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Novel techniques for enhancement and segmentation of acne vulgaris lesions

A. S. Malik[1], J. Humayun[1], N. Kamel[1] and F. B.-B. Yap[2]

[1]Centre for Intelligent Signal & Imaging Research, Universiti Teknologi Petronas, Tronoh, Malaysia and [2]Department of Dermatology, Hospital Kuala Lumpur, Kuala Lumpur, Malaysia

Background: More than 99% acne patients suffer from acne vulgaris. While diagnosing the severity of acne vulgaris lesions, dermatologists have observed inter-rater and intra-rater variability in diagnosis results. This is because during assessment, identifying lesion types and their counting is a tedious job for dermatologists. To make the assessment job objective and easier for dermatologists, an automated system based on image processing methods is proposed in this study.
Objectives: There are two main objectives: (i) to develop an algorithm for the enhancement of various acne vulgaris lesions; and (ii) to develop a method for the segmentation of enhanced acne vulgaris lesions.
Methods: For the first objective, an algorithm is developed based on the theory of high dynamic range (HDR) images. The proposed algorithm uses local rank transform to generate the HDR images from a single acne image followed by the log transformation. Then, segmentation is performed by clustering the pixels based on Mahalanobis distance of each pixel from spectral models of acne vulgaris lesions.
Results: Two metrics are used to evaluate the enhancement of acne vulgaris lesions, i.e., contrast improvement factor (CIF) and image contrast normalization (ICN). The proposed algorithm is compared with two other methods. The proposed enhancement algorithm shows better result than both the other methods based on CIF and ICN. In addition, sensitivity and specificity are calculated for the segmentation results. The proposed segmentation method shows higher sensitivity and specificity than other methods.
Conclusion: This article specifically discusses the contrast enhancement and segmentation for automated diagnosis system of acne vulgaris lesions. The results are promising that can be used for further classification of acne vulgaris lesions for final grading of the lesions.

Key words: acne vulgaris – acne lesions – enhancement – segmentation – acne grading

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ACNE VULGARIS is a very common skin disease that affects 85% of the adolescent population. Biologically, acne appears when the skin pores, which are often called hair follicles, get blocked. Acne causes itchiness, discomfort, and disturbs the normal skin functions. Acne lesions are ugly or, at least, unpleasant to look at which causes psychological distress, social problems, and low self-esteem (1). In 2009, a community-based study for Korean adolescents (2) revealed that higher the severity of acne condition, more is the mental stress and social impairment. Thus, effective and quick treatment of acne is necessary.

Dermatologists need to evaluate the effectiveness of their treatment by assessing the severity of acne condition. It has been observed that if a same patient is examined by two or more different dermatologists, the results are not exactly the same. In statistics, this scenario is known as inter-rater reliability, which gives the score that how much consensus or homogeneity is there among judges while rating. More surprisingly, it has been seen that if a dermatologist examines the same patient at different times within a day or on different days, his current result may vary from his previous result. This is known as intra-rater reliability. Furthermore, most of the acne grading scales require counting of lesion types, which is time-consuming and tedious job for dermatologists. Acne vulgaris has five different structures including comedone, papule, pustule, nodule, and cyst. So, it requires considerable effort by dermatologists to differentiate between different structures and features of lesions.

The poor score of inter-rater and intra-rater reliability is due to subjective methodologies used by dermatologists and thus it has an impact on precision and accuracy of the diagnosis results. To eliminate the inter- and intra-rater reliability, the diagnosis procedure of acne requires some objective measures. If the diagnostic procedure is automated, it will remove inter and intra-rater reliability and tedious part of the job as well. Such automated diagnostic system shall include feature extraction, segmentation, depth estimation, and many more operations that can be performed in a more objective and efficient way through image processing.

Current assessment methods

Up till now, more than 25 acne grading methods have been developed by dermatological experts (3). In this study, we consider only global acne grading system (GAGS) because it is one of the most widely used and the Malaysian dermatologists also utilize GAGS (3). GAGS was devised by Doshi et al. (4) in 1997. In this grading system, six different regions are assessed separately, i.e., forehead, chin, left cheek, right cheek, nose, upper chest, and back. The scoring table for GAGS is shown in Table 1. Later in 2008, GAGS was modified by Eichenfield et al. (5). by removing the non-facial regions from the assessment criteria, i.e., chest and back. It was termed as modified GAGS.

Related Work

Due to subjectivity of human interpretation, computerized assessment of skin disease has become an important research area, e.g., computer aided diagnosis (CAD) system of melanocytic skin lesions (6). CAD systems help scan the digital images and highlight the abnormalities in images. CAD systems have been employed for assisting physicians in various other medical areas too including breast cancer detection using mammography images, lung cancer detection using computed tomography, etc.

