Skin Analysis Using Sulcus Cutis Extraction

CHRISTOPHER TSE†1 CHIKAKO SHIBATA†2
HIROKI TAKAHASHI†2

Abstract: In an effort to create a smartphone application which can analyze images of skin in order to obtain information about skin health, a reliable image segmentation method is needed. This research focuses on the analysis and segmentation of sulcus cutis in magnified images of human skin, specifically experimenting with the use of the watershed segmentation algorithm. Just using this algorithm was not sufficient until combined with other algorithms such as Contrast Limited Adaptive Histogram Equalization (CLAHE) and a bilateral filter. These two algorithms improved the watershed algorithm's ability to perform the desired segmentation, although currently research is still being performed to increase the accuracy of the output of the watershed algorithm. Currently the process relies heavily on manual user input, and the methods used may need to be changed in order to automate the process when put into a smartphone application.

Keywords: Image Segmentation, Marker-Controlled Watershed Segmentation, Skin Analysis, Skin Health

1. Introduction

In recent years, people of all ages have developed greater interest in their skin health and skin care [1]. The only ways one can obtain information about the condition of their skin is, however, to request an examination using specialized equipment at beauty product stores or send images of their skin over the internet to skin care specialists in order to perform an examination. These methods require commuting to the store and waiting long periods of time for the results of the examination, but most of all, both of which consume time.

It is also rather uncommon for patients to visit a dermatologist simply for a regular check up on their skin condition, unlike recommended yearly visits to a doctor for a physical checkup. Patients mostly visit when they have a problem such as acne, skin discoloration, skin lesions, or if they wanted to request a special examination for a medical condition [3]. While the skin is usually treated with beauty products, its health should also be properly maintained. The availability of a smartphone application which could inform the user about the condition of their skin would alert many people about possible deterioration of their skin condition, and they would take preventative action.

The objective of this research is to increase the accuracy of sulcus cutis extraction techniques used in previous research. In this paper, a smartphone camera is used to take images of the skin, then the taken images are analyzed to give the condition of the skin texture as well as possible changes in condition over time. Factors such as skin color, spots, and texture condition can all be taken into account for analysis. Within these factors, the texture condition is the most prone to change, which is why this is the main factor used as comparison.

2. Background

2.1 Sulcus Cutis, Crista Cutis, and Skin Texture

Sulcus cutis is the name given to the grooves and depressions in the skin, and the areas which these lines surround and appear raised up are called crista cutis. This pattern created by the lines and raised areas make up the texture of the skin. Figure 1 below shows sulcus cutis and crista cutis overlaid onto a sample image of skin.

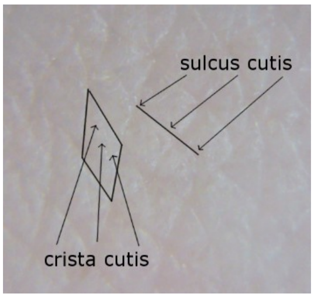
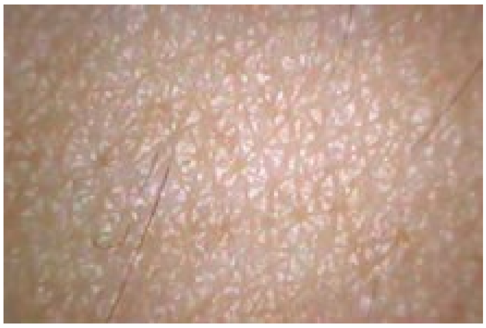


Figure 1: Sulcus cutis and crista cutis overlaid on skin



(a) Desirable condition

(b) Undesirable condition

Figure 2: Skin condition

†1 University of Oklahoma

†2 The University of Electro-Communications

In general, skin condition is considered healthy when the sulcus cutis is thin and the crista cutis have a small average surface area which line up in an orderly fashion. The opposite would be unhealthy skin which demonstrates thick sulcus cutis and crista cutis with large surface area which are arranged in an unorderly fashion [2]. The skin texture can be widely affected by humidity, ultraviolet rays, as well as stress and routine daily activities, and so these must be taken into account when taking measurements and performing analysis.

