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The Development of Skin Image Analysis Device Based on Embedded System

摘要：皮膚表象決定視覺年紀，醫學研究指出保養皮膚的重要性，預防老化的功能性保養品可延緩皮膚老化，然而消費者對於使用後的改善效果，僅能以自身的感覺來認定，無法明確數據化。常見使用介電型態皮膚檢測儀來檢測膚質，而皮膚細紋與光澤檢測大都以目視方式配合色卡進行比對，然而介電型態皮膚檢測儀數據無法直接對應皮膚表象，目視方式更是存在許多誤差。為此，本研究以數位影像處理為基礎，透過嵌入式系統來實現皮膚光澤與細紋檢測裝置，使用者可透過此裝置進行皮膚影像擷取、分析與計算，比較皮膚使用保養品前後的差異。本研究以乾燥部位皮膚做為檢測目標，最後在實驗章節來展現研究結果

Abstract. Skin appearance is a key determinant of perceived age. Medical studies have verified the importance of skin care, stating that functional anti-aging products can defer skin aging. However, the effects of these products are largely self-perceived by users. These self-perceptions are difficult to quantify. The most common equipment for measuring skin quality is the dielectric analyzer, while fine lines and luster are largely measured visually with a color chart. However, the data produced by dielectric analyzers are not directly associated with skin appearance, and visual measurements contain considerable bias. Therefore, in this paper, a digital image processing method was developed for skin analysis; wherein an embedded system was used to develop a device for measuring luster and fine lines. Users can use this device to extract, analyze and compute skin images, and compare the differences in skin quality before and after using skin care products. The skin area affected by high ankle strains was selected as the target of analysis. The research outcomes are presented in the “Experiment” chapter.

1 Introduction

With the perpetual advancement in aesthetic medicine technology, aesthetic medicine has become the third largest industry in the world, second only to the aviation and automobile industries. A report published by Medical Insight indicated that the global aesthetic medicine industry achieved an average annual compound growth rate of 10.9% in the recent decade and that the growth rate in Asia exceeded the global average growth and achieved between 13% and 15%. Due to cultural influences, the demand for anti-aging products is extremely high in Asia. Perceived age is highly valued in Asia. Despite the inability to stop aging, functional anti-aging skin care products can be used to defer skin aging and keep healthy. After all, the soft and smooth skin that has luster and elasticity is a sign of good health. Skin can be characterized into three layers [1]: epidermis, dermis, and hypodermis. The stratum corneum is the outermost layer of the epidermis and serves as the body’s first line of defense. Corneocytes are non-living cells that stack on top of one another to form the stratum corneum. Aging causes corneocytes to build up in the stratum corneum, increasing dryness, shedding, and fine lines and expediting wrinkles, dullness, coarseness, and stiffness. Medical studies [2-4] have verified that retinoic acids, alpha hydroxy acids, antioxidants (vitamin C, vitamin E, catechin, and curcumin) and stem cell products can protect the skin from aging.

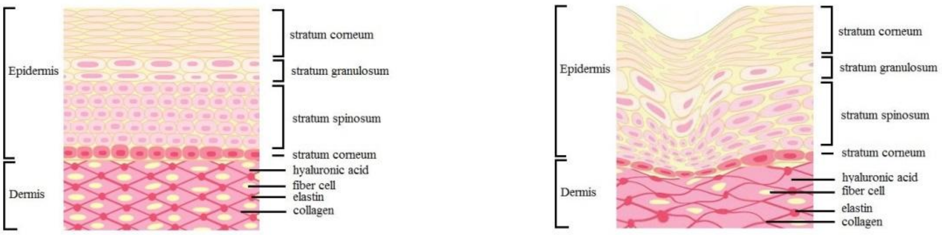
Currently, many commercial anti-aging, anti-wrinkle, and moisturizing products are available on the market. However, users and aesthetic medical professionals have always been skeptical about whether these products are effective, leading to the rise in demand for skin analyzers. Currently, the market does not offer a consumer skin analyzer centered on measuring wrinkles, luster, whitening, and coarseness. Take the luster measurement for example, complexion is currently measured visually with the help of color charts. This method is extremely inaccurate, which is caused by several factors: inconsistent ambient lighting causes discoloration; color charts are only good rough estimates and outcomes cannot be quantified; previous observations cannot be clearly recorded; and people perceive color differently. In addition, conventional skin analyzers use dielectric constants as the measure for determining skin properties. However, water content in the stratum corneum influences conductivity and, by extension, dielectric constants. These analyzers are unable to show skin appearance results directly, and only present relative outcomes to reflect skin appearance.