In dermatology, polarized light photography is basically used as means of separating information carried by the light reflected by stratum corneum (outermost layer of the Epidermis) and the light remitted after crossing epidermis and papillary dermis (7). In 1997, Phillips et al. (8) studied polarized light photography for assessment of acne lesion. In that study, it was concluded that polarized light photography improves the visualization of inflammatory lesions. However, polarized filter needs to be adjusted every time and only a portion of subsurface features were visible.

In dermatological imaging, fluorescence photography has enhanced the visual details in several cases. Porphyrins formed by Propionibacterium acne produce fluorescence in UV. Lucchina et al. (9) and Pagoni et al. (10)used this idea and monitored acne lesions. A common criticism on these methods is that projection of UV rays can be dangerous in some cases.

Another modality used in dermatological diagnosis is the multispectral camera. Fuji et al. (11) studied multispectral images of acne lesion to classify the types of acne lesion based on reflectance properties. However, the variety of skin colors was not handled in their experiments. Another drawback of multispectral equipment is its high cost.

As discussed above, the current methods related to acne provide better visualization for the dermatologists who then assess the acne lesions manually. However, there is no automated acne lesions assessment and grading method available so far. An automated method requires preprocessing/enhancement and segmentation of acne lesions before the grading of acne. Therefore, this research addresses enhancement and segmentation of acne lesions.

TABLE 1. Global acne grading system scoring criteria

Region	Region factor (F)	Severity (S)		Local score (FxS)	Acne severity criteria	
Forehead	2	Score	Type		Mild	1–18
Right cheek	2	0	Nil		Moderate	19–30
Left cheek	2	1	Comedone		Severe	31–38
Chin	1	2	Papule		Very severe	>39
Nose	1	3	Pustule			
Chest and Back	3	4	Nodule			
Total score						

Methodology

Figure 1 shows the major steps involved in the proposed methodology for acne diagnosis system utilizing image processing techniques. First, close-up images of five regions of the face are captured, i.e., forehead, chin, nose, left cheek, and right cheek. From these images, region of interest is manually cropped out on which further processing is performed. Then, the image is enhanced using our proposed contrast enhancement algorithm, which is described in the next section. By applying this contrast enhancement, the segmentation gives more promising results. On the preprocessed image, our proposed segmentation algorithm is applied that separates the lesion from the normal skin. After segmentation, certain features need to be extracted based on which the lesions will be identified and classified. This information is sufficient for any grading system such as GAGS (as discussed earlier) to calculate the severity of acne. In this study, the enhancement and the segmentation steps of the proposed framework are discussed in detail.

Contrast enhancement

In this study, the contrast enhancement process is carried out by increasing the dynamic range of pixels. Dynamic range can be defined as a ratio between the smallest and the largest possible values of changeable quantity. Humans have high visual dynamic range by virtue of which they can see the details in a bright sunny region and dark-shaded region of a scene simultaneously. For an imaging device or a camera, it is measured in bits. Thus, for an 8-bit monochrome camera, there are only $2^8 = 256$ different levels in which intensities of a scene can be represented. Hence, for the acne lesion images, high dynamic range (HDR) is desirable, so that acne lesions can easily be differentiated from the skin.

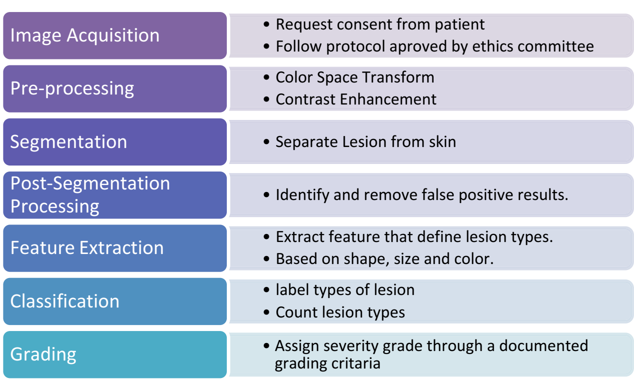

Fig. 1. Proposed methodology framework for automated diagnosis system of acne lesions.

The HDR image can be produced through a set of low dynamic range (LDR) images of the same scene, captured at different exposure settings of the camera. The proposed enhancement method creates the LDR images artificially, i.e., instead of producing multiple LDR images by changing exposure settings of the camera, artificial images are created using local rank transform (LRT) (12). Later on, logarithmic tone mapping is applied to make it displayable on LDR device.

