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UNIVERSITI TEKNOLOGI PETRONAS

DIGITAL ASSESSMENT OF FACIAL ACNE VULGARIS

by

ROSHASLINIE BINTI RAMLI

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DIGITAL ASSESSMENT OF FACIAL ACNE VULGARIS

by

ROSHASLINIE BINTI RAMLI

A Thesis

Submitted to the Postgraduate Studies Programme

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BANDAR SERI ISKANDAR,

PERAK

SEPTEMBER 2013

DECLARATION OF THESIS

Title of thesis	Digital Assessment of Facial Acne Vulgaris

I ROSHASLINIE BINTI RAMLI,

hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTP or other institutions.

Witnessed by

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Signature of Author	Signature of Supervisor
Lot 4795-A, Kg Nibong, Jalan Panji Alam, 21100, Kuala Terengganu, Terengganu	Assoc. Prof. Dr. Aamir Saeed Malik
Date : _____	Date : _____

DEDICATION

In memory of my father

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Last but not least, this dissertation is dedicated to my late father who has been my constant source of inspiration.

ABSTRACT

Acne is chronic disorder of the pilosebaceous units with excess sebum production, follicular epidermal hyperproliferation, inflammation and Propionibacterium acnes (P acnes) activity. Dermatologists use manual methods such as direct visual assessment and ordinary flash photography to assess the acne. However, these manual methods are very time consuming and may result in intra-observer and inter-observer variations, even by experienced dermatologists. To address these issues, there have been a number of research conducted using computational imaging methods for aiding in the acne diagnosis but they fail while solving more complex classification problems, cannot be used for real-time analysis, are semi-automated methods and they lack flexibility. The objective of this research is to develop a computational imaging method for automated acne grading. The first step is pre-processing which involves lighting compensation and skin detection in which the skin is separated from non-skin regions. Then, we have developed a clustering method that automatically selects the suitable number of clusters (K-value) and identifies acne clusters in the image. For each K-value, the cluster that has the minimum area is selected; this is because acne has very small area compared to skin. Finally, the true acne image is selected from these minimal area clusters using a Support Vector Machine (SVM) classifier which is build using colour and texture properties of acne and skin. Colour and diameter are the main features extracted to classify acne blobs into different acne classes; papule, pustule, nodule or cyst. A modified Global Acne Grading System (mGAGS) table is developed using Graphical User Interface (GUI) and used to determine the severity level of the facial acne such as mild, moderate, severe and very severe. The Kappa agreement test is used in order to evaluate the agreement of severity scores between proposed method and dermatologist. As a result, the Kappa value for Acne grading is evaluated and indicated as almost perfect agreement with 0.82. Hence, the severity level results from the proposed method can be used as an indicator for dermatologist to give the medication for treating the acne lesions.

ABSTRAK

Jerawat adalah gangguan kronik yang berlaku pada pilosebaceous bahagian kulit dengan pengeluaran sebum yang berlebihan, pembiakan folikel epidermis yang berlebihan, keradangan, dan aktiviti bakteria Propionibacterium (P jerawat). Dermatologi menggunakan kaedah manual seperti penilaian visual secara langsung dan fotografi cahaya yang biasa untuk menilai jerawat. Walau bagaimanapun, kaedah-kaedah manual adalah sangat memakan masa dan boleh mengakibatkan perbezaan keputusan antara dermatologi itu sendiri dan dermatologi dengan dermatologi yang lain, walaupun oleh dermatologi yang berpengalaman. Untuk menangani isu ini, beberapa penyelidikan telah dijalankan dengan menggunakan kaedah pengimejan komputasi untuk membantu dalam diagnosis jerawat tetapi tidak berjaya menyelesaikan masalah klasifikasi yang lebih kompleks, tidak boleh digunakan untuk analisis masa nyata, separa automatik dan sistem kekurangan fleksibiliti. Objektif kajian ini adalah untuk membangunkan satu kaedah pengimejan komputasi bagi penggredan jerawat secara automatik. Langkah pertama dalam pra-pemprosesan adalah melibatkan pampasan lampu dan pengesanan kulit di mana kulit dipisahkan dari kawasan-kawasan bukan kulit. Kemudian, kami membangunkan satu kaedah kelompok yang memilih nombor kelompok (nilai K) yang sesuai secara automatik dan mengenal pasti kelompok jerawat dalam imej. Untuk setiap nilai K, kelompok yang mempunyai keluasan minimum dipilih, ini adalah kerana jerawat mempunyai kawasan yang lebih kecil berbanding dengan kulit. Akhirnya, imej jerawat yang betul dipilih daripada kelompok kawasan minimum dengan menggunakan pengelas mesin sokongan vector yang dibina menggunakan sifat-sifat warna dan tekstur jerawat dan kulit. Warna dan diameter adalah ciri-ciri utama yang diekstrak untuk mengklasifikasikan gumpalan jerawat ke dalam kelas jerawat yang berbeza; papule, pustul, nodul atau sista. Jadual Sistem Penggredan Jerawat Global yang diubahsuai dibangunkan menggunakan Antara muka Pengguna Grafik dan digunakan untuk menentukan tahap keterukan jerawat muka seperti ringan, sederhana, teruk dan sangat teruk. Ujian persetujuan Kappa digunakan untuk menilai persetujuan skor keterukan

antara kaedah yang dicadangkan dengan dermatologi. Hasilnya, nilai Kappa bagi penggredan jerawat dinilai dan menunjukkan persetujuan yang hampir sempurna dengan 0.82. Oleh itu, keputusan tahap keterukan daripada kaedah yang dicadangkan boleh digunakan sebagai penunjuk untuk dermatologi dalam memberikan ubat untuk merawat luka-luka jerawat.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
Cb	Chroma Blue
Cr	Chroma Red
CAD	Computer-Aided Diagnosis
CMYK	Cyan Magenta Yellow Black
DSLR	Digital Single Lens Reflector
FP	False Positive
FN	False Negative
GAGS	Global Acne Grading System
HSV	Hue Saturation Value
LDF	Linear Discriminant Functions
MATLAB	Matrix Laboratory
mGAGS	modified Global Acne Grading System
MOH	Ministry of Health Malaysia
MSI	Multispectral Image
NMRR	National Medical Research Register
PDT	Photodynamic therapy
LHE	Pulsed light and heat energy
ROI	Region of Interest
RGB	Red Green Blue
SVM	Support Vector Machine
TP	True Positive
TN	True Negative

CHAPTER 1
INTRODUCTION

1.1 Background of the study

1.1.1 Digital imaging in dermatological diagnosis

Digital imaging is a versatile technique that has been frequently used in dermatology to record and process visual images. Nowadays, it has increasingly become a powerful tool in transforming the field of dermatology by providing better diagnostic tools for dermatologists. Digital imaging is designed to emulate the capability of human vision. Human and computer vision appear to have the same function. A computer vision system processes images acquired from an electronic camera, which is just-like the human vision system where the brain processes images derived from the eyes. As a result, digital imaging is a sophisticated system that senses and acts on visual stimuli to perform various tasks such as image acquisition, manipulation, analysis, storage and display.

Studies on quantitative analysis of medical images by computer have been reported since the 1960s. Since then, computer-aided diagnosis (CAD) has become one of the major research subjects in medical imaging and diagnostic radiology [1]. Dermatology is one of the medical fields that has benefited from digital imaging as it is the branch of medicine which deals with the skin and its diseases.

Generally, dermatologists assess the skin visually. Therefore, the assessment is subjective. However, the human visual system may not have the accuracy and consistency in analyzing an object. In fact, inter and intra-observer variability occurs during assessment. To overcome these problems, computer-aided diagnosis which is digital assessment were recognized and used. Digital assessment means the assessment is involving or relating to the use of computer technology.

The first step in digital imaging system is image acquisition. Images can be captured either by analog camera or by digital camera. The most famous and useful digital camera is digital single lens reflector (DSLR). Image sensor of DSLR camera is physically larger than that in digital compact camera, thus producing better quality image [2]. Moreover, images are captured in digital format, which is very convenient for storage and further processing in computer. After the image has been obtained, various methods of processing can be applied to the image to perform the many different vision tasks required today.

1.1.2 Acne Vulgaris

Acne is a common skin disease that affects 85% of adolescents at some time during their lives [3]. Acne affects the areas of skin with densest population of sebaceous follicles which are the face area, the upper part of the chest area and the back area [4]. The prevalence and severity of acne on the face, chest and back areas is reported to be 92%, 45% and 61% respectively [5].

There are several common types of acne such as Acne Vulgaris, Acne Conglobata, Acne Excoriee, Acne Rosacea, Acne Cosmetica, Pomade Acne, Acne Fulminans, Acne Keloidalis Nuchae, Acne Chloracne, Acne Mechanica and Acne Medicamentosa [4]. Acne type is differentiated mainly based on lesion type as well as the underlying cause. For example, Acne Cosmetica is caused by cosmetics use, Mechanica in people who like to lean their face on the hands or pressure areas from helmets, Medicamentosa due to topical medicine applied on the skin, pomade acne due to use of talcum powder [6].

The commonest form of acne is Acne Vulgaris, with 99% sufferers being afflicted with it. Therefore in this thesis, the main point is on Acne Vulgaris only. Acne Vulgaris is defined as common type of acne and comprise of comedones (whitehead and blackhead), papules, pustules, nodules, cysts as shown in Figure 1.1 and in some cases, scarring [7].

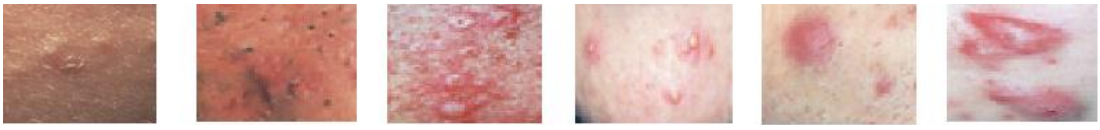


Figure 1.1 Types of Acne Vulgaris Lesions

1.1.3 Modified Global Acne Grading System (mGAGS)

Currently, there are more than 25 different grading systems for assessment of acne severity. However, in Malaysia, GAGS and mGAGS are being used extensively by dermatologist. Global acne grading system (GAGS) was introduced by Doshi *et al* in 1997 [8]. This grading system divides the face, chest, and back into six locations (forehead, right cheek, left cheek, nose, chin, chest and upper back). However, Lawrence *et al* [9] modified this grading system by removing nonfacial areas (chest and upper back) and name it as the modified Global Acne Grading System (mGAGS). The mGAGS score is calculated by multiplying lesion severity grades (0 = no lesions, 1 = comedones, 2 = papules, 3 = pustules and 4 = nodules) by assigned factors of 1 or 2 based on surface area, distribution and density of pilosebaceous units to obtain local scores for each location. These local scores are added to obtain the global score, which corresponds to a global acne grade (0 = none, 1-13 = mild, 14-22 = moderate, 23-28 = severe and >29 = very severe).

1.2 Problem Formulation and Statement

Manual methods such as direct visual assessment and ordinary flash photography are used by dermatologists to assess the acne as shown in Figure 1.2. These methods are very time consuming and tedious. Generally, they rely on approximation for counting lesions and hence the assessment is quite subjective measure that varies from one dermatologist to another (inter-rater variability) as well as it may vary for the same dermatologist at different times for the same patient (intra-rater variability). Inaccurate assessment of the acne's severity status leads to improper clinical decisions regarding treatment and may prolong the healing duration for the acne condition. Therefore, a digital assessment method to achieve more consistent result for diagnosing the grade of acne needs to be developed that will also help in improving treatment efficacy.

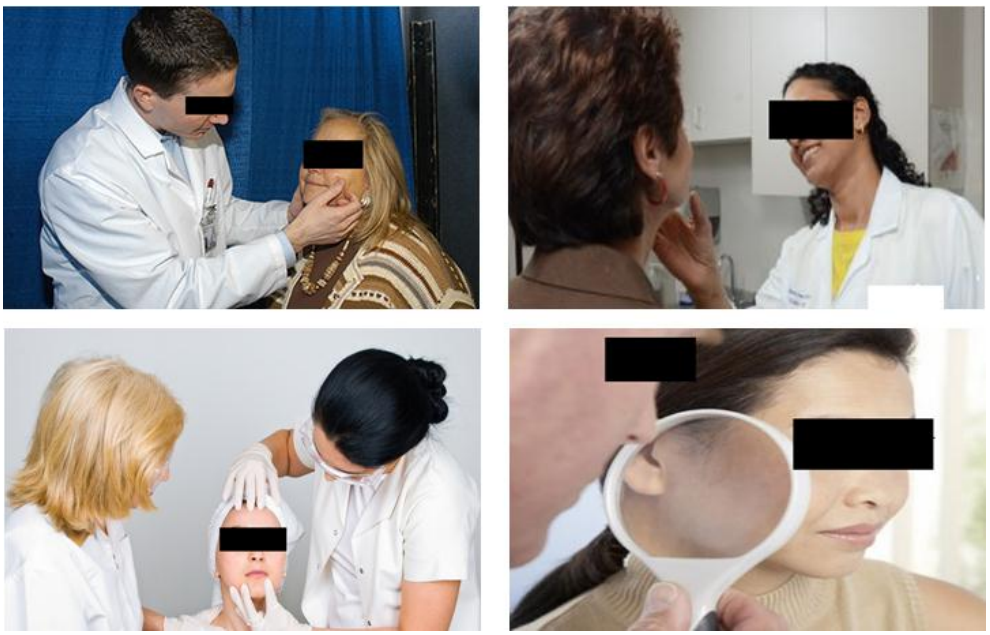


Figure 1.2 Example of direct visual assessment by dermatologists

To address these issues, there have been a number of research conducted using computational imaging methods for aiding in the acne diagnosis but they fail while solving more complex classification problems, cannot be used for real-time analysis, are semi-automated methods and they lack flexibility. From the literature search using Google Scholar, Scopus and ISI databases, it has been found that there has been no research work reported for automatic acne grading. This research work is the first attempt in this direction.

Moreover, acne lesion can appear in a wide variety of colour and size. For colour, it is affected by patient's original skin colour while for size, it is affected by degree of severity. The skin colour is related to the level of pigmentation. Higher level of pigmentation is indicated by dark skin colour whereas lower level of pigmentation is indicated by fair skin colour. The typical appearances of acne lesion on patients with low pigmentation are reddish for papule, pustule, nodule and cyst. On patients with medium pigmentation, the lesion (papule, pustule, nodule and cyst) appears less red than on patients with low pigmentation whereas on those with high pigmentation, the lesion (papule, pustule, nodule and cyst) appears dark.

Furthermore, size for papule and pustule are less than 5 mm whereas nodule and cyst are more than 5 mm. This variation in size is difficult to distinguish if the lesion is in between 4 to 6 mm. The difference in sizes indicates the different types of acne lesions which gives different severity level.

Hence, manual assessment which is visual assessment may not be accurate in determining the colour due to varying illumination inside the room or eye problem. Besides, visual assessment also cannot verify the size of lesion itself unless there is indicator like ruler sticker. Thus, objective and accurate assessment of acne lesions is important in determining treatment efficacy. Hence, this research aims to develop consistent digital assessment method for acne lesions by using Matrix Laboratory (MATLAB). MATLAB is a numerical computing environment and fourth-generation programming language. Image processing in computing environment such as MATLAB is widely employed to characterize various features like colour, texture, shape and motion. In this research, we utilize and develop methods related to colour, texture and shape features to classify various types of acne lesions based on their colour properties, texture properties and the regular/ irregular shape characteristics.

1.3 Research Objective

The objective of this research is to develop imaging techniques for a computer vision system for classifying acne grades based on modified Global Acne Grading System (mGAGS). The system will aid dermatologists in the diagnosis of acne grade as well as help in monitoring the treatment. The quality of assessment given to acne patients is expected to improve significantly using such system. To achieve this main objective, the following specific objectives were taken into account:

(i) Develop an automated modified K-means clustering method to separate skin and lesion.
(ii) Develop a classifier to distinguish type of acne lesion using colour and size properties.
(iii) Develop an automated acne grading system based on mGAGS.

1.4 Scope of Work

This work will concentrate on modifying the existing K-means clustering in order to cluster the skin, scar and lesion for acne vulgaris cases. Feature extraction using colour and size will be investigated to distinguish the types of acne vulgaris. The score for different types of acne will be determined automatically. The system will be validated and compared with dermatologists' manual assessment.

Modified Global Acne Grading System (mGAGS), which consists of facial part only will be used instead of Global Acne Grading System (GAGS) due to limitations in obtaining data of chest and back since the data collection is from volunteer patients in Hospital Kuala Lumpur in which only the images of the faces areas are made available.

1.5 An Overview of Thesis Structure

This thesis is organized in five chapters including this introduction. In Chapter 2, the medical review of acne is introduced. It covers explanation of acne types, acne vulgaris lesions types, causes, treatments and assessments. Global Acne Grading System (GAGS) as standard method for dermatologist in assessing severity of acne is also discussed in this chapter. Finally, related works on assessing acne lesions are reviewed.

The approaches in solving the problem are discussed in Chapter 3. Chapter starts with explanation of instruments for data acquisition that is DSLR camera. Then, CIELAB colour space is used. Furthermore, image processing techniques and data clustering method such as automated modified K-means clustering, SVM classifier and feature extraction using colour and size are introduced in this chapter.

The methods are applied on the datasets and the results are discussed in Chapter 4. The results using the proposed methods are compared with the dermatologists' manual assessment. The sensitivity and specificity are computed. Chapter 5 gives the conclusion of the work, summarizes the achievements and contribution of this thesis and recommendations for future work.

CHAPTER 2
LITERATURE REVIEW

In this chapter, medical backgrounds of Acne are described, covering the type of Acne, its causes, symptoms, grading systems, and treatments. The gold standard for dermatologist in assessing the severity of acne, namely Global Acne Grading System (GAGS) will be discussed in this chapter. However, since we just focused on facial, we used modified Global Acne Grading System (mGAGS). The related works in determining mGAGS objectively are reviewed at the end of this chapter. This chapter also consists of approaches, basic theory and techniques that are used in this thesis. The equipment's set-up, data acquisition process, colour spaces and image segmentation technique are described in this chapter. Pattern classification as a way in categorizing data is described in the end of this chapter.

2.1 Acne

When hair follicles called skin pores inside the human skin become blocked, acne will occur, clinically. Sebaceous glands located around hair follicles produce an oily substance called sebum which normally drained to the surface through the hair follicles, trapped within the skin pore when the hair follicles become blocked. From that, bacteria known as Propionibacterium acnes [10] eventually attack the sebum thereby producing skin inflammation and acne. Figure 2.1 below shows the schematic view of hair follicle & sebaceous gland.

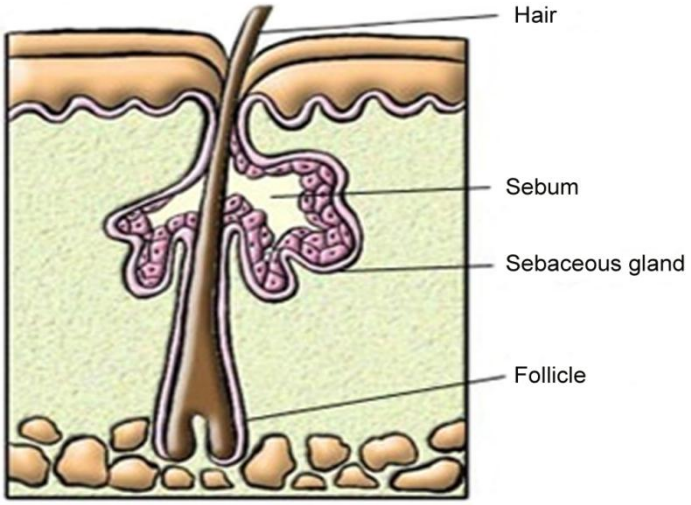


Figure 2.1 Schematic view of hair follicle & sebaceous gland

Acne is a common skin disease that affects 85% of adolescents [3] at some time during their lives. Acne affects the areas of skin with densest population of sebaceous follicles which is face, the upper part of the chest and the back [4]. The prevalence and severity of acne on the face, chest and back was shown to be 92%, 45% and 61% respectively [5]. Every year, the total cost is estimated to exceed US$1 billion for acne treatment [11].

2.1.1 Types of Acne

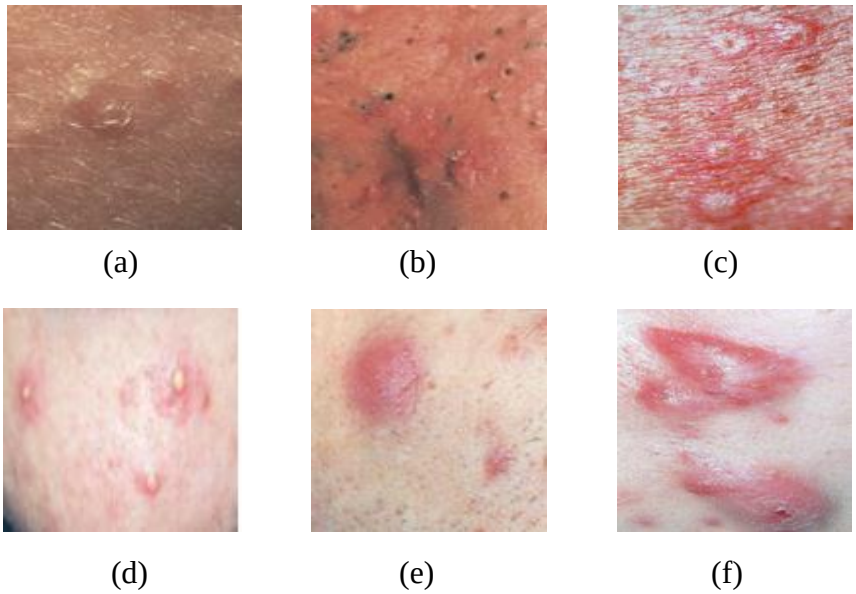
Generally, acne has various types such as Acne Conglobata, Acne Excoriee, Acne Rosacea, Acne Cosmetica, Pomade Acne, Acne Fulminans, Acne Keloidalis Nuchae, Acne Chloracne, Acne Mechanica and Acne Medicamentosa [4]. But acne vulgaris is common acne prevalent in 99% of the acne cases and it is differentiated mainly based on lesion type as well as the underlying cause., e.g., acne cosmetica is caused by cosmetics use, mechanica in people who like to lean their face on the hands or pressure areas from helmets etc, medicamentosa due to topical medicine applied on the skin, pomade acne due to use of talcum powder. In this research, we focus on acne vulgaris only. The lesions seen in acne vulgaris are comedones, papules, pustules, nodules, cysts and in some cases, scarring [7].

2.1.2 Types of Acne Vulgaris lesions

Acne vulgaris is characterized by non-inflammatory and inflammatory. The non-inflammatory is open and closed comedones the inflammatory is papules, pustules and nodules. A closed comedo is a whitehead and an open comedo is a blackhead. A whitehead is an acne lesion that forms when oil and skin cells block the opening of hair follicle. This usually appears on the skin as small, whitish bumps and under the surface of the skin. The chronic whitehead is called as milia and it is tiny white bump that occurs when normally sloughed skin cells get trapped in small pockets on the surface of the skin. They are common across the nose and upper cheeks (Fig 2.2a). A blackhead is non-inflammatory acne lesion that is filled with excess oil and dead skin cells. Blackhead is called open comedo because the surface of the skin remains open with dark appearance such as black and brown colour (Fig 2.2b).

Swelling, heat, redness and pain occur as a reaction of tissue to disease and these symptoms are classified as inflammation. It is caused by chemical irritation from sebum mechanism for instance fatty free acids. Papules become visible on the skin as a small and firm pink bump (Fig 2.2c). Frequently, papules are considered an intermediary step between non-inflammatory and inflammatory, but obviously papules are inflammatory lesions. Pustules are full of visible pus which emerges red at the base with a yellowish or whitish center with small round lesions that are inflamed (Fig 2.2d). Pustules do not contain a large amount of bacteria. Papules and pustules comprise about 90% of total cases.

Nodule is similar to a papule, but is greater than either 5 or 10mm in both width and depth, and most frequently centered in the skin (Fig 2.2e). Cysts are large pus-filled lesions that are usually present deep within the skin. The cysts are very painful lesions, as they are inflammatory (Fig 2.2f). Cysts form as a result of the contents of a comedo spilling over the surrounding skin and due to the response of the local immune system in producing pus. The cysts often leave deep scars. Generally patients are mix of non-inflammatory and inflammatory acne. Table 2.1 provides the details of all the above mentioned lesions.



(a) (b) (c)

(d) (e) (f)

Figure 2.2 Types of Acne Vulgaris lesions

(a) Whitehead (b) Blackhead (c) Papule (d) Pustule (e) Nodule (f) Cyst

Table 2.1 Details of Acne Lesions

Acne Lesion	**Size**	**Colour**	**Pus**	**Effect**	**Comments**
Whitehead	Tiny	Whitish	No	No pain, non-inflammatory	Chronic whitehead is called milia
Blackhead	Tiny	Black or brown	No	No pain, non-inflammatory	Not dirt but black due to excess oil and dead cells
Papule	Less than 5mm in diameter	Pink	No	Warm and painful, inflammatory	Very common
Pustule	Less than 5mm in diameter	Red at the base with a yellowish or whitish center	Yes	Warm and painful, inflammatory	Very common
Nodule	5 to 10mm in diameter	Pink and red	No	Warm and painful, inflammatory	Nodule is similar to papule but is less common
Cysts	More than 5mm	Red	No but has liquid inside	Warm and painful, inflammatory	Least common

2.1.3 Causes of Acne

There are various causes for acne including genetic, hormonal, sebaceous activity, bacteria, climate, chemical and psychological. Generally, acne is due to more than one factor but the dominant factor is genetics. If both parents had acne, three out of four children will have acne. If one parent had acne, then one out of four children will have acne. However, similar to other genetic conditions, not every family will have the same pattern, with acne vulgaris sometimes skipping generations.

Hormonal activity such as menstrual cycles and puberty is one of the causes for acne. During puberty, the increase in male sex hormones called androgens cause the sebaceous gland which is located around hair follicle, to grow larger and make more sebum. While it is typically thought of as a male hormone, it is present in both men and women. Sebaceous gland is affected when their activity become hyperactive compared to normal activity. *Propionibacterium acnes* or sometimes called as *P acnes* will attack the sebum which is trapped under the skin surface when the hair follicles become blocked.

In hot climate, sebaceous gland produces more oily substance called sebum which may cause acne. Chemical factors like facial wash and exposure to certain chemical compounds, particularly linked to toxic exposure to dioxin, may also cause acne. Stress is a psychological factor that makes sebaceous gland hyperactive and may cause acne.

2.2 Acne Assessment

There are more than 25 different grading systems to assess acne severity published in literature. Lehmann et al [12] has surveyed at least 25 scales for assessing the global severity of acne. However, the existence of so many grading systems indicates a lack of consensus on this issue. Hence, no grading system is considered to be a global standard. Generally, all the grading systems stress different emphasis on counting acne lesion and for the comparison of the patients to a photographic standard. Grading system aims to address simplicity, accuracy and quick assessment.

For the method of acne lesion counting, the number of open and closed comedones, papules, pustules and nodules are counted. For photographic method, the

patient photos are compared with photographic standard. Carmen Thomas of Philadelphia was the first person who used a scoring system for acne vulgaris. Starting in the 1930s, she used lesion counting in her office notes [13]. However, the first grading system was introduced by Pillsbury et al in 1956 [14]. It is based on overall estimate of the type of lesion, the number of lesions and the predominant lesion.

Table 2.2 provides the grading introduced in [14]. If patients have comedones which are blackhead and blackhead joining with very rare small cysts in their face, they are classified as Grade 1. Grade 2 is for patients that have comedones and very rare pustules and small cysts restricted to their face. For patients that have many comedones with small or large papules and pustules spread out but still restricted to the face are labelled as Grade 3. Grade 4 means patients have many comedones combined with deep lesions on the face and the upper trunk.

Table 2.2 First Grading System [14]

Grade	**Description**
Grade 1	Comedones and occasional small cysts confined to the face
Grade 2	Comedones with occasional pustules and small cysts confined to the face
Grade 3	Many comedones and small and large inflammatory papules and pustules, more extensive but confined to the face
Grade 4	Many comedones and deep lesions tending to coalesce and canalize, and involving the face and the upper aspects of the trunk

In 1958, James and Tisserand presented an alternative grading scheme in their review of acne therapy [15]. Table 2.3 provides the grading system presented by them. Grade 1 is selected if there are blackheads, whiteheads and few papules dominant at the effected skin area as described in Table 3. Then Grade 2 is identified if there are blackheads, whiteheads, papules and few pustules prevalent on patients' skin. Grade 3 is defined with a lot of papules, pustules and a few cysts at face, neck and upper portions of the trunk. Grade 4 is when the condition becomes more severe with cysts getting worse.

Table 2.3 Grading system by James and Tisserand

Grade	**Description**
Grade 1	Simple non-inflammatory acne- comedones and a few papules
Grade 2	Comedones, pastules and a few pustules
Grade 3	Larger inflammatory papules, pustules and a few cysts; a more severe form involving the face, neck and upper portions of the trunk
Grade 4	More severe, with cysts becoming confluent

In 1966, Witkowski and Simons prompted lesion counts for assessing the severity of acne vulgaris [15]. They recorded the number of closed comedones, open comedones, papules, pustules, and nodules. Papules and pustules were divided into small and large lesions. Nodules or cysts were termed as abscesses. Their method was that lesions were counted on one side of the face as a time-saving measure and this has been their underlying concept. Then, once they were recognized, the number of lesions on the left side was assumed nearly equal to those on the right side. This concept was extended with the acne flow form and the acne questionnaire [15].

The acne flow is for keeping good records on acne patients and each dermatologist can easily produce his own form in which it provides accurate method of entering and retrieving information and evaluating progress. A printed questionnaire can be used in order to find out the reasons of acne flares or failures in response,. This method is more accepted by patients and improves result efficiency.

In 1971, Frank created a numerical grading of each type of lesion on the face, chest, and back [15]. He proposed grading from either 0 to 4 based on severity and provided a table for recording the results (Table 2.4). The number of lesion based on types of lesion was counted. Then, he used the James and Tisserand method of grading to give grading which is shown in Table 2.3.

Table 2.4 The Frank numerical grading table

Types of lesion	**Numbers of lesion**
Comedones	e.g: 10
Papules	e.g: 7
Pustules	e.g: 5
Cicat	e.g: 2

In 1975, Plewig and Kligman, in their textbook, introduced numerical grading [9]. They calculated separately the comedonal acne and papulopustular acne and overall severity were graded with grade 1 to grade 4 depending on number of lesion (Table 2.5). The term comedonal acne is used to describe a form of non-inflammatory acne which consists of whiteheads and blackheads. The papulopustular acne is inflammatory acne which contains both papules and pustules.

Patient who has fewer than 10 whiteheads and blackheads per half face has Grade 1 for comedonal acne, while Grade 1 for papulopustular shows patient has fewer than 10 papules and pustules per half face. For Grade 2 comedonal acne, patient has between 10 and 25 whiteheads and blackheads per half face, while Grade 2 for papulopustular means patient has between 10 and 20 papules and pustules per half face. Grade 3 for comedonal acne indicates that patient has between 25 and 50 whiteheads and blackheads per half face, and Grade 3 for papulopustular shows that patient has between 20 and 30 papules and pustules per half face. Grade 4 for comedonal acne means that patient has more than 50 whiteheads and blackheads per half face, while Grade 4 for papulopustular indicates patient has more than 30 papules and pustules per half face. This grading is shown in Table 2.5.

