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DEVELOPMENT OF A COMPREHENSIVE METHOD FOR THE DERMATOSCOPIC IMAGES ANALYSIS OF THE FACIAL SKIN WITH ACNE

K. G. Selivanova, A. A. Trubitsin, O. G. Avrunin
Kharkiv National University of Radio Electronics, 14, Nauky Ave., Kharkiv, 61166, Ukraine
e-mail: karina.selivanova@nure.ua
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Background: One of the most common inflammatory chronic and recurrent skin diseases is acne ("acne vulgaris"), which appears itself as open or closed comedones and inflammatory skin lesions in the form of papules, pustules, nodes, etc. It has been established that acne is one of the most common dermatoses, since, according to modern data, it affects about 9.4% of the population. During adolescence, up to 90% of people suffer, and in adulthood — about 20% with varying degrees of severity. Currently, there are many approaches to treating this disease through various cosmetic treatments such as phototherapy, ultrasonic skin cleansing, mesotherapy, chemical peels, and medication. Therefore, the development of methods and means of differential diagnosis of acne is one of the urgent tasks in the field of biomedical engineering, dermatology, and clinical medicine, since this allows timely identification of the localization of the disease, its causes, and prescribing appropriate treatment. However, the solution to the problem of monitoring the dynamics of external manifestations of the disease is possible only with the use of combined mathematical methods for image analysis.
Objectives: To develop a comprehensive method for analyzing dermatoscopic images for monitoring the external manifestations of acne disease during treatment and isolating the affected areas of the facial skin.
Materials and Methods: Dermatological preclinical researches of the skin were conducted in the laboratory of 3D-biomedical technologies of the Department of Biomedical Engineering of the Kharkiv National University of Radio Electronics, using a digital videodermatoscope BIO Bm6+ in daylight and a portable skin analyzer Skin Scope F-102 in the ultraviolet range. Clinical researches were conducted based on the Department of Pediatric Propaedeutics #2 of the Kharkiv National Medical University. The development of a software tool for image analysis was conducted out in Python programming using the libraries OpenCV, Scikit-image, Numpy, PIL, Mathplotlib. Determination of the affected skin areas and calculation of the parameters of inflammation were carried out using multi-Otsu methods and morphological segmentation of digital dermatoscopic images.
Results: During the research, automated software was developed that allows to analyze in dynamics the nature of inflammatory processes and the area of facial skin lesions, as well as to carry out a differential diagnosis of acne disease. The proposed method for the analysis of dermatoscopic images makes it possible to perform color segmentation and obtain a map of the gradations of skin inflammations to control the dynamics during the prescribed treatment.
Conclusions: The comprehensive method of analysis of dermatoscopic images of the skin of the face makes it possible to effectively control the condition of the skin of the face from acne during treatment, while analyzing the degree of inflammatory processes and the area of lesions, where, using the developed

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software, in an automated mode, red gradations are calculated to detect the boundaries of inflammation, geometric parameters and percentage of lesions in relation to healthy facial skin.
KEY WORDS: acne; post-acne; facial skin; dermatology; dermatoscopic imaging; color image segmentation; multi-Otsu method.

Acne ("acne vulgaris") is a chronic inflammatory disease that appears itself as open or closed comedones and inflammatory skin lesions in the form of papules, pustules, nodules, and more [1]. Acne is one of the most common dermatoses. According to current data, acne affects 9.4% of the population. This disease affects about 90% of people in adolescence and sometimes in adulthood: about 20% of people experience moderate to severe forms of the disease [2]. There are many approaches to treating acne: phototherapy, ultrasonic skin cleansing, mesotherapy, chemical peels, and medication. Today, dermatological and cosmetic offices often use a combination of these methods [1–3].

In adolescence, boys and girls suffer from acne while at a more mature age, acne is more common among women (9.8%) than among men (9%) [3]. This disease affects all ethnic groups, and there is no verified information on whether race affects the incidence of this disease [3–4]. Therefore, one of the important tasks in acne treatment is to evaluate the effectiveness of therapy by monitoring its external manifestations. The purpose of this research work is the development of a comprehensive method of dermatoscopic images analysis for monitoring the acne disease external manifestations during treatment and isolating the affected areas of the facial skin. Currently, dermatological research methods are among the most effective in identifying affected skin areas [5].

MATERIALS AND METHODS

Dermatological preclinical researches of the skin were conducted in the laboratory of 3D-biomedical technologies of the Department of Biomedical Engineering of the Kharkiv National University of Radio Electronics, using a digital videodermatoscope BIO Bm6+ in daylight and a portable skin analyzer Skin Scope F-102 in the ultraviolet range. Clinical researches were conducted based on the Department of Pediatric Propaedeutics #2 of the Kharkiv National Medical University [6].