Jayanta et al. (12) has discussed the interesting properties of rank transformation. In their work, pixel intensities are transformed to their local rank for edge extraction and enhancement, so they referred it as LRT. The precise mathematical definitions are discussed in their publication. We have utilized the LRT method to create a number of LDR images artificially. It has been observed that the +ve δ in LRT extracts the edges, whereas −ve δ smooths the areas. The image is first transformed to the YCbCr color space. Cb and Cr components, which contain the color information, remain intact and are combined back after LRT is applied to the Y component. Equation (1) as described in (12) is used to compute the enhanced image I.

$$I = Y + \lambda * \mathrm{LRT}(Y, \delta 1) + \gamma * \mathrm{LRT}(Y, \delta 2) \quad (1)$$

where $\delta I < 0$ and $\delta 2 \geq 0$

λ and γ are used for providing weight age to the smooth details and edge details, respectively. These details are added to the original luminance component Y resulting in an enhanced image I. In the proposed methodology, multiple exposures are created by setting up different values of λ and γ. With the multiple values of λ and γ parameters, smooth/edged details become enhanced at different levels (12). Sum of λ and γ is kept equal to 1 for consistency of edge and smooth details otherwise upper limit of the pixel intensity values will be saturated.

Through these artificial exposures, HDR image is generated from Debevec and Malik (13) method who suggested using response function and radiance map directly from multiple exposure images of the scene. Finally, tone mapping is applied. Tone mapping compresses the wide dynamic range of HDR image into much narrower dynamic range, which is compatible to displayable device. Ward et al.'s (14) approach is used that takes the logarithm of luminance mimicking the behavior of our eyes followed by applying histogram equalization for restoring the saturation and contrast lost by logarithmic luminance compression. Figure 2 illustrates the process of the proposed enhancement methodology. The proposed enhancement methodology steps are summarized as following:

1 The image to be enhanced is first transformed into YCbCr space.
2 The LRT is applied only on Y component, while Cb and Cr remain unchanged.
3 The transformation is applied over Y component using (1). By varying the λ and γ values in Eq. (1), smooth/edged details become enhanced at different levels. In this way, multiple LRT images are created using Y component of the original image.
4 Cb and Cr components are recombined to the LRT-transformed Y components.
5 The local rank-transformed YCbCr images are converted back to the RGB color space, thus creation of artificial exposures is completed.
6 Next, the HDR image is created using these artificial exposures. HDR radiance map is derived using approximation of sensor reciprocity constraint (13).
7 Finally, Ward's approach of contrast limited adaptive histogram equalization (14) is applied on HDR image to make it displayable on LDR device.

Segmentation

In terms of image processing, segmentation is partitioning of image into significant and disjoint fragments. A segmentation algorithm has been developed for acne vulgaris lesion. Instead of applying conventional color spaces, mapping of RGB color pixels to visible electromagnetic spectrum is performed as it provides finer discrimination between shades of red brown and purple. RGB color of the image is approximately mapped to the equivalent visible spectrum from 380 to 720 nm with the steps of 1 nm. Average spectral models for different class of colors are first selected from various images. The algorithm classifies the lesion and non-lesion pixels based on Mahalanobis distance from the spectral models. Candidate pixel is labeled as an entity whose spectral model is least distant.