Based on the above-mentioned reasons, this paper developed a method in which users of skin care products can effectively and scientifically track the improvement of their skin. To achieve this objective, a skin analyzer for measuring luster and fine lines was developed using a system-on-chip ARM architecture coupled with computer vision technology. The device offers image processing, feature capturing, imaging storage, and color quantization and comparison functionalities. In terms of methodology, a consistent optical imaging device was used to capture skin images. The images were then processed using an image processing algorithm run on the ARM processor, embedded Linux operating system, and Node.js[7] server. The skin images were processed using a self-developed algorithm coupled with a color quantization algorithm, geometric features, and fine lines measurements to obtain quantified skin image data. The data were then analyzed to determine the level of improvement. In the software and hardware architecture, the proposed device featured a web interface to enable users to conveniently operate it. Users need only access their web browser to connect to and operate the device, making it extremely convenient and cross-platform compatible while overcoming hardware limitations. The hardware configuration and image processing algorithm of the proposed device are discussed in the “Methodology” chapter. The performance of the skin image quantization algorithm is demonstrated in the “Experiment” chapter.

2 Skin structure

The skin [1,5] is the largest organ on the human body. It is connected to the digestive, respiratory, and urinary systems to provide protection, prevent dehydration, regulate temperature, and absorb nutrients. The skin consists of the epidermis, dermis, and hypodermis, and each skin layer contains hair follicles, arrector pili muscles, nails, sebaceous glands, and sweat glands. The skin system comprises skin, sweat glands, sebaceous glands, hairs, and nails.

Skin ages [5] intrinsically and extrinsically. Intrinsic aging refers to aging over time. The proliferation of skin fibroblasts decelerates, leading to a decline in the collagen fibrin, elastic fibrin, and hyaluronic acid content in the dermis. Slowly, the skin loses elasticity and forms static fine lines (fine lines that are observable without facial movement). Intrinsic aging is inevitable. Extrinsic aging is associated with life habits, such as staying up late, smoking, excessive drinking, exposure to sunlight, and prolonged exposure to dry air, leading to the formation of wrinkles. Among these habits, exposure to sunlight is the root cause of skin aging, and they are unrelated to age. Wrinkles are also formed from the excessive use of facial muscles. Depending on wrinkle depth, wrinkles can be categorized into fine lines, coarse lines, and grooves. Fine lines mainly appear on the epidermis, while dynamic wrinkles and grooves extend to the dermis. Skin aging deforms the epidermis, changes the size and shape of cells, expedites cell degeneration, and reduces melanin and Langerhans cells. In the dermis, skin aging causes the loss of stromal cells and atrophy; reduces fibroblasts, mast cells, and blood vessels; and induces nerve ending degradation. In the skin appendages, it lightens hair color, induces hair and glandular loss, and reduces sebum secretion leading to dry skin. The functional influences of skin aging include stunted immune functions, dry skin, poor temperature regulations, and paresthesia. Using topical skin care products such as aloe-vera, AHA, Q10, and vitamin-A-acid can improve aging skin [6]. Moisturizing skin care products activate the stratum corneum. A-acid can improve skin coarseness, reduce fine lines and pigmentation, and mitigate skin cancer.



(a) (b)

Fig. 1. Skin structure: (a) normal skin;(b) aging skin.

3 Methodology

The hardware composition of the proposed skin analyzer primarily comprises an ARM chip that serves as the core processor and an embedded Linux operating system that runs the Node.js web server. The overall software architecture is written in HTML5 and JavaScript was adopted to run the image processing algorithm. The procedures of the algorithm included image preprocessing, color quantization, fine lines detection, and appearance improvement computations. The objectives of the image processing algorithm were to detect luster and fine lines. Previous skin observations revealed that after using moisturizer, the moisture content of the stratum corneum increased, wrinkle depth reduced, appearance became smoother, and luster increased. Therefore, increased luster and reduced fine lines were selected as the criteria for skin improvement. Image preprocessing was required to remove skin textures, fine hairs, and moles from the images, and to retain the remaining portion of images for skin appearance analysis. Texture was used as an alternative feature for evaluating skin quality. Color analysis was performed to identify the complexion of the epidermis. Pixels with different color values are dispersed throughout the skin images. Therefore, a color quantization process [8] is required to calculate the principle complexion value. Once the representative complexion value is obtained, the Euclidean distance between the before and after images to obtain suitable appearances. To identify the optimal color quantization method, three algorithms were compared in this paper, specifically the Median-cut [9], K-means [10], and Self-organizing Maps (SOM) [11]. Finally, the time performance of the complexion analysis was tested. The skin image processing procedures can be broadly characterized into two stages, namely, preprocessing and feature capturing. The preprocessing stage included image capturing, gray-scale conversion, Sobel edge detection, image enlargement, and texture removal. The feature capturing stage included color quantization, color feature calculation, and feature documentation. Finally, the level of improvement was calculated.