Table 2.5 Classification of acne severity on lesion counting of comedonal and papulopustular per half face

Grade	**Comedonal**	**Papulopustular**
1	Fewer than 10 comedones	Fewer than 10 inflammatory lesions
2	Between 10 and 25 comedones	Between 10 and 20 inflammatory lesions
3	Between 25 and 50 comedones	Between 20 and 30 inflammatory lesions
4	More than 50 comedones	More than 30 inflammatory lesions

In 1977, Christiansen et al counted the total number of comedones, papules, and pustules on the face instead of counting on half face [15]. The area containing the most lesions was used as the test area. Lesions within a cardboard ring having an inner diameter of 5 cm were counted. For each visit, overall evaluation was made using a six-point scale which is shown in Table 2.6.

Table 2.6 Scale of acne severity based on percentage of reduction

Scale	**Percentage of reduction**	**Level**
4	100% reduction	Excellent
3	75–99% reduction	Good
2	50 –74% reduction	Moderate
1	1– 49% reduction	Insufficient
0		Unchanged
-1		Worse

Scale 4 means the total number of patient's lesion was 100% reduced compared to last visit. It is classified as excellent. Then scale 3 indicates that the total number of patient's lesion was reduced by 75% - 99% compared to last visit. It is classified as good. Scale 2 shows that the total number of patient's lesion was reduced by 50% - 74% compared to last visit. It is classified as moderate which means that the improvement due to the treatment is more than 50% compared to the last visit. Scale 1 means that the total number of patient's lesion was reduced by 1% - 49% compared to last visit. The treatment is not very effective as it is classified as insufficient which means that the patients' recovery is less than 50%. When patients do not have any reduction in term of total number of lesions since the last visit, they are in scale 0 and classified as unchanged. However, when the total number of lesion increased compared to last visit, they are in scale -1 and classified as worse. It indicates that the treatment is not effective and needs to be changed.

In 1977, Michaelson et al counted the number of lesions on the face, chest and back [13]. Each type of lesion was assigned a severity index (Table 2.7). The severity index is given based on types of lesion. The severity index is increasing based on most severe of the types of lesion. For example, severity index of comedones which consists of blackhead is 0.5 compared to papules that have severity index 1.0. It is because papules are more severe than comedones. Same goes to pustule, infiltrates and cysts. Infiltrates is an abnormal substance that accumulates gradually in cells such as nodules.

Table 2.7 Severity Index based on types of lesion

Severity Index	**Types of lesion**
0.5	Comedones
1.0	Papules
2.0	Pustules
3.0	Infiltrates
4.0	Cysts

By multiplying the number of each types of lesion by its severity index and adding each product, these authors obtained a total score that represented the severity of the disease for each visit. For example, the patient has 5 comedones and 8 papules. The number of each type of lesion is multiplied with its severity index, i.e., 0.5 comedones are multiplied with 0.5 severity index and 8 papules are multiplied with 1.0 severity index. After multiplying, each product was added to get the total score. In the above example, the total score is 10.5. The total score will be calculated on every visit and compared with earlier scores to check whether the score is increasing or decreasing. If the total score is decreasing, it means the number of lesion is reduced. But if the total score is increasing, it means the number of lesions is rising and hence the treatment should be changed.

Cook et al (1979) created such a method which evaluated acne's severity on a zero to eight scale anchored to photographic standard that illustrate grades 0, 2, 4, 6 and 8 [16]. They devised a system for photographing both sides of patient's face on a single exposure using a front-surface mirror. Then, independent examiners graded the photographs at the end of the study according to Table 2.8. This method was supposed to be used in larger clinical trials, although the authors recommended lesion counting in pilot studies.

Patients with comedones and small papules in their face are given Grade 0 and Grade 2 is for patients with few pustules or 36 papules and comedones which are only visible from 2.5m away. Grade 4 is classified if there are red lesions such as papules, pustules and they are inflamed. Grade 6 shows patients' face is easily recognized with comedones and pustules at 2.5 m, while Grade 8 is for cysts that cover most of the face.

Table 2.8 Acne grading method by Cook *et.al* using photographic standards [16]

Grade	**Description**
0	Up to small scattered comedones and/or small papules are allowed
2	Very few pustules or 3 dozen papules and/or comedones; lesion are hardly visible from 2.5 m away
4	There are red lesions and inflammation to a significant degree; worthy of treatment
6	Loaded with comedones, numerous pustules; lesions are easily recognized at 2.5 m
8	Conglobata, sinus or cystic type acne; covering most of the face

In 1980, Wilson enhanced the system devised by Cook in 1976 and it was perfected at the 1978 American Academy of Dermatology meeting by inviting about 800 dermatologists to try his method [15].

In 1984, Burke et al presented the Leeds technique, which described two scoring systems. The first is an overall assessment of acne severity for use in routine clinic and second a counting system for detailed work in therapeutic trials. A scale of 0 (no acne) to 10 (the most severe) was used for grading [15].

In 1985, Samuelson graded patients based on a set of nine reference photographs and determined the response to therapy in two steps. First, he asked the patients to compare their present appearance with the nine-grade scale. Second, he required the physician to record observations of comparison of the status with the nine-grade scale [15].

For example, in step 1, doctors asked their patients to compare their present appearance with nine-grade scale. Then let's say patients said that their present appearance is the same with grade 5 in reference photograph. So in step 2, the physician recorded the observations of comparison of the status with the nine-grade scale. Then for next appointment, they did the same thing. The degree of change is classified as excellent if the grade is decreased 3 or more. For example, on first appointment patient is grade 5 and on second appointment, patient is grade 1. So the degree of change for that patient is excellent. If the grade is decreased two grades, the degree of change is classified as good while moderate if grade is reduced only one. There is no degree of change if there was no change compared to first appointment.

The degree of change is worse if the grade is increased by 1 and more. At the completion of the study, independent examiners would also grade the photographs. Table 2.9 shows the degree of change and its description.

Table 2.9 The degree of change and its description

The degree of change	**Description**
Excellent	There was a decrease of three or more grade numbers with reduced redness and tenderness
Good	There was a decrease of two grades with reduced redness and tenderness
Moderate	There was a decrease of one grade with reduced redness and tenderness
None	There was no change
Worse	There was an increase of one grade or more or an increase in redness or tenderness with the same grade

In 1994, photography with fluorescence was used for the first time to assess the severity of comedonal acne [15]. This method was explored by Lucchina group [17] and they graded their observations on a fluorescence scale. They grade with 0 if patients do not have any acne in their face. Grade 1 is given for patients that have mild acne while Grade 2 for moderate acne. Grade 3 classified for extensive acne such as shown in Table 2.10.

Table 2.10 The grade and scale

Grade	**Scale**
0	None
1	Mild
2	Moderate
3	Extensive

In 1996, Lucky et al assessed the reliability of acne lesions and they counted them [18]. Then they recorded on a facial template and divided into 5 facial segments which are right and left forehead, right and left cheek and chin (Figure 2.3).

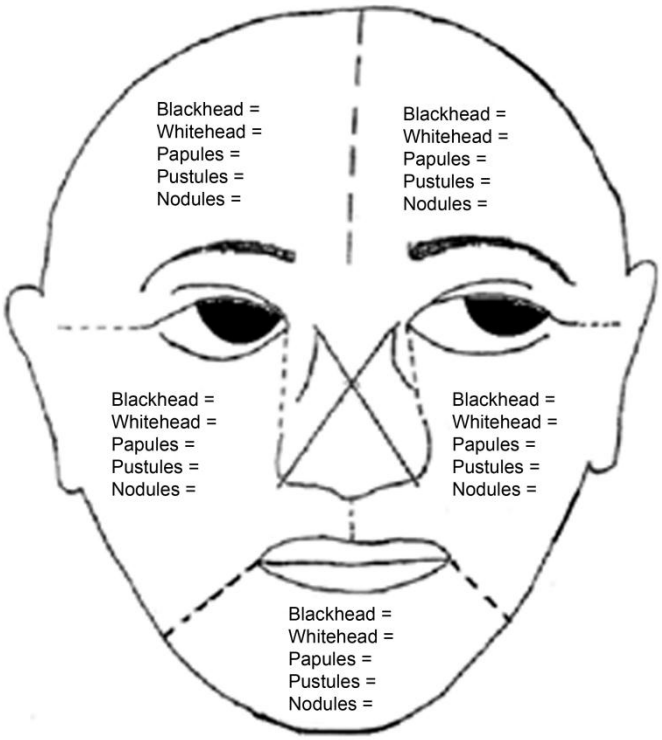


Figure 2.3 Facial template [18]

Each lesion type such as open comedones, closed comedones, papules, pustules and nodules within each template segment was counted. Hairline and jaw line defined perimeters of face and nose area were excluded. They assessed based on five grade classification of acne which are; very mild for patients just having few comedones, mild for patients having more comedones and few papules and pustules, moderate for patients having many papules and pustules, severe for patients having many papules and pustules with few nodules and very severe for patients having a lot of comedones, papules, pustules and nodules.

In 1997, Doshi et al introduced a global acne grading system (GAGS) [8]. This system divided the face, chest, and back into six locations (forehead, each cheek, nose, chin, chest and upper back) as shown in Figure 2.4. The six locations are graded separately on a 0 to 4 scale depending on the most severe lesion within that location (0 = no lesions, 1 = comedones, 2 = papules, 3 = pustules and 4= nodules). The score for each area is the product of the most severe lesion, multiplied by the area factor. These individual scores are then added to obtain the total score. For total score in between 1 to 18, the patient is classified as mild while for total score in between 19 to

30, patient is classified as moderate. If total score is in between 31 to 38 then the grade is severe and if it is more than 39 then it is very severe as shown as in Table 2.11.

Table 2.11 The Global Acne Grading System (GAGS) [8]

Location	**Factor (F)**	**Severity (S)**			**Local Score (FxS)**
Forehead	2	0	Nil		
Right Cheek	2	1	Comedone		
Left Check	2	2	Papule		
Nose	1	3	Pustule		
Chin	1	4	Nodule		
Chest and Upper Back	3				
		Total Score			

Acne Severity	
Mild	1-18
Moderate	19-30
Severe	31-38
Very severe	>39

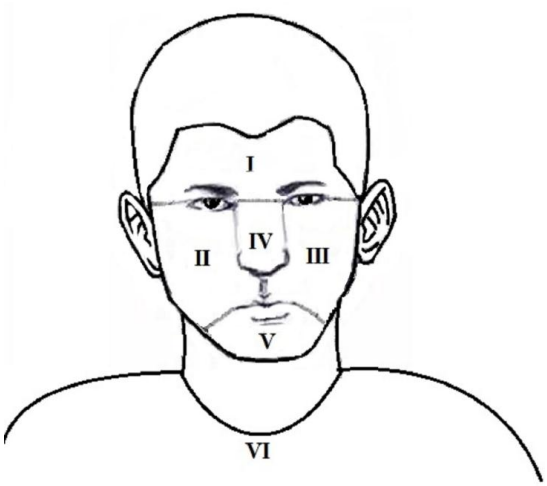


Figure 2.4 The six locations (I-VI) of the Global Acne Grading System (GAGS) [8]

For example, a patient who has comedones at forehead. Comedones is grade 1 as shown in Table 2.11, forehead is in location I as shown in Figure 2.4 and factor for location I is 2. So the local score is 2x1, i.e., 2. Then at the right cheek, patient has comedones, papules and pustules. Pustules are grade 3, right cheek is in location II and factor for location II is 2. So the local score is 2x3, i.e., 6. At the left cheek,

patient has comedones, papules and pustules. Pustules are grade 3, right cheek is in location III and factor for location III is 2. So the local score is 2x3, i.e., 6. At the nose, patient has comedones and papules. Papules are grade 2, nose is in location IV and factor for location IV is 1. So the local score is 1x2, i.e., 2. At the chin, patient has papules and nodules. Nodules are grade 4, chin is in location V and factor for location V is 1. So the local score is 1x4, i.e., 4. At the chest and upper back, patient has comedones and papules. Papules are grade 2, chest and upper back is in location VI and factor for location VI is 3. So the local score is 3x2, i.e., 6. The GAGS is the total of all local scores (2 + 6 + 6 + 2 + 4 + 6 = 26). So from Table 2.11, 26 indicate that the patient is moderate in terms of scale. A similar system was proposed by Dreno et al in 1999 [15].

Again in 1998, the Leeds technique was revised by Brien et al. The Leeds Revised Acne Grading System provides a photographic standard for acne grading of the face, back and chest [19]. These representations were selected over 1000 photographs by an expert panel of three dermatologists and four acne assessors. There are 12 grades for face and 8 grades for upper chest and back.

Table 2.12 The grade based on photographic standard [19]

Body Part	**Mild**	**Moderate**	**Severe**
Face	Grade 1 to Grade 4	Grade 5 to Grade 8	Grade 9 to Grade 12
Upper Chest and Back	Grade 1 to Grade 3	Grade 4 to Grade 5	Grade 6 to Grade 8

In 2008, Hayashi et al. used standard photographs and lesion counting to classify acne into four groups [20]. First, they classified acne based on the number of inflammatory eruption of half face. Second, they counted the lesions and divided the total number of lesions into four groups. For total number of lesions less than 5, grade is classified as mild while 6 to 20 as moderate. If total number of lesions in between 21 to 50, it is in severe group and more than 50 for very severe as shown as Table 2.13. Their judgment on severity grades were then compared with those of an expert panel of three dermatologists who evaluated half-face photographs of the same patients.

Table 2.13 The grade based on photographic standard and lesion counting [20]

Total number of lesion	**Group**
0-5	Mild
6-20	Moderate
21-50	Severe
>50	Very severe

In order to assess tretinoin pump for treatment of facial acne at phase 4, Lawrence et al [9] determined the grades by a score on the authors' modification of the Global Acne Grading System (mGAGS) described by Doshi et al [8]. The modification consisted in the removal of nonfacial areas (chest and upper back). The mGAGS score was calculated by multiplying lesion severity grades (0-4) by assigned factors of 1 or 2 based on surface area, distribution and density of pilosebaceous units to obtain local scores for each location. These local scores were added to obtain the global score, which corresponded to a global acne grade (0 = none, 1-13 = mild, 14-22 = moderate, 23-28 = severe and >29 = very severe).

Table 2.14 The modified Global Acne Grading System (mGAGS) [7]

Location	**Factor (F)**	**Severity (S)**			**Local Score (FxS)**	**Acne Severity**
Forehead	2	0	Nil			Mild 1-13
Right Cheek	2	1	Comedone			Moderate 14-22
Left Check	2	2	Papule			Severe 23-28
Nose	1	3	Pustule			Very severe >29
Chin	1	4	Nodule			
		Total Score				

Table 2.15 summarizes the acne assessment methods discussed in this section.

Table 2.15 Acne Assessment Method

Year	Acne Assessment	Assessment Method
1956	Pillsbury et al	Lesion Counting
1958	James and Tisserand	Lesion Counting
1966	Witkowski and Simons	Lesion Counting
1971	Frank	Lesion Counting
1975	Plewig and Kligman	Lesion Counting
1977	Christiansen et al	Lesion Counting
1977	Michaelson et al	Lesion Counting
1979	Cook et al	Photographic
1984	Burke et al	Photographic
1985	Samuelson	Photographic
1996	Luckt et al	Lesion Counting
1997	Doshi et al (GAGS)	Lesion Counting
1998	SC O'Brien et al (Leeds)	Photographic
2008	Hayashi et al	Photograph and Lesion Counting
2008	Lawrence et al (mGAGS)	Lesion Counting

Table 2.16 provides a reference for different types of acne grading system used in various countries in the world. We collected the following data from various publications as indicated by references in table 2.16.

Table 2.16 Country and Grading System

Country	Grading System
Hong Kong	Global Acne Grading System (GAGS) [21]
India	Global Acne Grading System (GAGS) [22]
Japan	Hayashi et al [20]
Jordan	Global Acne Grading System (GAGS) [23]
Korea	Korean Acne Grading System [24]
Malaysia	Leeds Grading System, Global Acne Grading System (GAGS) [25]
Saudi Arabia	Global Acne Grading System (GAGS) [26]
Turkey	Global Acne Grading System (GAGS) [27]
United Kingdom	Leeds Grading System [28]
United States of America	Investigator's Global Assessment (IGA) [29]

2.3 Treatments

Acne can lead to low self-esteem, loss of confidence and depression. Because of that, many acne patients are willing to pay more for good treatment that can give quick recovery and is effective. There are two ways for treating the acne which are; using conventional treatment such as topical and oral and using therapy such as laser and light therapies.

Treatment should be directed toward the known pathogenic factors involved in acne**.** The pathogenic factors include genetic, hormonal, sebaceous activity, bacteria, climate, chemical and psychological**.** Acne treatments consist of reducing sebum production, removing dead skin cells, reducing inflammation and killing bacteria with topical drugs and oral medications. Generally treatment is based on topical and systemic oral treatment.

2.3.1 Topical and Oral Treatments

Creams, lotions, gels and solutions are various formulations of topical medicines. Creams and lotions tend to be good for people with sensitive skin because it provides moisture. On the other hand, gels and solutions are generally alcohol based and tend to dry the skin. For that reason, those who live in hot, humid climates and patients with very oily skin may prefer them. Topical agents aim to reduce the number of microcomedones, comedones and inflammatory lesions.

Antibiotics (available as both topical and oral preparations), benzoyl peroxide, tretinoin, adapalene, and azelaic acid are several types of preparation of topical medicines that are used to treat acne [30]. Clindamycin and erythromycin are examples of topical antibiotics. For limiting and slowing the growth of bacteria and reducing inflammation, antibiotics and azelaic acid are used. An effective topical medicine for stopping the development of new comedones is Tretinoin which is a type of drug called a retinoid that contains an altered form of vitamin A. It works by unplugging existing comedones, thereby allowing other topical medicines, such as antibiotics, to enter the follicles. Newer retnoids or retinoid-like drugs, such as tazarotene or adapalene that help decrease comedone formation may also be prescribed by the doctor [4]. Topical therapy alone is used for treatment of mild acne vulgaris.

Oral treatments are indicated in moderate to severe acne. These include oral antibiotics, hormonal therapy and isotretinoin. The types of oral antibiotics commonly used are tetracycline, doxcycline, erythromycin and minocycline. Isotretinoin, a vitamin A derivative is indicated in severe acne vulgaris and nodulocyctic acne.

However**,** treatment choice depends on patient's condition whether the patient has mild, moderate, or severe acne. The grade and severity of the acne help in determining the following treatments. If they have moderate to severe acne with lesions deep in the skin, it is unlikely that topical medications will be effective for them. On the other hand, if they have only mild acne and rarely get pimples, then a topical medication may be the best acne medication for them. When a topical or systemic antibiotic is used, it should be used in conjunction with benzoyl peroxide to reduce emergence of bacterial resistance [31].

Sometimes there are side effects for certain people using prescription topical medicines such as stinging, peeling, scaling, burning, redness or discolouration of the skin. However, these side effects are usually reduced or lost after the medicine like retinoids is used for a period of time. At the beginning of treatment, the skin may look worse before improving.

2.3.2 Laser and Light Therapy

Besides those treatments, the laser treatment was introduced in 1990s. At this time, the laser became popular because it can eliminate old acne scars hence making this treatment as one of the best acne scar solutions. However, this treatment was very expensive. In 1996, Tina S. Alster et al determined the effectiveness of a high-energy, pulsed CO_2 laser in eliminating facial scars and there was 81.4% average clinical improvement observed in acne scars while using laser treatment [32]. However, the laser sources caused thermal damage to the skin and later laser research focused on prevention of damage to the skin.

Since 2000, phototherapy, which is mixture of blue and red light, is being used. In 2007, Konishi et al proposed acne phototherapy with a 1450-nm diode laser for patients with mild to moderate acne [33]. As a result, acne lesions were reduced by 63%. Phototherapy using this diode laser source was effective and well tolerated in acne patients. It is now a recognized mode of treatment

Narrow-band, high-intensity blue-light therapy was approved by the U.S. Food and Drug Administration (FDA) for treating acne. This is possibly being the most excellent light therapy for acne treatment. Blue light is being used to treat inflammatory acne vulgaris that has not responded to other acne therapies and it works by killing the acne-causing bacteria, *P. acnes*. Today, the blue-light do not contain ultraviolet (UV) light, which was a staple of former light therapy used to treat acne. UV light is no longer used to treat acne because it can damage the skin.

Kawada et al used acne phototherapy with a high-intensity, enhanced, narrow-band, blue light source. They treated 30 patients who have mild to moderate acne with blue-light therapy twice a week and up to five weeks. As a result, acne lesions decreased by 64% after five weeks. Nevertheless, not all patients showed improvement because 20% of them remained unchanged and the rest experienced a worsening of their acne [34].

Another group of researchers considered two causes of acne which are *P. acnes* and sebum production. So they combined pulses of light with heat in pulsed light and heat energy (LHE) therapy **t**reatment to destroy P. acnes, the acne-causing bacteria and decrease sebum (oily substance) production by reducing the sebaceous glands. FDA approved the system that combined pulses of green light and heat for treating mild to moderate acne.

In 2004, 19 patients who were receiving two LHE treatments per week for four weeks were diagnosed with mild to moderate acne by Elman et al. They saw reduction in both inflammatory and non-inflammatory lesions after eight treatments. Further improvement was seen one month after the last treatment, i.e., last treatment was two months earlier. They summarized that LHE technology is effective and safe for treating acne vulgaris [35].

The photodynamic (PDT) therapy also is used besides blue and red light. For certain types of skin disease like acne, Photodynamic therapy (PDT) is now a routine non-surgical treatment. Hong et al used photodynamic therapy (PDT) in 2005 for their research. Reduction in inflammatory (comedones) lesion count at 1, 3 and 6 months was 27.6%, 37.9% and 41.9% [36].

Aminolevulinic acid (ALA) with light therapy (i.e., photodynamic therapy or PDT) has two steps process of treatment that needs to be fulfilled by patients for

recovery. The first step is applying solution of 5-aminolevulinic acid (ALA) to the skin to be treated. The ALA is kept on the skin when used to treat acne for a period of time ranging from 15 to 60 minutes depending on the severity of the acne. ALA is a medication that increases sensitivity to light. The second step is removing the ALA and treating the skin with light therapy. Patients are instructed to use sun protection for 48 hours after treatment because ALA makes the skin more light sensitive. As a result, the studies indicate that treatment with blue or red light after the application of ALA is effective. On the other hand, red light may produce some undesirable side effects. The inflammation in acne lesions were successfully reduced among 10 patients after receiving multiple treatments of ALA + red-light therapy on their backs. Yet, the side effects from this treatment such as the development of folliculitis (an inflammation of hair follicles that resembles acne) and temporary darkening of the skin [37] limit it from being recommended as a new modality for the treatment of acne.

In 2004, one or two pulsed dye laser treatments to one-half of the face were used for 40 patients aged 13 and older who had facial acne. The other half of the face was left untreated. However, there was no reduction and difference between the treated and untreated sides after 12 weeks. Because there was no improvement shown when using the pulsed dye laser, it signifies this laser therapy is not a useful modality for treatment of the acne at this time unless further research proves otherwise [38].

However, the use of lasers and light therapies may not be the first choice for treating acne due to cost and the availability of other effective treatment modalities like oral retinoids.

2.3.3 Alternative Treatments

Alternative treatments for acne focus on self-care such as proper cleansing to keep the skin oil-free; eating a well-balanced diet high in fiber, zinc, and raw foods; and avoiding alcohol, dairy products [39], tobacco, caffeine, sugar, processed foods, and foods high in iodine, such as salt.

2.3.4 Summary of Acne Treatments

A very important point to be noted is that Acne treatment takes few months and improvement is seen after 1 to 2 months. Hence, it becomes significant to correctly assess the acne grade of the patients on every visit. Table 2.17 provides the summary of acne treatments.

Table 2.17 Summary of Acne treatments

Treatment Method	Type	Effect	Comments
Creams and lotions	Topical Treatment	Moisturizing the skin	Good for people with sensitive skin and mild acne
Gels and solutions	Topical Treatment	Reduces the numbers of microcomedones, comedones and inflammatory lesions	Suitable for oily skin and mild acne
Antibiotics and azelaic	Oral Treatment	To stop or slow the growth of bacteria and reduce inflammation	For moderate and severe acne
Tretinoin	Oral Treatment	For stopping the development of new comedones	For moderate and severe acne
Pulsed CO_2 laser	Laser therapy	Eliminating facial scars	81.4% improvement after treatment but the laser source damage the skin
Blue Light	Light therapy	Killing the acne-causing bacteria, P. acnes	Can treat inflammatory acne vulgaris
Mixture of blue and red light	Light therapy	Reducing the acne lesion from moderate to mild	Acne lesions were reduced by 63%
Photodynamic therapy (PDT)	Light therapy	Reducing the comedones	Lesion count reduced at 1, 3 and 6 months was 27.6%, 37.9% and 41.9%
Pulsed light and heat energy (LHE)	Light therapy	Killing the acne-causing bacteria, P. acnes and decrease sebum	Successful and safe for treating acne vulgaris
Aminolevulinic (ALA) with light therapy - PDT	Light therapy	Developing of folliculitis and temporary darkening of the skin	Effective but has side effects
Pulsed dye laser	Laser therapy	No reduction of acne after 12 weeks	Not effective. Further research required
Eating a well-balanced diet	Alternative Treatment	Reduces probability to get acne	Preventive measure

2.4 Summary

Acne affects people around the world as a common human skin disease. The grading system is one of the main issues because there is no global standardized grading. Additionally, grading is a subjective measure that varies from one dermatologist to another (inter-rater variability) as well as it may vary for the same dermatologist at different times for the same patient (intra-rater variability). This happens as a counting is a tedious process with the variety types of acne as well as the number of lesions. Thus, only approximate count leading to approximate acne grade can be given by dermatologists.

There are many approaches for acne treatment that have been used in order to recover from the acne. They include medicine as well as using modern equipment like laser and light therapies. Even though laser and light therapies give quick recovery, but topical agents and systemic antibiotics or retinoids are common treatment options for patients with acne vulgaris. It is because laser and light therapies are expensive and still need investigation to identify the side effects. All these treatments require few months for full recovery.

In this chapter, the detailed analysis of acne grading system as well as treatment has lead to the identification of issues related with acne that need to be addressed in order for effective acne treatment. The issues include treatment options, inter- and intra-rater variability and selection of acne grading system. Computational methods based on imaging techniques can be employed to address some of these issues, especially inter- and intra-rater variability directly will discussed in Chapter 3.

CHAPTER 3
METHODOLOGY

This chapter discussed about imaging equipment, data acquisition, colour spaces and computer vision process. Besides that, the methodology for digital image process such as pre-processing, image segmentation, post-processing and pattern classification techniques are discussed as well.

3.1 Digital Imaging

Digital imaging offers several advantages such as information obtained in digital form can be processed, stored, and transmitted from one place to another using communication networks. Images produced by digital systems can also be manipulated using computer software applications to increase diagnostic utility and electronically transmitted for referrals. In addition, digital imaging does not require chemical processing. Other advantages include image analysis and image reconstruction.

A few works were conducted in order to view acne lesions clearly but till now, there are no research work conducted in giving acne grading automatically. The acne lesion is assessed from digital images. Image acquisition is the important step in digital image system. Several constraints are identified of image acquisition in dermatological application in order to obtain consistent quality images. The main objective in assessing lesion area from digital images is to segment the lesion region from the entire image. Colour, grayscale, and texture information from the images are used to distinguish acne lesion from the normal skin.

3.1.1 Image Acquisition Setup

Complete and perfect image acquisition setup is the most important part in collecting data in order to get consistent and high quality images. The quality of images is affected by the quality of the camera, lighting condition, and position of the patient.

Choosing between a compact and a digital SLR camera is the first decision to make when starting out with data collection. A fine choice between a compact and a digital SLR camera is crucial when starting data collection because the criteria in choosing the camera, among others are, capable of capturing, higher resolution, bigger camera sensor size, less noise, faster camera autofocus, higher maximum frame rate and greater range of ISO speed settings. Since digital SLR camera has all these, it is chosen for capturing the images for data collection.

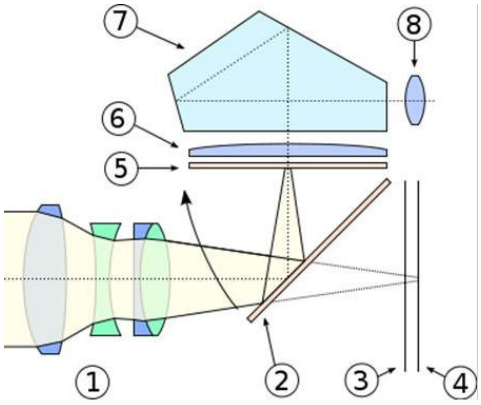
High resolution camera can capture a good quality image. Resolution shows the numbers of pixel that form the pictures. Pixels itself are the pictures small fragments with many colours. Therefore, higher resolution gives more image details of the skin, scar and lesion.

Camera sensor size impacts on image quality. There is a connection between sensor size and image quality. In general, a larger sensor provides lower noise and higher sensitivity. There is also a connection between sensor size and depth of field, with the larger sensor resulting in shallower depth of field at a given aperture.

The noise on the camera sensor should be minimum, in order to produce images with actual colour of the lesion. Spectral reflection and shadows can reduce the quality of the images. In order to avoid spectral reflection and shadows, the softbox will be used. The softbox can control the lighting uniformly and are more effective at reducing shadows. Softboxes are used heavily in portrait photography and many other types of commercial photography.

The light that comes from a softbox is directional and diffused making it a light that is easy to control. The Softbox eliminates hot spots and evenly distributes the light as well. Softboxes come in various sizes for different lighting circumstances. The larger the light source is relative to the subject, the softer the light will be. In addition, the closer a softbox is to the subject, the softer the light will be. For this reason, small softboxes are typically used for small object photography or for

dramatic lighting of larger objects. Larger softboxes are most often used for people photography.



Cross-section view of a DSLR.

1. Camera lens
2. Reflex mirror
3. Focal-plane shutter
4. Image sensor
5. Matte focusing screen
6. Condenser lens
7. Pentaprism/pentamirror
8. Viewfinder eyepiece

(a) (b)

(c)

Figure 3.1 Image acquisitions a) Digital single-lens reflex (DSLR) camera b) Cross-section view of a DSLR c) Photography setup

3.1.2 Imaging Equipment

In order to get a good and quality image, the consistency of colour information, equipment and environment should be concern. Consistency is essential for

monitoring condition of the lesion same between the images captured using camera and perceived by humans [40]. Light sources should be arranged to create homogenous and diffused light in order to avoid the appearance of shadow and specular reflection.

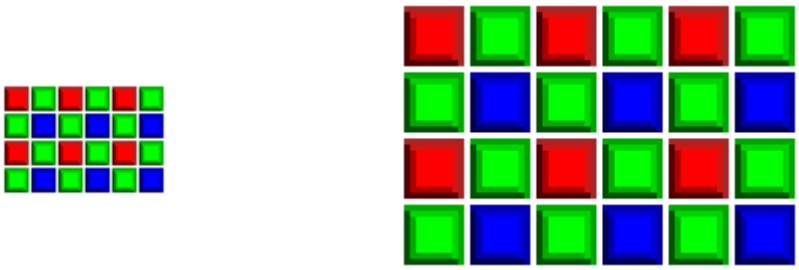
In order to calculate mGAGS, the types of acne lesion on patient's face must be determined. For this purpose, close up images of the forehead, right cheek, left cheek, nose and chin are digitally photographed for each patient. The Canon DSLR 500D shown in Figure 3.2 is used to capture the images. The camera has CCD sensor with 4,752 x 3,168 pixels resolution.

Figure 3.2 Canon DSLR 500D

In general, compact cameras as shown in Figure 3.3 have much smaller camera sensors than Digital Single Lens Reflector (DSLR) cameras. Camera sensor has significant impact on image quality.