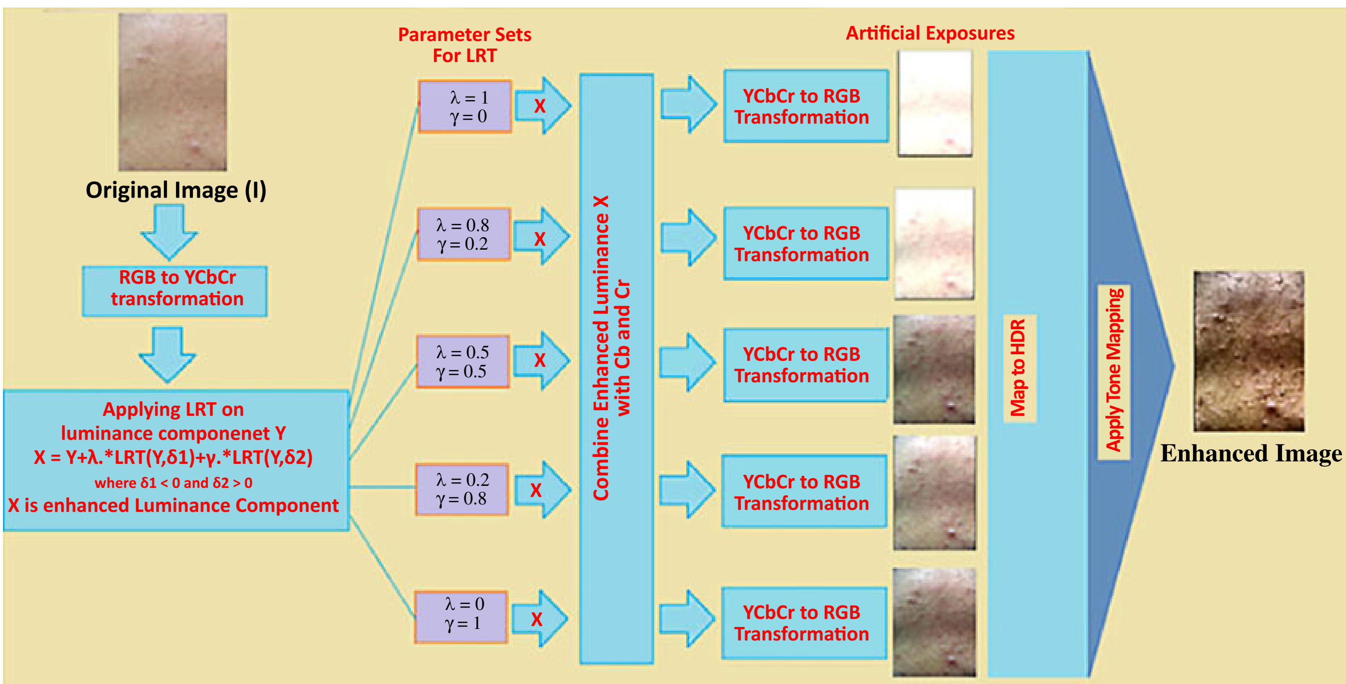

Fig. 2. Proposed contrast enhancement process flow diagram.

The proposed algorithm tends to classify the pixels purely based on spectral curve of its color. An effective technique has been proposed by Smits (15) for RGB to spectrum conversion of reflectance. The process flow diagram of RGB to spectrum conversion is illustrated in Fig. 3.

The pixels are classified into categories of red lesion, purple lesion, brown lesion, scar, and specular reflection. The pixels that belong to first three categories are classified as lesion pixels, whereas others are classified as non-lesion pixels. The segmentation algorithm consists of the following steps.

1 Average spectral model is calculated from the sample spectral models that are manually built through various example lesion images for each of the above-mentioned categories. These models are created only once and saved for reuse. Figure 4 shows the average spectral models for various categories.
2 RGB input image of lesion-affected area is first converted into spectral domain using the process shown in Fig. 3.
3 The spectral curve for each pixel is a test point, which has to be classified into one of the classes, i.e., red lesion, purple lesion, brown lesion, scar, and specular reflection. Then, for each of the given test point, Mahalanobis distance is computed for each class, and classifies the test point as belonging to that class for which the Mahalanobis distance is minimal.
4 Finally, a binary classified/segmented image is obtained in which pixels belonging to first three classes, i.e., (red lesion, purple lesion, and brown lesion) are classified as lesion pixels and the rest as non-lesion pixels.

