Detection of skin main layers in OCT skin images

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Abstract

The thickness of different layers of skin plays an important role in monitoring the skin health, skin aging and the diagnosis of many skin abnormalities such as seborrheic keratoses, basal cell carcinoma, malignant melanoma, psoriasis, and actinic porokeratosis. So far, detecting the first intensity peak and the immediate valley on the smoothed averaged A-line profile of the optical coherence tomography (OCT) B-scan image has been one of the most popular ways to find the skin layers. In this paper, we present an image processing algorithm to automatically detect stratum corneum layer and the boundaries between the main skin layers; epidermis, dermis, and hypodermis. The algorithm has been evaluated using 31 fingertip OCT images of variety of ethnic groups.

1 Introduction

Many different imaging modalities, including ultrasound imaging, dermatoscopy, spectrophotometric intracutaneous analysis (SIA) scopy, confocal microscopy, magnetic resonance imaging (MRI), multi photon microscopy, terahertz imaging and optical coherence tomography (OCT) have been studied by biomedical imaging researchers to investigate skin tissues and detect abnormalities. Among these imaging modalities, OCT offers the necessary axial and transversal resolutions and satisfactory penetration depth for skin diseases diagnosis [1]. OCT is an advanced high resolution, non-invasive imaging tool which produces three-dimensional (3D) images of skin microstructures. OCT systems can be implemented in frequency domain (FD) as well as time domain (TD). FD-OCT is implemented in the form of spectral domain or swept source. In TD-OCT, the coherence gate moves over the sample along the confocal gate (depth of focus) axially, and the peak of the interference signal is used to generate an A-line. Then B-scan is constructed from the A-lines. In FD-OCT though, an A-line is obtained at once by measuring the spectrum of the interference fringes and taking Fourier transform of it [2]. Skin layers are usually characterized by identifying the first and second intensity peaks of the A-line in B-scan OCT images corresponding to the top of the uppermost papillae and the valleys of the papillae. This approach is called Automatic Peak Detection (APD) [1]. In a number of studies traditional manual skin layers detection (MSLD) has been employed. In some studies, a semi-automatic border detection algorithm

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has been used by incorporating APD algorithm with user defined thresholds. These approaches are dependent on the border markers which are defined manually. In the model introduced in [3], different structural types of dermal papillae have been taken into account. The dermis/epidermis boundary detection algorithm in [4] employs a sequential classification on texture features to minimize the labelling required and to cope with the high inter- and intra- subject variability and low contrast. The APD algorithm in [5] finds the peaks in A-lines and chooses the ones which can pass the statistical thresholds. APD algorithms are strongly dependent on the extremums of the A-line intensity profile, unless an observer corrects the incorrectly detected points. Therefore if the intensity pixel values of A-line, shift or fade due to different factors such as skin disorders, lack of quality of optical devices, or speckle noise, the algorithm may miss some of the extremums. In this study we design a new APD algorithm based on a set of image processing techniques. With this algorithm the skin layers in the OCT B-scan image are detected regardless of the epidermal-dermal layer architecture which has been one of the main sources of error in many APD algorithms. We evaluated the results using OCT images obtained by a novel SS-OCT imaging system.

2 Material and methods

In this study a swept-source Fourier domain OCT (SS-OCT) from Michelson Diagnostic has been employed for imaging. The light source of the OCT is a super luminescent diode (SLD) works with central wavelength of 1305 nm and laser wavelength sweep range of 150nm. The penetration depth of the system was measured 1.5mm. The OCT is based on multi beam technology in which the depth of focus is composed of four consecutive confocal gates each 0.25mm. Utilizing the multi beam technology, the images obtained from the four channels are averaged to generate images with a higher signal to noise ratio (SNR) and contrast than those obtained from a conventional OCT. The images obtained from this OCT system are B-Scan images with the lateral and axial resolutions of 7.5μm and 10 μm, respectively. Our proposed skin layers detection algorithm is based on finding the high gradient of the pre-processed B-scan image obtained by the SS-OCT, followed by some morphological operations, labelling, object detection, edge linking and a thinning algorithm (see Figure 1). Due to the highly multiple scattering characteristic of skin, the OCT images are speckled and enhanced (pre-processing stage). Following the work introduced by Yasuno et. al. [5], every 3 A-lines of the B-scan images are moving-averaged to reduce the speckle noise. Moreover using histogram equalization algorithm used in [6], the images are enhanced. The resultant images have higher contrast and SNR. The B-scan image that has been enhanced and despeckled is split into two parts (top and bottom images) to separate the high intense stratum corneum region from the rest of the image. This prevents the effect of large dynamic range of the intensity values in the image, i.e. choosing appropriate hysteresis thresholds, due to the high back reflection from stratum corneum. As stratum corneum represents as a high gradient region on the gradient image, the deepest edge pixels are considered as where the image is split. The image above this region is "top image" and the image below that called "bottom image". Our edge detection algorithm is based on detecting high gradient pixels and hysteresis thresholding. The algorithm initially smoothes the image to eliminate the additive noise and highlights regions with high spatial derivatives. It then tracks along these regions and suppresses any pixel that is not maximum. Similar to Canny edge detection algorithm, the gradient profile is further reduced by a hysteresis thresholding scheme in which two thresholds are used, T1 and T2 (T1<T2). In this study, the higher threshold