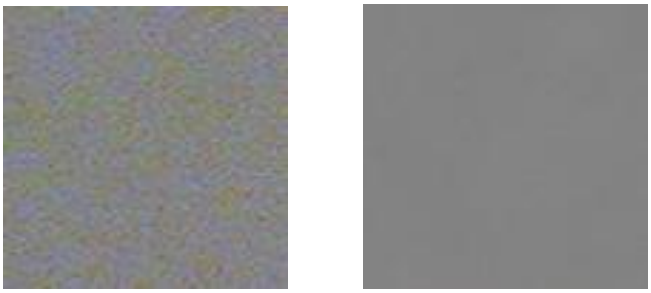
DSLR camera has large physical sensor size, therefore the images captured by DSLR give high quality than images captured by ordinary digital compact camera. Figure 3.4 show the different size of camera pixels between compact and DSLR camera. With the same resolution, the pixel size of DSLR is bigger than those of compact camera allowing better image capture. Additionally, Figure 3.5 shows the different images taken using large sensor and small sensor camera. The image taken by large camera sensor is proven in giving better image and less noise.

Figure 3.3 Compact camera



a) Compact camera pixels b) DSLR camera pixels

Figure 3.4 Camera pixels

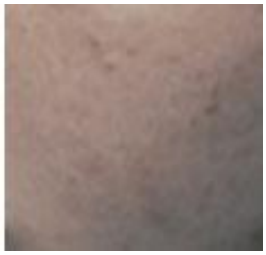


a) Small camera sensor b) Large camera sensor

Figure 3.5 Images taken using different camera sensor [76]

3.1.3 Imaging Techniques

For normal clinical evaluation, there is direct visual assessment and ordinary flash photography is used. Fluorescence photography was proposed in 1996 to evaluate the acne. Lucchina et al selected 40 patients with mild to moderate acne vulgaris and took photographs using flash and fluorescence at baseline, 4, 8 and 12 weeks [17]. Equipment for flash photographs included a Minolta X-700 camera body with a Tamron 90 mm macro lens and a Vivitar series-I-28 to 105 mm macro lens. For fluorescence photograph, they used the same camera body with flash photograph and included a Kodak Wratten #4 filter on the lens to block all UV light and pass only visible light. Figure 3.6 below shows photograph of subject with mild acne taken using flash and fluorescence photography. The darker areas in (b) correlate with closed comedones, papules, erythema and pigmentation.



(a) Flash photography

(b) Fluorescence image

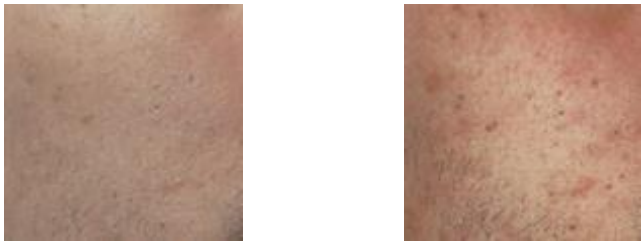
Figure 3.6 Subject with mild acne in left cheek. [17].

In 1997, Phillips et al became the first group that studied polarized light photography to assess the comedo counts and inflammatory acne lesion counts [41]. They compared the acne assessment obtained from clinical evaluation with assessments from photograph obtained with flash photography and with perpendicular polarized light photography.

For flash photography, they used Minolta X-700 with either a Tamron 90 mm macro lens fitted with a 2x tele-converter or a Vivitar Series 1 28-105 mm macro zoom lens to get standard photographs. For polarized light photography, they used Minolta 80PX ring flash with a linear polarizer affixed to the surface of the flash head. A similar linear polarizer was placed in front of the camera lens.

Both flash and polarized used the same camera lens and body. Besides that, a photographic table was used to maintain camera and flash positions over time. The full frontal pictures were taken with patient looking directly into camera lens. The right and left sides of the face for standard and polarized light photographs were taken with the patient looking at 45 degrees to the left or right of midline.

Figure 3.7 below shows the comparison between flash photograph and perpendicular polarized light photograph. They enhanced the visualization of skin features, colour and lighting and framing in perpendicular polarized photograph. As a result, comedo counts were easier and visible in flash photograph but more clearly delineated in perpendicular polarized light photograph.



(a) Flash photograph (b) Perpendicular polarized light photograph

Figure 3.7 Open comedones in right cheek. [41].

In 2001, Rizova and Kligman used both parallel and crossed polarizing light photography in combination with video microscopy and sebum production measurement. They also viewed the effects of adapalene gel 0.1% on inflammatory and non-inflammatory acne lesions. The parallel and crossed polarizing light photography, in combination with video microscopy and sebum production, measures the response of sebum to adapalene gel 0.1%. Sebum is oily substance that may cause acne. Adapalene is effective to prevent development of new lesions and good for treating inflammatory and non-inflammatory lesions. As a result, sebum secretion rates declined during treatment [42].

In 2008, Thy Thy Do et al studied the computer-assisted alignment and tracking of acne [43]. Images were taken using digital camera. This technique combined digital photography with photo editing software. The photographs taken every 2 weeks for 12 weeks used Nikon D1x digital camera at a resolution of 1960 x 3008 pixels (5.9 Megapixels) and fixed reproduction ratio equivalent to 1:6 on 35-mm film. Then, they used the software Picture Window Pro 4.0 (Digital Light & Colour, Belmont, Mass) for selected alignment.

A region of interest (ROI) with the most clinically major acne lesions was selected on 27 patients who have mild to moderate acne based on Leeds technique. Each patient's data set consisted of up to seven ROIs. The lesions were counted in each ROI and classified either open or closed comedones, papules, pustules and nodules. A ROI area is 400 x 400 pixels (2.8 x 2.8 cm of skins) was printed together on A4 template.

From first appearance, they assigned numbers to each new lesion after tracking inflammatory lesions. Then, they were monitoring lesion growth through consecutive weeks. This technique eliminated photographic inconsistencies such as variability of camera angle and framing.

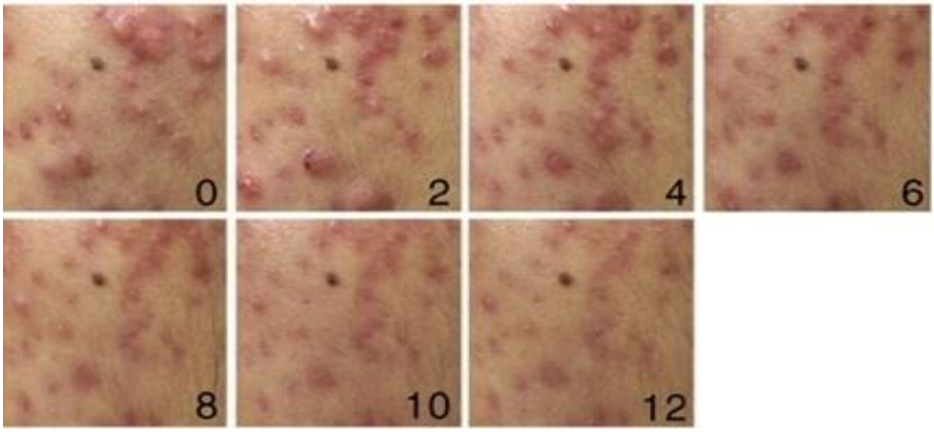


Figure 3.8 Region of Interest (ROI) with the most significant acne lesions was selected [43].

A group of another researchers used multispectral images for assessment of acne grade. Multispectral Image (MSI) is one that captures image data at specific wavelengths across the electromagnetic spectrum. MSI allows extraction of additional information that the human eye fails to capture with its receptor for RGB. Multispectral is a good solution to colour problems in medicine and it has significant impact in many fields including dermatology and dentistry [38].

In 2008, Hideaki Fujii et al used the spectral information, for the various type of acne skin lesions, acquired from the multispectral images (MSI) of the lesion [44]. 16-band multispectral camera (16 band 12 bits, 2048 x 2048 pixels) was used with two tungsten lamps.

Initially, they removed the shade and gloss in preprocessing and then they used spectral information at each pixel for classification. The relative reflectance which is the pixel value of the obtained object due to 3D shape of object, involves the effects of shades and gloss. Gloss of dielectric material has same spectral distribution as the illumination and the effect of gloss is eliminated with the projection. In order to remove the shades and shadows, the multispectral signal of the resulting image is normalized with respect to the total intensity of each pixel.

A combination of several linear discriminant functions (LDF's) for acne lesion is used for classification. They used 3 Fisher LDF's and 3 threshold values to consider 3 classes to classify acne types. Calculation of the Fisher LDF's were made from both reddish papule and pustule, both pustule and scar and both reddish papule and scar respectively. Through experimentation, the threshold values for these LDF's were determined. Multispectral imaging and LDF classifier were able to differentiate several skin lesions such as comedo, reddish papule, pustule and scar.

Youngwoo Bae et al (2008) introduced multimodal facial colour imaging modality for skin lesion's objective analysis. They used a conventional colour image, parallel and cross-polarization colour images and a fluorescent colour image [45]. They proposed fluorescent image analysis methods for quantitative evaluation of sebum related parameter such as pattern, area and density, average size and diameter of spots. Table 3.1 summarizes the various computational methods based on imaging techniques for assessment of acne lesions.

Table 3.1 Summarized of the imaging modality and its approach in acne analysis.

Year	Imaging modality	General Approach	Specific Method	Comments
1996	Fluorescence photography [17]	Comparing the counts of acne using flash and fluorescence photograph	Two filters were used for fluorescence photography for UVA transmittance and elimination of infrared light	Fluorescence photography appears to be a useful tool to chart the course of acne treatment
1997	Polarized light photography [41]	Comparing the acne assessment obtained from clinical with photograph obtained from flash photography and perpendicular polarized light photography	The polarizing filter on the camera was oriented at a right angle with respect to the linear polarizer on the ring flash	Comedo counts were easier in perpendicular polarized photograph than flash photograph
2001	Parallel-polarized and cross-polarized photography with videomicroscopy and sebum production measurement [42]	The parallel and crossed polarizing light photography used	Combined with video microscopy and sebum production measurement to assess the response of sebum to adaplene gel 0.1%	They used multiple methods. Hence, this method cannot be used for real time analysis.
2008	Computer-assisted alignment and tracking of acne [43]	Used digital photograph and select Region of Interest (ROI). Then, assigned numbers to each new lesion in ROI after tracked inflammatory lesions for every 2 weeks for 12 weeks	Combined with a software program with alignment capabilities	Count and characterize lesion types and monitoring acne lesion growth for 12 weeks
2008	Multispectral images (MSI) [44]	Applied a combination of several linear discriminant functions (LDF's) classifier with MSI	Used Fisher LDF to classify the different acne types	Classified comedo, papule, pustule and scar based on colour image

3.2 Colour space

Colour is the main features to show the different types of acne and the first step before analysis is by selecting the best colour space for better result.

Specific visual stimulus is as a result of the brain's reaction towards colour. Redundancy still remains at large although we can precisely describe colour by measuring its spectral power distribution (the intensity of the visible electro-magnetic radiation at many discrete wavelengths). Redundancy happens when the retina of the eyes samples colour uses only three broad bands, roughly corresponding to red, green and blue light. The signals from these colour sensitive cells (cones), together with those from the rods (sensitive to intensity only) are combined in the brain to give several different sensations of the colour [46]. These sensations have been defined by the CIE (see section 3.2.2)

The tri-chromatic theory describes the way three separate lights red, green and blue can match any visible colour which is based on the eye's use of three colour sensitive sensors. This is the basis on how photography and printing operate, using three different coloured dyes to reproduce colour in a scene. It is also the way the most computer colour spaces operate, using three parameters to define a colour.

A colour space is a method by which we can specify, create and visualize colour. As humans, we may define a colour by its attributes of brightness, hue and colourfulness. However, a computer may describe a colour using the amounts of red, green and blue phosphor emission required to match a colour.

A colour is thus usually specified using three co-ordinates or parameters. These parameters describe the position of the colour within the colour space being used. Different colour spaces are better for different applications, for example some equipment has limiting factors that dictate the size and type of colour space that can be used.

There are several colour spaces such as RGB (Red Green Blue), CMYK (Cyan Magenta Yellow Black), HSV (Hue Saturation Value) and CIELAB. RGB colour space is mainly used for display devices such as monitor, camera, and video. CMYK (Cyan Magenta Yellow Black) colour space is used for colour printing. HSV (Hue Saturation Value) colour space corresponds well with the way human define and

interpret colour. CIELAB colour space is a perceptually linear colour space and thus is widely used in colour management [47].

3.2.1 RGB

In the RGB model, red, green, and blue light is added together in various ways to reproduce a broad array of colours. This model is called additive, and the colours are called primary colours. The primary colours can be added to produce the secondary colours of light which are magenta (red plus blue), cyan (green plus blue), and yellow (red plus green). The combination of red, green, and blue at full intensities makes white [48]. Figure 3.9 shows the combination of RGB colour model.

Cone cells are sensitive to long (L), medium (M), and short (S) wavelengths. Any spectrum of light can be described by three values, which correspond to the respond of the three types of cone cells. In RGB colour space, any colour is represented by intensity values of three primary colours, namely red, green, and blue colour. Red colour stimulates L-cone cells, whereas blue spectrum stimulates S-cones. Green spectrum stimulates both L-cones and M-cones. This makes human eyes more sensitive to green colour since there are two types of cone cells are stimulated by this colour [49].

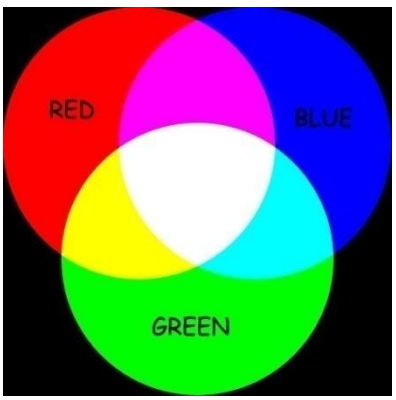


Figure 3.9 The RGB colour model

The main purpose of the RGB colour model is for the sensing, representation, and display of images in electronic systems, such as televisions and computers, though it has also been used in conventional photography. Typical RGB input devices are colour TV and video cameras, image scanners, and digital cameras.

3.2.2 CIELAB

In dermatology, colour and colour difference often convey important diagnostic information, especially when investigating lesion and more particularly, skin cancer. CIE L*a*b* (CIELAB) is the most complete colour space specified by the International Commission on Illumination (French Commission internationale de l'éclairage, hence its initials is CIE) [50]. CIELAB is extensively utilized in colour space and engineering applications after standardizing as a uniform colour space in 1976. CIELAB provides both a colour difference formula and correlates for common perceptual descriptors of colour.

As shown in Figure 3.10, the three coordinates of CIELAB represent the lightness of the colour (L* = 0 yields black and L* = 100 indicates diffuse white), its position between red/magenta and green (a*, negative values indicate green while positive values indicate red) and its position between yellow and blue (b*, negative values indicate blue and positive values indicate yellow) [51].

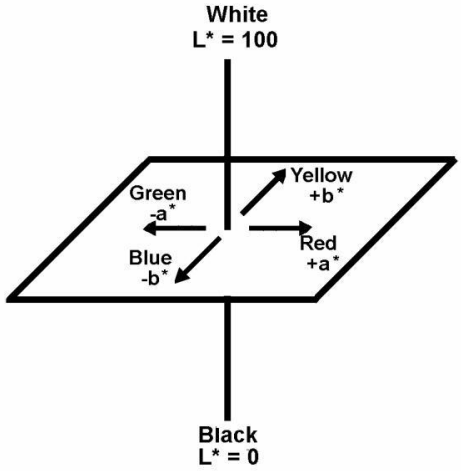


Figure 3.10 Diagram of CIELAB Colour Space [51]

The asterisk (*) after L, a and b are part of the full name, since they represent L*, a* and b*, to distinguish them from Hunter's L, a, and b. The difference between Hunter and CIE colour coordinates is that the CIE coordinates are based on a cube root transformation of the colour data, while the Hunter coordinates are based on a square root transformation.

Both spaces are derived from the primary space which is CIE 1931 XYZ colour space. These both "Lab" colour spaces is to create a space which can be

computed via simple formulas from the XYZ space, but is more perceptually uniform than XYZ [52]. Perceptually uniform means that a change of the same amount in a colour value should produce a change of about the same visual importance. CIELAB colour space is derived from CIEXYZ by following Equation 3.1.

$$
\begin{aligned}
L^* &= 116(Y/Y_n)^{1/3} - 16 \\
a^* &= 500\left[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}\right] \\
b^* &= 200\left[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}\right]
\end{aligned}
\qquad \text{(Equation 3.1)}
$$

CIEXYZ colour space is derived from RGB by following Equation 3.2.

$$
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad \text{(Equation 3.2)}
$$

X_n, Y_n, Z_n are the tristimulus values of the reference illuminant (light source). The reference illuminant is required in this transformation since light source influences the appearance of the sample colour. The most commonly used reference illuminant is D65 [53]. It is intended to represent average daylight throughout the visible spectrum. The X_n, Y_n, Z_n values of D65 are 95.047, 100, and 108.883, respectively [54].

3.3 Digital Image Processing

Assessment which is automated using digital image processing is needed to aid the dermatologists who are using manual assessment to avoid inter- and intra-rater reliability. There are three types of computerized processes in image processing which are low-level processes, mid-level processes and high-level processes. Low-level processes involve primitive operations such as image pre-processing to reduce noise, contrast enhancement and image sharpening. A low-level process is characterized by the fact that that both its inputs and outputs are images.

Mid-level processes on images involves tasks such as segmentation (partitioning an image into regions or objects), description of those objects to reduce them to a form suitable for computer processing and classification (recognition) of individual

objects. A mid-level process is characterized by the fact that its inputs generally are images but its outputs are attributes extracted from those images (e.g.: edges, contours and the identity of individual objects). Finally, high-level processes involves with recognizing object, as in image analysis.

3.3.1 Image Segmentation

Segmentation is one of the most common operations in medical image processing. Accurate segmentation of medical images is very important since it might affect the result of diagnose and medication error. Image segmentation is a process in image processing that partitioning a digital image into multiple segments (sets of pixels, also known as super pixels) and extract information from an image.

There are many image segmentation techniques such as thresholding, clustering methods, region-growing methods etc. but they have same goal to achieve. The goal of the image segmentation is to cluster pixels into salient image region such as regions corresponding to individual surfaces (skin), lesions and scars. Segmentation should stop when the objects or regions of interests in an application have been detected.

3.3.1.1 Thresholding

Thresholding is one of the most important approaches to image segmentation. In this method, pixels that are alike in grayscale (or some other feature) are grouped together. Often, an image histogram is used to determine the best setting for the threshold [55]. Otsu's method, named after its inventor Nobuyuki Otsu, is one of many binarization algorithms which converting a grayscale image to monochrome. It transforms the input image *f* into a binary image *g* as follows in Equation 3.3 [56]:

$$g(i,j) = \begin{cases} 1, & \text{for } f(i,j) \geq t \\ 0, & \text{for } f(i,j) < t \end{cases} \qquad \text{(Equation 3.3)}$$

where *i,j* are spatial information of the image, *t* is the threshold value, *g(i,j)* = 1 for region of interest and *g(i,j)* = 0 for background (or vice versa).

By analyzing the image histogram, the threshold value will be selected. Histogram contains information of the number of pixels that have certain grey value. Otsu's thresholding method determines threshold value that minimizes the weighted within-class variance. The threshold value is obtained from statistical properties of the image histogram [56].

3.3.1.2 K-means clustering

One of the hard clustering algorithm is K-means clustering. K-means clustering is an iterative method of cluster analysis which aims to partition an image into *k* clusters in which each partition belongs to the cluster with the nearest mean.

The algorithm is composed of the following steps:

1. Choose *k* cluster centers, either selected manually, randomly, or by a heuristic.
2. Assign each pixel in the image to the cluster that minimizes the distance between the pixel and the cluster center
3. Re-compute the cluster centers by averaging all of the pixels in the cluster
4. Repeat the two previous steps until convergence criterion is met

In this case, distance is the squared or absolute difference between a pixel and a cluster center. The difference is typically based on pixel colour, intensity, texture, and location, or a weighted combination of these factors. *K* can be selected manually, randomly, or by a heuristic.

Consider a data set with *n* number of patterns, ($x_{k,}$ k= 1,….,n),. For example, the data is partitioned into *c* cluster ($G_{i,}$ i= 1,….,c), where $c < n$. Initially, cluster centers ($v_{i,}$ i= 1,….,c) are randomly selected and each pattern is assigned to the nearest cluster centers. Euclidean distance is commonly used to calculate the distance. The *k*-means clustering is an iteration process to find cluster centers that minimize objective function given in Equation 3.4.

$$J = \sum_{i=1}^{c} \left(\sum_{k, x_k \in G_i} \left\| x_k - v_i \right\|^2 \right) \qquad \text{(Equation 3.4)}$$

The iteration is stopped when its improvement over previous iteration is below a predefined threshold. During iteration, the new cluster centers are recomputed using Equation 3.5.

$$v_i = \frac{1}{|G_i|} \sum_{k, x_k \in G_i} x_k \qquad \text{(Equation 3.5)}$$

Where $|G_i|$ is the size of G_i.

Since the number of clustering (K) is usually known for images of particular region of human anatomy [57], K-means is suitable for biomedical image segmentation.

3.3.2 Pattern Classification

Pattern classification is the organization of patterns into groups of patterns sharing the same set of properties or features. The kind of these features is not fixed and may include such as colour, size, texture etc. Figure 3.11 shows general procedure of pattern classifier.

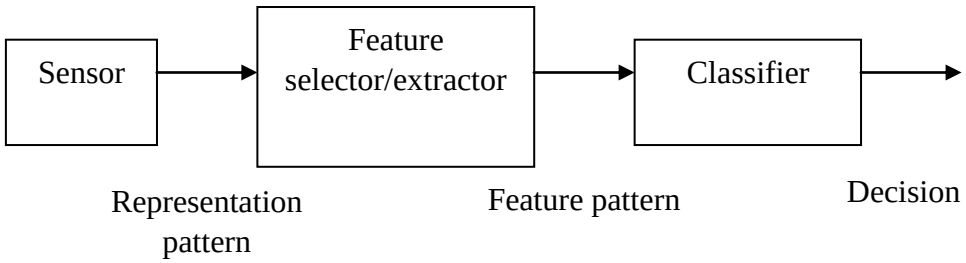


Figure 3.11 Pattern classifier

The input to a pattern classifier is a sensor that captures the data, which is represented by several features (characteristic). The original data set may contain some features which are redundant. Pattern representation often requires feature selection and/or extraction from the data set. Both of these techniques aim to select the most significant subset of features to be used in clustering. Feature selection identifies the features from the original features, whereas feature extraction obtains the features by transforming the original features [58].

The goal of classifier component is partition feature into several classes according to the features given by feature selector/extractor. There are two types of classification, namely supervised classification and unsupervised classification (clustering). In supervised classification, the system is provided with a training set which has been labeled with class membership. Based on the training set, the

classifier will classify the data set into proper class. In unsupervised classification, the system is not provided with labeled training set. Instead, it forms natural grouping of the input data [59].

3.3.2.1 Artificial Neural Network (ANN)

An artificial neural network (ANN) is a mathematical model or computational model based on the way that the brain performs computations. These models mimic the real life behaviour of neurons and the electrical messages they produce between input (such as from the eyes or nerve endings in the hand), processing by the brain and the final output from the brain (such as reacting to light or from sensing touch or heat). An ANN is used to model complex relationship between inputs and outputs or to find patterns in data. There are several types of ANN namely as Feedforward neural network, Radial basis function (RBF) network, Kohonen self-organizing network, Learning vector quantization etc [60]. Figure 3.12 shows the simplified view of artificial neural network.

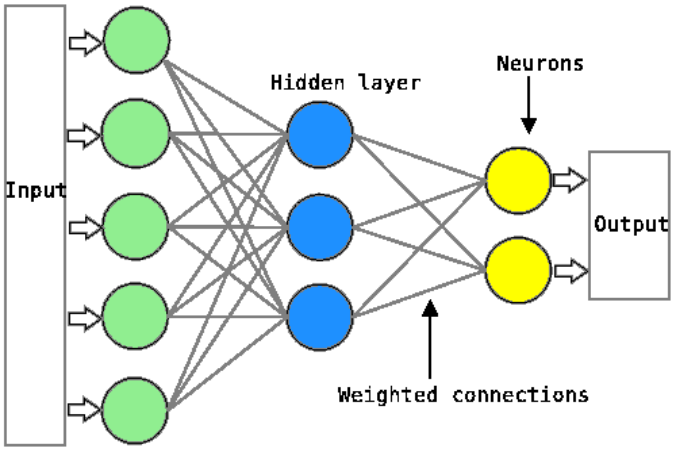


Figure 3.12 Simplified view of artificial neural network

An ANN has 3 basic layers which are input layer, hidden layer and output layer. Input layer is the layer of nodes that forms a passive conduit for data entering a neural network. While, the hidden layer is a layer of nodes between the input and output layer that contains the weight and processes data. Then, the output layer is the layer of nodes that produce the neural network result.

ANN Classification is an example of supervised learning. It is the process of learning to separate samples into different classes by finding common features between samples of known classes. Known class labels help to indicate whether the system is performing correctly or not. This information can be used to indicate a desired response, validate the accuracy of the system, or be used to help the system learn to behave correctly. The known class labels can be thought of as supervising the learning process [61].

Clustering is an example of unsupervised learning where the class labels are not presented to the system that is trying to discover the natural classes in a dataset. Clustering often fails to find known classes because the distinction between the classes can be obscured by the large number of features (genes) which are uncorrelated with the classes. A step in ANN classification involves identifying genes which are intimately connected to the known classes. This is called feature selection or feature extraction. Feature selection and ANN classification together have a use even when prediction of unknown samples is not necessary. It can be used to identify key genes which are involved in whatever processes distinguish the classes.

3.3.2.2 Support Vector Machine (SVM)

Support Vector Machine (SVM) is primarily a classier method that performs classification tasks. It is based on the concept of decision planes that define decision boundaries. A decision plane is one that separates between a set of objects having different class memberships. The svmtrain function in MATLAB uses an optimization method to identify support vectors s_i, weights α_i, and bias b that are used to classify vectors x according to the following Equation 3.6:

$$c = \sum_i \alpha_i \, k(s_i, x) + b \qquad \text{(Equation 3.6)}$$

where k is a kernel function. In the case of a linear kernel, k is the dot product. If $c \geq 0$, then x is classified as a member of the first group, otherwise it is classified as a member of the second group.

Kernel function svmtrain uses to map the training data into kernel space. The default kernel function is the dot product. The kernel function can be one of the following strings or a function handle:

- 'linear' — Linear kernel, meaning dot product
  — *u'*v*
- 'quadratic' — Quadratic kernel.
- 'polynomial' — Polynomial kernel (default order 3).
  — *(gamma*u'*v + coef0)^degree*
  where gamma is parameter needed for all kernels except linear (default: 1/(data dimension)) and coef0 is parameter needed for kernels of type polynomial and sigmoid (default: 0)
- 'mlp' — Multilayer Perceptron kernel with default scale [1 –1].

The svmclassify function uses results from svmtrain to classify vectors x according to the following Equation 3.7:

$$c = \sum_i \alpha_i \, k(s_i, x) + b \qquad \text{(Equation 3.7)}$$

where s_i are the support vectors, α_i are the weights, b is the bias, and k is a kernel function. In the case of a linear kernel, k is the dot product. If $c \geq 0$, then x is classified as a member of the first group, otherwise it is classified as a member of the second group.

Figure 3.13 shows the objects belong either to class green or red. The original objects (a) is rearranged using a set of mathematical functions, known as kernels. The process of rearranging the objects is known as mapping (transformation). The mapped objects (b) is linearly separable and, thus, instead of constructing the complex curve (a), SVM find an optimal line that can separate the green and the red objects [62].

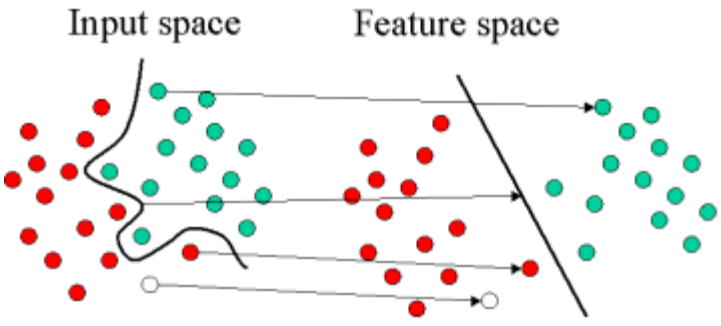


Figure 3.13 An example of SVM classifier

To construct an optimal hyperplane, SVM employees an iterative training algorithm to minimize an error function. SVM models can be classified into four distinct groups [63]:

- Classification SVM Type 1 (also known as C-SVM classification)
- Classification SVM Type 2 (also known as nu-SVM classification
- Regression SVM Type 1 (also known as epsilon-SVM regression)
- Regression SVM Type 2 (also known as nu-SVM regression)

3.4 Summary

Computational methods based on imaging techniques can be employed to address some of these issues, especially inter- and intra-rater variability directly. The uniform acne grading computational assessment will also lead to elimination of inter- and intra-rater variability which in turn leads to effective acne treatment and hence contribute directly to the existence of various grading system.

This chapter discussed about imaging equipment, data acquisition, colour spaces and computer vision process. Besides that, the methodology for digital image process such as pre-processing, image segmentation, post-processing and pattern classification techniques are discussed as well.

The appearance of a colour is affected by light source, object, and human vision. CIE as the International Commission on Illumination standardized that three components. Colour space is designed to represent a colour in standard way. RGB is widely used in capturing, storing, and displaying digital images. It follows trichromatic characteristic of human eyes. CIELAB colour space is derived in order to create a colour space which is perceptually linear with human eyes. Thus, in this work, images are analyzed in CIELAB colour space.

Segmentation is usually the main task in image processing. It is used to isolate one region from the others by analyzing similarity in some features. K-means is one of the common techniques in image segmentation process. Pattern classification such as Support Vector Machine (SVM) is used in this work to analyze characteristic of data obtained. The objective is to select the best set of features that gives high discriminatory ability.

CHAPTER 4
ACNE VULGARIS SEGMENTATION, CLASSIFICATION AND GRADING

This chapter discusses approaches, basic theory and techniques that are used in this thesis. The pre-processing, image segmentation technique, post-processing, feature extraction, pattern classification and grading are described in this chapter. For acne assessment, close up images of patient covering forehead, right cheek, left cheek, nose and chin are digitally photographed. The images are pre-processed in order to remove noise and unwanted regions. Acne lesions are segmented from the skin image, processed and enhanced for accurate segmentation. Suitable features such as size and colour are extracted from the segmented regions in order to classify the acne lesion to different acne types. Finally, the classification results from five close-up images are combined together in order to generate a grade for the acne similar to the way doctors grade acne patients. Figure 4.1 shows the process of acne assessment using image processing techniques.

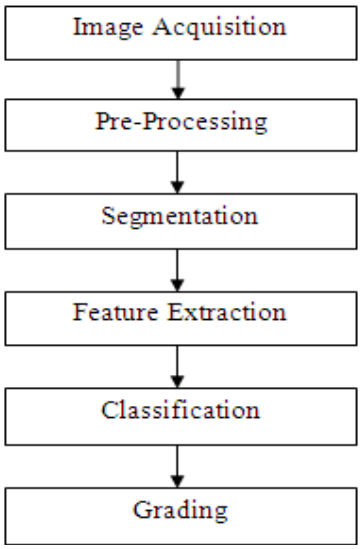


Figure 4.1 Acne assessment using image processing techniques

4.1 Image Acquisition

In order to assess and diagnose the acne vulgaris grading, close up images of forehead, nose, chin, left and right cheek are digitally photographed for each patient as shown in Figure 4.2.

Figure 4.2 is digitally edited for privacy reasons. The image acquisition setup is as shown in Figure 3.1.1 in Chapter 3. The Canon DSLR 500D is used to capture the images. The resolution is 15.1 effective megapixels (4752 x 3168) and the sensor is CMOS APS-C 22.3 x 14.9 mm (1.6 x conversion factor). Green colour is used for the background to facilitate the segmentation of skin. The distance between patients and the camera is fixed to 60 cm. According to technical specifications of the lens we used, minimum focus distance is 0.45m/1.5ft that is the object placed nearer than this distance cannot be focused correctly. Minimum focus distance is chosen to capture maximum details. Two big soft boxes are used for lighting to create a soft and uniform illumination. Soft light is a light source with a large surface area in relation to the subject, so that the light illuminates around the subject. All soft lights can benefit from the use of grids. These grids make it possible for the soft light to be controlled so that the light spread is confined to the subject and does not spill all over the set. Therefore, large soft box produced a broader and good projection of light towards patients. The shadows will be less pronounced and improving the wrap-around quality of the illumination on the subject.