Diagnostic research was conducted at the Department of Biomedical Engineering involving 17 people (10 males and 7 females) diagnosed with acne aged 18 to 32 years.

The survey included the patient's anamnesis and a study of the affected areas of the skin. The skin was researched with BIO Bm6+ dermatoscope. During the dermatoscopic checkup of the patients, the same light conditions were observed [7]. During the study, the device is pressed with slight pressure to the surface of the skin inflamed so that it is in the center of the contact plate. Then the image is sharpened using the focusing ring and the skin structure is examined under illumination built-in LEDs. After surveying each patient, the contact plate is disconnected from the dermatoscope and disinfected according to the standard technique [6]. Oil or liquid of the skin is removed from its surface, which makes the stratum corneum transparent and allows seeing the pigment structures in all layers of the skin, the size, and the shape of the superficial vessels of the dermis [7–8].

A portable skin analyzer Skin Scope F-102 which works in the ultraviolet range also was used for diagnostic research. When using such a device, it is possible to obtain high-quality images of the facial skin, which can be effectively used to assess the condition of the patient's skin during the first visit, and to track the effectiveness of the prescribed treatment. The use of ultraviolet radiation in skin diagnostics makes it possible to efficiently, quickly, and differentiate different skin features that cannot always be seen under normal lighting. In this case, different features appear in different colors [7–8].

Image analysis was executed using the Python language and the OpenCV, Scikit-image libraries. To study the dynamics of inflammation, dermatoscopic images were transferred from RGB to HSV color model; the ranges of colors characteristic of several stages of inflammation (severe inflammation, moderate inflammation, mild inflammation) and the investigated color h-channel of a dermatoscopic image were identified. Methods of morphological segmentation were used to isolate the affected skin areas for further assessment of the area the lesions [8].

RESULTS AND DISCUSSION

Software development for dermatoscopic image analysis based on the method multi-Otsu

The paper considers two approaches to obtaining segments of the affected skin areas. The first is the multi-Otsu method. This method is an extension of the original Otsu method with a multilevel threshold value [9]. As is known, the multi-Otsu method is a thresholding algorithm that is used to separate the pixels of an input image into several different classes, each one obtained according to the intensity of the gray levels within the image [10]. Multi-Otsu calculates several thresholds, determined by the number of desired classes. The default number of classes is 3: for obtaining three classes, the algorithm returns two threshold values.

This method presents a threshold that minimizes the variance within a class, which is defined as the weighted sum of the variances of two classes [9]:

$$\delta_{\varpi}^2(t) = \varpi_0(t)\delta_0^2(t) + \varpi_1(t)\delta_1^2(t), \tag{1}$$

where ϖ_0 and ϖ_1 probabilities of two classes separated by a threshold *t*, δ_0^2 and δ_0^2 – the deviation of these two classes, which value is within the range from 0 to 255 inclusively [10].

The first class is minimizing the within-class variance defined above $\delta_{\varpi}^2(\text{t})$, the second is to maximize the between-class variance using the expression below [9–10]:

$$\delta_b^2(\text{t}) = \varpi_1(\text{t})\varpi_2(\text{t})[\mu_1(\text{t}) - \mu_2(\text{t})]^2, \tag{2}$$

where μ_i is a mean of class i.

The probability P is calculated for each pixel value in two separated clusters C_1, C_2 using the cluster probability functions expressed as:

$$\varpi_1(\text{t}) = \sum_{i=1}^{t} P(\text{i}),$$
$$\varpi_2(\text{t}) = \sum_{i=t+1}^{I} P(\text{i}). \tag{3}$$

It should be noted that the image can presented as intensity function $f(\text{x}, \text{y})$, which values are gray-level. The quantity of the pixels with a specified gray-level i denotes by i. The general number of pixels in the image is n .The pixel intensity values for the C_1 are in $[1,\text{t}]$ and for C_2 are in $[\text{t}+1, \text{I}]$, where I is the maximum pixel value (255) [10–11].

The next phase is to obtain the means for C_1, C_2, which are denoted by $\mu_1(\text{t}), \mu_2(\text{t})$ appropriately:

$$\mu_1(t) = \sum_{i=1}^{t} \frac{iP(i)}{\varpi_1(t)},$$
$$\mu_2(t) = \sum_{i=t+1}^{I} \frac{iP(i)}{\varpi_2(t)}. \tag{4}$$

Now let's remember the above equation of the within-classes weighted variance. We will find the rest of its components (δ_1^2, δ_2^2) mixing all the obtained above ingredients [11–12]:

$$\delta_1^2(t) = \sum_{i=1}^{t} [i - \mu_1(t)]^2 \frac{P(i)}{\varpi_1(t)},$$
$$\delta_2^2(t) = \sum_{i=t+1}^{I} [i - \mu_2(t)]^2 \frac{P(i)}{\varpi_2(t)}. \tag{5}$$