Comparing Figure 2(a) with Figure 2(b), Figure 2(a) shows a desirable skin condition where the sulcus cutis create relatively smaller crista cutis and are arranged in orderly triangular and rectangular shapes in a grid-like formation. Conversely, Figure 2(b) shows sulcus cutis running across the skin in a non-orderly fashion, creating random shapes and layouts of varying shapes and sizes.

2.2 Previous Research

In a similar research, Sakashita et al. [4] equipped a small lens used for close-up photography onto a smartphone camera which would be able to magnify the skin. The skin first had a layer of eyeliner makeup applied onto it in order to make the lines more distinct and therefore easier to extract using a segmentation algorithm. However, this method requires the user to apply the eyeliner whenever an analysis needs to be done and then washed off afterwards each time, and the results were inconclusive about the changes in skin condition.

In the research performed by Shibata et al. [6], similar research was done using a lens equipped onto a smartphone based off the research by Sakashita et al. In this research, the watershed segmentation algorithm was experimented with, along with binarization of the image and using the CLAHE [9] algorithm to improve the accuracy of the segmentation results.

In another research, Kobayashi et al. [5] used an opaque white substance to create a replica mold of the skin texture. Using the replica, a magnified image was taken and analysis was performed on the image. However, the replica proved to take a large amount of effort and time in order to make which made this method inaccessible for general use.

3. Sulcus Cutis Extraction Procedure

3.1 Photography Environment

As shown in Figure 3, a special lens is used in tandem with a smartphone camera to take an image of the skin. It is a lens made to be easily attached to the top of a smartphone and positioned over the camera lens. The ideal place for the image to be taken is the place under and behind the chin, reason being the fact that it is the least likely spot for ultraviolet rays from the sun to hit due to its position, and the minimal chance that it would suffer physical injury and other physical stimulus and compared to other body parts such as the arms, hands, or legs. This makes the condition of the skin in those areas the closest to that of a baby's compared to the rest of the body [7]. Although that would be the ideal part of the skin to photograph, it is very difficult for a user to take the picture of the area behind their chin without the help of another person. Other candidates are the cheek and back of the elbow. Since the cheek would still require help from a mirror to be used alone, the experiment done in this paper focuses on using an image taken from the back of the elbow. Figure 3 shows the photography method, and Figure 4 shows the resulting 1836x3264 pixel image.

Figure 3: Photography method

Figure 4: Resulting image from photography

Certain issues were found during the trials of photographing the skin. One of the issues which had the most effect was the lighting. Due to the way the light enters the photographed region, a slight change in the angle of the phone when taking the photo or photographing in a different location causes large variations in how well the image is illuminated. In addition, the lens is only able to fully focus on the area close to the center of the region being photographed with the image becoming more and more blurred near the edges of the photograph.

3.2 Computer Environment Setup

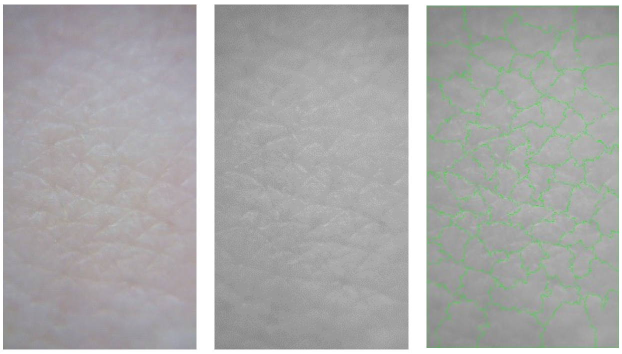
The computer environment the experiments were conducted on was Windows 8.1. The software used for the image editing and analysis consists of a combined use of MATLAB 2015 and Visual Studio Community 2015 along with the OpenCV Library (Open Source Computer Vision). The open source Processing language in which some techniques of this study is implemented is also used. The open source GNU Image Manipulation Program (GIMP) was also used for various general image editing use.