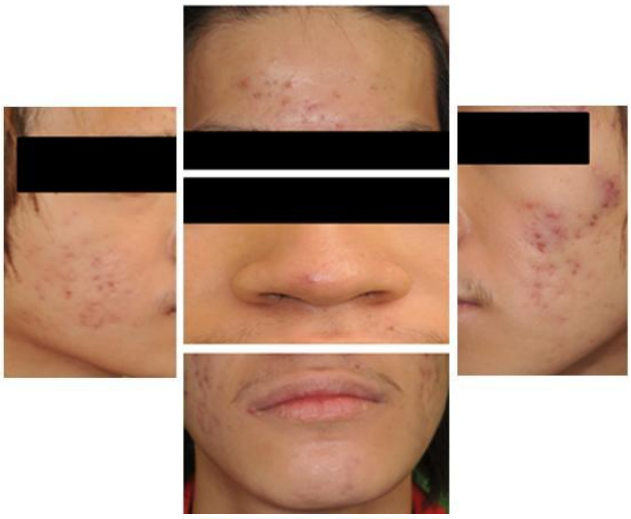


Figure 4.2 Close up images of forehead, nose, chin, left and right cheek

4.1.1 Dataset

The data is obtained from patients with acne attending the Dermatology Clinic, Department of Dermatology Hospital Kuala Lumpur and the Outpatient Department Hospital Kuala Lumpur during the study period. The study is conducted at the Dermatology Clinic, Department of Dermatology, Hospital Kuala Lumpur and the Outpatient Department Hospital Kuala Lumpur. This centre is chosen from Hospital Kuala Lumpur because it is the major dermatological centre in Kuala Lumpur and Selangor, and the tertiary referral centre for dermatology in Malaysia. Hospital Kuala Lumpur is well-resourced with trained personnel and investigative tools essential in the fields of Dermatology, Laboratory and Radiology.

This study protocol has been registered with the National Medical Research Register (NMRR) [72]. The NMRR is the web-based tool designed to support the implementation of the National Institute of Health (NIH) guidelines on the conduct of research in the Ministry of Health Malaysia (MOH).

The data is obtained from patients who have mild, moderate, severe and very severe acne vulgaris. There are 4 grades and the targeted data collection are 100 patients. The determination of the sample size can be done based on the margin error equation [73]. The margin error equation is used to determine a maximum error between the population mean μ (true value) and the sample mean $\bar{x}$ (observed from the collected data). The population data is assumed normally distributed. Only the population standard deviation can be provided to the equation whereas the population mean is unknown. The equation is given as follows,

$$E = Z_{\alpha/2}\frac{\sigma}{\sqrt{n}} \qquad \text{(Equation 4.1)}$$

Variable E represents the margin of the error of the unknown population mean. The error is determined from the sample mean $\bar{x}$ of sample data. If the mean of sample $\bar{x}$ has the same value with the population mean,μ then E will be equal to zero. Variable $Z_{\alpha/2}$ refers to the critical value of normal distribution table (the bell curve). The term α is used to define the level of confidence. Any positive value less than 1 can be applied but in order to have meaningful results, the value of α should be close to 1.

All patients are female and male with acne vulgaris and do not have any other type of dermatological diseases. All patients signed the informed consent forms that contain the nature and objective of the study. Patients who are at the age of 18 years old and more is allowed to give consent while patients who aged less than 18 years old need to get permission from their respective guardians. Appendices A and B show the consent form used during the study.

4.2 Pre-processing

Image pre-processing is typically performed to transform a source image into a new image which is fundamentally similar to the source image, but differs in certain aspects such as lighting compensation, improved contrast etc. The objective of pre-processing is to improve the quality of the image and make it ready for further processing by removing the irrelevant noise and unwanted parts in the image [64].

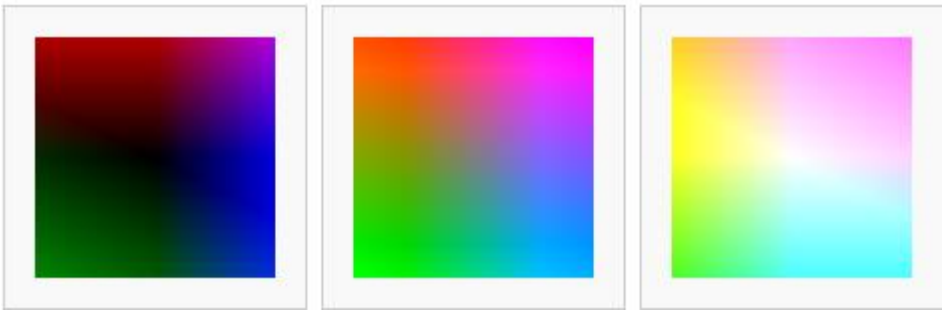
4.2.1 Lighting Compensation

In the data acquisition step, the images acquired consist of skin and non-skin parts. The input colour image is in the RGB format. Since the RGB components are subject to the lighting conditions or ambient illumination, the skin detection may fail if the lighting condition changes. Therefore, a lighting compensation is proposed for first step in pre-processing and before extracting the skin. First, the luminance (greyscale) image is extracted using the equation below.

$$Y = 0.299R + 0.587G + 0.114B \qquad \text{(Equation 4.2)}$$

Figure 4.3 shows how luminance (Y component) affects the colour of images. The resultant luminance of an object is the result (product) of the illumination and the spectral reflectance of the object. Figure 4.3 (a) is under exposed, (b) balanced exposed and (c) is over exposed. The over exposed and under exposed conditions can caused difficulties in identifying details in images. An under exposed image is too dark, while an over exposed image is too bright. Under exposed images generally have blocked shadows (regions of darkness where light is blocked) with no visible

detail, while over exposed images generally have blocked highlights. Therefore, the illumination should be adjusted for a balanced exposure.



(a) (b) (c)

Figure 4.3 RGB images under different illuminations

After the luminance (Y) is extracted from the RGB image, the luminance, Y is computed and averaged as shown in Figure 4.4. The objective of computing the luminance is to determine whether the image has been properly illuminated, in which incorrect illumination can result in over exposed or under exposed images.

Here, Ymax is defined as the maximum Y value for a normally (balanced) exposed image and this value is found by averaging over a number of good exposure images of different types of lesions. While Ymin is the minimum value for normally (balanced) exposed image and this value is also found by averaging over a number of good exposure images of different lesions. Yavg is the average luminance of an image.

Therefore, the luminances of 100 good exposure images are computed in order to determine the Ymax and Ymin. As a result, Ymin and Ymax are 80 and 200 respectively. These values are used as the reference values of Ymin and Ymax.

To compensate for under or over illumination, a correction factor, Yfactor is computed based on the difference between the average luminance, Yavg of the current image and Ymax or Ymin as follows:

1. If Yavg is greater than Ymax, then Yfactor is set to less than 1 in order to reduce the illumination of the image. If the difference between Yavg and Ymax is very large, this fraction will be smaller.

   Yfactor = (Ymax / Yavg) when Yavg > Ymax

2. If Yavg is less than Ymin, then Yfactor is set greater than 1 in order to increase the overall illumination of the image. If the difference between Yavg and Ymin is very large, this fraction will be smaller.

   Yfactor = (Ymin / Yavg) when Yavg < Ymin

3. The image is remained the same for balanced exposed.

   Yfactor = 1 when Ymin ≤ Yavg ≤Ymax.

The new value of global Y factor is multiplied with Red, Green and Blue channels. Figure 4.5 shows results of employing the lighting compensation.

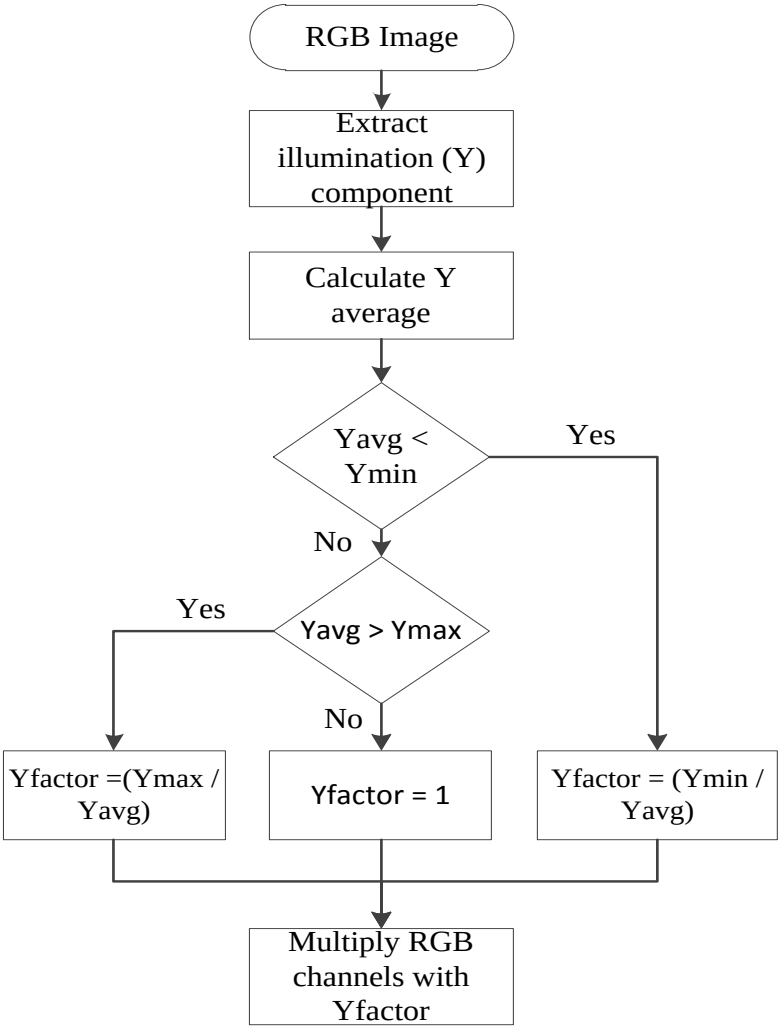
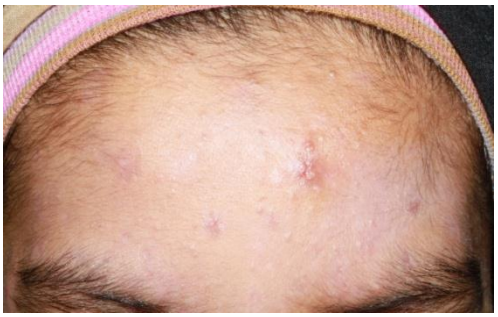
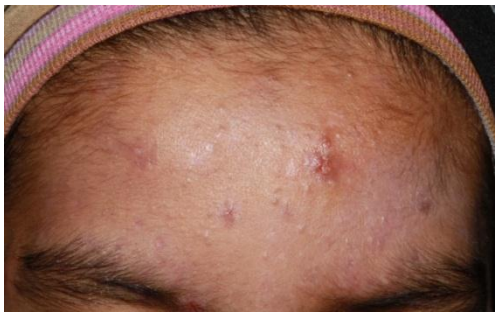


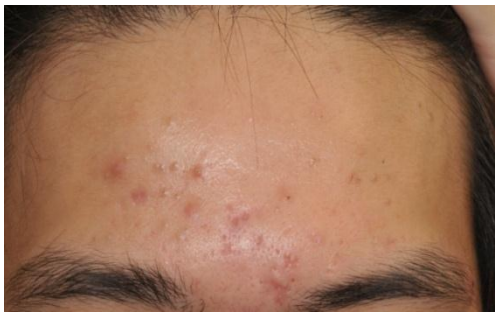
Figure 4.4 The process of lighting compensation



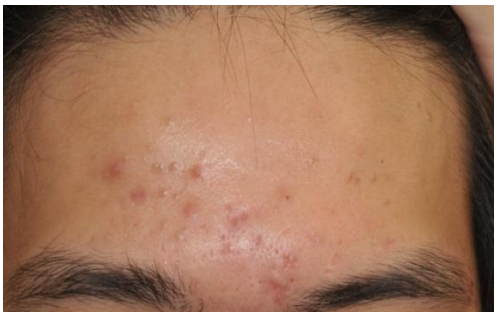
a) Over exposed image



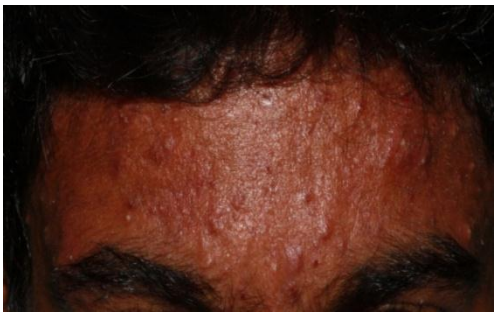
b) Corrected image
(decreased the Y factor)



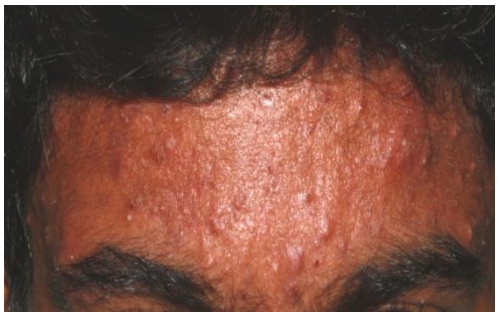
c) Balanced exposed image



d) Corrected image
(no change)



e) Under exposed image



f) Corrected image
(increased the Y factor)

Figure 4.5 Before and after lighting compensation

4.2.2 Skin Detection

After lighting compensation, the image is ready for detecting the skin based on the statistical distribution of its colour components. In 1975, Thomas B. Fitzpatrick, a Harvard dermatologist developed a skin scale name as The Fitzpatrick Scale [65] as shown in Figure 4.6. This skin scale is a numerical classification scheme for the colour of skin. It has been a well-recognized tool for dermatology research into skin colour. The Fitzpatrick Scale categorises skin into the 6 phototypes which are:

- Type I (scores 0-7) White; very fair; freckles; typical albino skin.
- Type II (scores 8-16) White; fair.
- Type III (scores 17-24) Beige; very common.
- Type IV (scores 25-30) Beige with a brown tint; typical Mediterranean Caucasian skin.
- Type V (scores over 30) Dark brown.
- Type VI Black.

Based on Hani *et al* [66] who conducted data collection in Hospital Kuala Lumpur for skin pigmentation analysis, participants skin types ranges from skin type III to V. Malaysians comprises of several main ethnicities such as Malay, Chinese and Indian, but there were also participants from other ethnicities such as African, Arabic, Cambodian and Caucasian as shown in Figure 4.7.

In the skin colour detection process, each pixel was classified as skin or non-skin based on its colour components. Therefore, according to Inseong *et al* [67] human skin has a specific colour range in the Chroma blue – Chroma red (Cb-Cr) space as shown in Figure 4.8. The detection window for skin colour was determined based on mean and standard deviation for a dataset of 164 images and plotted in Cb-Cr space. These 164 images consist of all types of skin starting from Type I to VI and Malaysian skin phototypes are included. Thus, skin pixel is in the range of 10 to 35 for Cr components and -20 to 0 for Cb components as shown by the detection window in the Figure 4.8 and their histogram distribution is shown in Figure 4.9.

Hence, in order to detect skin pixel in a properly illuminated images the Cr-Cb components are computed and if the values satisfy that range and the pixel is

considered as skin otherwise it is considered as non-skin. Figure 4.10 shows the process of skin detection.

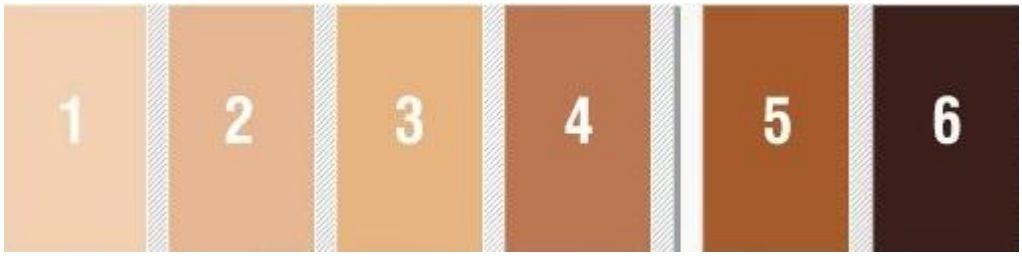


Figure 4.6 Fitzpatric scale [65]

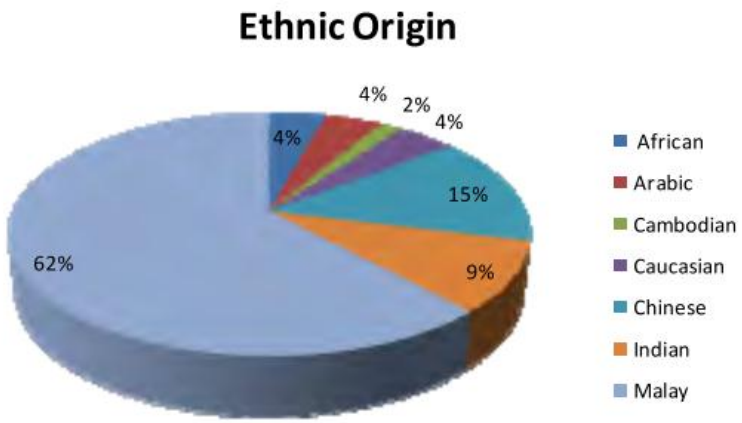


Figure 4.7 Ethnic Origin Distribution [66]

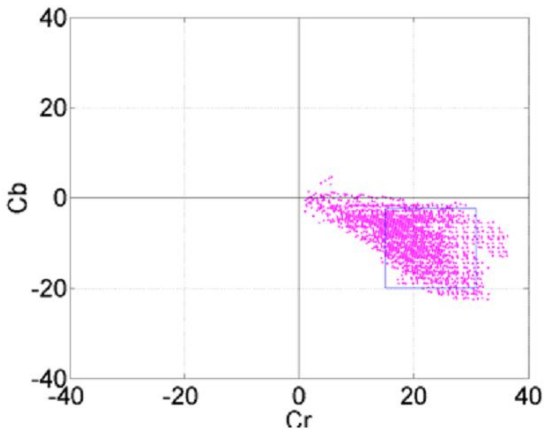


Figure 4.8 Skin pixels in YCbCr colour space [67]

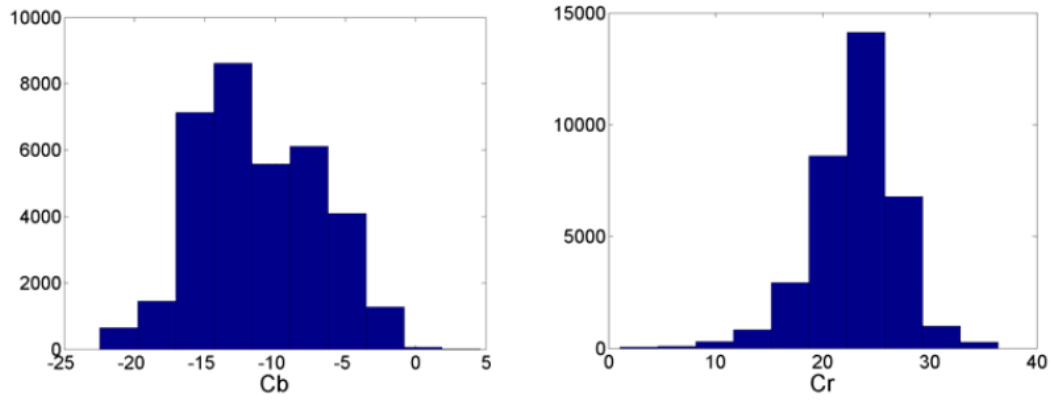


Figure 4.9 (a) Histogram distribution of Cb (b) Histogram distribution of Cr [67]

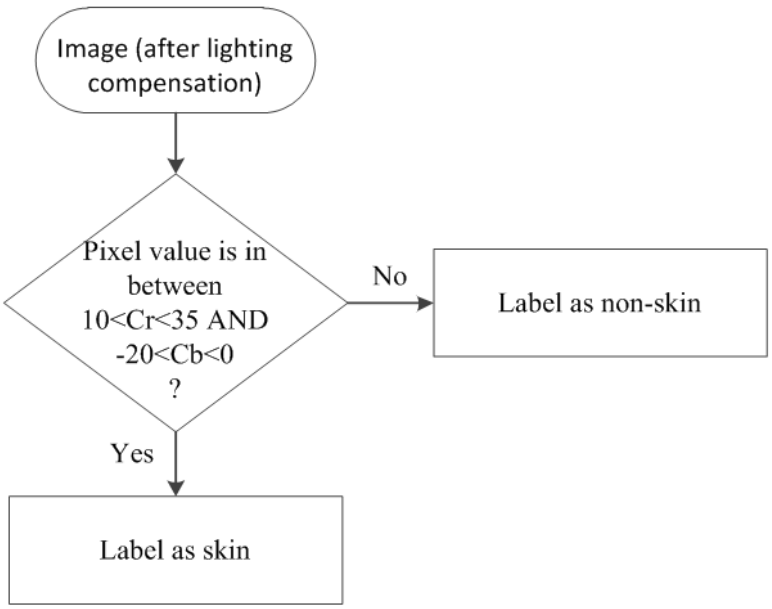
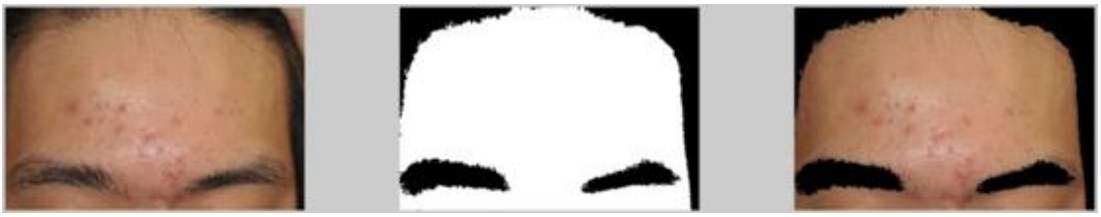


Figure 4.10 Process of Skin Detection

Figure 4.11 (a) shows the image after lighting compensation process. Then Figure 4.11 (b) shows the binary image with white pixel referring to skin pixel, while black pixel is to non-skin pixel. Finally skin detection is achieved using mask shown in Figure 4.11 (c). At this stage, acne and scar are still categorized as skin. However, in next segmentation stage, acne, scar and skin will separated using automated modified k-means clustering.



(a) (b) (c)

Figure 4.11 Skin Detection

4.2.3 Image Conversion

There are major colours in the human image such as red, pink, yellow, white and black. Therefore, it is easy to see the difference between these colours from one another. The L*a*b* colour space (also known as CIELAB or CIE L*a*b*) enables to quantify these visual differences.

Since the segmentation in next stage uses CIE L*a*b* colour space, the images after skin detection are converted from RGB to CIE L*a*b* colour space. In CIE L*a*b* colour space, the a* axis represents degree of redness to greenness with positive values represent red and negative values represent green. Therefore, the background colour is chosen based on high contrast colour to the human skin. Hence, background can be easily differentiated from the image. Red is known as the most dominant colour of human skin [64]. Using green colour for the background is expected to highlight that pixels belonging to the human skin. Skin pixels will have positive values and pixels belonging to the background will have negative values for the CIE a* band.

4.3 IMAGE SEGMENTATION

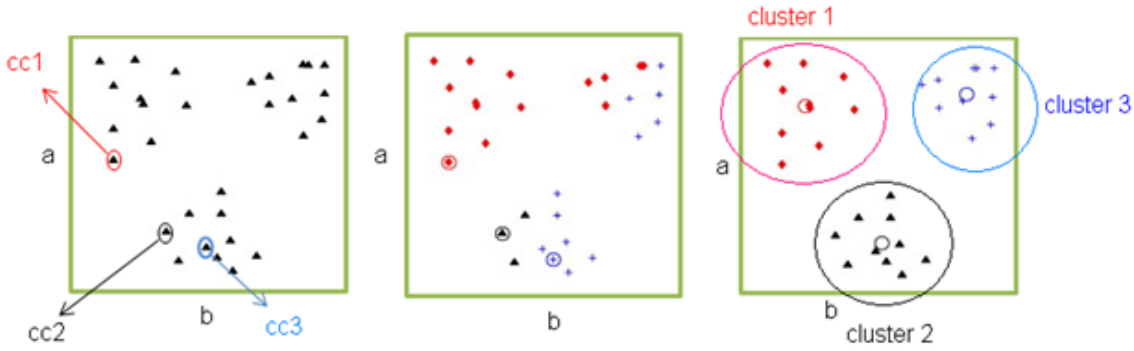
4.3.1 General K-means algorithm

K-means is suitable for biomedical image segmentation since the number of clusters (K-value) is usually known for images of particular region of human anatomy [57]. At the beginning, the number of clusters, a positive integer number, K-value is chosen. In our implementation, the inputs to k-means algorithm are the a* and b* channels of the facial images that contains skin area only (close up image).

The steps in K-means process are as follows:

1. Choose *k* cluster centres randomly in a* and b* channel such as Figure 4.12 (a). CC1 is cluster centre 1, CC2 is cluster centre 2 and CC3 is cluster centre 3. Cluster centre is the centre that is closest to each pixel.
2. Assign each pixel in the image to the minimum cluster distance between the pixel and the cluster centre such as Figure 4.12 (b).
3. Averaging the minimum cluster distance between the pixel and the cluster centre of all the pixels in the cluster for re-computing the cluster centre.
4. Repeat the two previous steps until convergence criterion is met which is no pixels change to any cluster such as Figure 4.12 (c).

In this case, distance is the squared or absolute difference between a pixel and a cluster centre. The difference is typically based on pixel colour, intensity, texture, and location, or a weighted combination of these factors. The process of this clustering is shown in Figure 4.13.



(a) (b) (c)

Figure 4.12 Illustration of K-means algorithm (a) Two-dimensional input data with three clusters centre that chosen randomly (b) three seed points as cluster centre and initial assignment of the data points to clusters (c) final clustering obtained by K-means algorithm at convergence.

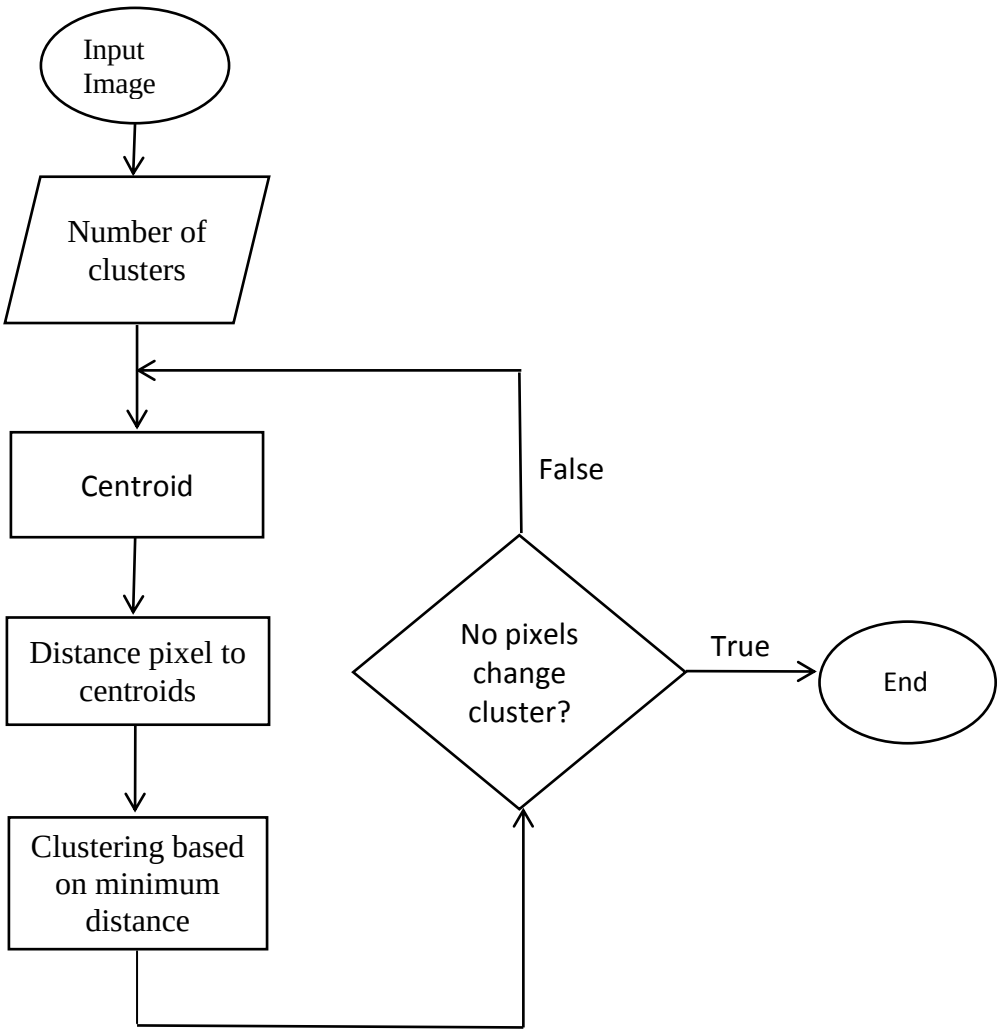


Figure 4.13 Process of K-means clustering

Firstly, an input image is loaded to k-means clustering algorithm and the number of clusters, K-value is chosen. K-value is chosen from three to nine in order to clustering the normal skins, acne lesions and scar. The number of clusters is chosen as they represented the actual distribution of acne pixel in the image. The minimum K-value is three since the image have at least three clusters (skin, acne and scar). Furthermore, the maximum of K-value is nine since values more than nine are found to be more complex without any significant improvement in the segmentation result.

Then, the centroid of each cluster is determined randomly. The distance of every pixel in a* and b* channel from the centroid is calculated using Euclidean distance. Each pixel is clustered based on minimum distance to centroid. The process of allocating pixels to clusters is repeated till the time no further movement of pixel from one to another cluster (system reaches stability). Once the process gets out of the loop, we have the final image grouped into K number of clusters.

4.3.1.1 The problems with an existing K-means clustering

The two major problems with the existing K-means clustering are follows:

a. Choosing the number of clusters

b. Choosing the cluster that represent acne among the clustering results

K-means requires predefining the number of clusters that we want to segment the image to. Usually the number of cluster is not fixed and it can vary from image to image. Even images from the same patient might require different number of cluster depending on the part of the face been address. Therefore, it is hard to fix a specific number of clusters (K) that can be applied to all images. The second problem with K-means clustering is how to choose the cluster that represents the acne. Because cluster centres are initialized randomly and even if we predefine initial cluster centres the final value can change drastically depending on the image condition, it is not possible to predefine the cluster index that represent acne unless by evaluating the content of the cluster using a suitable fitness function.

Due to these previous problems, this research focuses on producing an automated method for selecting the number of clusters and the optimal clusters index for K-mean cluster of acne images.

4.3.1.2 Automated modified K-means clustering

In order to overcome the previously mentioned problems with K-means clustering, we proposed a method for automatically selecting the suitable number of clusters and the optimal cluster index. The solution starts by executing the K-means clustering using different K values. Then for each K we choose the image that contains the minimum number of pixels. This is because acne represents only small part of the face compared to skin. After choosing the clusters with minimum area, we evaluated the content of each cluster using its colour and texture properties. In this step an SVM classifier is employed to classify the content of the clustered image into acne/skin classes. Among the retained clusters, the cluster index (the K-value) that gives the highest percentage of acne is chosen to be the result of the automated K-means method. Therefore, this method does not require predefining the number of clusters (K-value) or identifying which cluster is acne. Moreover, the whole process is fully automated in one system. Figure 4.14 shows the flow of automated K-means clustering process.