It should be noted that if the threshold was chosen incorrectly the variance of some class would be large. To get the total variance we simply need to summarize the within class and between-class variances [13–14]:

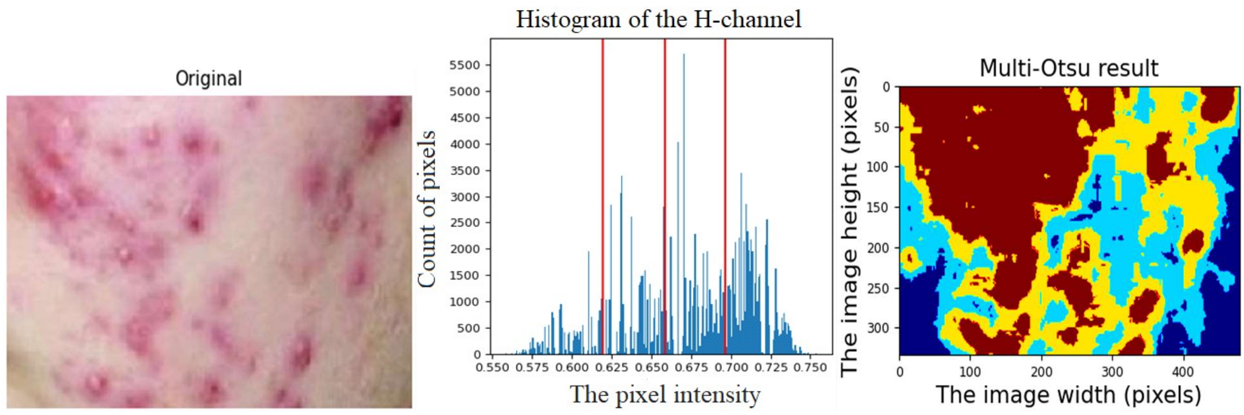
$$\delta_T^2 = \delta_\varpi^2(t) + \delta_b^2(t)$$
$$\text{where } \delta_b^2(t) = \varpi_1(t)\varpi_2(t)[\mu_1(t) - \mu_2(t)]^2. \tag{6}$$

The total variance of the image (δ_T^2) does not depend on the threshold.

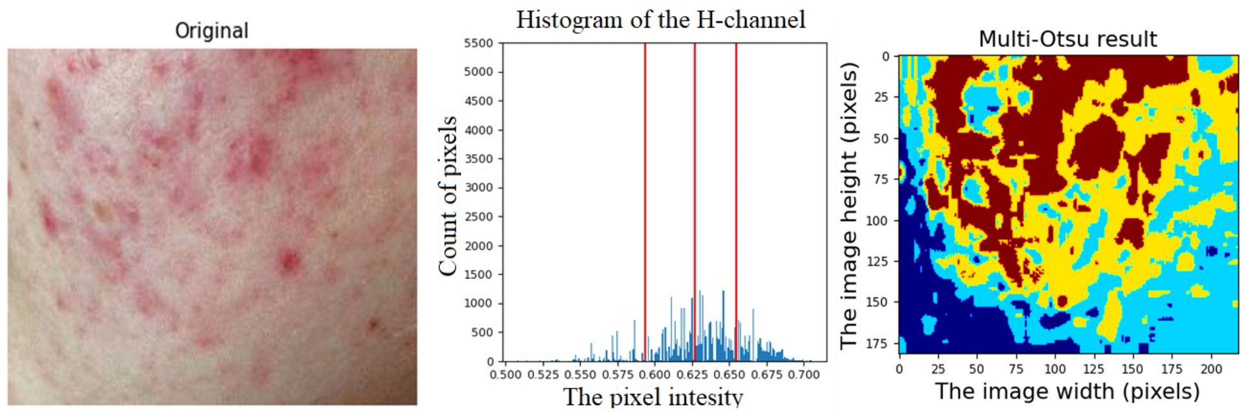
The developed software on based the multi-Otsu algorithm consists of these steps [8–9]:

- processing of the input dermatoscopic image in gray gradation;
- calculation the histogram and intensity level probabilities;
- determination of multiple thresholds and multiple classes for dermatoscopic image;
- replace image pixels into white in those regions, where saturation is greater than, and into black in the opposite cases [9–14].