3.3 Sulcus Cutis Extraction

The main objective of this paper is to find a reliable method of extracting the skin texture. Since one of the points of interest of the indicators of skin health is the area of the crista cutis, extraction of the sulcus cutis boundaries is necessary.

3.3.1 Watershed Algorithm

In this paper, the watershed segmentation algorithm will be the main method tested. Figure 5 shows the process of applying the watershed algorithm onto the original taken image. The watershed segmentation algorithm is a particular technique of performing segmentation on an image through the analysis of the intensity levels, meaning that it works best on a grayscale image. Figure 5(a) is the original image as shown in 4 scaled down to 550x978, and then converted to grayscale in Figure 5(b). The output of the watershed algorithm is shown in Figure 5(c) as green lines overlaid onto the image.



(a) Scaled original (b) Grayscale (c) Watershed output

Figure 5: Applying watershed algorithm to image of skin

This algorithm uses the 3-D map of the intensity levels of a grayscale image, and uses the peaks and valleys in order to find the boundaries of segmentation. Figure 6 is a simple visual representation of the concept of the watershed algorithm's process.

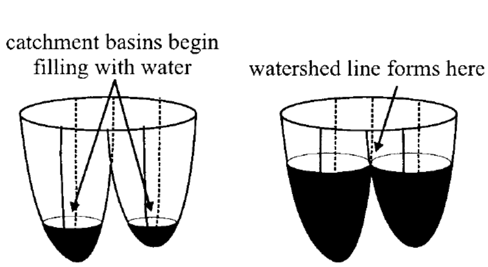
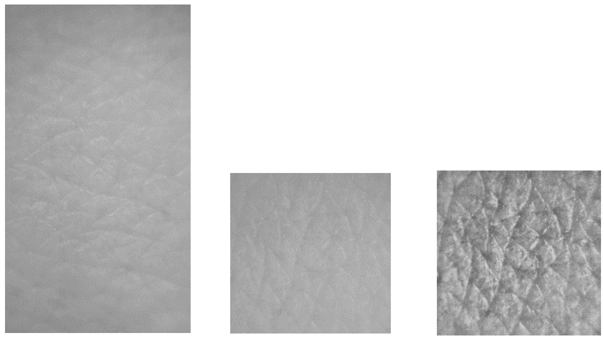


Figure 6: Visual representation of watershed algorithm [10]

In general, the algorithm looks for the lowest values which create the dips and valleys of the 3-D intensity map, and the algorithm begins to fill it with water. As the water level rises, the water from two separate basins will eventually merge into one when the border separating them is overtaken by the water, which are used as the points where the algorithm decides to draw the segmentation boundaries. A variant of the watershed algorithm is used in this paper called marker-controlled watershed segmentation [8], which means that instead of letting the calculations run automatically, the user can first place markers on the image in order to tell the image at which points the water should begin to fill from.

3.3.2 CLAHE [9]

Since the watershed algorithm works through the analysis of the intensity of the given image, the surrounding areas of the image are very different in lighting. Additionally, the focus is also not very clear on the surrounding area. Therefore, for the sake of consistency, the surrounding areas which were darker and out of focus were cropped. The resulting image is a square 600x600 image as shown in Figure 7(b).