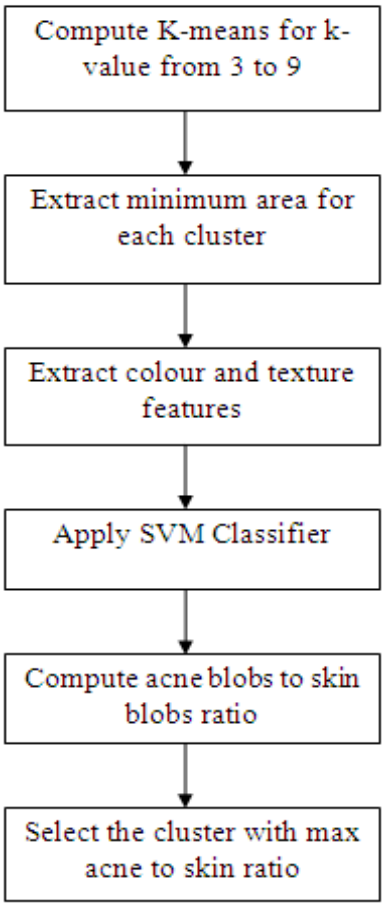


Figure 4.14 Flow of automated k-means clustering process

4.3.2 Features

In order to discriminate acne and non-acne, several features were used such as mean, variance, skewness, kurtosis, contrast, correlation, energy, homogeneity and entropy as shown in Figure 4.15. In addition, Table 4.1 indicates the explanation and mathematical equation for those features. Therefore, 520 samples of skin and 520 samples of acne itself are selected manually and tested using colours and textures properties. The results are shown in Figure 4.16 to 4.24. Those figures illustrates the separation of acne and skin in a* and b* components.

Colour	**Texture**
• Mean	• Contrast
• Variance	• Correlation
• Skewness	• Energy
• Kurtosis	• Homogeneity
	• Entropy

Figure 4.15 Colour and Texture properties

Table 4.1 Mathematical equation for colours and textures properties

Descriptor	Explanation	Formula
Mean	Average or mean value of array.	$\frac{1}{n}\sum_{i=0}^{n} a_i$
Variance	A measure of how far a set of numbers is spread out. The variance is the square of standard deviation.	$\frac{1}{n-1}\left(\sum_{i=1}^{n}(X_i-\bar{X})^2\right)$ Where $\bar{x}$ is the arithmetic mean of the data *x*.
Skewness	A measure of the asymmetry of the data around the sample mean. The skewness of the normal distribution is zero.	$s=\frac{E(x-\mu)^3}{\sigma^3}$ where μ is the mean of *x*, σ is the standard deviation of *x*, and *E*(*t*) represents the expected value of the quantity *t*.
Kurtosis	A measure of how outlier-prone a distribution is. The kurtosis of the normal distribution is 3.	$k=\frac{E(x-\mu)^4}{\sigma^4}$ where μ is the mean of *x*, σ is the standard deviation of *x*, and *E*(*t*) represents the expected value of the quantity *t*.
Correlation	A measure of how correlated a pixel is to its neighbour over the entire image. Range of values is 1 to -1, corresponding to perfect positive and perfect negative correlations.	$\frac{\sum_i\sum_j(i-\mu_x)(j-\mu_y)P_d(i,j)}{\sigma_x\sigma_y}$
Contrast	A measure of intensity contrast between a pixel and its neighbour over the entire image.	$\sum_i\sum_j(i-j)^2P_d(i,j)$
Energy	A measure of uniformity in the range [0, 1]. Uniformity is 1 for a constant image.	$\sum_i\sum_j P_d^2(i,j)$
Homogeneity	Measures the spatial closeness of the distribution of elements in G to the diagonal.	$\sum_i\sum_j\frac{P_d(i.j)}{1+\lvert i-j\rvert}$
Entropy	Measures the randomness of the elements of G.	$-\sum_i\sum_j P_d(i,j)logP_d(i,j)$

4.3.2.1 Colours properties

a) Mean

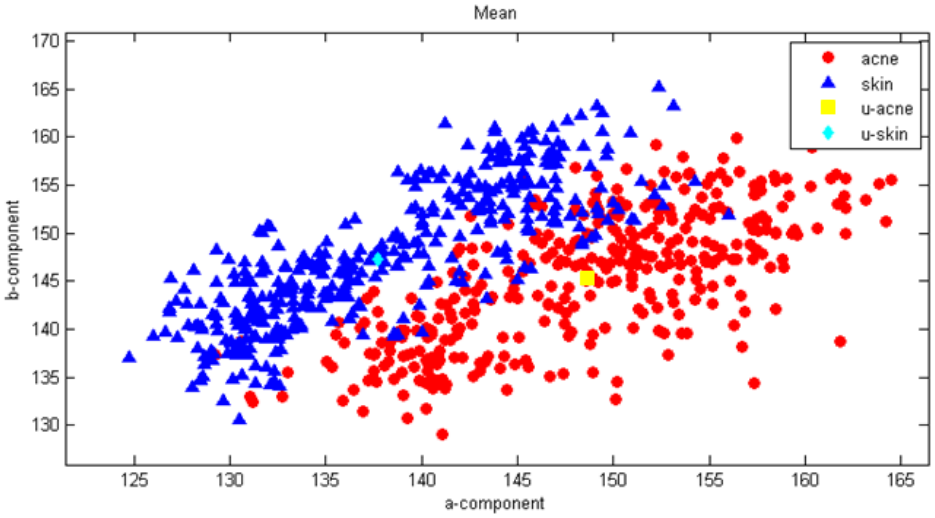


Figure 4.16 Mean of acne and skin in a* and b* components

Figure 4.16 shows that the mean of acne and skin pixels based on their a* and b* values for 520 samples of skin and 520 samples of acne. The red circle button indicates the acne pixels, while blue triangle indicates the skin pixels. Meanwhile, the yellow square indicates the centroid of the acne pixel means. Turquoise diamond indicates the centroid of the skin pixel means. Mean is an average value of the selected point of acne and skin along different dimensions of an array. The acne pixel means have a* component values ranging from 129 to 164 and b* component values ranging from 128 to 160. For skin, it is from 124 to 156 for the a* component and from 130 to 165 for b* component. Consequently, the points of acne and skins are well separated with the average of total mean points of acne which are 148 in a* component and 145 in b* component. Furthermore, the average of total mean points of skin are 138 in a* component and 147 in b* component. It is therefore possible for the mean of acne and skin in a* and b* components to be used as a feature to differentiate between acne and skin.

b) Variance

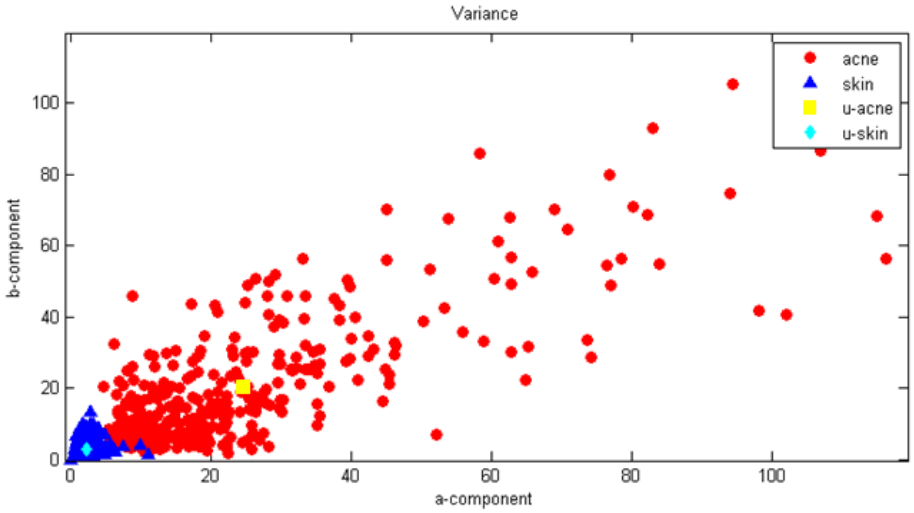


Figure 4.17 Variance of acne and skin in a* and b* components

Figure 4.17 illustrates the variance of acne and skin in a* and b* components from 520 samples of skin and 520 samples of acne. The variance is a measure of how far each value in the data set is from the mean. It shows the squared differences from the mean. The variance for acne is around 5 to 112 in a* component and 1 to 102 in b* component. For skin, the variance is around 0 to 11 in a* component and 0 to 17 in b* component. The mean of the variance values of acne and skins are well separated with the mean of total variance points of acne which are 20 in a* component and 24 in b* component and for skin, 2 in a* component and 3 in b* component. Thus, the variance of acne and skin in a* and b* components can also be used as a feature to differentiate between acne and skin.

c) Skewness

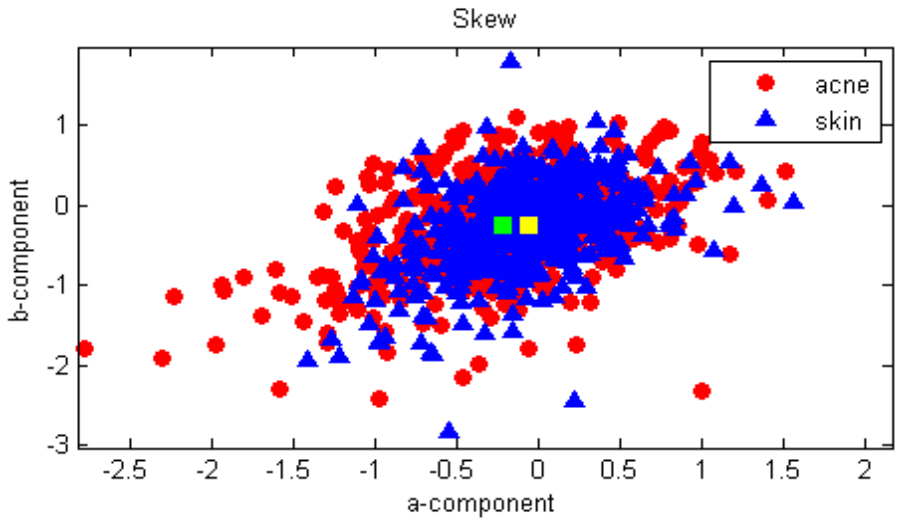


Figure 4.18 Skewness of acne and skin in a* and b* components

Figure 4.18 demonstrates the skewness of acne and skin in a* and b* component obtained from 520 samples of skin and 520 samples of acne. The red circle button indicates the acne points, while blue triangle indicates the skin points. Skewness measure the asymmetry of the data around the sample mean. In negative skewness, the data are spread out more to the left of the mean than to the right. The data in positive skewness are spread out more to the right. Thus, zero is the skewness of the normal distribution or any perfectly symmetric distribution. It can be seen from the figure that the skewness for acne is around -2.9 to 1.5 in a* component and -2.5 to 1.1 in b* component. Besides, the skewness for skin is around -1.4 to 1.6 in a* component and -2.9 to 1.8 in b* component. However, there are overlapping points of acne and skins in skewness while the mean for both are very close. The skewness does not show a good separation of acne and skin points in a* and b* components and hence cannot be used as a feature to differentiate between acne and skin.

d) Kurtosis

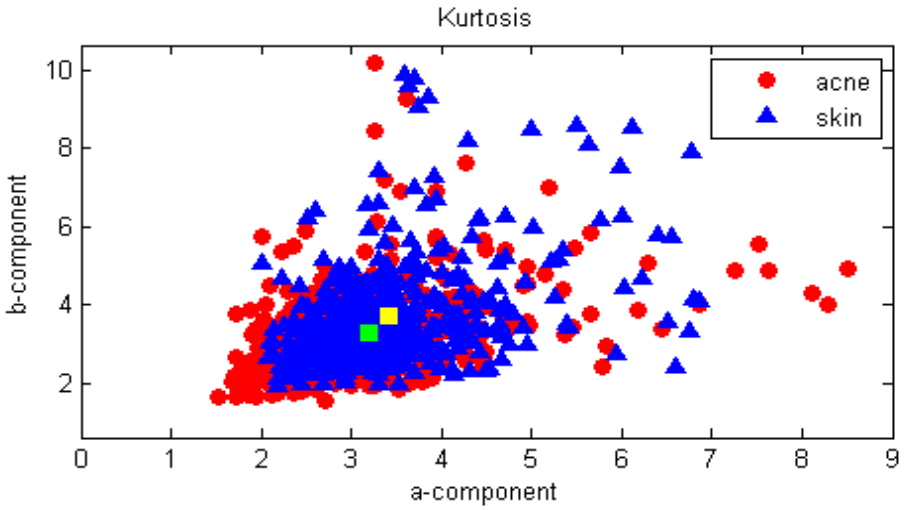


Figure 4.19 Kurtosis of acne and skin in a* and b* component

Figure 4.19 portrays the kurtosis of acne and skin in a* and b* component obtained from 520 samples of skin and 520 samples of acne. Kurtosis measure of how outlier-prone a distribution is. The kurtosis of the normal distribution is 3. Distributions that are more outlier-prone than the normal distribution have kurtosis greater than 3 while distributions that are less outlier-prone have kurtosis less than 3. The kurtosis for acne is around 1.5 to 8.5 in a* component and 1.8 to 10.2 in b* component. The kurtosis for skin is around 2 to 6.9 in a* component and -1.9 to 10 in b* component. However, there are many overlapping points of acne and skins in kurtosis and the mean of both are very close. In the kurtosis analysis, there is little separation of acne and skin in a* and b* components and thus it cannot be used to differentiate between acne and skin.

4.3.2.2 Textures properties

An important approach to region description is to quantify its texture content. There are three principal approaches used in image processing to describe the texture of a region namely statistical, structural and spectral.

Statistical approaches yield characterizations of textures as smooth, coarse, grainy and so on. Structural techniques deal with the arrangement of image primitives, such as the description of texture based as the description of texture based on regularly spaced parallel lines. Spectral techniques are based on properties of the Fourier spectrum and are used primarily to detect global periodicity in an image by identifying high-energy, narrow-peaks in the spectrum. Here, the statistical approaches are used such as contrast, correlation, energy, homogeneity and entropy.

a) Contrast

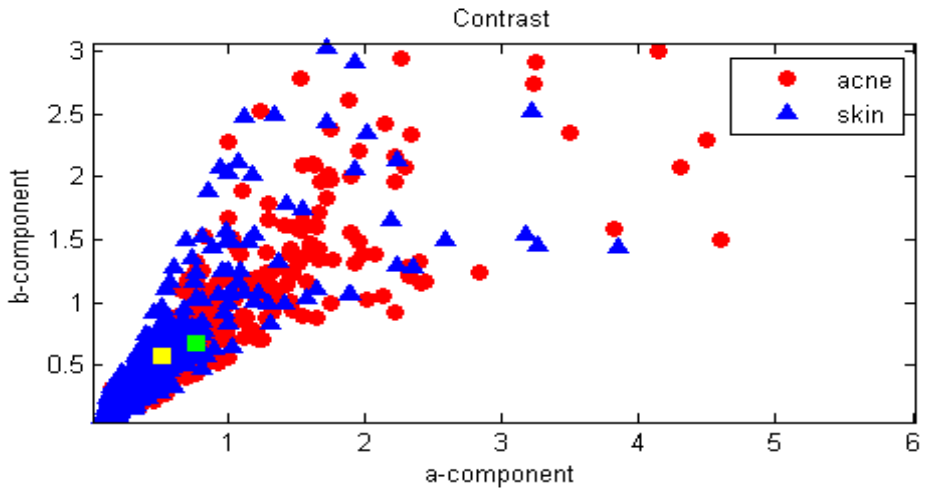


Figure 4.20 Contrast of acne and skin in a* and b* components

Figure 4.20 shows that the contrast of acne and skin in a* and b* components obtained from 520 samples of skin and 520 samples of acne. Contrast is the difference in luminance and/or colour that makes an object or its representation in an image or display distinguishable. The contrast for acne is around 0 to 4.6 in a* component and 0 to 3 in b* component. The contrast for skin is around 0 to 3.9 in a* component and 0 to 3.1 in b* component. However, a lot of the points of acne and skins in contrast are overlapped to each other and the mean of both are very close.

The contrast did not show the good separation of acne and scar in a* and b* components and thus cannot be used as a texture properties to differentiate between acne and skin.

b) Correlation

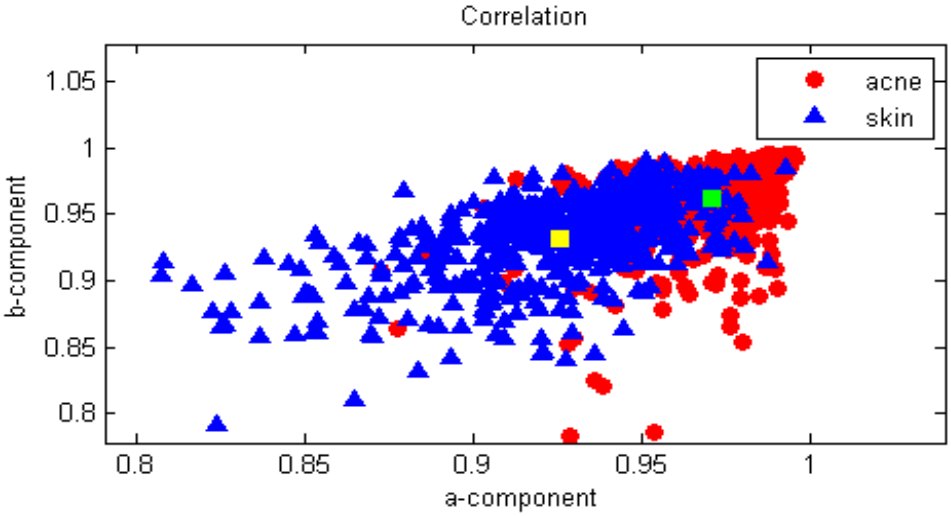


Figure 4.21 Correlation of acne and skin in a* and b* components

Figure 4.21 portrays that the correlation of acne and skin in a* and b* components obtained from 520 samples of skin and 520 samples of acne. Correlation is a measure of how correlated a pixel is to its neighbour over the whole image. The correlation for acne is around 0.88 to 0.99 in a* component and 0.78 to 1 in b* component. The correlation for skin is around 0.81 to 0.99 in a* component and 0.79 to 0.99 in b* component. However, the correlation points for acne and skin overlapped and the mean of both are very close. The correlation-based texture analysis does not show good separation of acne and skin in a* and b* components and therefore cannot be used to differentiate between acne and skin.

c) Energy

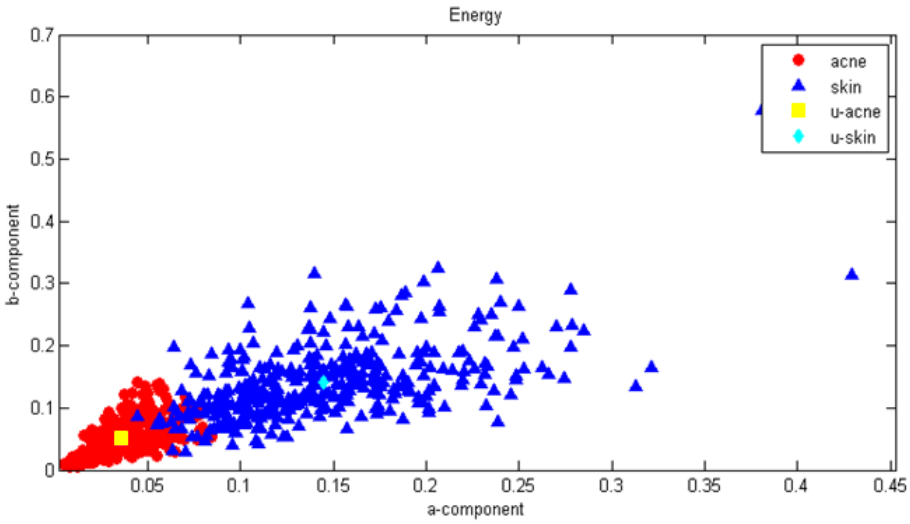


Figure 4.22 Energy of acne and skin in a* and b* components

Figure 4.22 demonstrates that the energy of acne and skin in a* and b* components obtained from 520 samples of skin and 520 samples of acne. The energy is the sum of squared elements in the gray-level co-occurrence matrix. Energy is also known as uniformity, uniformity of energy, and angular second moment. The energy for acne is around 0 to 0.08 in a* component and 0 to 0.15 in b* component. The energy for skin is around 0.04 to 0.43 in a* component and 0.02 to 0.32 in b* component. The points of acne and skins are well separated with the mean of total energy points of acne at 0.03 and skin at 0.14. Therefore, the energy of acne and skin in a* and b* component can be used as a texture feature to differentiate between acne and skin.

d) Homogeneity

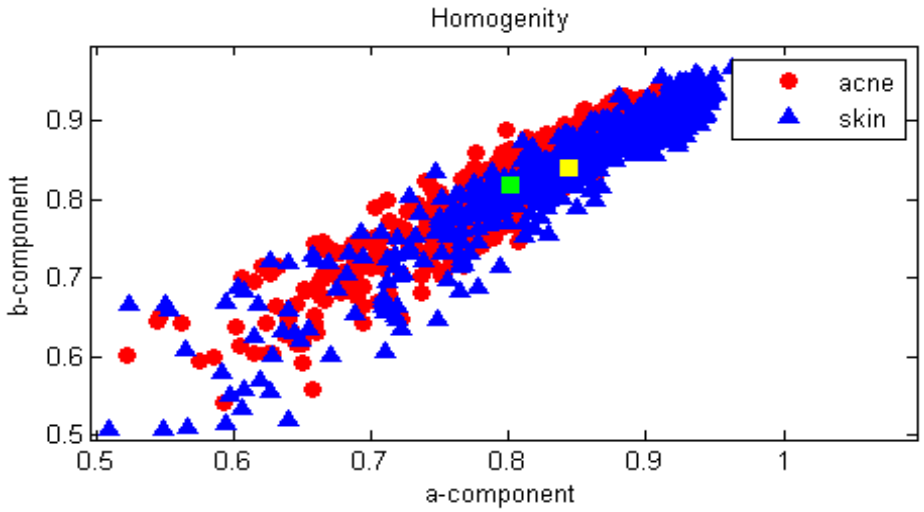


Figure 4.23 Homogeneity of acne and skin in a* and b* components

Figure 4.23 illustrates that the homogeneity of acne and skin in a* and b* components obtained from 520 samples of skin and 520 samples of acne. Homogeneity is a value that measures the closeness of the distribution of elements in the gray-level co-occurrence matrix (GLCM) to the GLCM diagonal. The homogeneity for acne is around 0.52 to 0.91 in a* component and 0.53 to 0.92 in b* component. The homogeneity for skin is around 0.5 to 0.95 in a* component and 0.5 to 0.96 in b* component. The homogeneity points of acne and skins are overlapped and the mean of both are very close. The homogeneity-based texture analysis does not provide separation of acne and skin in a* and b* components and thus cannot be used as a texture feature to differentiate between acne and skin.

e) Entropy

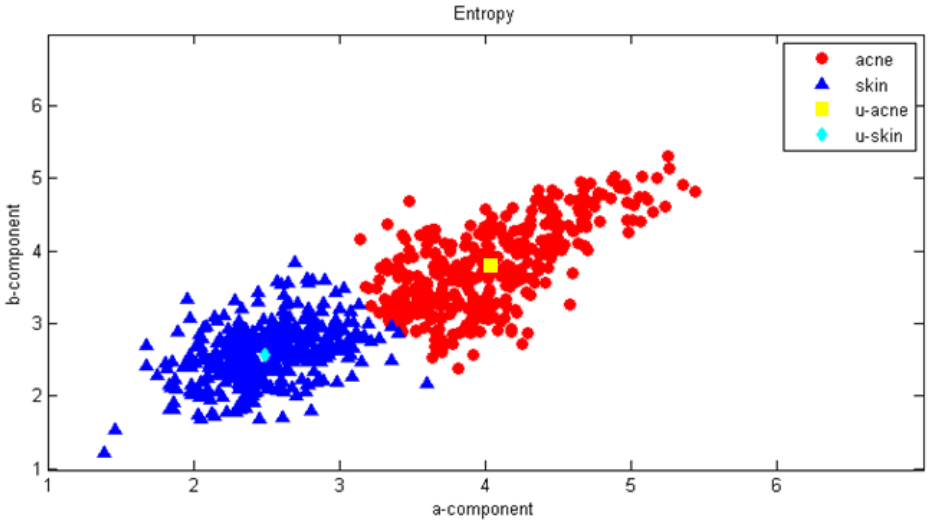


Figure 4.24 Entropy of acne and skin in a* and b* components

Figure 4.24 depicts that the entropy of acne and skin in a* and b* components obtained from 520 samples of skin and 520 samples of acne. The entropy is the measures of the randomness of the element of gray-level co-occurrence matrix (GLCM). The entropy for acne is around 3.1 to 5.5 in a* component and 2.3 to 5.2 in b* component. For skin, the entropy is around 1.4 to 3.7 in a* component and 1.1 to 3.8 in b* component. The entropy points of acne and skins are well separated with the mean of total entropy points of acne are 4 in a* component and 3.7 in b* component and for skin, 2.5 in both a* component and b* component. The value of entropy for acne is higher than skin. From the above entropy-based texture analysis, the entropy of acne and skin in a* and b* components can be used as a texture feature to differentiate between acne and skin.

Table 4.2 Summary of colour and texture analysis

Descriptor/ colour component	Acne		Skin		Feature to distinguish acne and skin
	a*	b*	a*	b*	
Mean	129-164	128-160	124-156	130-165	Yes
Variance	5-112	1-102	0-11	0-17	Yes
Skewness	-2.9-1.5	-2.5-1.1	-1.4-1.6	-2.9-1.8	No
Kurtosis	1.5-8.5	1.8-10.2	2-6.9	1.9-10	No
Contrast	0-4.6	0-3	0-3.9	0-3.1	No
Correlation	0.88-0.99	0.78-1	0.81-0.99	0.79-0.99	No
Energy	0-0.08	0-0.15	0.04-0.43	0.02-0.32	Yes
Homogeneity	0.52-0.91	0.53-0.92	0.5-0.95	0.5-0.96	No
Entropy	3.1-5.5	2.3-5.2	1.4-3.7	1.1-3.8	Yes

4.3.2.3 Selected Features:

As shown in Table 4.2, not all colour and texture features provide good separation between skin and acne lesion. In order to build a classifier that classifies the image content into acne/skin, the chosen feature must have good separation between skin and acne. From the table, it can be seen that only mean and variance form suitable colour features while energy and entropy form suitable texture features for distinguish acne and skin. Using these four features (Mean, Variance, Entropy, Energy), a support vector machine classifier is developed to classify acne and skin.

4.3.2.4 Building an SVM classifier:

In order to build an SVM Classifier, 520 samples of acne lesions and 520 samples of skin lesions are obtained from participant of different skin colours having acne lesion of different severity scores. Using samples representing the possible situations will make the classifier more accurate in different conditions. Support vector machine classification is used because of its simplicity and its ability to linearise nonlinear features space in order to achieve good separation between the data classes. In the SVM implementation, 70% of the data is used for training and 30% for cross validation and testing. A linear SVM kernel is used because the separation between

the acne and skin groups in the previous figures (Figure 4.16, 4.17, 4.22 and 4.24) are nearly linear. Figure 4.25- 4.28 show the results of SVM classifier learning for the four chosen features.

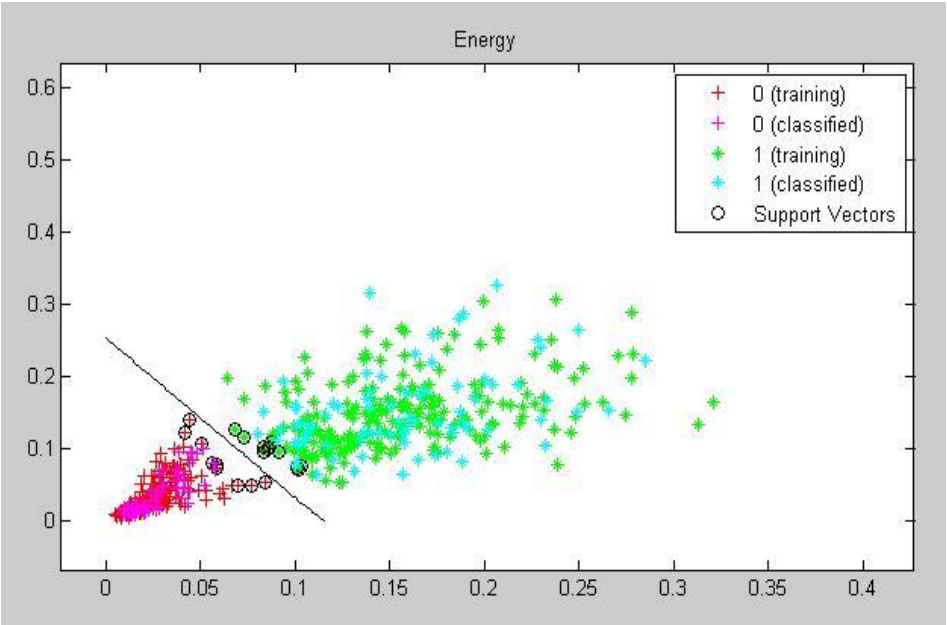


Figure 4.25 Energy separation using SVM Classifier

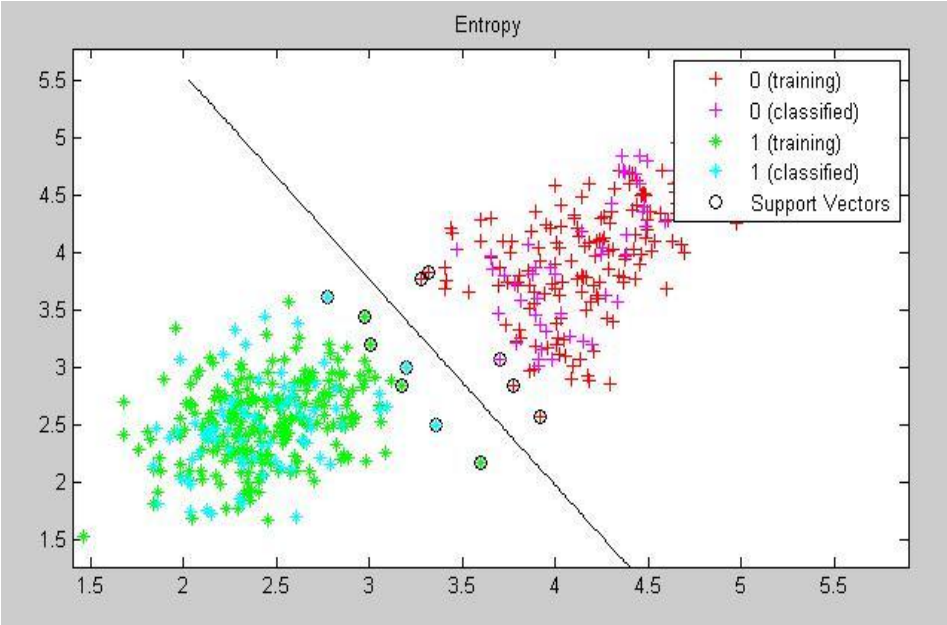


Figure 4.26 Entropy separation using SVM Classifier

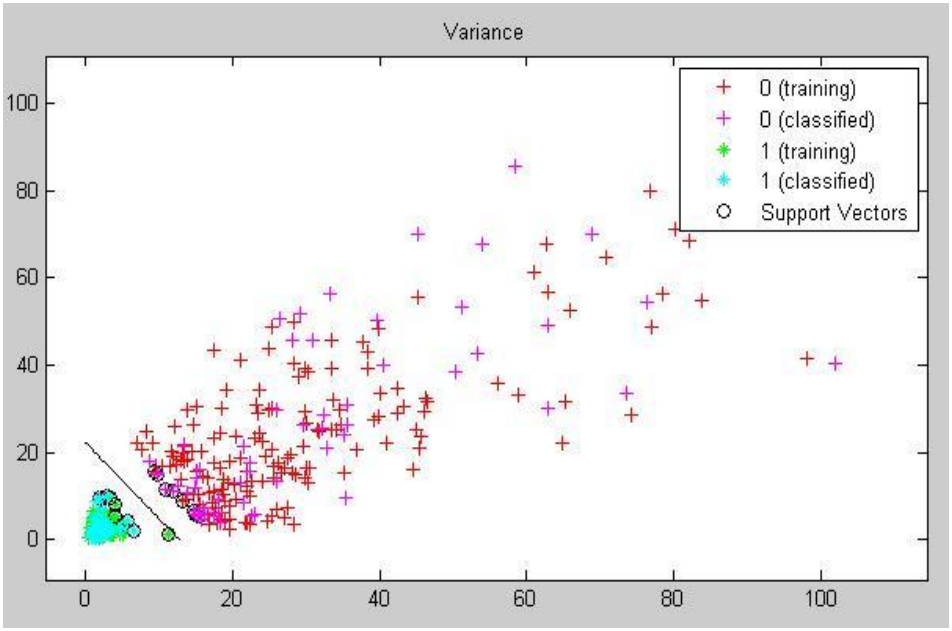


Figure 4.27 Variance separation using SVM Classifier

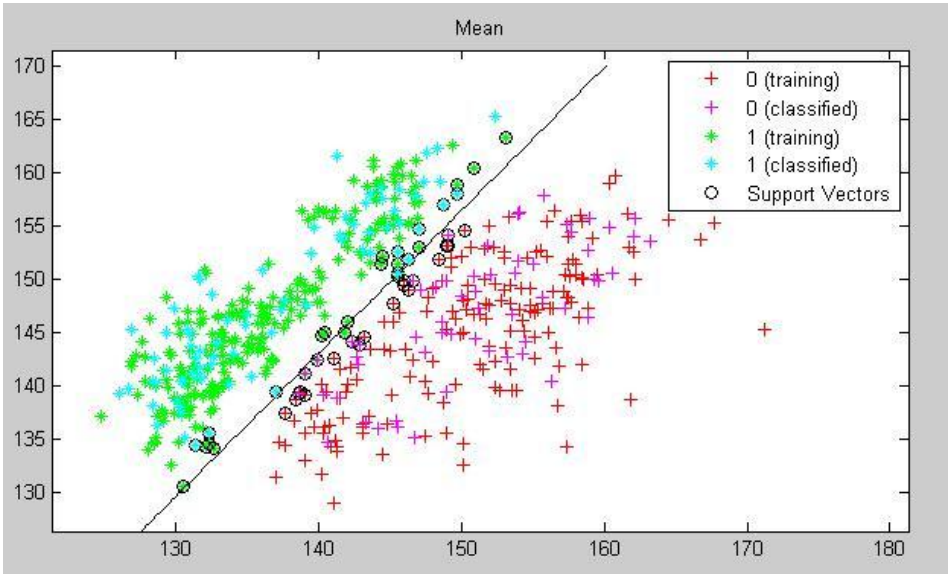


Figure 4.28 Mean separation using SVM Classifier

The figures show the SVM classifier with good separation has been built using the four features. Figure 4.25 illustrates the energy separation using SVM Classifier. Even the support vectors of acne (red) and skin (green) for energy are a bit close to margin, it still can give the good separation since no overlapped between them after training and classified. Furthermore, Figure 4.26 demonstrates the entropy separation using SVM Classifier and Figure 4.27 shows the variance separation using SVM

Classifier. From these 2 figures, we can see the support vector for entropy and variance are far and diverge from margin which can give the good separation. This is because of value of entropy and variance for acne and skin are far. Maximum margin is most stable under perturbations of the inputs. While Figure 4.28 displays the mean separation using SVM Classifier, the support vector of acne and skin for mean is too close and narrow to margin. This is because of the mean value of acne and skin are near. However, it still can give the good separation because not all the support vector of acne is adjoining to the support vector of skin. From these 4 figures, it is prove that acne and skin can be separated using SVM Classifier.