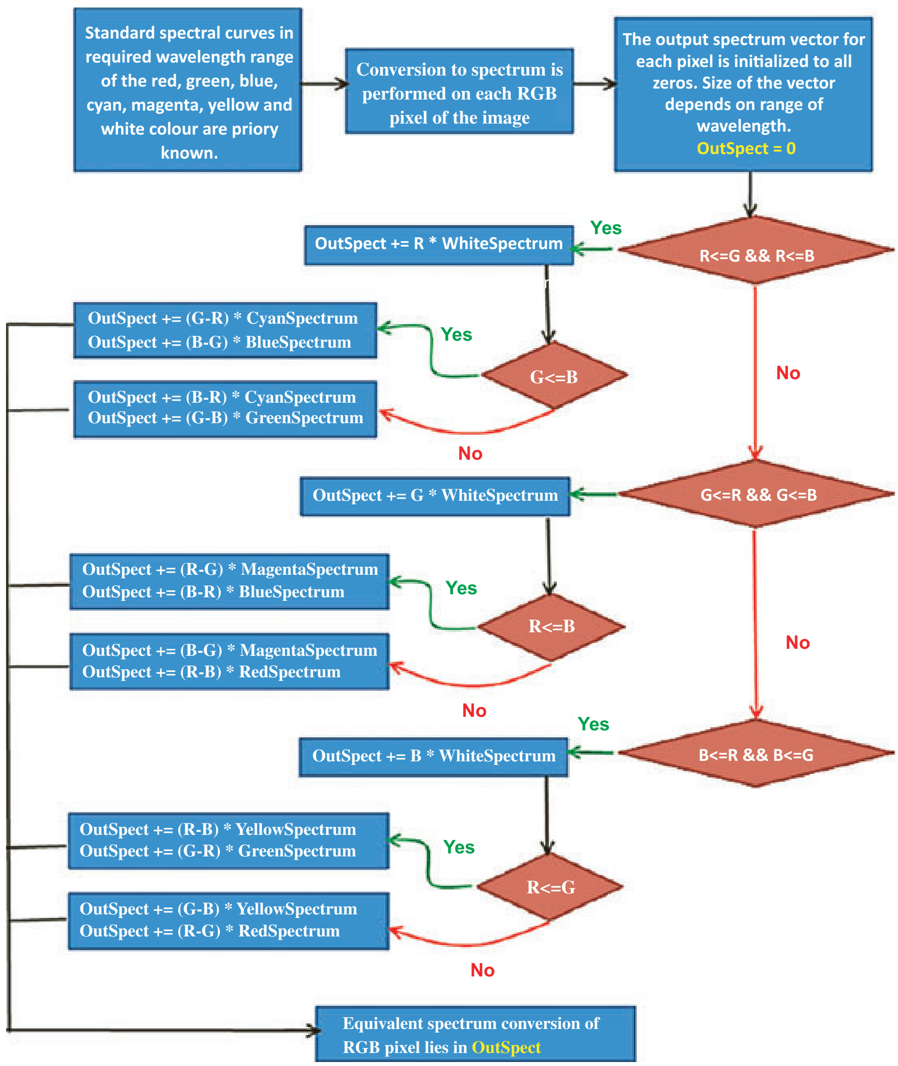

Fig. 3. Diagram of process flow of RGB to spectrum conversion.

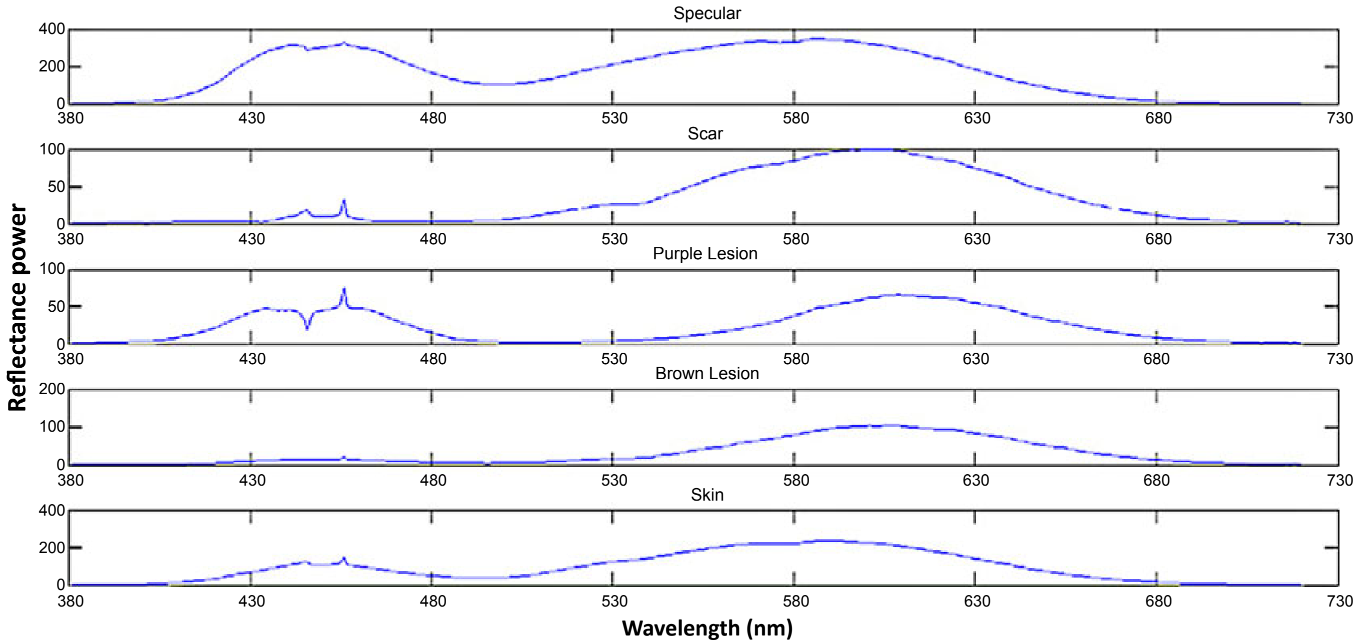

Fig. 4. Average spectral models.