(a) Original grayscale from Fig. 5(b) (b) Cropped and rotated clockwise 90◦ (c) After running CLAHE

Figure 7: Process of applying CLAHE

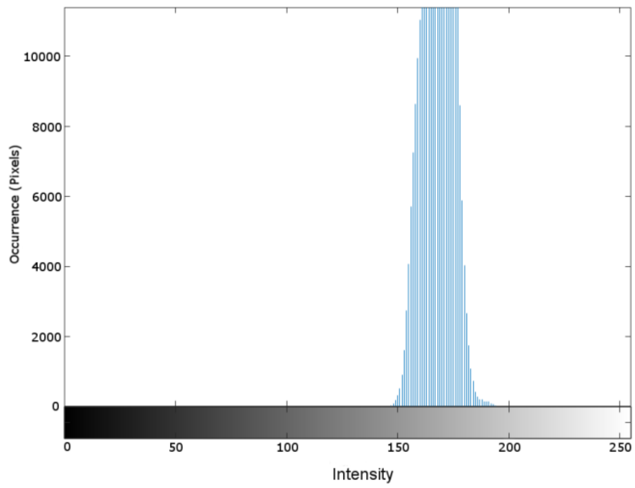


Figure 8: Intensity histogram of Fig. 7(b)

As seen in Figure 8, the range of intensity in the image in Figure 7(b) only ranges approximately from 150 to 200. By increasing the range of available intensities, the watershed algorithm will be less likely to detect small changes and include them in the output of the segmentation as error. In Figure 9, the intensity histogram of the image in Figure 7(c) can be seen, and that the intensity range is increased to from 100 to over 200.

The CLAHE algorithm is a contrast enhancement algorithm which is used in this paper in order to improve the contrast and increase the visibility of the sulcus cutis in the image taken using the smartphone camera. From the regular photo, it is difficult for the watershed algorithm to detect the sulcus cutis since the shades of gray in the image do not vary as much, and may cause human error when providing input into the algorithm from being unable to clearly distinguish the lines.

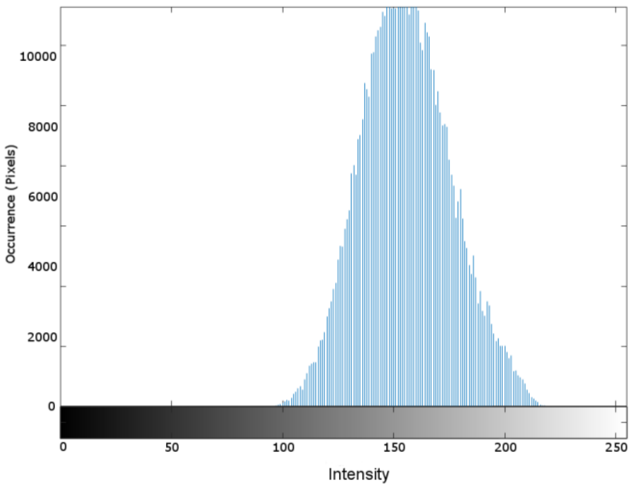


Figure 9: Intensity histogram of Fig. 7(c)

The CLAHE algorithm helps by averaging the intensity levels in the image so that the relatively darkest part of the image is shown with a dark shade of grey, the lightest parts stay bright, and the rest of the intensities are normalized in between. The image first has the top of bottom areas trimmed off, as they are a relatively darker shade than the center part of the image, and would be applied by the CLAHE algorithm.

3.4 Bilateral Filter

The use of a bilateral filter before running the watershed algorithm was also experimented with in an attempt to increase the accuracy of the calculated segmentation. Bilateral filters are edge-preserving filters, and so will keep the sulcus cutis intact while potentially reducing any noise in the crista cutis which the watershed algorithm may mistakenly mark. In the research from Shibata et al., it was seen that although the watershed segmentation managed to locate segmentation boundaries, For this paper, the tested image was run through the bilateral filter three times. If f(i,j) is the input image and g(i,j) is the output image, then the filter is defined as given in formulas (1) and (2).

$$g(i,j) = \frac{\sum\sum f(i+m, j+n) h(i,j,m,n)}{\sum\sum h(i,j,m,n)} \quad (1)$$

$$h(\cdot) = \exp\left(-\frac{m^2+n^2}{2\sigma_1^2}\right)\exp\left(-\frac{(f(i,j)-f(i+m,j+n))^2}{2\sigma_2^2}\right) \quad (2)$$

The two parameters which control the effect of the filter are σ_1 and σ_2, and in the experiments conducted for this paper they were set to 4 and 12 respectively.