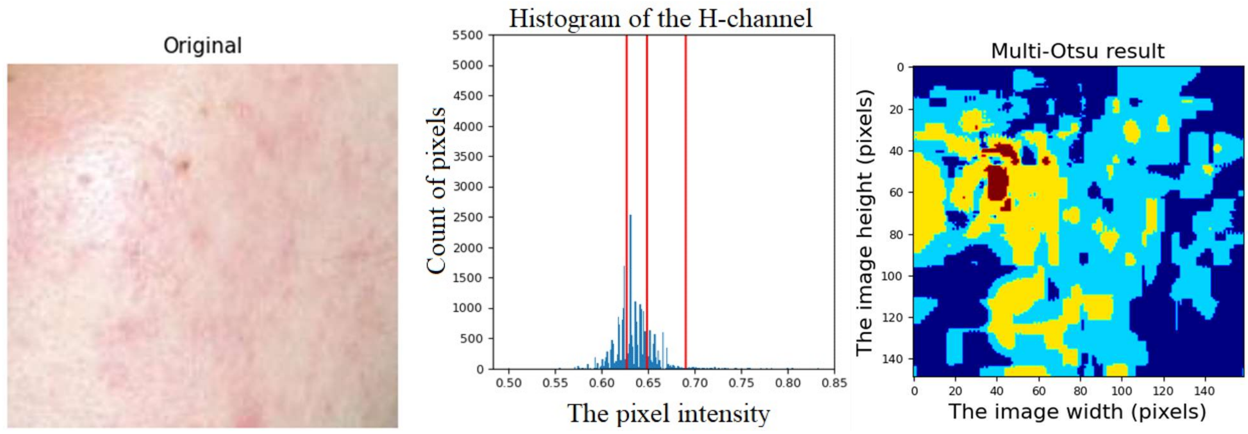
The dynamics of acne disease in the clinical case of patient #5432 in the 1st, 7th, and 14th days of treatment is shown in Fig. 1. Obtained results of images analysis by method multi-Otsu for the clinical case of 1st, 7th, and 14th days of the treatment are shown also in Fig. 1 *a*, *b*, *c*. The input dermatoscopic images were transformed from the RGB color model to HSV. Obtained histogram demonstrates the calculation of brightness pixels for the H-channel of the HSV color model and the determination of three thresholds for the redness skin. The third picture represents a color segmentation map of the skin inflammations for the dynamic evaluation of acne and calculation of its parameters for making further decisions. The colors of the segmented areas of the dermatoscopic image by method Otsu were selected to display the determined boundaries with the most contrast using library OpenCV. Multi-Otsu results for map colors demonstrate an accurate location of acne redness.



a



b



c

Fig. 1. An example of dermatoscopic images analysis by the multi-Otsu method of 1st (*a*), 7th (*b*), and 14th (*c*) day of #5432 patient acne treatments.

Software development for dermatoscopic image analysis based on the mathematical morphological operations

The second method is mathematical morphological operations, which were used for software development for dermatoscopic image analysis [15–17].

The sequence of stages of the developed software based on the second method consists of 6 basic units, which are represented in Fig. 2 [15].

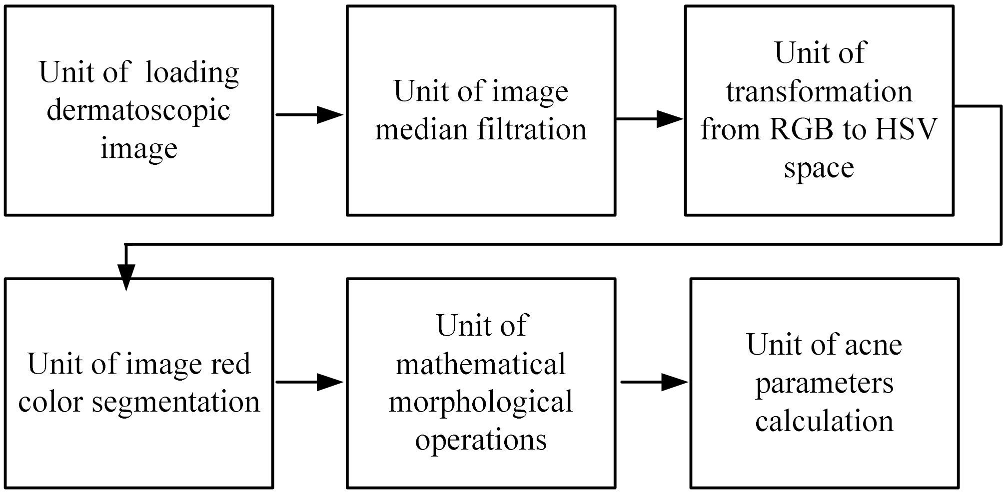


Fig. 2. A structure diagram of developed software for dermatoscopic image analysis by mathematical morphological operations.