Results and Discussion

Data acquisition

The image dataset from the acne vulgaris patients was collected from the dermatological department at Hospital Kuala Lumpur under supervision of the dermatologist. This center is chosen because it is the major dermatological center in Kuala Lumpur region, and is also the tertiary referral center in Malaysia. Figure 5 shows the image acquisition setup used at the hospital.

Total of 98 patients with acne vulgaris disease were photographed. Table 2 shows the data acquisition details. These severity grades were analyzed by dermatologists according to GAGS grading criteria.

Fig. 5. Image acquisition setup.

TABLE 2. Number of patients with severity conditions in our dataset

Severity condition	No. of patients
Mild	39
Moderate	32
Severe	21
Very severe	6

Measurement metrics

Currently, based on the published literature survey, there is no specific enhancement and segmentation method for acne lesions. Therefore, the proposed methodology for contrast enhancement of acne lesion is compared with decorrelation contrast stretching (16) and Kedir Mohammad et al. (17) contrast enhancement approach. Decorrelation stretch is a technique, which involves the mapping of original color values of the image to a new set of color values with a wider range. Kedir Mohammad et al. (17) method applies SVD on each channel of the input color image and replaces the highest singular values by the Singular Values of high-quality reference image in a weighted manner.

Two objective measures are used to compare the results of image enhancement process, i.e., contrast improvement factor (CIF) and image contrast normalization (ICN). The CIF is the ratio of contrast between object (lesion) and background (non-lesion). Hence, higher CIF value is preferred. ICN incorporates both standard deviation and average contrast. If value of ICN obtained is small enough, meaning that standard deviation is also small, the more homogeneous will be the intensity distribution.

Contrast enhancement

Six qualitative criteria have been identified, which are commonly observed in contrast enhancement visualization. These criteria are presented with their interpretation in Table 3.

For each positive rating provided by the rater, there is an addition of score 1 and each negative score provided by the rater has subtraction of score 1. The Maximum score achievable is 3, i.e., if the enhanced image has all good qualities and no bad quality. The Minimum score achievable is −3, i.e., if the enhanced image has all bad qualities and no good quality. Hence, this is a new proposed qualitative measurement in general and for acne lesion contrast enhancement in particular. Figure 6 shows that proposed method has the highest score.

A more critical analysis of the qualitative criteria provided by raters is given in Fig. 7. It can be seen that the proposed method does not contain any of the negative criteria.

Figure 8 shows the enhancement results, whereas quantitative results are provided in Tables 4 and 5.

As shown in Table 4, the proposed method displays better CIF value than Kedir Mohammad et al. method. Among all techniques, Decorrelation method is quite competitive in showing good CIF value. However, Table 5 shows that decorrelation method has worst results. Lower value of ICN is preferable. The bar plot in Fig. 9 shows ICN values of all the five regions collectively.

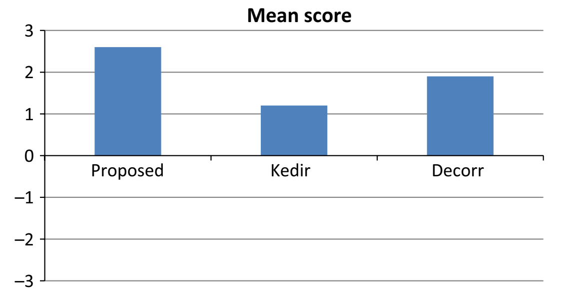

Fig. 6. Mean of qualitative scores assigned by various raters.

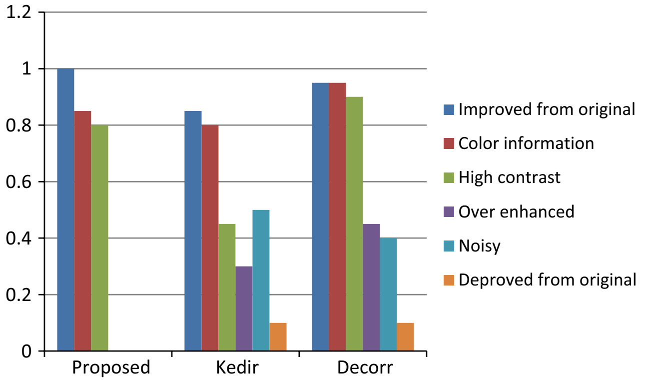

Fig. 7. Normalized results of each qualitative remark for each method.