3.1 Skin image Preprocessing

To prevent the system from incorporating skin texture, fine hairs, and moles into color evaluation, image preprocessing was performed to remove unnecessary noise. In this paper, noise is defined as the texture of the skin. Skin is essentially an uneven surface with considerable texture. Such texture is a blend of moderate and thin geometric lines. Additionally, arm hair and melanin cells (commonly known as moles) are also beyond the scope of color quantization. The Sobel algorithm [8] was used for edge detection during preprocessing. The edges that were detected reflected the texture, fine hairs, and moles on the skin image. The Sobel algorithm can highlight the high-frequency data in images. Therefore, it is ideal for detecting texture pixels in the images. In this paper, to enhance edge detection, the range of edges was expanded by using morphological expansion[8], the obtained edges were then removed, and the remaining portion underwent color quantization (as shown in Fig. 2). Fig. 2(a) is original skin image, and Fig. 2(b) is the skin image after removing skin lines.

3.2 Color quantization algorithms

Color is distributed throughout an image in the form of pixels. To identify the primary color of the skin, a color quantization algorithm is required to calculate principal color. This is achieved by determining the color with the most pixels (largest area) in the image. This color is selected as the representative color and color feature. Color quantization algorithms can be broadly characterized into two types, namely, clustering algorithms and splitting algorithms. Clustering algorithms can produce more useful and accurate quantization outcomes, but require more time. Moreover, researchers that apply clustering algorithms also take into account the problems of convergence and computation speed. Splitting algorithms are the opposite. They have faster computation but produce less favorable quantization outcomes than their clustering counterparts. To identify the ideal method, we compared the quantization performance of three algorithms: median-cut algorithm, K-means clustering algorithm, and SOM algorithm.

3.3 Median-cut algorithm

Median-cut algorithm was proposed by Heckbert in 1982 [9] and is a type of non-average color quantization method. This method uses analysis techniques to segment the color space repeatedly until a similar color is reached. The surface is segmented vertically with a single color axis, and the element with the largest pixel difference range out of the three color axis will be used as a standard for segmenting. Sorting is used and then the middle gray scale value is used as the segmenting point.

3.4 K-means clustering algorithm

K-means is a clustering algorithm proposed by MacQueen in 1967. The amount of clusters must be defined before using the algorithm. Afterwards the center point of the cluster, the sum of the distance between the vector points and the extreme values need to be found to achieve the goal of optimal clustering. In 1995, Verevka applied this method to color quantization[10].

3.5 Self-organizing maps algorithm (SOM)

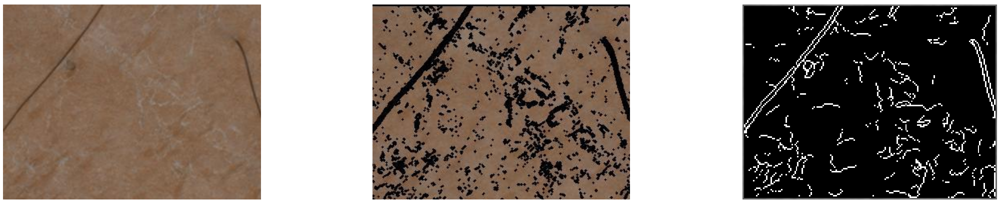
In 1994, Dekker proposed a color quantization method using SOM[11]. It has relatively quick calculation time, and is able to raise sample counts and significantly improve quantization quality. This method mainly employs a one dimensional self-organizing map where the network contains every cluster's neurons. Through a self-learning process, every neuron obtains a weight vector which has representative value. After self-learning, the pixels are also reflected in the nearest weight vector. The algorithm runs in two stages, specifically, the comparison stage and the learning stage. In the comparison stage, the distance between the selected weighted vectors and pixel groups can be determined.

3.6 Representative color, and root mean square error

Due to the fact that after color quantization, the coloring is not only of one single color, in order to find the main color, this method takes the color with the most pixels to be the representative color for the examined section. This method complies with the method recognized by testing personnel. The root mean square error (RMSE)[8] is used to evaluate the color quantization outcomes. This is also to compare the outcomes of same units. The similarity between the quantized image and original image increases as the difference between the RMSE values of the two images decreases.