The first step of the software is loading the dermatoscopic image on the module. Input data for analysis are 24-bit color JPG images with 422x279 resolution. This format is one of the most common formats for working with bitmaps and is supported by many modern display devices [16]. The color depth of all input images was 8 bits/pixel, with color representation in the RGB model. The second step is using a median filter, which is applied to reduce the noise level in the image [17]. The third step of digital image processing is the transformation from the RGB to HSV color model for further analysis, using standard formulas [15–17]:

$$H = \begin{cases} 0, \mathit{if} \ \max = \min \\ 60 \times \dfrac{g-b}{\max - \min}, \mathit{if} \ \max = \mathrm{r \ i \ g} \geq b \\ 60 \times \dfrac{g-b}{\max - \min} + 360, \mathit{if} \ \max = \mathrm{r \ i \ g} < b \\ 60 \times \dfrac{b-r}{\max - \min} + 120, \mathit{if} \ \max = g \\ 60 \times \dfrac{b-r}{\max - \min} + 240, \mathit{if} \ \max = \mathrm{b} \end{cases} \tag{7}$$

$$S = \begin{cases} 0, \mathit{if} \ \max = 0 \\ 1\text{-}\dfrac{\min}{\max} \end{cases}$$

$$V = \max$$

Components H ∈ [0, 360], S, V, R, G, B ∈ [0, 1]. MAX is the maximum value of R, G and B, and MIN is the minimum of them.

For detection of skin inflammations on the dermatoscopic image was used segmentation by red color. For color segmentation, need select the parameters by which segmentation will be executed. For human skin with inflammation, the threshold values were [14, 75, 60] and [360, 255, 255] shades of red in the HSV color model. The obtained values will be used to find inflammation in dermatoscopic images taken under standard lighting. After segmentation, the developed module executes the morphological expansion of the image using the dilation operation. In this case, the binary gradient mask uses vertical and horizontal structural elements [18]. This operation allows filling in the gaps within the obtained limit to eliminate the probability of false boundaries [19].

The next stage is filling the contours of the resulting boundaries, it is necessary to realize mathematical operation – smoothing. Smoothing is executed using the erosion operation. It allows getting smoother and more "natural" boundaries, corresponding to the object contours without capturing neighboring pixels [20]. Most inflammations on human skin do not have clear boundaries, after localizing the point of inflammation intensity it is necessary to search for related areas to obtain more reliable information about the localization and the degree of inflammation and to objectively assess the skin lesions area [15–20].

The last step after finding the boundaries is the calculation of the technical parameters of the found boundaries (i.e. the size of the skin lesions). In this case, the informant result is the original image with the highlighted limits of inflammation in the calculated area [21].

In this article to determine the area of the lesions, the use of the method of mathematical morphology was investigated. For this, the original image was converted from an RGB color model to a binary one. Further, using the methods of erosion and dilation, the affected areas of the skin were isolated [15–25].

The erosion of the binary image A by the structural element B is defined as:

$$A \ominus B = \{z \in E | B_Z \sqsubseteq A\}, \tag{8}$$

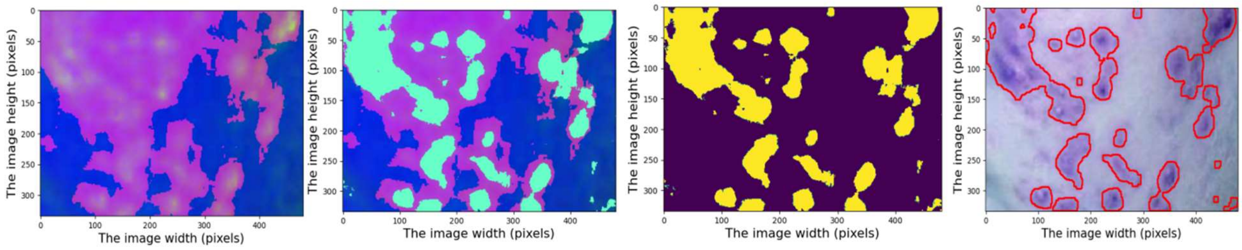
where B_Z is the transfer of B to the vector z, ie $B_Z = \{b + z | b \in B\}$, $\forall_Z \in E$.