TABLE 4. Comparison using contrast improvement factor

Region/method	Proposed	Decorrelation	Kedir Mohammad et al.
Left cheek	4.163	4.352	2.589
Right cheek	3.857	7.796	2.385
Chin	1.721	3.129	1.389
Nose	0.894	1.549	0.674
Forehead	3.040	3.238	1.986
All regions	2.735526	4.01326	1.805019

Segmentation

Next, the segmentation is applied over the enhanced image to differentiate the lesion from the skin. The proposed segmentation method is tested quantitatively using specificity and sensitivity/recall. Table 6 shows the average sensitivity and specificity of the algorithm with

TABLE 3. Interpretation of qualitative properties or criteria

Criterion	Interpretation	+ve/−ve
High contrast	Intensity value difference between various objects is obvious and high	+
Color information	Color information is present in the enhanced image. Enhance image is not Gray Scale image	+
Improved from original	As compared with original, details are clearer in enhanced image	+
Over enhanced	Lesion area seems to be extended wider in the enhanced image	−
Noisy	Image appears to be noisy if intensity variation in smooth areas is frequent	−
Worsen from original	As compared with original, details are less clear in enhanced image	−

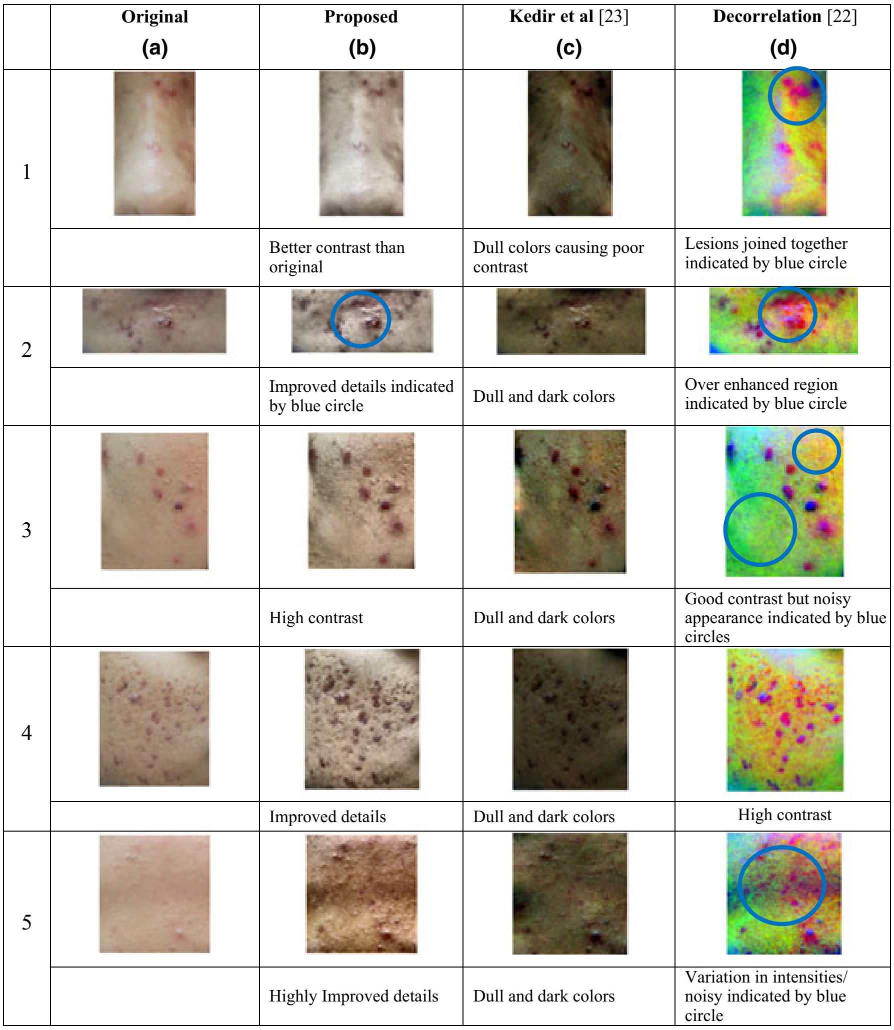

Fig. 8. Qualitative results of contrast enhancement.

TABLE 5. Comparison using image contrast normalization

Region/method	Proposed	Decorrelation	Kedir Mohammad et al.
Left cheek	1.614	1.501	2.363
Right cheek	2.022	3.372	1.913
Chin	1.281	1.750	1.213
Nose	1.285	1.195	1.209
Forehead	1.750	1.392	1.843
All regions	1.977	3.146	2.168

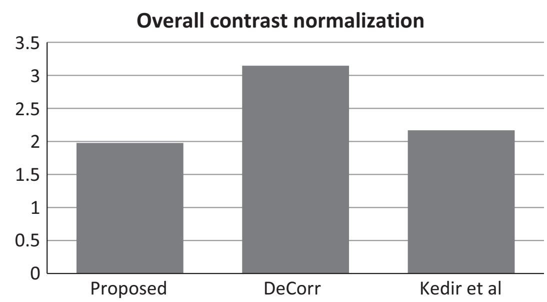

Fig. 9. Overall image contrast normalization.

respect to the severity grade of acne disease. The proposed method shows specificity >80% and has better sensitivity score than other two methods.