4.3.3 Area

In order to develop on automated modified K-means clustering, the following criteria must be met with the process shown in Figure 4.29.

a) Minimum Area
b) Colours and features separation using SVM classifier

Initially, we selected a number of cluster groups where each group contains the number of clusters to which the input image is segmented. In this implementation we chosen clusters groups ranging from k-value equal to 3 till k-value equal to 9 where the minimal number of clusters is 3 and the maximum is 9. At each step we chosen one group and we apply the k-means algorithm using the given k-value and as a result k-number of segmented images are extracted. Here the input to the k-means algorithm is the a and b channels of the skin face image after non skin areas have been removed as explained in section 4.2.2. After that, the total area within each segment is computed and divided by the full image area. It is obvious that acne represent very small percentage of the face area compared to skin even at the very severe stages. Therefore, we choose the segmented image with the minimal area as a candidate for the acne image. The previous process is applied to all k-values chosen and the minimal area cluster (segmented image) is stored as acne candidate.

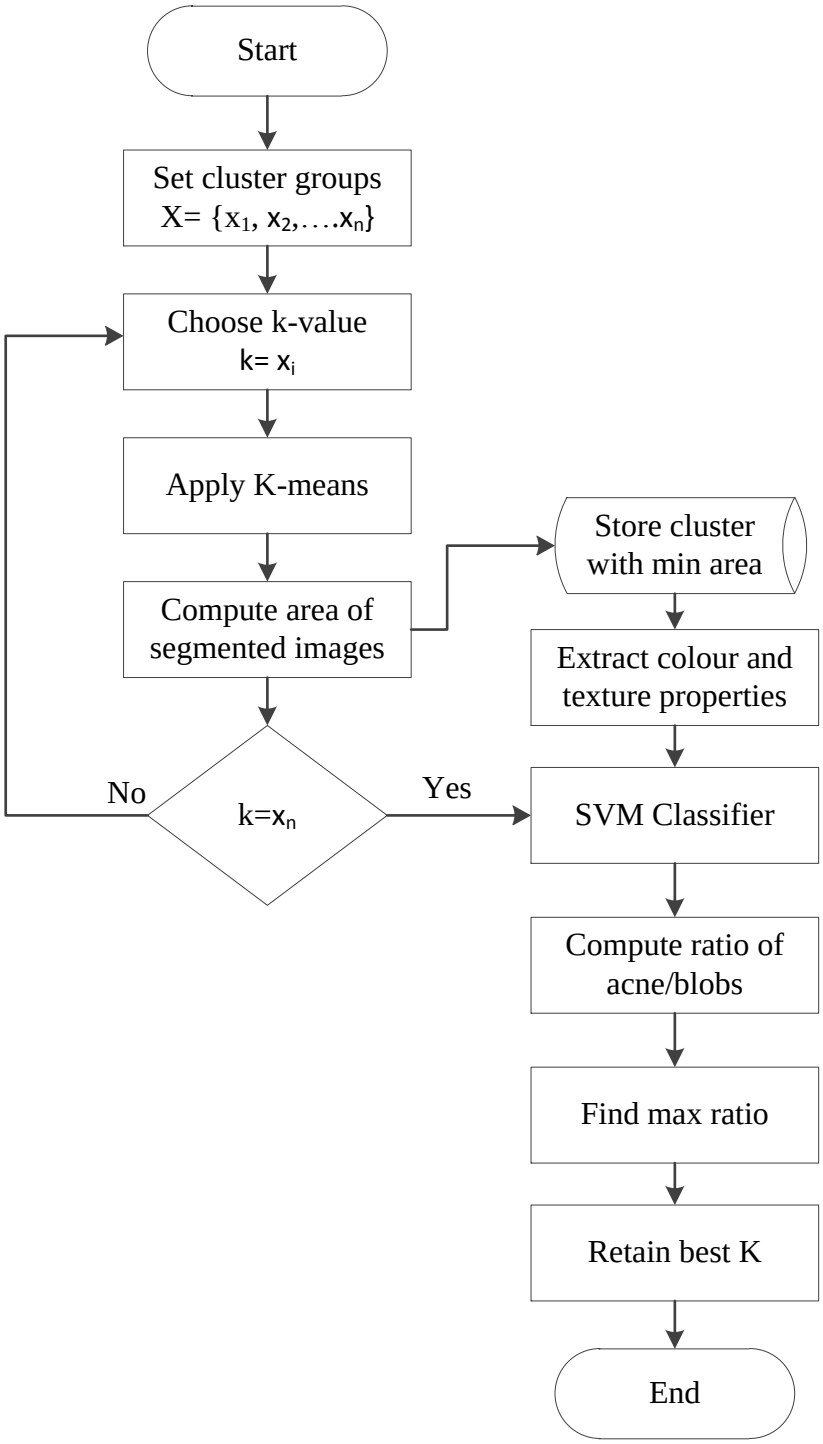
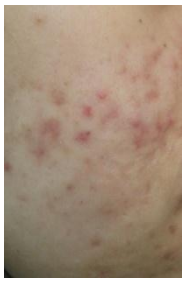


Figure 4.29 Process of automated modified K-means clustering

After completing the k-means process for all clusters, a set of minimal area images are return which are consider as candidate for acne image. At this stage, colour and texture properties of the pixels that represent these segmented images are analyzed to select the best acne candidate using SVM classification. Each segmented

image contains a number of blobs that represent acne candidates. For each blob in every segmented image, colour and texture properties are computed. Colour properties represented the mean and the variance of both a* and b* channels for the blob and texture features represent the entropy and the energy for both a* and b* channels for each blob in the segmented image. After that, these colour and texture features are fed into SVM classifier which classifies these blobs into skin/acne based on the above given features. Finally, after applying this classifier on all the segmented images, the image that has the maximum ratio of acne blobs to the total number of blobs in the image is chosen as the acne image.

Figure 4.30 shows an example of minimum area for K-value equal to five. The input data is segmented to five clusters and cluster number two indicates the minimum area among others clusters (7%) is chosen as a minimum area. The information on the minimum area is stored in database.

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				
Percentage of Area		15%	7%	27%

Item	Cluster 4	Cluster 5
Images		
Percentage of Area	26%	25%

Figure 4.30 Segmented images with percentage of area

Then, Figure 4.31 shows the minimum cluster for each k-value from three to nine. The images of minimum area of each k-value are checked with SVM classifier.

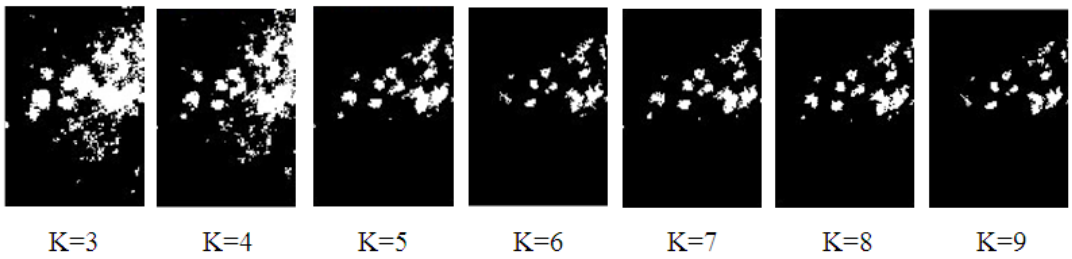
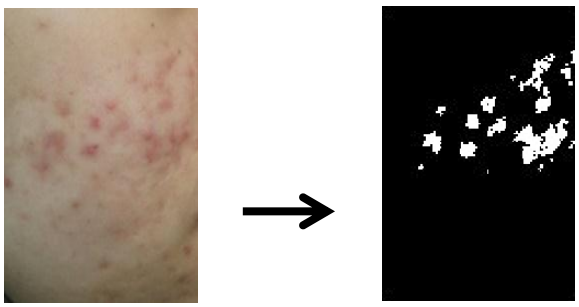


Figure 4.31 Minimum area images of each K-value

Then, using the best 4 features which are energy, entropy, mean and variance that is trained using Support Vector Network (SVM) classifier, the best cluster that have high percentage of acne is chosen among the minimum area images. The result is shown in Figure 4.32. The minimum area of k-value equal to eight with 40% percentage of acne is chosen as final result.



(a) (b)

Figure 4.32 (a) Original Image (b) Final Result using SVM Classifier

4.4 Post-Processing

Post processing is a procedure done by correcting images from different errors. Typically, post processing uses morphological operators that are able to detect edges, enhance contrast, remove noise, thin regions, segment an image into regions, or perform skeletonization on regions. Morphological functions include erosion and dilation, opening and closing, labelling of connected components, watershed segmentation, reconstruction, distance transform.

The images obtained from segmentation stage has a very small void area that needs to be removed before feature extraction. This void area is smaller than the void area that is produced from segmented yellow spot (pus) in pustule. Besides that, there is unconnected components as well. Figure 4.33 shows the example of void area). The morphological operator such as erosion, dilation and connected-component are used for post-processing process.

Erosion and dilation operations are fundamental to morphological processing. The basic effect of the operator is to erode away the boundaries of regions of foreground pixels. Thus, areas of foreground pixels shrink in size and holes within those areas become larger.

Whilst, dilation is to gradually enlarge the boundaries of foreground regions. Thus, areas of foreground pixels grow in size while holes within those regions become smaller.

Furthermore, connected-component scans an image, pixel-by-pixel in order to identify connected pixel regions. All pixels in a connected component share similar pixel intensity values. Figure 4.34 portrays the result of before and after post-processing.

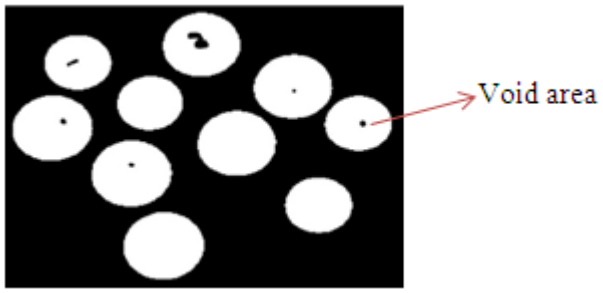


Figure 4.33 Example of void area

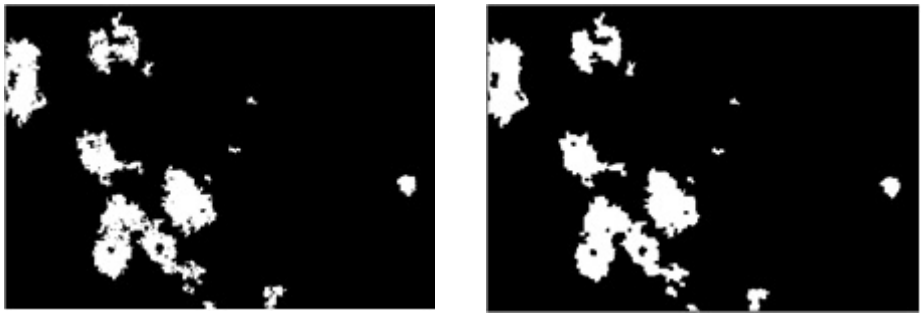


Figure 4.34 a) Before Post-processing b) After Post-Processing

4.5 Feature selection

After segmentation, discriminative features are extracted from the lesion. Feature can be defined as any distinctive aspect, quality or characteristic which may be symbolic such as colour or numeric such as height. Pattern is defined as composite of features that are characteristic of an individual. In classification, a pattern is a pair of variables {x,w} where x is a collection of observations or features (feature vector) and w is the concept behind the observation (label).

Features are usually inspired by ABCD rule (asymmetry, border irregularity, colour and diameter) [68]. In dermatology, a simple ABCD rule helps dermatologists to detect skin lesions such as melanoma and non-melanoma [69].

For asymmetry in cases of skin cancer, spots do not look the same on both sides. On the other hand, normal moles or freckles are completely symmetrical. For border, a mole or spot has blurry and/or jagged edges. For colour, a mole having more than one hue is not normal and needs to be evaluated by a doctor. Normal spots usually appear in one colour. This also occurs during lightening or darkening of the mole. Melanoma cells usually continue to produce melanin, which accounts for the cancers appearing in mixed shades of tan, brown and black. For diameter, if the lesion is larger than 1/4 inch or 6mm, it needs to be examined by a doctor. This includes areas that do not have any other abnormalities (colour, border, asymmetry).

However, for acne cases, diameter and colour are the main features to be chosen in order to diagnose the acne grading. Table 4.3 shows the diameter and colour for acne lesion. The asymmetry and border are not chosen since all acne types are not symmetrical and have borders. In this stage, the features of skin lesion are extracted to feed into classifiers. Therefore, the feature should be measurable, high

sensitivity, high specificity, high probability of true positive and negative response in order to get accurate result.

Colour plays an important role in dermatology [70] and the most straight-forward feature that humans perceive when viewing an image. Human vision is more sensitive to colour information than gray levels so colour become the best feature to extract. The extraction of the colour features is performed in the CIELAB colour space, where Euclidean distance corresponds to the human visual system's notion of distance or similarity between colours [71]. Common colours for acne are pink, red, whitish, black and brown.

Diameter is the length of a straight line passing through the centre of a circle and connecting opposite points on its circumference. In dermatology, diameter is one of the main features that were used to determine the level of severity.

A major criteria to distinguish between the types of acne is the acne size. Nodule and cysts are the most severe acne type compared to others acne lesion and are more than 5mm in diameter. Papule, pustule and comedone are less than 5mm. Therefore, once the system detected the nodule and cysts, it can automatically give a severity level 4 also even if there are other types of acne. Thus, a circle with 5mm in diameter is used as a reference (Figure 4.35). The pixel size for that circle is calculated and kept as a record.

Table 4.3 Size and colour for acne lesion

Acne Lesion	**Size**	**Colour**
Comedone	Tiny	Whitish, black or brown
Papule	Less than 5mm in diameter	Pink
Pustule	Less than 5mm in diameter	Red at the base with a yellowish or whitish centre
Nodule Cysts	More than 5mm in diameter	Pink and red

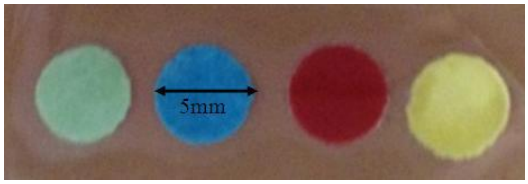


Figure 4.35 Ruler Sticker

Figure 4.36 shows the feature extraction process for acne. Firstly, the reference blob is identified. The reference blob that is a 5mm circle is pasted into patient's face as ruler sticker or indicator. Then, the pixel size of diameter of reference blob is calculated. Next, the pixel size of the blob of each lesion is identified and calculated. If pixel size of diameter blob for lesion is bigger than the pixel size of reference blob, the blob is automatically labelled as nodule and cysts.

However, when the pixel size of lesion blob is less than pixel size of reference blob, the area of each blob and area of filled blob are calculated. The filled area is scalar specifying the number of pixels corresponding to the blob with holes filled in while the area is the scalar specifying the actual number of pixels in the blob. Next, if the pixel size of filled area is bigger than area of that blob, the blob automatically is labelled as pustule. This indicates that there is hole inside the blob. Other than that, the blob automatically labelled as papule.

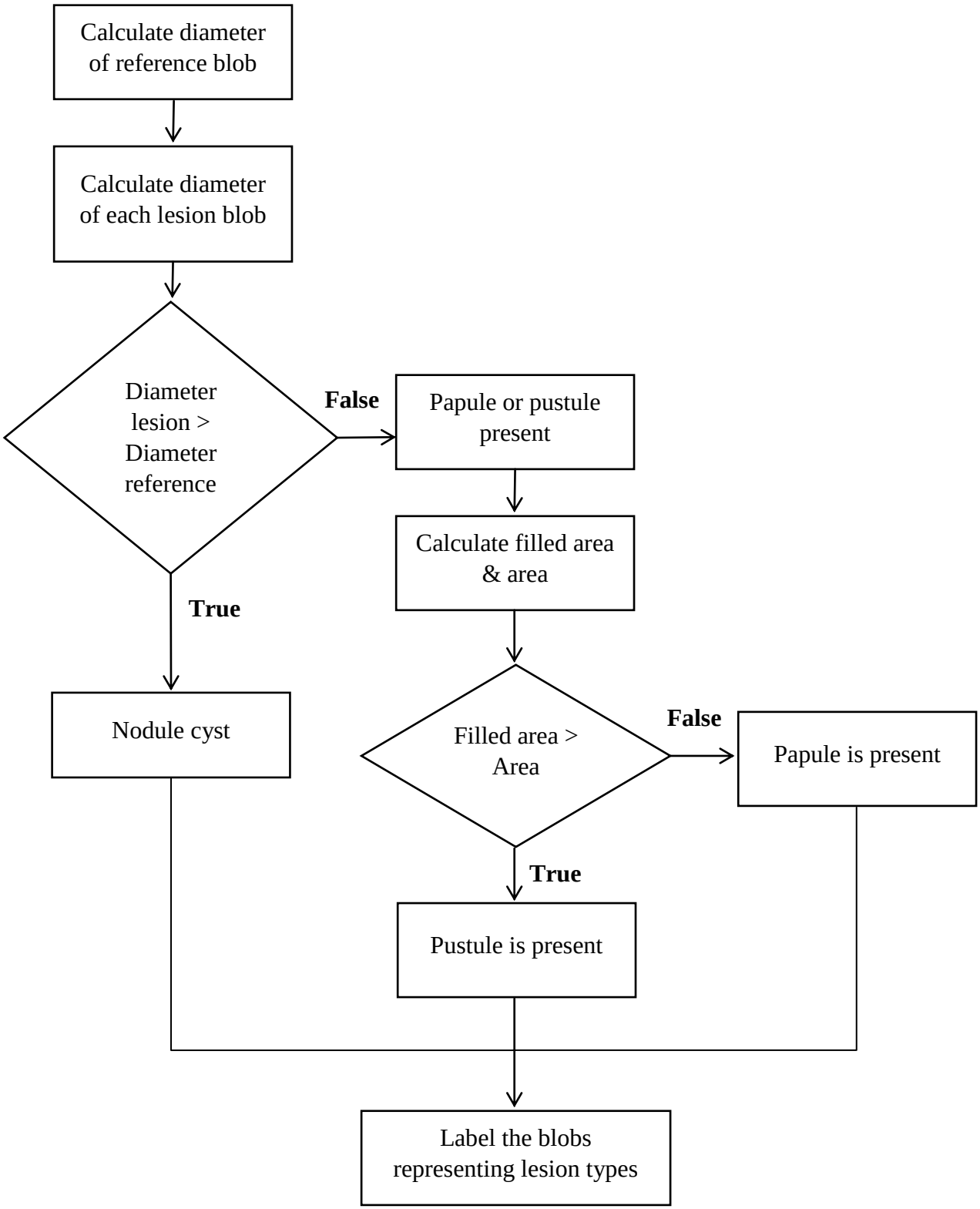


Figure 4.36 Feature Extraction Process

4.6 Grading

The modified Global Acne Grading System (mGAGS) divides the face into five locations (forehead, nose, chin, right and left cheek) as shown in Figure 4.37. The five locations are graded separately on a 0 to 4 scale depending on the most severe lesion within that location (0 = no lesions, 1 = comedones, 2 = papules, 3 = pustules and 4= nodules). The score for each area is the product of the most severe lesion, multiplied by the area factor. These individual scores are then added to obtain the total score. For total score in between 1 to 13, the patient is classified as mild while for total score in between 14 to 22, patient is classified as moderate. If total score is within 23 to 28 then grade is severe and if more than 28, it is graded very severe as shown as in Table 4.4.

Table 4.4 modified Global Acne Grading System (mGAGS)

Location	**Factor (F)**	**Severity (S)**			**Local Score (FxS)**	**Acne Severity**	
Forehead	2	0	Nil			Mild	1-13
Right Cheek	2	1	Comedone			Moderate	14-22
Left Check	2	2	Papule			Severe	23-28
Nose	1	3	Pustule			Very severe	>28
Chin	1	4	Nodule				
		Total Score					

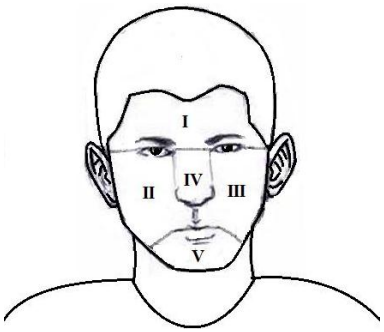


Figure 4.37 The five locations (I-V) of the modified Global Acne Grading System (mGAGS) [9]

4.7 Summary

There are a few major steps and milestones involved in our methodology for building the acne diagnosis system through image processing techniques. The first step is image acquisition. In this step we acquire close-up photographs of five different regions of face which are forehead, nose, chin, right cheek and left cheek. A high resolution DSLR camera is used for image acquisition.

The second step is pre-processing which is involves with lighting compensation and skin detection. Lighting compensation is used for checking the illumination of the images. If the illumination is under exposed and over exposed, the illumination will be corrected with the balanced illumination factor. The skin detection is used for separating the skin and non-skin regions. Since acne lesion can be recognized by its colour dissimilarity from normal skin, the CIE La*b* colour space is used to measure any dissimilarity between skin colours.

Acne segmentation has been performed using K-means clustering algorithm for the third step. Traditional K-means clustering suffers from two problems; firstly it requires predefining the number of clusters required. Secondly, there is no automated way to select which clusters are acne among the retrieved clusters. In this work, we have developed a clustering method that automatically selects the suitable number of clusters (K-value) and identifies acne clusters in the image. This automated clustering is achieved by using a range of K-values. Then for each K-value, the cluster that has the minimum area is selected; this is because acne has very small area compared to skin. Finally, the true acne image is selected from these minimal area clusters using a SVM classifier which is build using colour and texture properties of acne and skin. From that, the energy, entropy, mean and variance are produced the good separation between acne and non-acne. Therefore, the SVM classifier has been build using these four features.

Next step is post-processing which a procedure is done by correcting images from different errors such as removing the small holes and connecting the unconnected components. After that, the feature extraction is performed using color and size properties to classify acne blobs into different acne classes; papule, pustule, nodule or cyst. Once the types of acne has been detected, it will be calculated using modified standard grading system to determine the severity level such as mild,

moderate, severe and very severe. This severity level is an indicator that dermatologist used to give the medication for treating the acne lesions.

CHAPTER 5
RESULT AND DISCUSSION

The methods for acne assessment discussed in Chapter 4 are applied on a dataset obtained from Hospital Kuala Lumpur. Results from the objective assessment are compared with the results obtained from the assessment conducted by dermatologist. The advantages and limitations of the objective methods are discussed in this chapter.

5.1 Segmentation

5.1.1 Colour conversion

The images that finish the pre-processing process are converted to CIE La*b* colour space. This colour space is chosen since it is easy to distinguish these colours from one another. Figure 5.1 shows the original images and converted images. In CIE L*a*b* colour space, the a* channel represents the degree of redness to greenness with positive values represent red and negative values represent green. The b* channel represents the degree of blueness to yellowness.

Therefore, in a* channel, white areas (high intensities) indicates the redness. It is helpful to recognize lesion since papule, pustule and nodule cyst are around that range. In the b* channel, normal skin which is yellowish appears brighter (higher intensities) compared to lesion area.

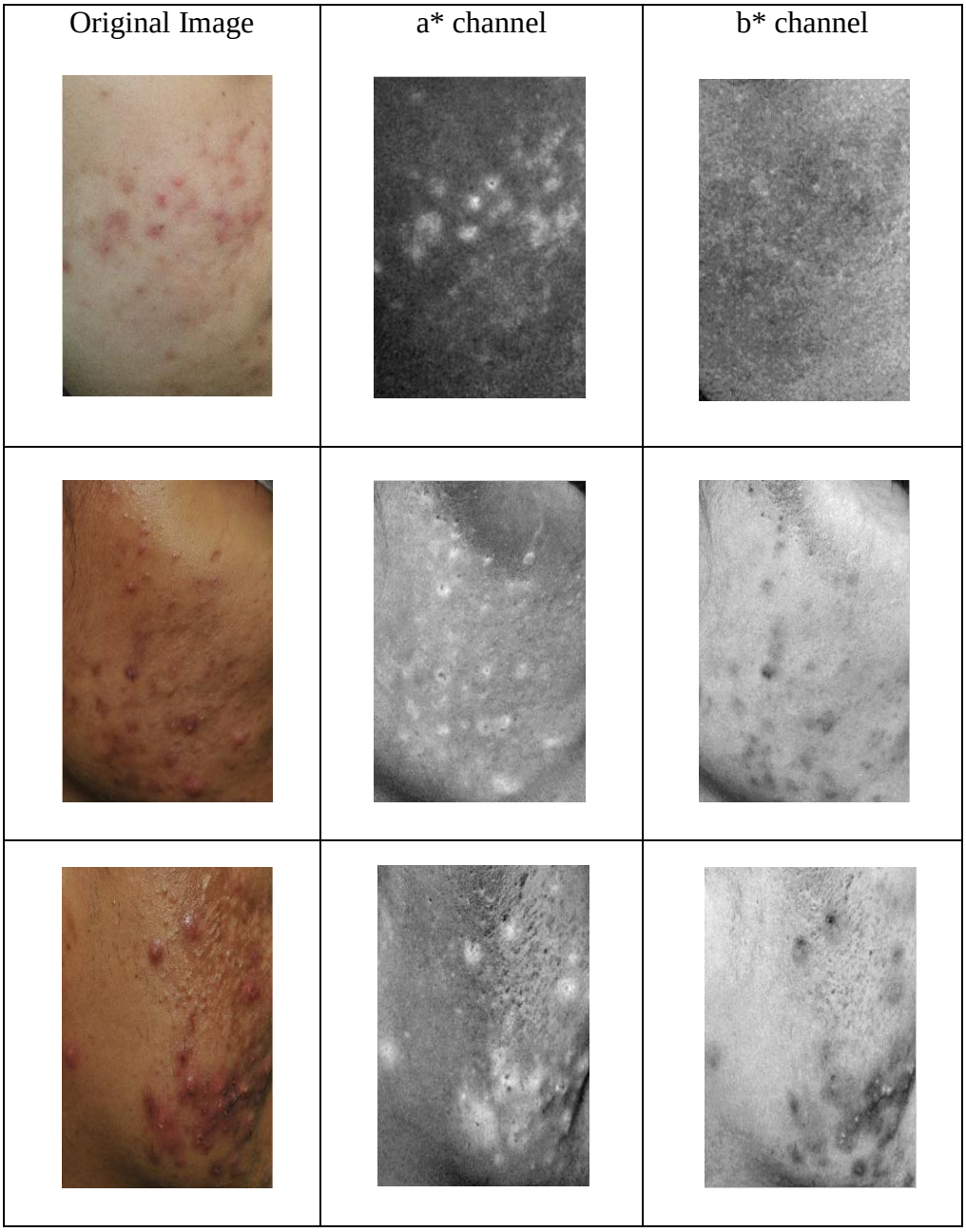


Figure 5.1 Colour conversion from RGB to CIELa*b*

5.2.2 K-means clustering

A major step is the segmentation of acne lesion from skin. The segmentation process is performed based on the automated modified K-means clustering method discussed in the Chapter 4. The method that is modified from the existing K-means clustering method determines the minimum area for every cluster. The results are illustrated in Figure 5.2 to Figure 5.15. Furthermore, this method is combined with SVM trainer in order to separate the acne with skin. The results are illustrated in Figure 5.17 to Figure 5.20.

