, b) median filter with 3x3 kernel, c) vertical Gauss blurring with $\sigma = 2$, d) the proposed filtering method.

4. CONTOURS

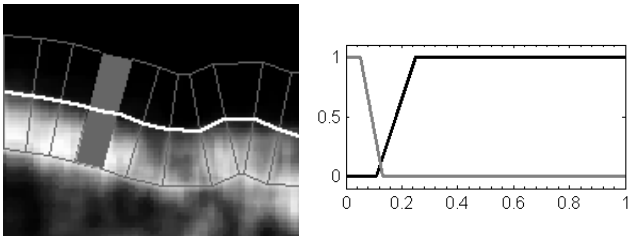
Our goal is to measure derma thickness in a sequence of ultrasound images. One image from the sequence is to be marked up manually by the doctor. The necessary markup consists of three lines roughly representing boundaries of epidermis and derma (see lines E, D, F in Figure 2).

We track these lines through the sequence using active contours. Each line has its own set of external forces that control the active contour movement. See sections 4.1-4.3 for details. One force common to all the lines is a modified gradient vector flow force described in section 4.2. All forces act along the contour normal (this means that the GVF force, for example, is projected onto the normal when applied at a control point). In our model magnitude of all forces is less than or equal to 1.

4.1 Capturing outer boundaries of skin tissues

The outer boundaries of skin tissues separate the dense internal region (mostly white) from exterior which is transparent for the ultrasound and appears dark on the image. The gradient vector flow force will, of course, generally push the contours towards these boundaries, but other edges may be strong enough locally in some regions. We introduce a local adjusting force that allows the contours to overcome these local attractors.

For each segment connecting a pair of control points two adjacent regions are examined (see Figure 4a). We calculate average intensity in these regions. If the region on the outer side has high average intensity, we need to push the contour towards the exterior. Likewise, if the region on the inner side is too dark, the contour must be pulled back. Magnitudes of the two forces that provide such a behavior depend linearly (but are bounded) on the average intensities (see Figure 4b). The local adjusting force is the sum of these forces.



a) **b)**

Figure 4. Calculation of boundary adjusting forces.
a) Patch analysis example. White line is the contour being adjusted, the patches corresponding to the 4th segment are shown in solid gray. Other patches are outlined in gray.
b) Plot of forces magnitude versus average patch intensity (assumed pixel values are in range [0, 1]). Gray line describes the force that pull the contour down (depends on the patch below the contour), the black line describes the opposite force.

4.2 Separating the epidermis

The boundary D between derma and epidermis is sometimes hard to detect. First, there are regions without any significant change in image intensity at the boundary. And there may be regions where the epidermis is extremely thin. In the first case, the segmentation cannot be reliably done using only an edge-attracting external force like GVF [5]. If the second case takes place (or, ultimately, both of them), the segmentation will likely fail, detecting the outer boundary, E, instead of D.

In order to detect the line D correctly in all cases, we employ a modified gradient vector flow force, and add a thickness constraint to the active contours that track lines E and D.

The GVF force may tend to attract contour tracking the line D to the outer boundary if the epidermis is rather thin. We propose a modification of GVF that suppresses gradient flow through regions with high intensity. This effectively stops attracting the line D contour towards line E, as there is bright epidermis region between them. From the mathematical point of view, this is achieved by adding an additional coefficient that weakens the smoothness constraint imposed onto the force components, so the modified force field minimizes the following functional:

$$\varepsilon = \iint \left(\mu \cdot W \cdot \left(|\nabla p|^2 + |\nabla q|^2 \right) + |\nabla M|^2 \cdot |\mathbf{F} - \nabla M|^2 \right) dxdy,$$

where $F = (p,q)^T$ is the force field, M is the edge map, μ is a regularization coefficient, and W is the smoothness weakening coefficient. It is defined as follows (I denotes image intensity):

$$W = \begin{cases} 1-2I, & 1-2I \geq 0, \\ 0 & \text{otherwise.} \end{cases}$$

Prior to evaluating active contours, we measure the epidermis thickness from the manual markup. We add a force that maintains the distance between active contours tracking lines E and D so that it corresponds to the epidermis thickness from manual markup. For each control point on one of the contours, we detect the nearest point on the other contour. The distance between these points dictates whether a repulsing or attracting force should be applied to the control point. An example that shows how the force depends on this distance is shown in Figure 5.

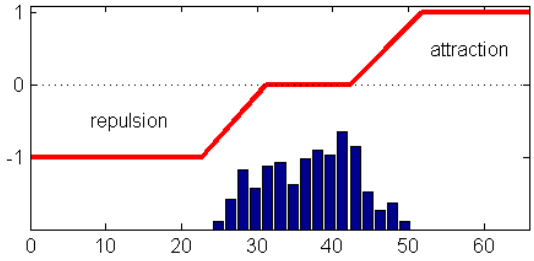


Figure 5. Plot of the distance maintaining force against the distance between contours in pixels. The histogram of distances in the markup is given below the plot.

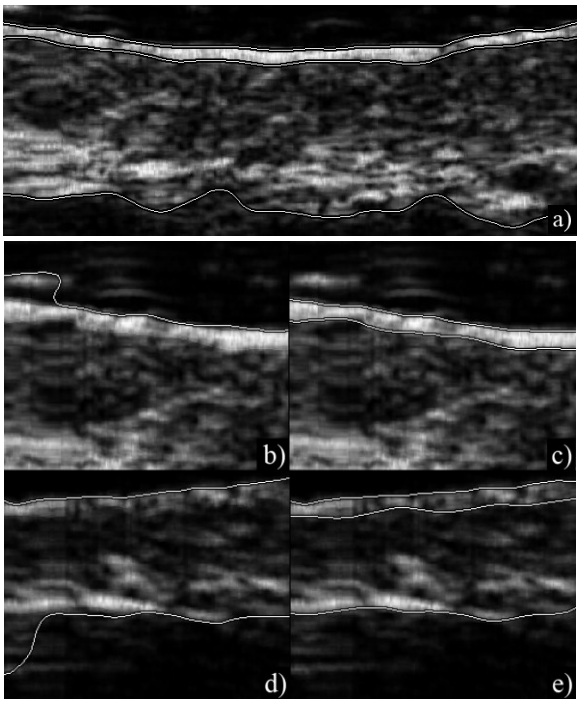


Figure 6: a) example of the epidermis and the dermis segmentation result, b),d) are fragments of the result of single-frame snakes algorithm segmentation, c),e) are fragments of the result of our multi-frame snakes segmentation.

4.3 Cross-frame links

Since we process a sequence of frames, we expect the resulting contours to move smoothly in time (i.e. between frames). To achieve this, we evaluate all the contours for all frames simultaneously, with an additional force that links a contour tracking a line, say line E, in one frame, to the contours that track the same line E in the previous and the next frames. For each control point we detect the nearest point of the corresponding contour from a neighboring frame. Magnitude of the force that pulls the control point towards its nearest point on a neighboring frame is proportional to the distance between points. The forces acting on a single control point are summed together and, like the other forces, bounded to be not greater than 1 in magnitude.

5. RESULTS

Typical example of an image series segmentation result is shown in Figure 6a (only one frame is presented). Obtained derma thickness value for this series is 306.25µm with standard deviation 27.5µm. A comparison of multiframe and single-frame active contour results for border detection is presented in Figure 6b–6e. Single-frame snakes often produce inaccurate results (see Figure 6 b, d for examples). The proposed method is much more robust due to the use of constraints that limit contour changes in neighboring frames and control epidermis thickness (see Figure 6 c, e).

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6. REFERENCES

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