4. Results

4.1 Ground Truth

To evaluate the accuracy of the segmentation results in this paper, the precision and recall definitions are used. These are two measures of relevance when comparing results to a predefined ground truth which is what would be considered as the correct and desired output.

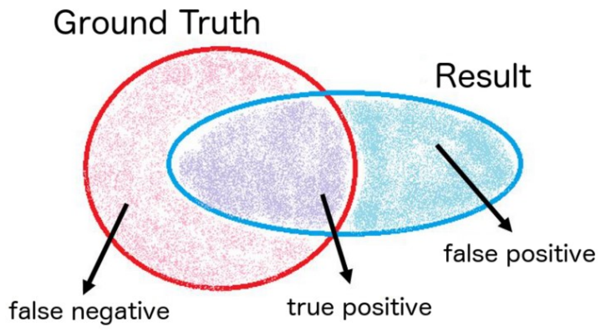


Figure 10: Defining true positive, false positive, and false negative

By comparing the regions formed by the contours obtained through segmentation, the true positives, false positives, and false negatives can be obtained as shown in Figure 10. The equations for precision and recall are defined as follows.

$$precision = \frac{true\ \ positive}{true\ \ positive + false\ \ positive} \quad (3)$$

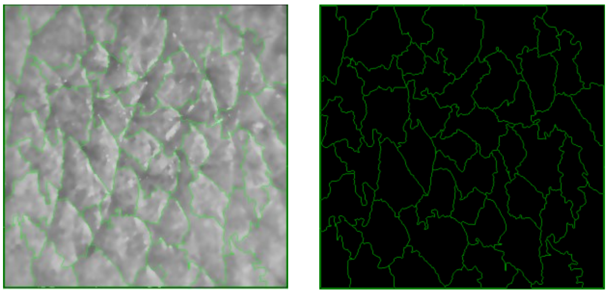
$$recall = \frac{true\ \ positive}{true\ \ positive + false\ \ negative} \quad (4)$$

Through the use of these two values, a measure of accuracy can be calculated. In this paper, the F-measure which is also known as the F1 Score will be used as a test of accuracy. F-measure considers both precision and recall, and can be interpreted as weighted average of the two values as given in Formula (5).

$$F - measure = \frac{2 \times precision \times recall}{precision + recall} \quad (5)$$

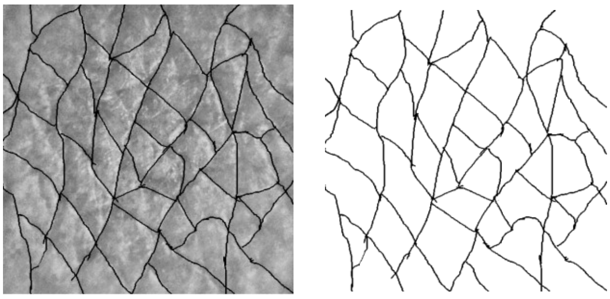
4.2 Comparison Method and Result

The positives and negatives are calculated using the region bounded by the boundaries obtained by the watershed algorithm shown in Figure 11, and is compared against a hand drawn ground truth image which has lines drawn to show ideal sulcus cutis extraction as illustrated in Figure 12.



(a) Output from watershed algorithm (b) Output extracted onto a black background

Figure 11: Segmentation result data



(a) Manually drawn ground truth boundaries on image (b) Ground truth boundaries extracted onto white background

Figure 12: Ground truth data

To compare the results, the average precision and recall for the results using the plain image, using CLAHE, and using a bilateral filter after CLAHE were calculated then used to calculate the F-measure for each variation of the experimental image. The obtained values are shown in Table 1.