5.2.2.1 Segmented Images and Minimum area

By using K-means clustering, the original image is segmented based on K-value from three to nine. The areas of every segmented image are computed in order to determine the minimum area.

a) K-value equal to 3

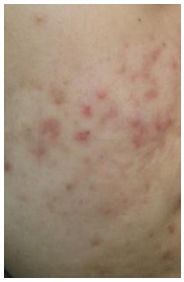
Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Figure 5.2 Segmented Images with K-value equal to 3

Figure 5.2 shows the segmented images with cluster K-value equals to three. It is found that, Cluster 3 has the minimum (smallest) area compared to Cluster 1 and Cluster 2 with 829479 pixels constituting 19% of total image as shown in Figure 5.3. From visual observation of the image in Cluster 3, this segmented image is not good because it does not only segment the acne lesion but the skin as well.

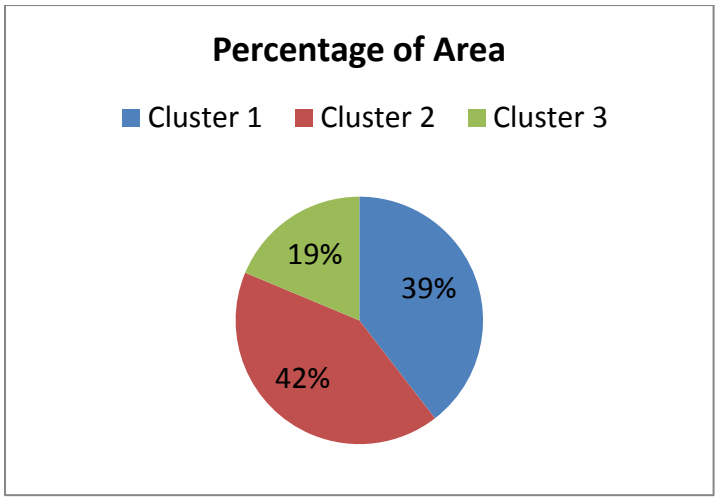
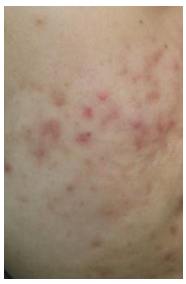


Figure 5.3 Percentage of Area for each cluster

b) K-value equal to 4

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Item	Cluster 4
Images	

Figure 5.4 Segmented Images with K-value equal to 4

Figure 5.4 portrays the segmented images with cluster K-value equals to four. Here, Cluster 2 has the minimum area with 679876 pixels or 16% of total image as shown in Figure 5.5. Similarly, from visual observation of the Cluster 2 image, the segmentation process is not correct because it does not only segment the acne lesion but skin as well.

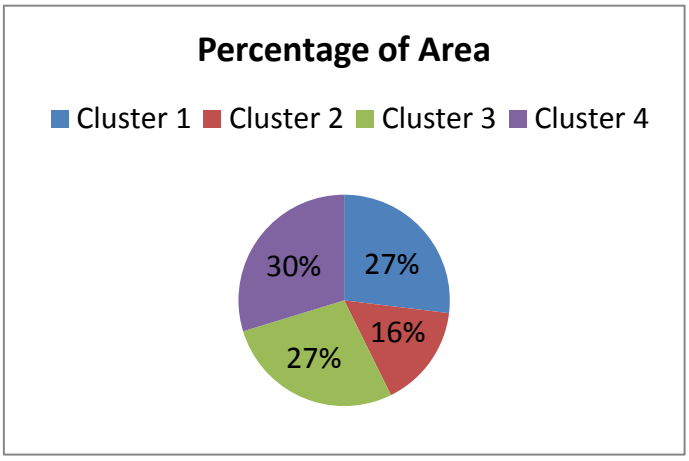
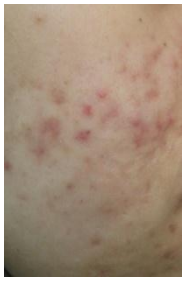


Figure 5.5 Percentage of Area for each cluster

c) K-value equal to 5

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Item	Cluster 4	Cluster 5
Images		

Figure 5.6 Segmented Images with K-value equal to 5

Figure 5.6 depicts the segmented images with cluster K-value equals to five. In this case, Cluster 2 has the minimum area with 285302 pixels or 7% of the total image as shown in Figure 5.7.

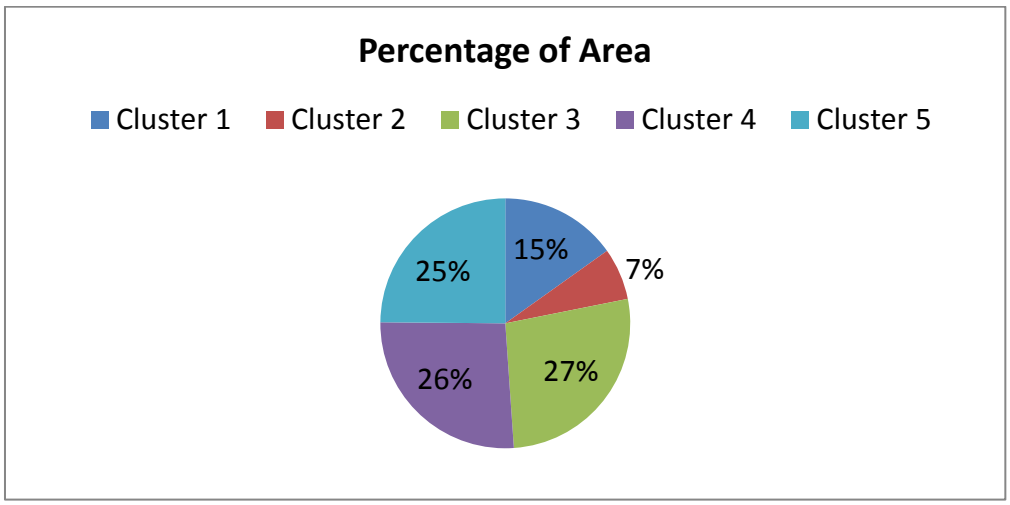
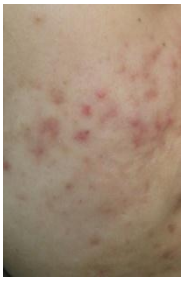


Figure 5.7 Percentage of Area for each cluster

d) K-value equal to 6

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Item	Cluster 4	Cluster 5	Cluster 6
Images			

Figure 5.8 Segmented Images with K-value equal to 6

Figure 5.8 illustrates the segmented images with cluster K-value is equal to six. Cluster 1 has the minimum area compared to other clusters with 190049 pixels or 4% of the total image as shown in Figure 5.9.

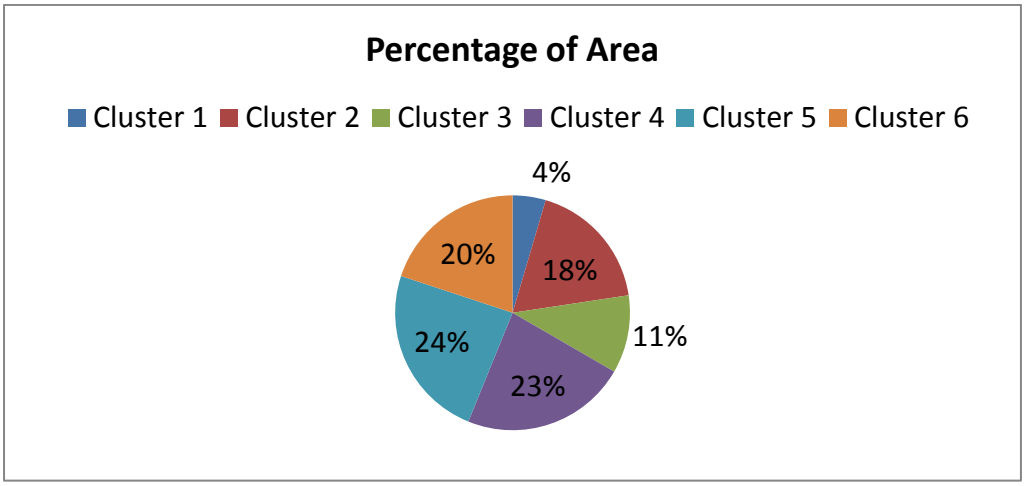
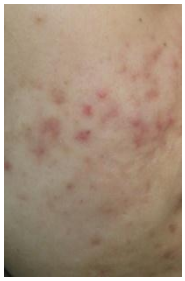


Figure 5.9 Percentage of Area for each cluster

e) K-value equal to 7

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Item	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Images				

Figure 5.10 Segmented Images with K-value equal to 7

Figure 5.10 demonstrates the segmented images with cluster K-value is equal to seven. Cluster 1 has the minimum area compared to other clusters with 243379 pixels or 6% of the total image as shown in Figure 5.11.

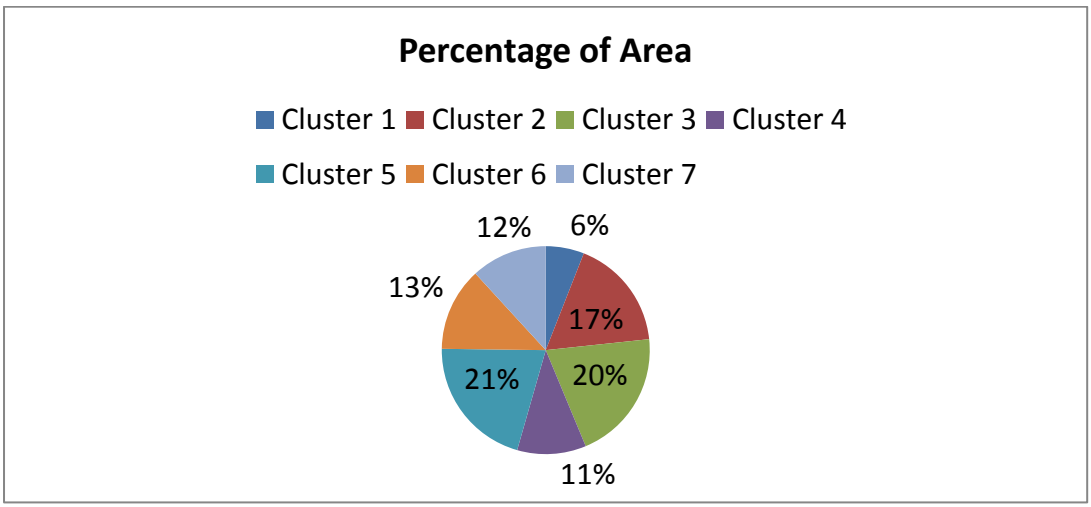
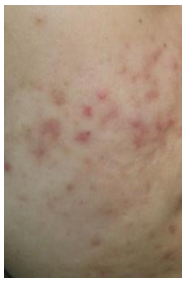


Figure 5.11 Percentage of Area for each cluster

f) K-value equal to 8

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
				

Figure 5.12 Segmented Images with K-value equal to 8

Figure 5.12 shows the segmented images with cluster K-value which is equal to eight. Cluster 7 has the minimum area compared to other clusters with 241654 pixels or 6% as shown in Figure 5.13. From visual observation of Cluster 7 image, this segmentation of acne is very good.

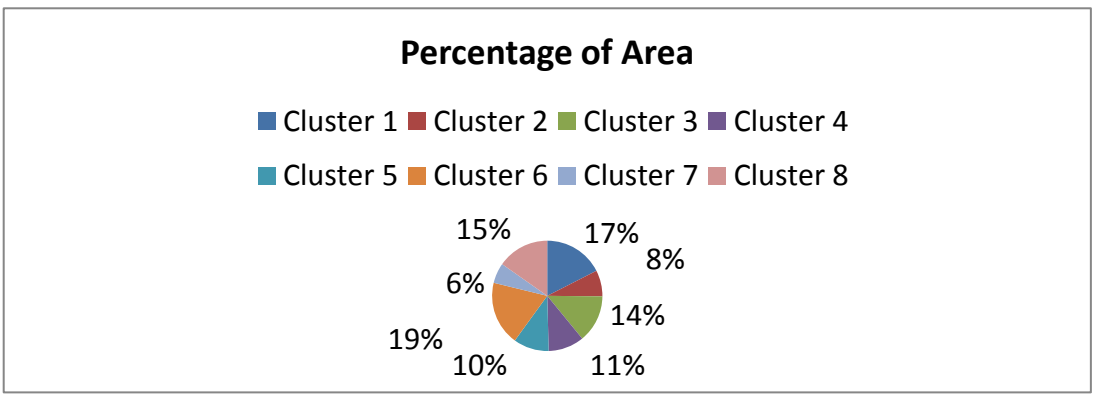
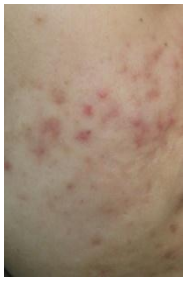
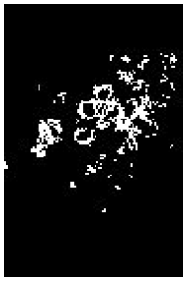


Figure 5.13 Percentage of Area for each cluster

g) K-value equal to 9

Item	Original Image	Cluster 1	Cluster 2	Cluster 3
Images				

Item	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Images				

Item	Cluster 8	Cluster 9
Images		

Figure 5.14 Segmented Images with K-value equal to 9

Figure 5.14 portrays the segmented images with cluster K-value equals to nine. Cluster one has the minimum area compared to other clusters with 154573 pixels or 4% of the total image as shown in Figure 5.15.

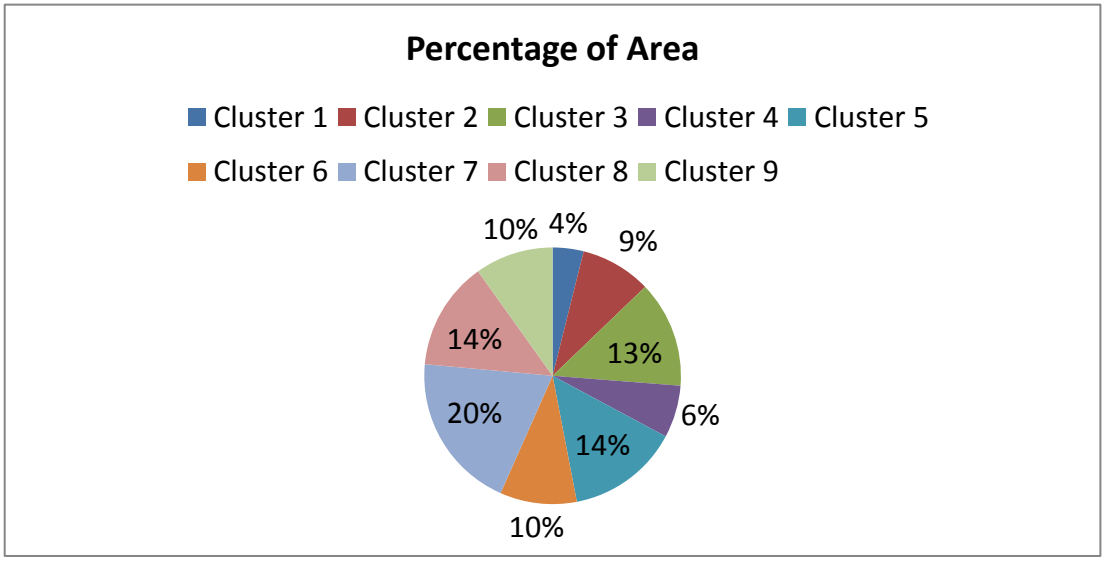


Figure 5.15 Percentage of Area for each cluster

The minimum area data for every K-value three to nine (Figure 5.16) is stored in database to be tested with an SVM classifier in order to choose the best segmented images.

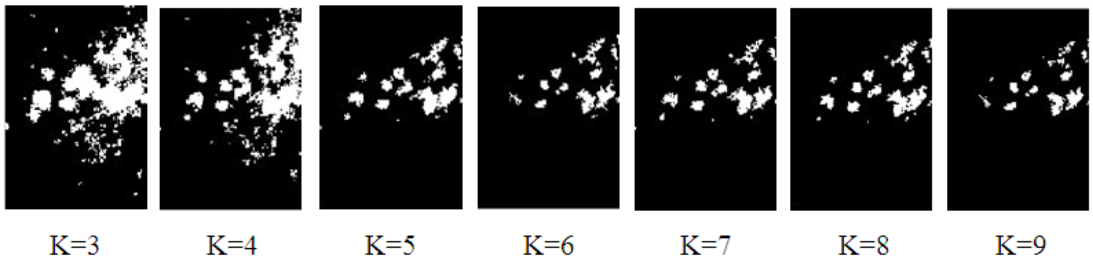


Figure 5.16 Cluster images having the minimum segmented areas

5.2.2.2 SVM Classifier

The SVM classifier uses the results of minimal area clusters extracted for each K-value in the previous section to selects the best candidate among them that classifies the blobs in each cluster into skin or acne. The cluster that has the maximum percentage of acne blobs will be selected as the best candidate for the segmented acne image.

As shown in Figure 5.17, the first row shows the original image, the second row shows the minimal area cluster for each K-value. The third row shows the results of applying SVM classification on each blob in every image. Red colour means the blob is classified as acne while blue colour means the blob is classified as skin.

For K = 3, only 4.7% of the number of blobs are classified as acne. Although this represents 87% of the total area of the blobs in this image but it is dominated by large blobs that are classified as acne. This image contains many skin areas that has been selected as acne and as a result, it is not the chosen as the acne image candidate.

For K = 4, this cluster contains blobs with smaller size than K=3 where 10.8% of them have been classified as acne while the rest is skin. The remaining K-values of the percentage of acne is 20%, 35.7%, 31.3%, 40% and 33.3% respectively for K = 5 till K = 9. Therefore, the best-segmented acne image for this set of images is when K=8 with 40% of acne blob.

However, it has to be noted that when the K-value is high the blobs image tends to have small blobs that are more accurate in localizing acne and they contain less skin components in them. Thus, the tendency to achieve higher acne blobs ratio. The best candidate selected is compared with the ground truth segmentation as shown in the last row in order to determine the specificity, sensitivity and accuracy.

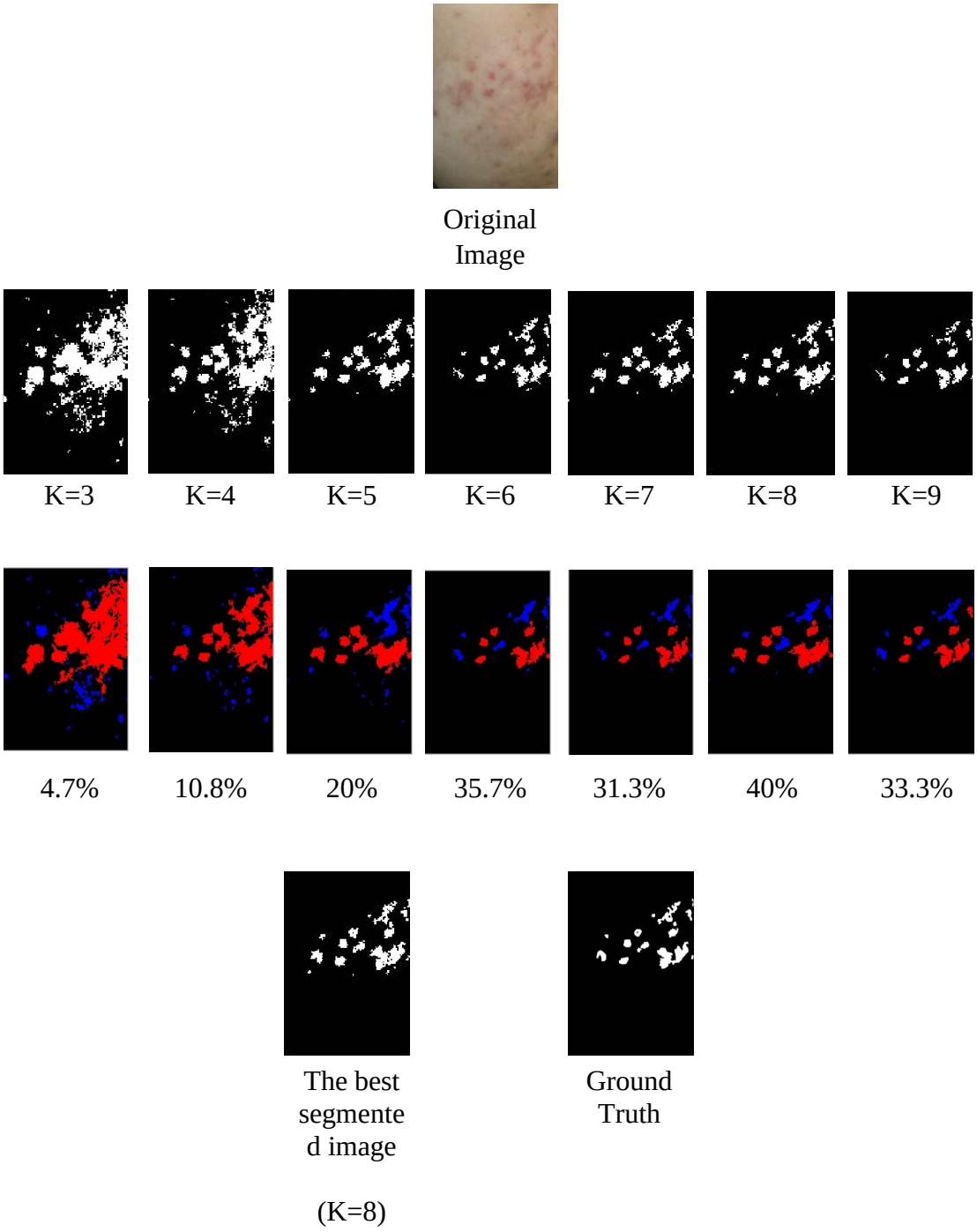


Figure 5.17 Original Image (row 1), Minimum area of each cluster (row 2), percentage of acne blob (row 3), the best-segmented acne image and Ground Truth (row 4)

In Figure 5.18, the first row shows the original image of the collected sample. The second row portrays minimum area of each cluster represented by a k-value (number of cluster). The value of K is from three to nine. Among the seven images shown, the best segmented is chosen. The selection criterion is based upon highest percentage of acne lesion compared to skin and scar using SVM classifier. The image having K = 3 is selected as the best segmented image as its acne lesion is 33.3 %. This best segmented image is then later on compared with ground truth in order to count the specificity, sensitivity and accuracy.

Similarly, from Figure 5.19 the best-segmented image is opted among the seven images thus shown. The image of K = 6 and an acne lesion = 96% (highest) is chosen as the best segmented image here. A comparison is later on carried out of this best segmented image with ground truth in order to count the specificity, sensitivity and accuracy.

Finally, from Figure 5.20 the best-segmented image is K = 6 with an acne lesion blob of 75%. At a later stage, comparison between segmented image and ground truth is used to count the specificity, sensitivity and accuracy.

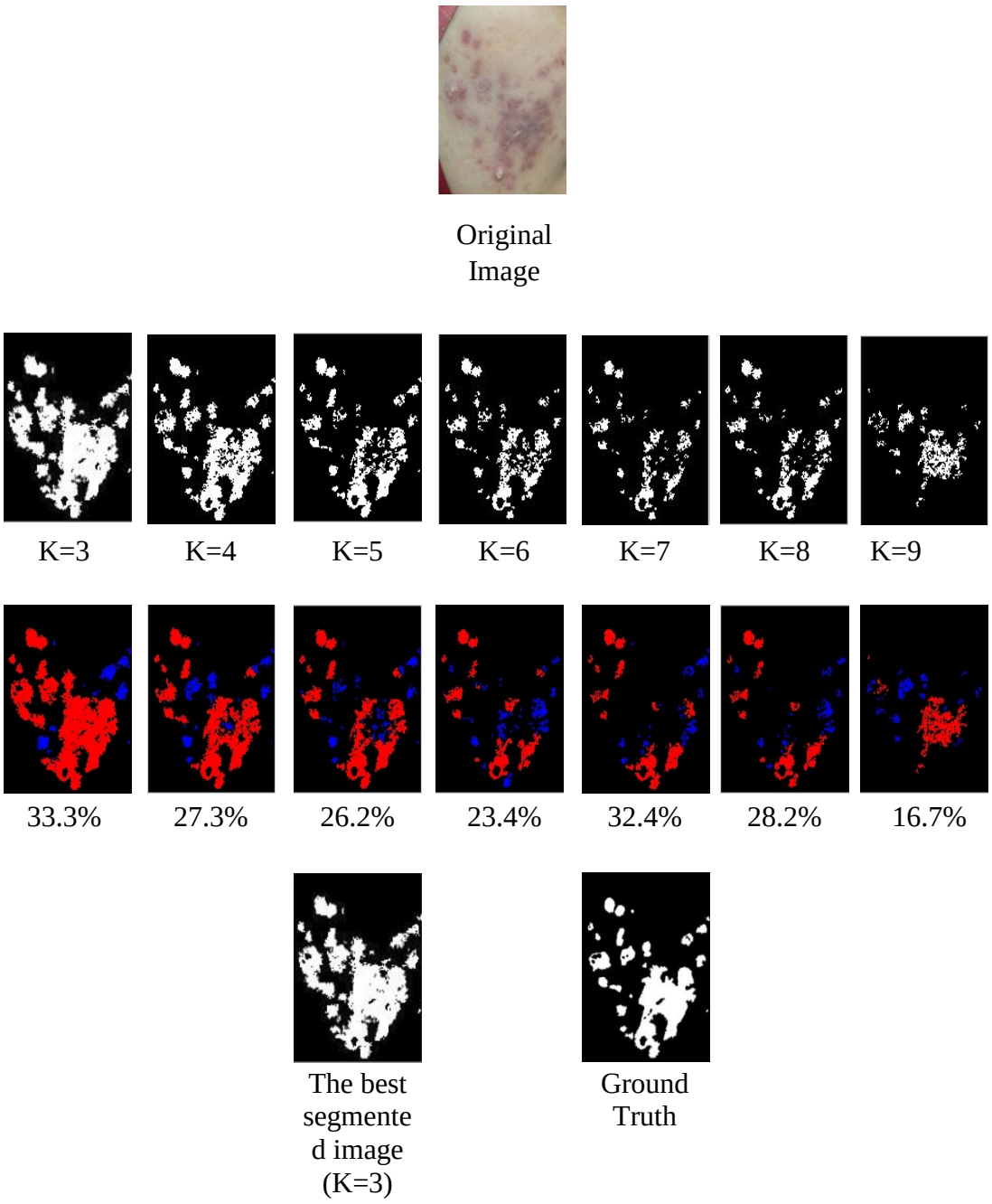
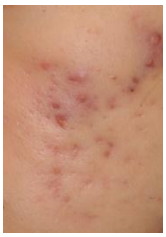
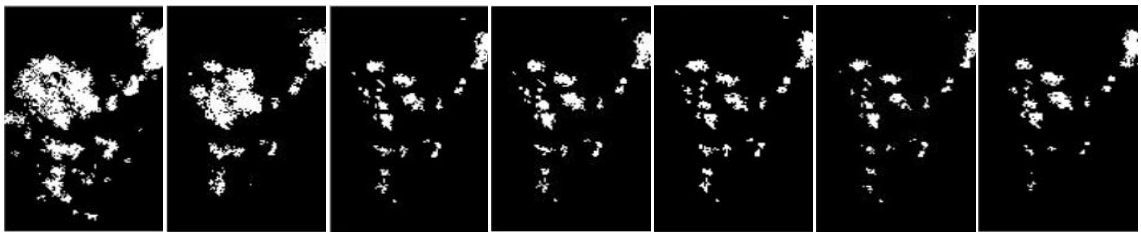


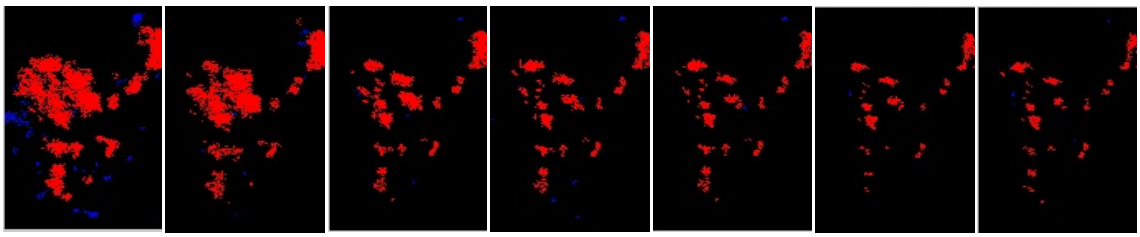
Figure 5.18 Original Image (row 1), Minimum area of each cluster (row 2), percentage of acne blob (row 3), the best-segmented acne image and Ground Truth (row 4)



Original Image



K=3 K=4 K=5 K=6 K=7 K=8 K=9

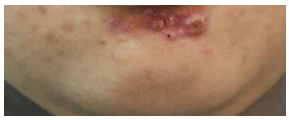


31.8% 67.9% 76.7% 96% 90.9% 77.8% 78.8%

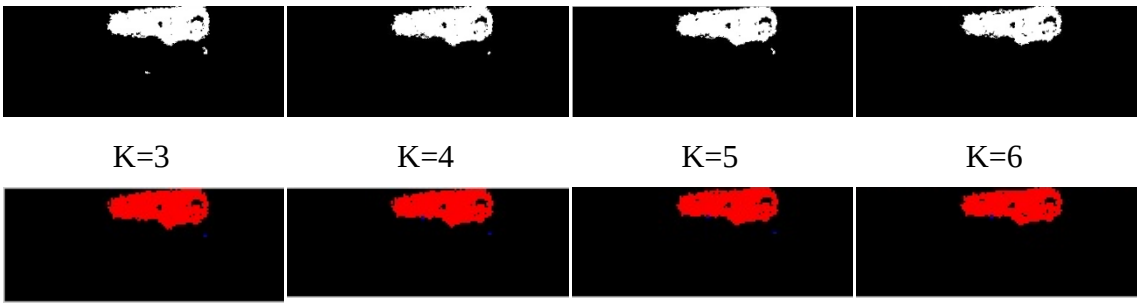
The best segmented image (K=6)

Ground Truth

Figure 5.19 Original Image (row 1), Minimum area of each cluster (row 2), percentage of acne blob (row 3), the best-segmented acne image and Ground Truth (row 4)



Original Image



K=3 K=4 K=5 K=6

50% 33.3% 33.3% 75%

K=7 K=8 K=9

50% 33.3% 50%

The best segmented image

(K=6)

Ground Truth

Figure 5.20 Original Image (row 1), Minimum area of each cluster (row 2), percentage of acne blob (row 3), the best-segmented acne image and Ground Truth (row 4)

5.2.3 Performance Analysis

The segmented images are compared with the reference images to measure the performance of the proposed automated K-means clustering method. Reference images are obtained by segmenting lesion manually from the digital images as benchmark. The receiver operating characteristic (ROC) analysis is used as an indicator of the performance. The ROC curve is a plot of sensitivity against 1-specificity and thus, the sensitivity and specificity must first be determined.

Sensitivity measures the proportion of actual positives which are correctly identified and specificity measures the proportion of negatives which are correctly identified. In addition, accuracy gives overall performance of the classifier.

Several terms are commonly used along with the description of sensitivity, specificity and accuracy. They are true positive (TP), true negative (TN), false positive (FP) and false negative (FN).

True positive (TP) is acne lesions correctly segmented as acne lesions while true negative (TN) is skin correctly segmented as skin. Both true positive and true negative suggest a consistent result between diagnostic test and the proven condition (also called standard truth). However, no medical test is perfect. Therefore, false positive (FP) indicates that skin incorrectly segmented as acne lesions and false negative (FN) means acne lesions incorrectly segmented as skin. Both false positive and false negative indicate the results are opposite to the actual condition.