value is chosen as a fraction of maximum intensity of the image and the ratio of T1/T2 is considered 0.4. The hysteresis thresholding scheme in the edge detection algorithm helps finding the gradients along the skin borders even if some of the edge pixels are displaced or faded. For the top image, after detecting the border pixels belong to stratum corneum, there might be disconnections between the pixels. A morphological filter using closing followed by opening is used to connect the border pixels. An eight-pixel horizontal line kernel and two-pixel vertical line kernel are used by the morphological operators. The detected borders are then overlayed on the top image. For the bottom image, initially the edge detection algorithm with the same hysteresis threshold ratio as that of top image, is applied in order to detect the border pixels. A morphological filter is then employed in which the morphological operators use an eight-pixel horizontal line kernel and a three-pixel vertical line kernel to connect the border pixels. Another morphological filter is used with ten pixels disc kernel due to the fact that the borders have different structural types of dermal papillae than just linear or close to linear. The size of the kernel used in the morphological filter is based on the thickness and structure of the skin layers in different sites of body [1,4]. The resultant image is labelled such that each label represents an object. The exterior boundaries of objects as well as boundaries of the holes inside the objects are traced using a 4-connected neighbourhood and 8-connecteed neighbourhood windows to count the number of boundary pixels for each of the objects. This represents the object size. The object size is calculated for every object detected, and those objects with object size larger than half of the maximum object size are maintained. A directional thinning algorithm is utilized to reduce the thickness of the borders. In the thinning algorithm, each A-line is scanned and the closest border pixels to the surface of the image are kept. The morphological filtering, object size calculation, and object reduction are repeated until the number of the remaining objects is two. The obtained two objects are the border between epidermis and dermis (epidermis-dermis), and the border between dermis and hypodermis (dermis-hypodermis). The borders overlayed on the bottom image are shown in Figure (1). The boundaries resulted from the processing of the top image and bottom image are then merged together to reconstruct the output image on which the skin layers are identified.

3 Results

The algorithm was tested on a 2.2 GHz Pentium IV computer with 4GB memory. We used Matlab 2010b for programming. The stages of the algorithm and performance of the skin layers detection algorithm on the skin image taken by the SS-OCT after applying the histogram equalization and the speckle reduction algorithms is shown in Figure 1. To evaluate our skin layers detection algorithm, a set of fingertip images including 31 images of variety of ethnic groups are used. The detected borders are compared with manually delineated borders. The manual segmentation is performed by a dermatologist using *Paint* software. The quality of epidermis and dermis layers detection are evaluated by calculating the number of border pixels in both layers that are correctly detected divided by the total number of border pixels obtained from the manual segmentation. This rate for the epidermis and dermis layers is calculated for every image (see Figure 1). The same approach was used to calculate the quality of stratum corneum layer detection and plotted in Figure 2(a). The curve in Figure 2(a) shows that on average the epidermis and dermis layers can be detected with about 90 percent accuracy and that for the detection of stratum corneum is 98 percent true positive. We found experimentally that the skin layers cannot be detected correctly if there is an inter-