The dilation of A using the structural element B is defined as:

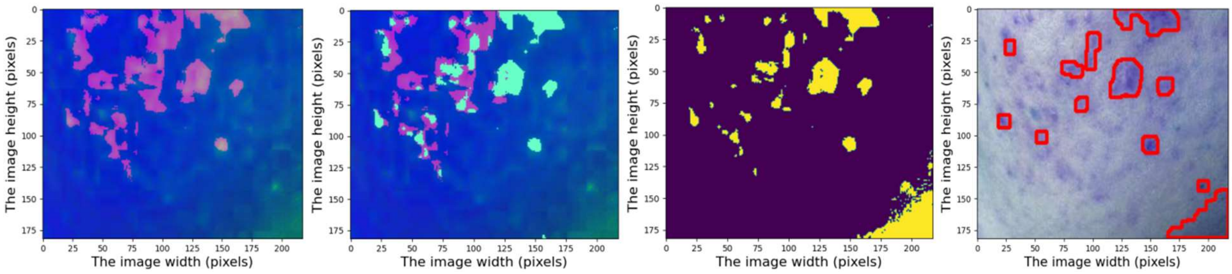
$$A \oplus B = \bigcup_{b \in B} A_b \quad . \tag{9}$$

To implement both operators need to enter the kernel parameter. It is advisable to use a 5×5 core. Also using these operations, it is necessary to specify the number of iterations for the most accurate result. In the case of fuzzy objects, such as inflammation on human skin, 1 iteration is used for erosion operations and 2 a re used for expansion operations. Obtained results are represented in Fig. 3. The color range (upper and lower bounds of the color) for the acne areas determination corresponds to this range of the HSV image. In the clinical case of 1st, 7th, and 14th day during treatment of patient #5432 dermatoscopic images were transformed into different color models: HSV, GRAY, Binary, and BGR for detection acne boundaries and accuracy calculation geometric parameters using mathematical morphologies. All obtained images were represented by the requirements of the computer coordinate system.

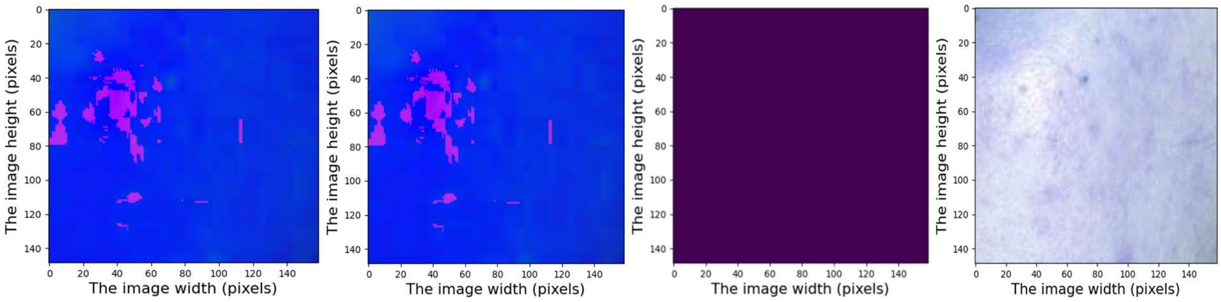
Fig. 4 shows the experimental results of the survey skin in ultraviolet light for example #387 and #394 patients with closed comedones for prescribing cosmetological procedures and dermatological treatments. The resolution of the obtained digital images is 750×750 pixels. Detection of closed comedones on the skin was executed mathematical morphological operations [20–25].