Table 1: Average precision and recall for each image, and the resulting F-measure

Image Tested	precision	recall	F-measure
Plain Grayscale	0.471	0.770	0.585
CLAHE	0.544	0.748	0.630
CLAHE + Bilateral Filter	0.570	0.750	0.648

It is observed that the F-measure increased when running the watershed algorithm on an image after having applied the CLAHE algorithm and bilateral filter first. Although there were slight variations in the value of the precision and recall, the overall accuracy measure is shown to have increased after applying these algorithms to the image before running the watershed segmentation algorithm. It is important to note that while an increase in F-measure as seen in Table 1, the accuracy measurements depend heavily on the ground truth image, that is to say, the accuracy of a given image can vary should the drawer of the ground truth image change.

5. Future Works

There are several aspects with the procedure of the experiment done in this paper which can be considered for future improvement. The CLAHE algorithm uses a few input parameters which change the result, and therefore further testing on these initial parameters should be considered.

The bilateral filter was shown in this paper to improve the results. Here the filter was run three times on the image before performing segmentation, and that can be changed along with other parameters pertaining to the filter which can be experimented with. Aside from the bilateral filter and CLAHE algorithm, other methods of improving the accuracy of the segmentation should be researched.

Aside from using image altering techniques, research can be done about the photography itself. A change in the type of lens used or even methods during the photography of the skin to reduce the effect of lighting and blur may result in an image that has much clearer display of the sulcus cutis and then be combined with the currently used techniques to create a better image for use with the watershed segmentation algorithm.

Finally, aside from F-measure, other types of accuracy evaluation of the segmentation which may be more appropriate to use should be researched in order to more clearly judge the results. The current method involves simple direct comparisons of the boundary areas and counts the pixels without taking into account any tolerance in errors for the area which the sulcus cutis themselves encompass. This error tolerance should be taken into account for a more accurate representation of the results.

6. Conclusion

In this paper, although ideal photography conditions of the skin using the lens could not be met, extraction of the sulcus cutis was possible, and through the use of the CLAHE algorithm and a bilateral filter, the accuracy of the segmentation can be raised. The goal of creating a smartphone application which can perform these tasks still requires much work as many of these steps still required much manual input and work from the user in order to get the results. The app should be simple and easy to use with minimal work required from the user to get the final result.

References

[1] マイボイスコム株式会社, “自主企画アンケート結果スキンケア（第３回）”, http://www.myvoice.co.jp/biz/surveys/20815/index.html, 2015

[2] 大久保真, “スキンケア大学 肌のキメをふっくら整える正しい保湿ケア, http://www.skincareuniv.com/article/005911, 2015

[3] Centers for Disease Control and Prevention, “National Ambulatory Medical Care Survey Factsheet Dermatology”, http://www.cdc.gov/nchs/data/ahcd/NAMCS_2010_factsheet_dermatology.pdf, 2010

[4] 坂下京柊, 高橋裕樹, “皮溝抽出による肌解析”, 映情学技報告, 39, 14, pp.133-136, 2015

[5] 小林宏, 橋本卓弥, 山崎和広, 平井義和, “画像解析による肌のキメの定量的指標の提案と実用化”, 映情学技法,映像表現・芸術科学フォーラム, 40/ 11 無, 2016

[6] 柴田智加子, 高山夏樹, 高橋裕樹, “キメ分析に基づく肌状態変化計測”, 日本機械学會論文集, C 編, 76, 764, pp.922-929, 2010

[7] 西岡倫代,満倉靖恵,福見稔,赤松則男, “遺伝的画像解析による肌のキメの測定”, 信学技報, NC, 104, 140, pp.65-69, 2004

[8] R. C. Gonzalez and R. E. Woods, “Digital Image Processing”, Upper Saddle River, NJ, PrenticeHall, 2002.

[9] K. Zuiderveld, “National Ambulatory Medical Care Survey Factsheet Dermatology”, Contrast limited adaptive histogram equalization, Graphics Gems IV, pp.474-485, 1994

[10] M. Rettmann, X. Han, C. Xu, J. Prince, “Watershed Segmentation of the Human Brain Cortex”, http://iacl.ece.jhu.edu/prince/ws/