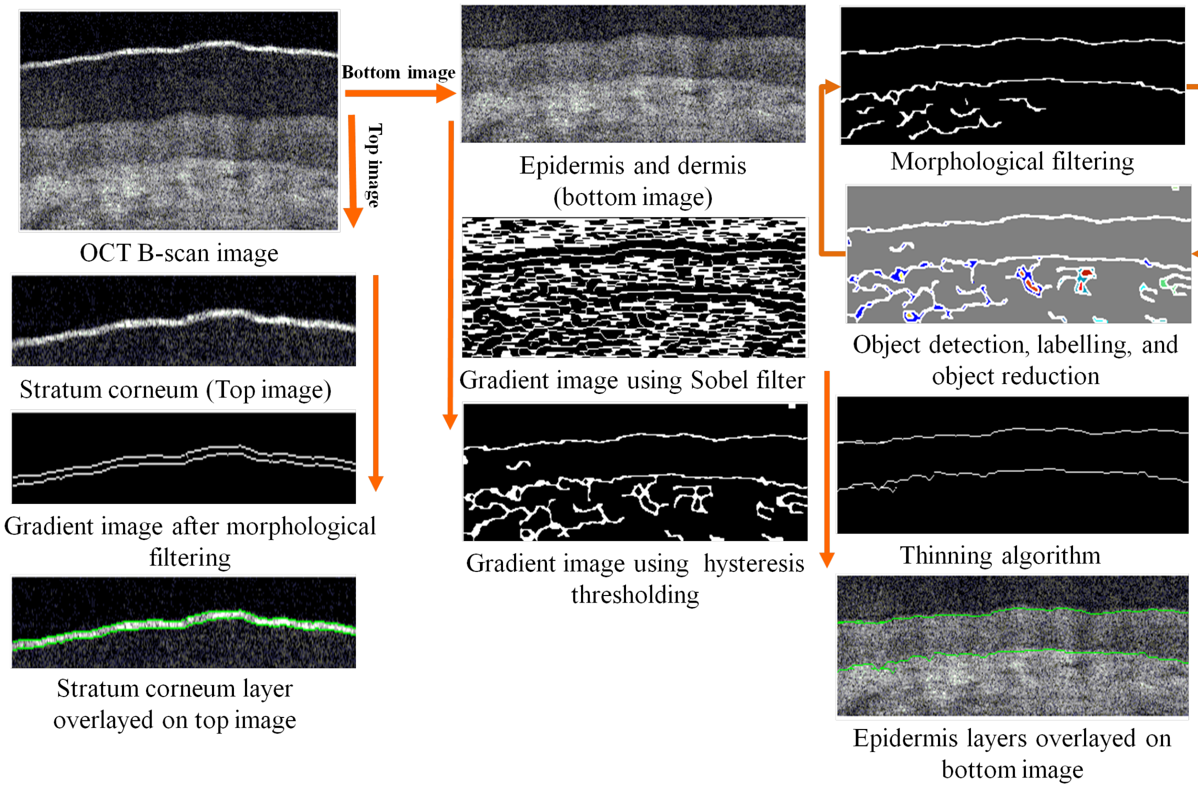

Figure 1: Results of the proposed skin layer detection algorithm applied on the enhanced OCT B-scan

section between veins, sweat ducts, hair follicle and the borders. We implemented a simple APD algorithm using identifying the extermums of the A-lines in B-scan OCT image, and applied on the same image as the one in Figure 1. The result of the segmentation is shown in Figure 2(b); the stratum corneum has been detected almost correctly, however with a few incorrect border pixels in epidermis; the epidermis-dermis border and dermis-hypodermis are not identified with satisfaction. Comparison between our skin layers detection algorithm and the simple APD algorithm described above shows that our skin layers detection algorithm detects the skin main layers more precisely with thinner borders.

4 Conclusion

In this paper, a set of algorithm is presented for automatically detection of stratum corneum layer and the boundaries between the main skin layers; epidermis, dermis, and hypodermis. The algorithm is based on detecting the high gradient pixels of the pre-processed B-scan image followed by morphological filtering, object detection and a thinning algorithm. The pre-processing stage includes an image enhancement based on histogram equalization and a speckle reduction based on moving average filtering. The results showed that our skin layer detection algorithm is more precise than the common automatic peak detection (APD) algorithms. The major novelty of our algorithm is that it can automatically detect the borders regardless of the epidermal-dermal layer architecture. The advantage of the algorithm proposed in this paper is the robustness of the method and improved connectivity of the boundary. Thirty one fingertip OCT images of variety of ethnic groups were segmented us-

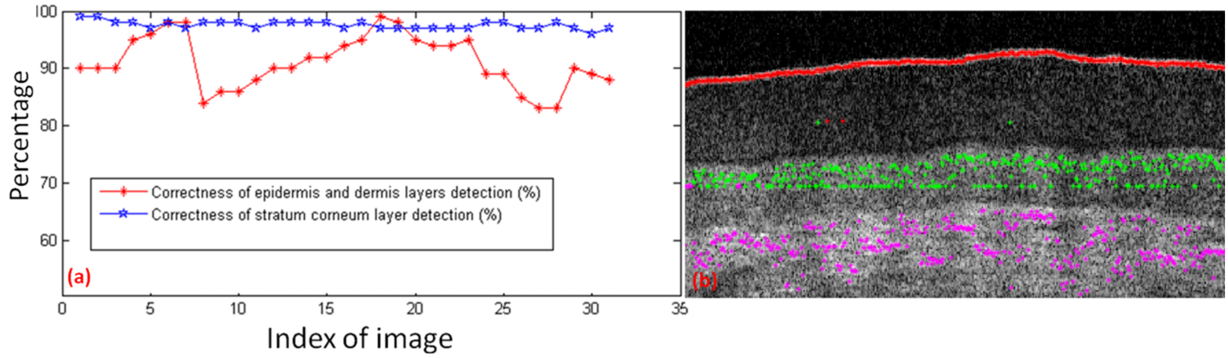

Figure 2: (a) Evaluation of the skin layers detection algorithm by comparing the number of correct border pixel detected with the ones extracted manually,(b) segmented OCT skin image using a simple APD algorithm.

ing our algorithm. Comparing the results from manual segmentation with those obtained from our algorithm showed that our skin layers detection algorithm is quite promising and reliable. The aim of the proposed skin layers detection algorithm is to assist dermatologists in diagnosis, prescribing and monitoring the treatment, of the skin diseases characterized with epidermal thickness change. To increase the reliability of our skin layers detection algorithm, we are now investigating a new speckle reduction algorithm specifically for OCT skin images.

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