a

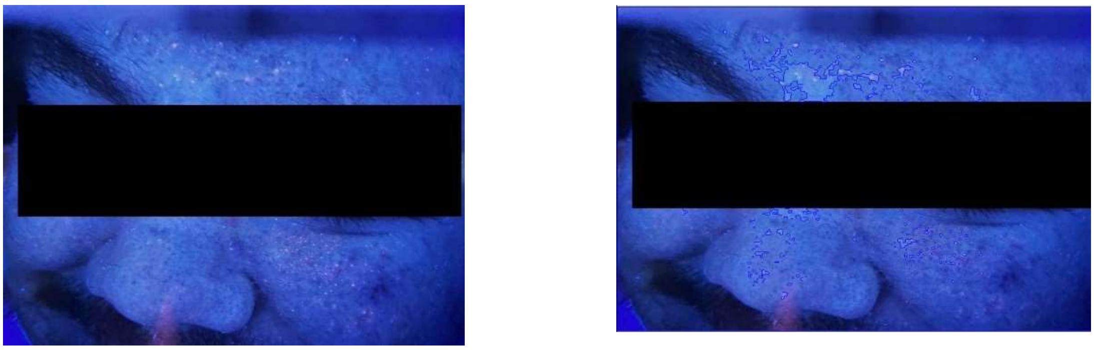


b

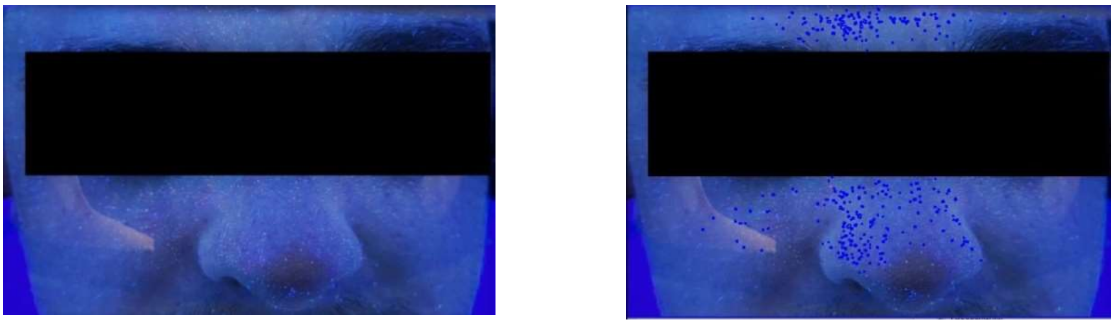


c

Fig. 3. An example of dermatoscopic image analysis for detection acne using morphological operations of the 1st (*a*), 7th (*b*), and 14th (*c*) day treatment of #5432 patient.



a b



a b

Fig. 4. An example of the patients' skin in UV illumination during the survey (*a*) and the result of image analysis with highlight contours of closed comedones on the skin (*b*).

CONCLUSIONS

The developed comprehensive method for analyzing skin lesions with acne allows automated control of the external appearance of this disease dynamics. The use of this software is especially advisable during therapy, which can make it possible to timely adjust acne intensity and treatment regimen. The developed module works with two types of images — obtained under daylight and UV illumination. The developed module makes it possible to effectively and objectively assess the degree of the disease by guiding the geometric parameters of inflammation on the skin, as well as by visualizing the highlighted contours of inflammation in images.

The investigated multi-Otsu method allows obtaining a map of the gradations of inflammation in one image. The obtained color spectrum is present in all images to interpret the results. The combined method of dermatoscopic image analysis makes it possible to effectively monitor the condition of the patient's skin by analyzing the degree of inflammatory processes and the area of the lesions but does not have the advantages of the first method for tracking the gradations of inflammation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

Authors' ORCID ID

Karina Selivanova ORCID: https://orcid.org/0000-0003-1002-0761
Alexey Trubitcin ORCID: http://orcid.org/0000-0002-7581-1700
Oleg Avrunin ORCID: https://orcid.org/0000-0002-6312-687X

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РОЗРОБКА КОМПЛЕКСНОГО МЕТОДУ АНАЛІЗУ ДЕРМАТОСКОПІЧНИХ ЗОБРАЖЕНЬ ШКІРИ ОБЛИЧЧЯ З АКНЕ

К. Г. Селіванова, О. О.Трубіцин, О. Г. Аврунін
Харківський національний університет радіоелектроніки, пр. Науки, 14, Харків, Україна, 61166
e-mail: karina.selivanova@nure.ua

Актуальність. Одним із найпоширеніших запальних хронічних та рецидивних захворювань шкіри є акне («acne vulgaris»), що проявляється як відкриті або закриті комедони і запальні ураження шкірного покрову у вигляді папул, пустул, вузлів тощо. Встановлено, що акне є одним із розповсюджених дерматозів, оскільки вражає, за сучасними даними, близько 9,4% населення. У підлітковому віці страждають до 90% людей, а в зрілому — близько 20% з різними ступенями тяжкості. Наразі існує багато підходів до лікування цього захворювання за допомогою різноманітних косметологічних засобів, таких як: фототерапія, ультразвукове очищення шкіри, мезотерапія, хімічний пілінг та медикаментозне лікування. Тому розробка методів та засобів

диференціальної діагностики акне є однією з актуальних задач в галузі біомедичної інженерії, дерматології та клінічної медицини, оскільки це надає змоги, своєчасно виявити локалізацію захворювання, його причини та призначити відповідне лікування. Однак вирішення задачі моніторингу за динамікою зовнішніх проявів захворювання можливе лише при застосуванні комбінованих математичних методів аналізу зображень.

Метою роботи є розробка комплексного методу аналізу дерматоскопічних зображень для моніторингу за перебігом зовнішніх проявів захворювання акне під час лікування та виділення уражених ділянок шкіри обличчя.

Матеріали й методи. Дерматологічні доклінічні дослідження шкіри обличчя були проведені на базі лабораторії 3D-біомедичних технологій кафедри біомедичної інженерії Харківського національного університету радіоелектроніки із використанням цифрового відеодерматоскопа BIO Bm6+ при денному світлі та портативного аналізатора шкіри Skin Scope F-102 в ультрафіолетовому діапазоні. Клінічні дослідження були проведені на базі кафедри пропедевтики педіатрії № 2 Харківського національного медичного університету. Розробка програмного засобу для аналізу зображень була виконана у середовищі програмування Python із використанням бібліотек OpenCV, Scikit-image, Numpy, PIL, Mathplotlib. Визначення уражених ділянок шкіри обличчя та розрахунок параметрів запалень проводились методами мульти-Оцу та морфологічної сегментації цифрових дерматоскопічних зображень.