3.7 Skin fine lines detection

A novel edge drawing algorithm (ED) is needed in fine line detection for skin image. Consequently, the edge drawing algorithm proposed by Topal et al. [12] was adopted. The edge detection method was applied to execute this procedure. A commonly adopted edge detection methods are the Sobel, Canny, Prewitt, Roberts, Laplacian etc.. This method was adapted from a traditional edge detection algorithm, incorporating direction maps, gradient maps, and edge maps to identify anchor points. Finally, anchor points were connected to form a boundary line. Because the width of the ED boundary line was one pixel, which was insufficient as a cutting line, the corners of the boundary line were enhanced to obtain the skin fine lines (see Fig. 2(c)).



(a) (b) (c)

Fig. 2. Skin lines removal: (a) original skin image; (b) skin image after removing skin lines; (c) skin fine lines image.

4 Experiments

This section entails the detection and analysis of the skin images. The skin images of ten participants aged between 16 and 53 (male and female) were selected as the experiment samples. These images were the skin area affected by high ankle strains, where there is less sebum secretion and the common over-drying leads to skin coarseness phenomenon, thus it is easy to observe the skin changes before and after using skin care products. All tests were performed using the same imaging equipment (white LED lighting, image spatial resolution is 0.01367 mm/pixel) and moisturizer (NIVEA extra white firming body lotion). The moist, oil, and soft outcomes of the high ankle strains area produced by the skin analyzer (MyB ST-100) were compared (Table 1). Three tests were designed. The first test was an RMSE evaluation using a complexion analysis with three color quantization algorithms. Six quantization colors were defined. The second test was a comparison and evaluation of luster improvement outcomes. The third test was a comparison and evaluation of fine lines improvement outcomes. Table 1 is shown the measurement results of moist, oil and skin soft by using ST-100 device. In addition, time was also evaluated in the second and third tests. All tests were conducted on a PC. The PC is equipped with Intel(R) Core (TM)2 Quad CPU 2.40GHz and Win7 OS. The front-end calculation refers to using the Chrome browser.

Three experiments are described as following:

- *Experiment 1: comparison of the RMSE results for three color quantization algorithms*

The skin on the dorsum of the hand of five participants was selected as the test samples in this test. The skin texture was removed before applying the three color quantization algorithms. Then, the RMSE between the quantization outcomes and the original images was calculated. The KM algorithm produced the most favorable results (achieving the smallest RMSE all ten times), followed by the Median-cut algorithm. The SOM algorithm produced the least favorable results. Therefore, the KM algorithm was selected as the color quantization algorithm in this paper. Table 2 is experimental results.

- *Experiment 2: comparison experiment of skin gloss improvement*

According to the outcomes of the first test, the KM algorithm was applied to evaluate the level of luster improvement. The ten skin images in Table 1 were examined and compared to determine whether luster was recovered after using moisturizer. "Sample A" is the image of skin before using moisturizer, and "Sample B" is the image of skin after using moisturizer. The similarity between pure white RGB (255,255,255) and the complexion value before using moisturizer was adopted as the K factor for current state of skin quality (denominator), the similarity between pure white and the complexion value after using moisturizer was adopted as the D factor for current state of skin quality (numerator), and the skin improvement value (V) was adopted as the V=(1-(D/K))*100%. Except Sample 7 which exhibited negative improvement, all the other samples showed positive improvement at different levels. Sample 4 exhibited the highest improvement of 7.2%. In comparison with outcomes in Table 1, before applying moisturizer, no data were measured for four samples tested (No. 3~6) with the ST-100 and three samples (No. 2, 7, 8) produced low values (no data); after applying skin care products, all samples could be measured. The levels of improvement are listed in the right column of the table. A comparison of the data in the two tables shows that improvement levels produced by the two methods were inconsistent. For the ST-100, effective data could not be retrieved from seven of the samples prior to applying the moisturizer. Moreover, improvement could only be quantized in levels rather than precise values. The outcomes produced by the proposed image detection method indicated that most of the samples exhibited improvement in luster after applying the moisturizer. Only Sample 7 showed negative improvement. This was because the imaging position was different, which caused discrepancies in the image analysis outcomes. Subsequently, the image processing time for each sample was within 15s.

- *Experiment 3: skin fine lines improvement*

In this test, improvement in fine lines was evaluated. The ST-100 was unable to detect the improvement of fine lines. Therefore, only the proposed image detection method was used in this test. The ED algorithm was adopted for wrinkle detection. ED results were then converted to obtain the sum of the fine lines, which served as the fine lines data. The improvement level of skin fine lines is shown in Table 4, where $S_1(S_2)$ is pixel number of skin fine lines in ED line image. The computation time of skin fine lines detection is about 16 milliseconds.