Figure 10 shows the segmented images after applying the proposed segmentation method over three enhancement methods.

TABLE 6. The quantitative results of segmentation

Severity	Method	Sensitivity	Specificity
Mild	Proposed	0.62	0.80
	Kedir Mohammad et al.	0.50	0.79
	Décor	0.65	0.79
Moderate	Proposed	0.66	0.83
	Kedir Mohammad et al.	0.51	0.78
	Décor	0.59	0.83
Severe	Proposed	0.72	0.84
	Kedir Mohammad et al.	0.35	0.76
	Décor	0.47	0.82
Very severe	Proposed	0.70	0.85
	Kedir Mohammad et al.	0.40	0.75
	Décor	0.48	0.84

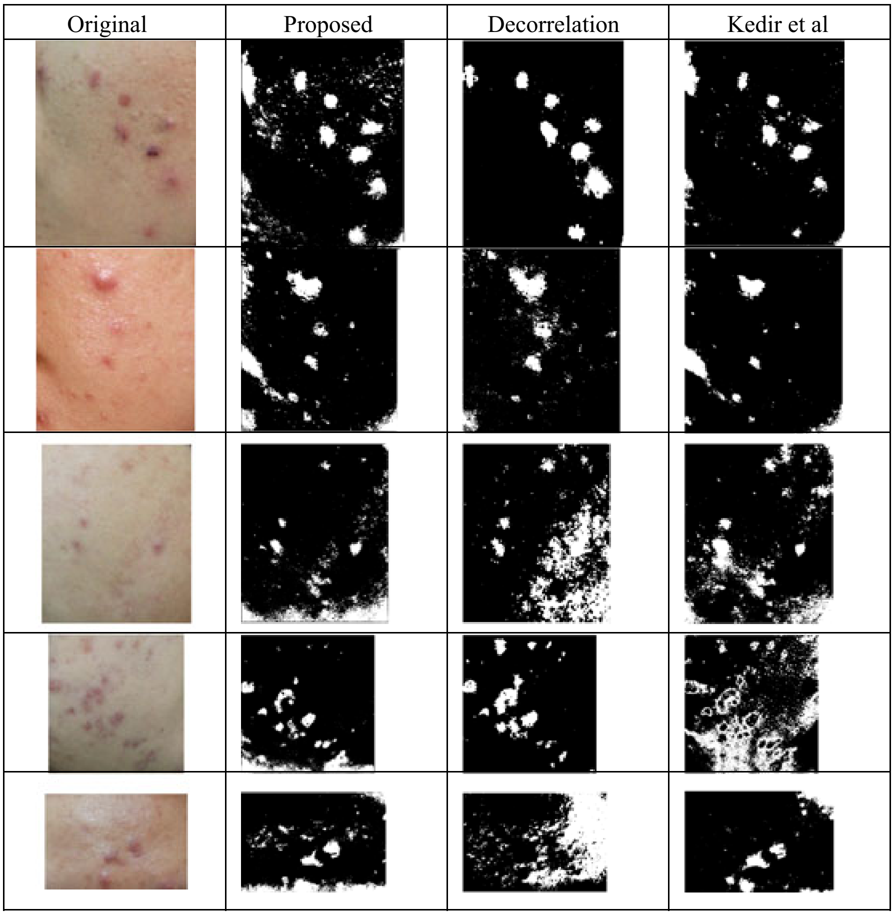

Fig. 10. Qualitative/visual comparison of segmentation results.

Conclusion and Future Recommendations

The work in this article concerns the development of a computerized diagnosis system for identifying severity of acne vulgaris lesions. To the best of our knowledge, this is first attempt to automate the diagnosis of acne vulgaris lesions. Contrast enhancement and segmentation are two of the key and preliminary milestones of such a system. Our main contribution is addressing the contrast enhancement of Digital Single Lens Reflex images of acne vulgaris lesion and its segmentation.

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Address:
A. S. Malik
Associate Professor
Centre for Intelligent Signal & Imaging Research
Department of EE, Universiti Teknologi Petronas (UTP)
Bandar Seri Iskandar, Tronoh, 31750 Perak Malaysia
Tel: +605-368-7853
Fax: +605-365-7443
e-mail: aamir_saeed@petronas.com.my