Результати. У ході досліджень був розроблений автоматизований програмний засіб, який дозволяє проаналізувати у динаміці характер запальних процесів та площу уражень шкіри обличчя, а також провести диференційну діагностику захворювання акне. Запропонований метод аналізу дерматоскопічних знімків дозволяє виконати кольорову сегментацію та отримати карту градацій запалень шкіри для контролю за динамікою під час призначеного лікування.

Висновки. Комплексний метод аналізу дерматоскопічних зображень шкіри обличчя дозволяє ефективно контролювати стан шкіри обличчя з акне під час лікування, аналізуючи при цьому ступінь запальних процесів і площу уражень, де за допомогою розробленого програмного засобу в автоматизованому режимі розраховуються градації червоного кольору для детектування границь запалень, геометричні параметри та відносна частка уражень шкіри обличчя.

КЛЮЧОВІ СЛОВА: акне; постакне; шкіра обличчя; дерматологія; дерматоскопічні зображення; сегментація кольорових зображень; метод мульти-Оцу.

РАЗРАБОТКА КОМПЛЕКСНОГО МЕТОДА АНАЛИЗА ДЕРМАТОСКОПИЧЕСКИХ ИЗОБРАЖЕНИЙ КОЖИ ЛИЦА С АКНЕ

К.Г. Селиванова[1], О.О.Трубицын[1], О.Г. Аврунин[1]
Харьковский национальный университет радиоэлектроники, пр. Науки, 14, Харьков, Украина, 61166
e-mail: karina.selivanova@nure.ua

Актуальность. Одним из наиболее распространенных воспалительных хронических и рецидивирующих заболеваний кожи является акне («acne vulgaris»), которое проявляется в виде открытых или закрытых комедонов и воспалительных поражений кожного покрова — папул, пустул, узлов и т.д. Установлено, что акне является одним из распространенных дерматозов, поскольку поражает, по современным данным, около 9,4% населения. В подростковом возрасте страдают до 90% людей, а в зрелом – около 20% с разными степенями тяжести. В настоящее время существует много подходов к лечению этого заболевания с помощью различных косметологических средств, таких как фототерапия, ультразвуковая очистка кожи, мезотерапия, химический пилинг и медикаментозное лечение. Поэтому разработка методов и средств для дифференциальной диагностики акне является одной из актуальных задач в области биомедицинской инженерии, дерматологии и клинической медицины, поскольку это позволяет своевременно выявить локализацию заболевания, его причины и назначить соответствующее лечение. Однако решение поставленной задачи мониторинга за динамикой внешних проявлений заболевания возможно только при применении комбинированных математических методов анализа изображений.

Цель работы. Разработка комплексного метода анализа дерматоскопических изображений для мониторинга внешних проявлений заболевания акне во время лечения и выделения пораженных участков кожи лица.

Материалы и методы. Дерматологические доклинические исследования кожи были проведены в лаборатории 3D-биомедицинских технологий кафедры биомедицинской инженерии Харьковского национального университета радиоэлектроники с использованием цифрового видеодерматоскопа BIO Bm6+ при дневном свете и портативного анализатора кожи Skin Scope F-102 в

ультрафиолетовом диапазоне. Клинические исследования были проведены на кафедры пропедевтики педиатрии №2 Харьковского национального медицинского университета. Разработка программного средства для анализа изображений была выполнена в среде программирования Python с использованием библиотек OpenCV, Scikit-image, Numpy, PIL, Mathplotlib. Определение пораженных участков кожи и расчет параметров воспалений проводились методами мульти-Оцу и морфологической сегментации цифровых дерматоскопических изображений.

Результаты. Во время проведения исследований было разработано автоматизированное программное средство, позволяющее проанализировать в динамике характер воспалительных процессов и площадь поражений кожи лица, а также провести дифференциальную диагностику заболевания акне. Предлагаемый метод анализа дерматоскопических снимков позволяет выполнить цветовую сегментацию и получить карту градаций воспалений кожи для контроля динамики во время назначенного лечения.

Выводы. Комплексный метод анализа дерматоскопических изображений кожи лица позволяет эффективно контролировать состояние кожи лица с акне во время лечения, анализируя при этом степень воспалительных процессов и площадь поражений, где с помощью разработанного программного средства в автоматизированном режиме рассчитываются градации красного цвета для детектирования границ воспалений, геометрические параметры и доля поражений кожи лица.

КЛЮЧЕВЫЕ СЛОВА: акне; постакне; кожа лица; дерматология; дерматоскопические изображения; сегментация цветных изображений; метод мульти-Оцу.