5 Conclusions

This paper introduced a skin image analyzer equipped with an ARM processor to detect skin appearance. The device is coupled with a self-developed image processing algorithm to calculate luster and fine lines, enabling users to compare the difference before and after using skin care products and evaluate the effectiveness of these products. Compared to conventional dielectric skin analyzers, the proposed image detection method can better measure luster and fine lines. A number of image processing method were compared in this paper. Outcomes revealed that KM outperformed the other algorithms. It was combined with self-designed features, to remove skin texture, fine hairs, and moles on the skin images and obtain luster results accurately. Moreover, an edge detection method was employed to measure fine lines. This method produced excellent results. In this paper, we found that the accuracy of the imaging position significantly influences detection outcomes. In future, researchers can aim to improve skin imaging position and investigate the feasibility of using the proposed device in testing other skin areas.

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Table 1. Measurement results of moist by ST-100 device (moist/oil/soft).

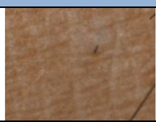
NO	Tester Age	Sample A	Sample B	Moist Improvement Level
1	16 years Male	Moist 33% (1/3/1)	Moist 34% (2/3/2)	1 level
2	21 years Female	Moist Lo (1/1/1)	Moist 34% (2/3/2)	1 level
3	23 years Male	No data	Moist 33% (1/2/1)	1 level
4	24 years Male	No data	Moist 33% (1/2/1)	1 level
5	53 years Male	No data	Moist 34% (2/3/2)	2 level
6	53 years Female	No data	Moist 34% (2/1/2)	2 level
7	22 years Female	Moist Lo (1/1/1)	Moist 40% (3/2/3)	2 level
8	22 years Male	Moist Lo (1/1/1)	Moist 35% (3/2/3)	2 level

9	21 years Female	Moist 33% (1/3/1)	Moist 35% (2/1/2)	1 level
10	22 years Female	Moist 33% (1/2/1)	Moist 35% (3/1/3)	2 level

Table 2. Comparison of the RMSE results for color quantization of skin images.

Sample No	Color Quantization Algorithms		
	Median-cut	KM	SOM
1	RMSE: 10.56	RMSE: 9.81	RMSE: 10.86
2	RMSE: 7.64	RMSE: 6.80	RMSE: 9.06
3	RMSE: 13.01	RMSE: 12.17	RMSE: 13.15
4	RMSE: 11.00	RMSE: 10.45	RMSE: 14.52
5	RMSE: 11.74	RMSE: 10.43	RMSE: 12.66
6	RMSE: 11.59	RMSE: 11.17	RMSE: 16.92
7	RMSE: 5.90	RMSE: 5.48	RMSE: 7.49
8	RMSE: 9.40	RMSE: 9.11	RMSE: 12.5
9	RMSE: 8.58	RMSE: 7.96	RMSE: 9.72
10	RMSE: 12.56	RMSE: 11.63	RMSE: 20.34

Table 3. Experimental results of improvement level (ms: millisecond)

NO	Sample A	Representative Color / Computation Time	Sample B	Representative Color / Computation Time	Level V (%)
1		RGB(142,104,74) 7769 ms		RGB(150,111,80) 7527ms	4.8%
2		RGB(128,106,88) 6049 ms		RGB(128,108,93) 6020 ms	1.8%
3		RGB(142,95,60) 9055 ms		RGB(149,100,62) 9937ms	2.5%
4		RGB(144,98,66) 6498 ms		RGB(135,109,91) 6218ms	7.2%
5		RGB(132,93,63) 8755 ms		RGB(147,99,62) 8231ms	3.3%
6		RGB(144,96,60) 10489 ms		RGB(142,97,62) 14473ms	0.4%
7		RGB(136,108,87) 5347 ms		RGB(141,99,67) 5652ms	-6.6%
8		RGB(132,98,72) 5998 ms		RGB(132,109,92) 5078ms	7.0%

9		RGB(133,100,74) 6454 ms		RGB(137,103,78) 5864ms	2.3%
10		RGB(155,100,58) 7482 ms		RGB(156,101,59) 6282ms	0.4%

Table 4. Experimental results of skin fine lines improvement.

NO	Sample A: Skin fine lines (S_1)	Sample B : Skin fine lines (S_2)	Level (%) $100*(S_1-S_2)/S_1$
1	3611	3389	6%
2	9693	5014	48%
3	8520	5966	29%
4	6890	2046	70%
5	4827	12323	-155%
6	12146	7855	35%
7	3119	8369	-168%
8	11528	2476	78%
9	2583	1058	59%
10	7946	3616	54%