Sensitivity, specificity and accuracy are described in terms of TP, TN, FN and FP.

$$Sensitivity = \frac{TP}{TP + FN} \qquad \text{(Equation 5.1)}$$

$$Specificity = \frac{TN}{TN + FP} \qquad \text{(Equation 5.2)}$$

$$Accuracy = \frac{TP + TN}{TN + TP + FN + FP} \qquad \text{(Equation 5.3)}$$

5.2.3.1 Segmentation Analysis

The ground truth is segmented manually from digital image and validated by dermatologists. Then, the segmented images from automated K-means clustering method are compared with the ground truth and the ratio of TP, TN, FN and FP are calculated. TP ratio is the ratio of sum of pixels value in TP image divided by sum of pixels value in the ground truth image. FP ratio is sum of pixels value in the FP image divided by sum of pixels value in the ground truth. TN ratio is the sum of pixels value in the TN image divided by the sum of pixels value in the negative of the ground truth image (GT '). FN is the sum of pixels value in the FN image divided by the sum of pixels value in the negative of the ground truth image.

$$TP\ ratio = \frac{\sum TP}{\sum GT} \qquad \text{(Equation 5.4)}$$

$$FP\ ratio = \frac{\sum FP}{\sum GT} \qquad \text{(Equation 5.5)}$$

$$TN\ ratio = \frac{\sum TN}{\sum (1 - GT)} \qquad \text{(Equation 5.6)}$$

$$FN\ ratio = \frac{\sum FN}{\sum (1 - GT)} \qquad \text{(Equation 5.7)}$$

Consider the example of the image in Figure 5.21; the first row shows the original image, the segmented image using our automated K-means clustering method and the ground truth image been segmented manually. If we compare the segmented image with the ground truth visually, we can see there is a good match between the two images although the segmented images have a number of small blobs that does not exist in the ground truth and it has holes and disconnected blobs.

Second row shows the TP, TN, FP and FN image respectively computed by comparing the segmented image with the ground truth. The true positive image matches the ground truth image with some holes been added to it and due to this holes, the ratio of TP is 0.8809 which is 88.09% correct.

Similarly the TN image should contains regions that are not in the ground truth image which scores TN ratio of 98.61%; this value should ideally be 100% but

because of some acne lesion that exist in the ground truth but not been detected by the segmentation method, this value is the less than the ideal case. The false positive image contains image regions that are incorrectly segmented by the segmentation method and they do not exist in the ground truth image. The FP ratio of this image is 1.39% which is supposed to be 0%. Similarly, FN image is acne lesion that has been segmented by skin as the segmentation algorithm. In this image the FN ratio is 11.91% while the ideal value of the FN ratio is 0%. Based on the TN, TN, FP and FN extracted from the image, the sensitivity for this image is 88.1%, the specificity is 98.6% and the accuracy is 93.4%.

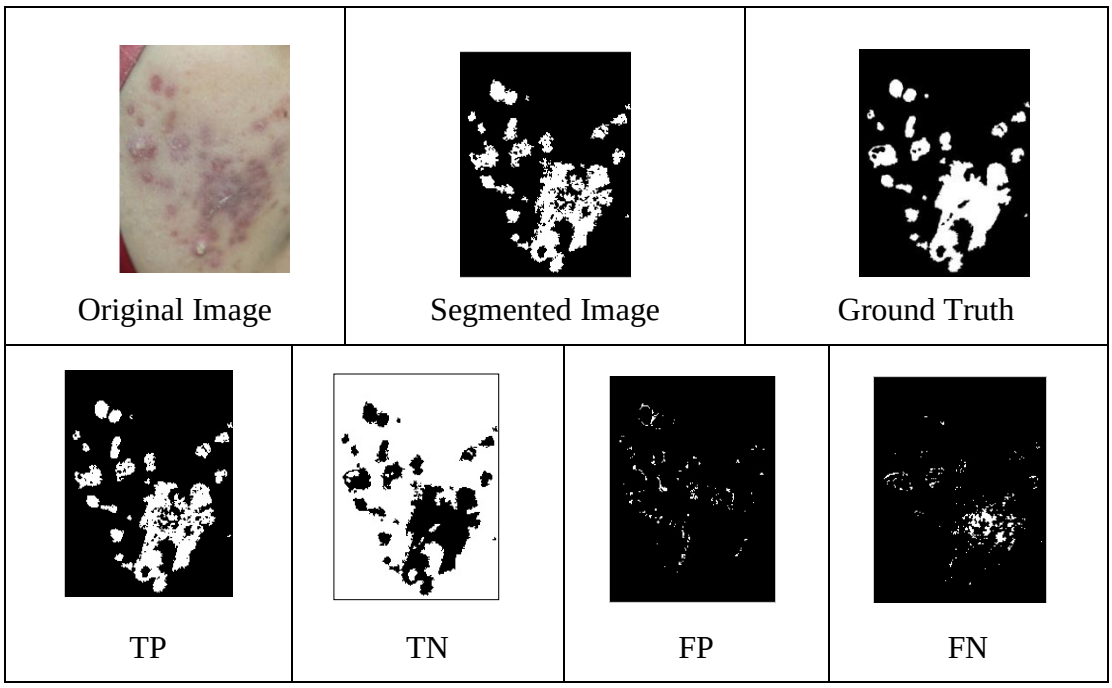


Figure 5.21 Image Analysis (without post-processing**)**

As we can see in the previous image, there is high ratio of FN, which reduces the sensitivity of the segmentation method. This FN exists due to holes in the segmented blobs and disconnected blobs. A possible solution for this problem is the post-processing step that fills the holes in the image blobs and connects disconnected blobs using morphological operators such as erosion, dilation and filling.

Figure 5.22 shows the segmentation method applied for the previous image in Figure 5.21 followed by post-processing step, which fills the holes first then applied

dilation and erosion to connect disconnected blobs. The table shows most of the small blobs in the segmented image have been removed and the small holes were retained.

The large holes have been kept because they indicate the presence of pustule and nodule acnes. After the post-processing, the TP ratio has increased from 88.1% to 95.91%. However, the TN ratio haven reduced from 98.61% to 95.92%. This is because post-processing step introduces false positive blobs in the segmented image due to morphological dilation process. However, this reduction is still acceptable as values greater than 95%, are accepted in medical procedures.

The FN ratio has reduced due to post-processing from 11.91% to 4.09% and the FP ratio has increased from 1.39% to 4.0%. This TP ratio and reduction in FN ratio increases the sensitivity of the image by large value from 88.1% to 95.9%, and the specificity reduces from 98.6% to 95.9% and the final accuracy of this segmentation increases from 93.4% to 95.9%.

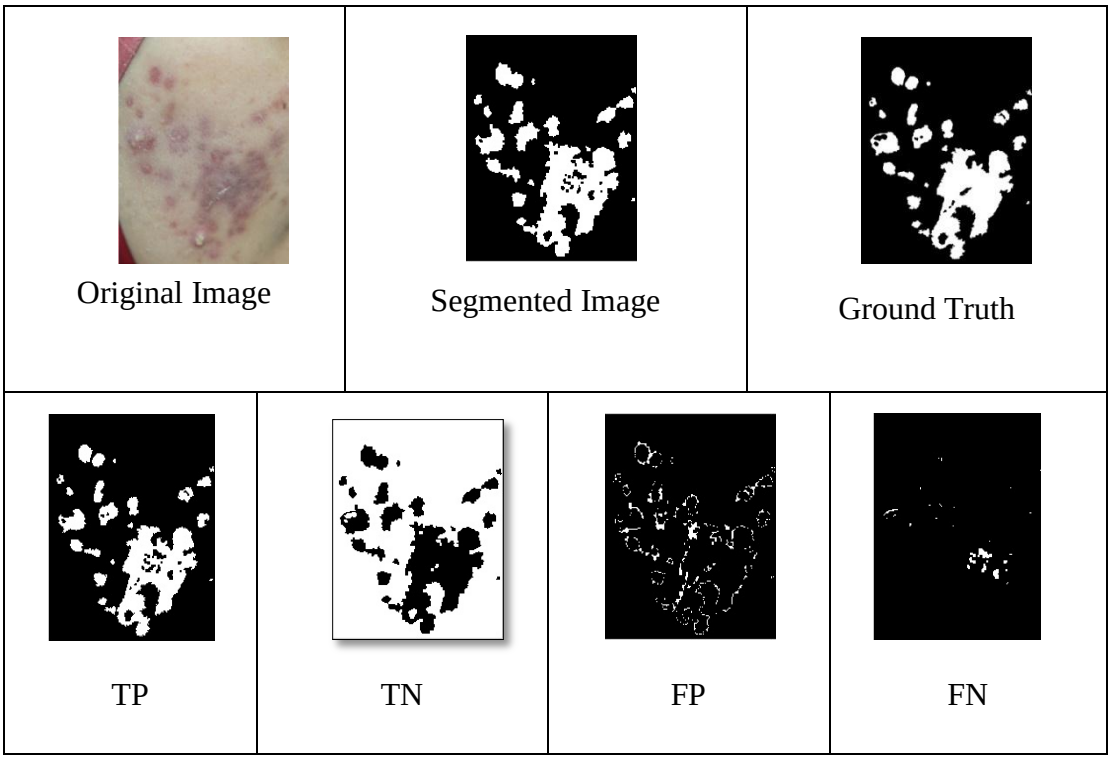


Figure 5.22 Image Analysis (with post-processing)

5.2.3.2 ROC curve

In order to validate the accuracy of our automated segmentation method, we have tested this method on 50 images of different acne types and skin colour types. The results of segmenting these 50 images have been compared with their respective ground truth images and for each image the sensitivity, specificity and accuracy have been computed with/without post-processing step. Table 5.1 shows the average sensitivity, specificity and accuracy computed for both approaches. Without post-processing the average overall sensitivity is 83.99% while when the post-processing step is added, the average sensitivity have increased to 90.02%. The average overall specificity for the 50 subjects without post-processing is 98.32% and when the post-processing step is added, the specificity is reduced to 97.16% due to the increase in FP ratio induced by the post-processing step. Similarly, the overall accuracy of the system without the post processing step is 91% and after the post-processing, this ratio has increased to 93.62%.

Table 5.1 Average sensitivity, specificity and accuracy for segmented images with and without post-processing

`	Sensitivity	Specificity	Accuracy
Without post-processing	83.6%	98.3%	91%
With post-processing	90%	97.2%	93.6%

Figure 5.23 shows the receiver operating characteristics (ROC) curve for the 50 images tested without the post-processing. The ROC curve shows the sensitivity plotting against 1-specificity. The figure shows the minimum and maximum sensitivity values of 63% and 98%, and the minimum and maximum specificity values of 88% and 99.98% respectively. Therefore, the minimum sensitivity value, 63% shows moderate proportion of actual positives which are correctly identified and the maximum sensitivity value, 98% shows very high proportion of actual positives which are correctly identified. The minimum specificity value, 88% shows high proportion of negatives which are correctly identified, 99.98% shows very high proportion of negatives which are correctly identified.

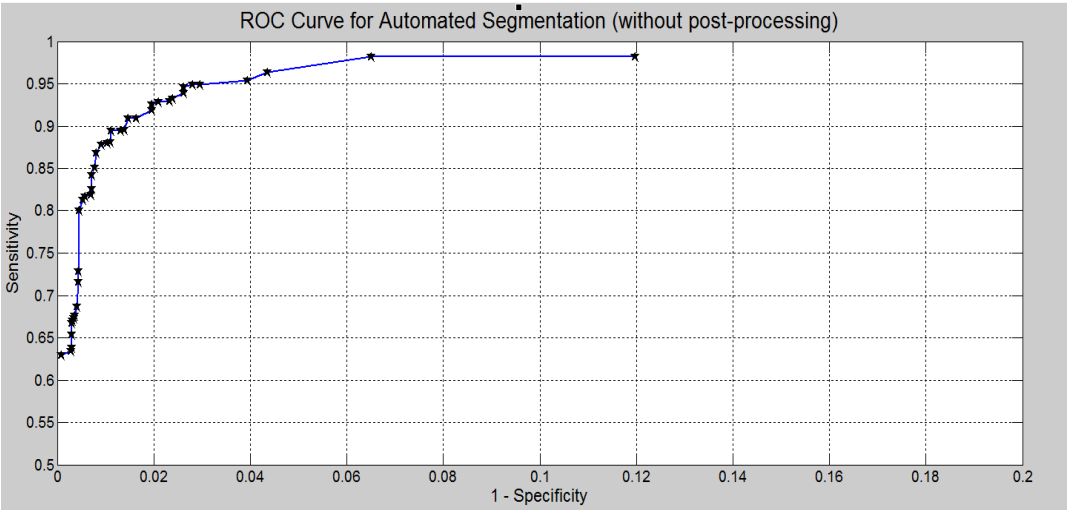


Figure 5.23 ROC Curve for Automated Segmentation (without post-processing)

Figure 5.24 shows the receiver operating characteristics (ROC) curve for the 50 images tested with the post-processing. The ROC curve shows the plot of sensitivity against 1-specificity. It can be seen that the minimum and maximum sensitivity values are 72% and 99% respectively. The minimum specificity value is 85% while the maximum value is 99%. The minimum and maximum values of sensitivity with post-processing are increased compared to without post-processing. This is because morphological operation in post-processing helps to fixed the segmented proportion of actual acne or skin. However, the minimum and maximum values of specificity with post-processing are little bit decreased compared to without post-processing. This is because morphological operation in post-processing decreased the segmented proportion of negative acne or skin.

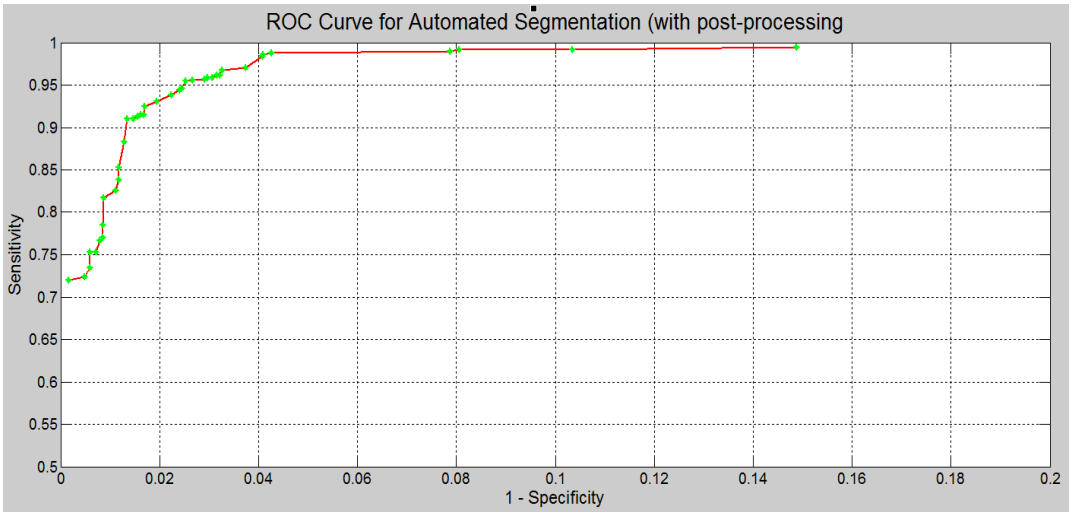


Figure 5.24 ROC Curve for Automated Segmentation (with post-processing)

5.2 Classification and modified Global Acne Grading System (mGAGS)

First, the original images are visualized using Graphical User Interface (GUI) as in Figure 5.25. These images consist of five locations which are forehead, right cheek, left cheek, nose and chin. Every location has their factor. For nose and chin, the factor is 1. While the factor of right cheek and left cheek is 2.

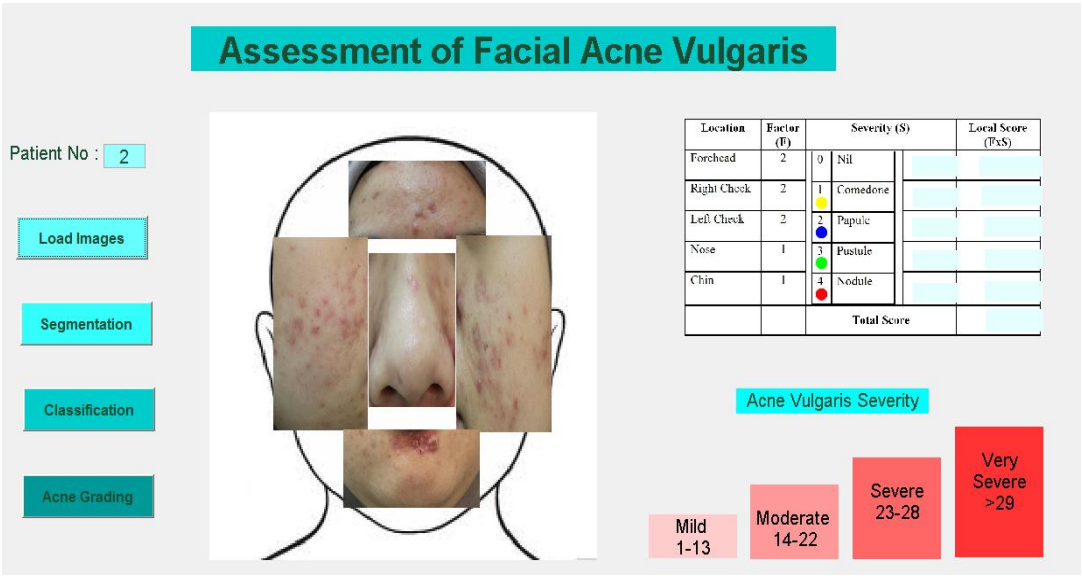


Figure 5.25 Original Images

After the original images are loaded to GUI, those images are segmented using automated K-means clustering method. This method separates the lesion and skin as portrayed in Figure 5.26.

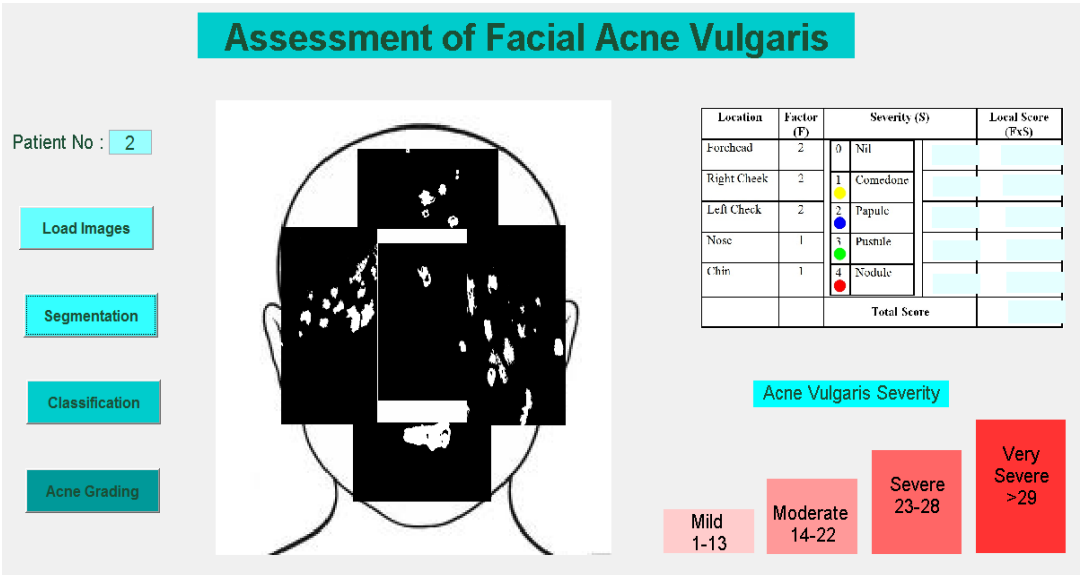


Figure 5.26 Segmented Images

The classification process categorizes all pixels in a digital image into one of several types of acne lesion. Feature extraction based on colour and size is tested on segmented images in order to classify types of acne. The 5 mm blue ruler sticker (Figure 5.27) is used as an indicator to measure the pixel sizes of 5 mm in every image. The pixel size for that 5 mm ruler sticker is calculated and kept in the record. The blue colour is chosen since red and yellow are the lesion colour while green colour is the background colour. Note that, nodule cysts is typically more than 5 mm and the papule, pustule and comedone are normally less than 5 mm. Therefore, once the system detected the nodule cysts, it automatically give the severity 4 even though also if there are have other types of acne. This is because the nodule cysts is the most severe compared to others acne lesions.

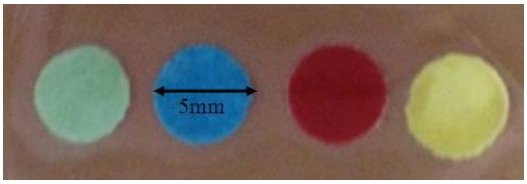


Figure 5.27 Ruler Sticker

Figure 5.28 shows the classification results for forehead, nose, chin, right and left cheek. The red circle indicates nodule with its severity as four, green circle indicates pustule and its severity is three. The blue circle indicates papule with its severity which is two and yellow circle indicates comedone with its severity which is one.

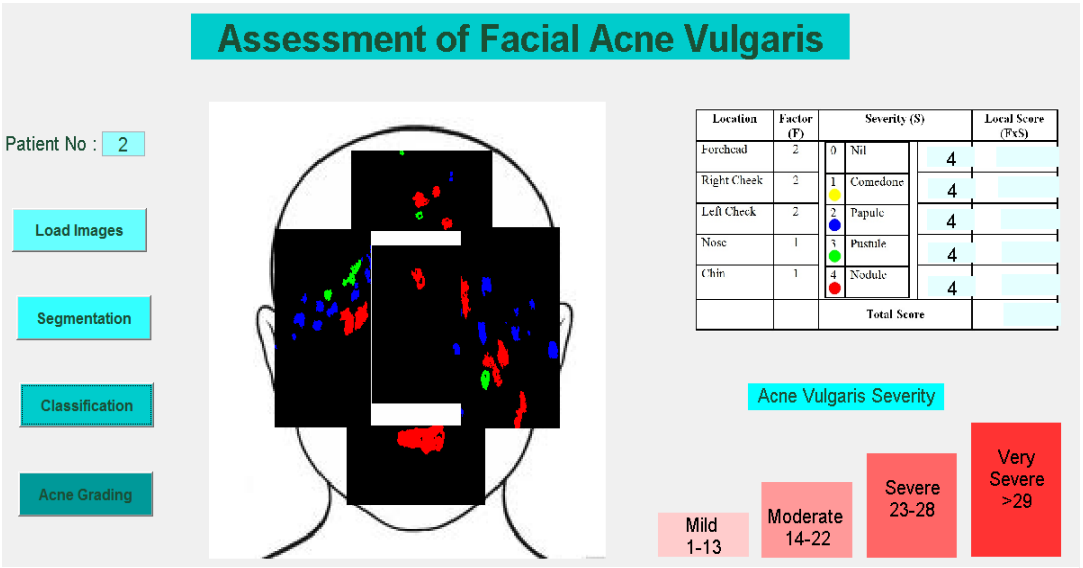


Figure 5.28 Classification results

The score for each area is the product of the most severe lesion, multiplied by the area factor. These individual scores are then added to obtain the total score. For a total score in between 1 to 13, the patient is classified as mild while for a total score in between 14 to 22, the patient is classified as moderate. For a total score is between 23 and 28, then grade is severe and if more than 29 it is very severe as shown as in Figure 5.29.

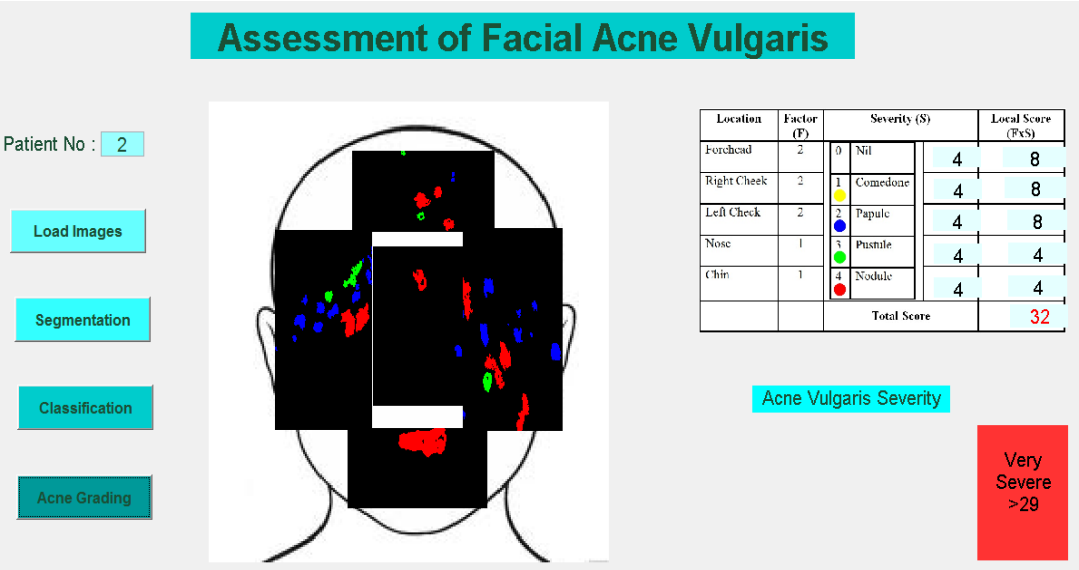


Figure 5.29 mGAGS Result

Table 5.2 shows the example of acne severity score for 5 patients. The severity score is given by the subjective (dermatologist) and objective (computer) methods**.** The local score is multiplication of severity and factor of every location and as a result, the total acne severity, mGAGS is summation of local score.

For these 5 examples, the objective method (computer) gives the same score with reference lesions except for one case (highlighted in Table 5.2). This case has no acne but our algorithm detected comedone lesion. This is because our algorithm automatically classifies comedone whenever there is no blob of lesion detected. Nevertheless, for papule, pustule and nodule cysts, the results for subjective and objective give the same score.

Table 5.2 modified Global Acne Grading System (mGAGS) given by the subjective (dermatologist) and objective (computer) methods

Patient No.	Location	Dermatologist		Computer	
		Severity	Local Score	Severity	Local Score
Patient 1	Forehead	3	6	3	6
	Right Cheek	3	6	3	6
	Left Cheek	3	6	3	6
	Nose	2	2	2	2
	Chin	0	0	1	1
	mGAGS		20		21
Patient 2	Forehead	4	8	4	8
	Right Cheek	4	8	4	8
	Left Cheek	4	8	4	8
	Nose	4	4	4	4
	Chin	4	4	4	4
	mGAGS		32		32
Patient 3	Forehead	1	2	1	2
	Right Cheek	3	6	3	6
	Left Cheek	3	6	3	6
	Nose	2	2	2	2
	Chin	1	1	1	1
	mGAGS		17		17
Patient 4	Forehead	3	6	3	6
	Right Cheek	3	6	3	6
	Left Cheek	3	6	3	6
	Nose	2	2	2	2
	Chin	3	3	3	3
	mGAGS		23		23
Patient 5	Forehead	2	4	2	4
	Right Cheek	3	6	3	6
	Left Cheek	4	8	4	8
	Nose	2	2	2	2
	Chin	2	2	2	2
	mGAGS		22		22

In evaluating the performance of the proposed algorithms in classification and grading of acne severity, an agreement test is conducted. An agreement test is conducted using Cohen's kappa (K) coefficient that was introduced in 1960 [74]. This test measures the strength of inter-observer agreement that in this case is between the dermatologist and automated proposed algorithm of acne severity.

The equation for K is:

$$\text{Kappa (K)} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} \qquad \text{(Equation 5.8)}$$

where Pr(*a*) is the relative observed agreement among raters, and Pr(*e*) is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly saying each category. Kappa coefficient equals to 1 if there is a complete agreement between observers when giving response to a variable of N subjects. For classification, this agreement test is conducted for 50 patients' severity results separately for forehead, right cheek, left cheek, nose and chin. Results of agreement test are shown in Table 5.4 to Table 5.8.

The result of agreement test indicates the level of interpretation in agreement between dermatologist and proposed algorithm result of acne severity. In 1977, Landis gave a more complete list of how Kappa might be interpreted [75] as given in the following Table 5.3. This table is used as an indicator for level of interpretation on Kappa.

Table 5.3 Landis interpretation on Kappa

Kappa	**Interpretation**
<0	Poor Agreement
0.0 - 0.20	Slight Agreement
0.21 - 0.40	Fair Agreement
0.41 - 0.60	Moderate Agreement
0.61 - 0.80	Substantial Agreement
0.81 - 1.00	Almost Perfect Agreement

a) Kappa calculation for forehead

In this section, the computations are shown for calculation of Kappa for forehead. First, we calculate the proportion of units where there is agreement, Pr (a), which is (00, 11, 22, 33 and 44) as highlighted in Table 5.4 divided by grand total that is 50.

Pr (a) = 43 / 50 = 0.86

Thus, its means number of observed agreements is 43 which is 86% of the observations.

Table 5.4 Measure of agreement using Kappa coefficient between dermatologist and proposed algorithms in acne severity for forehead

		DERMATOLOGIST					
		0	1	2	3	4	TOTAL
PROPOSED METHOD	0	0	0	0	0	0	0
	1	2	7	0	0	0	9
	2	0	0	13	1	1	15
	3	0	0	2	17	0	19
	4	0	0	0	1	6	7
	TOTAL	2	7	15	19	7	50

Then, we calculate the proportion of units which would be expected to agree by chance, Pr (e). The expected numbers agreeing are found as in chi-squared tests, by multiplication of total row divided by grand total and total column divided by grand total.

$$\Pr(e) = \sum_{i=0}^{m} (P_{i+} \; X \; P_{+i}) \qquad \text{(Equation 5.9)}$$

Where m is number of units, P_{i+} are the row probabilities (total row divided by grand total) and P_{+i} is column probabilities (total column divided by grand total)

Dermatologist gives score 0	:	2	:	50	=	0.04
Proposed method gives score 0	:	0	:	50	=	0
Both give score 0	:	0.04	x	0	=	0

Dermatologist gives score 1	:	7	:	50	=	0.14
Proposed method gives score 1	:	9	:	50	=	0.18
Both give score 1	:	0.14	x	0.18	=	0.03
Dermatologist gives score 2	:	15	:	50	=	0.3
Proposed method gives score 2	:	15	:	50	=	0.3
Both give score 2	:	0.3	x	0.3	=	0.09
Dermatologist gives score 3	:	19	:	50	=	0.38
Proposed method gives score 3	:	19	:	50	=	0.38
Both give score 3	:	0.38	x	0.38	=	0.14
Dermatologist gives score 4	:	7	:	50	=	0.14
Proposed method gives score 4	:	7	:	50	=	0.14
Both give score 4	:	0.14	x	0.14	=	0.02

Therefore, number of agreements expected by chance:

Pr (e) = 0 + 0.03 + 0.09 + 0.14 + 0.02 = 0.28

As a result, it is 28% of the observations.

Finally, $\text{Kappa} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} = \frac{0.86 - 0.28}{1 - 0.28} = 0.81$

Based on Landis interpretation on Kappa, the value of 0.81 - 1.00 is almost perfect agreement. Hence, the Kappa value for forehead, 0.81 shows the strength of agreement considered as very good. The calculation in forehead is applied to right cheek, left cheek, nose and chin. Table 5.5 shows Kappa results for individual face region.

b) Kappa results for individual face region

Table 5.5 shows the Kappa results for forehead, left cheek, right cheek, nose and chin for 50 images.

Table 5.5 Kappa results for individual face region

Face Region	**Kappa (K)**
Forehead	0.81
Left Cheek	0.93
Right Cheek	0.93
Nose	0.68
Chin	0.83

For right and left cheeks, the Kappa value is 0.93. The Kappa value for chin is 0.83 while for nose is 0.68. For forehead, right cheek, left cheek and chin the Kappa values are above 0.81 which indicates almost perfect agreement. However, for nose the agreement is substantial.

c) Kappa results for Acne grading

Table 5.6 shows the Kappa results for acne grading for 50 patients.

Table 5.6 Kappa results for Acne grading

		DERMATOLOGIST				
		Mild	Moderate	Severe	Very Severe	TOTAL
PROPOSED METHOD	Mild	5	0	0	0	5
	Moderate	3	16	0	0	19
	Severe	0	1	19	0	20
	Very Severe	0	0	0	6	6
	TOTAL	8	17	19	6	50

From Table 5.6, Kappa result for Acne grading is 0.82. Based on Landis interpretation on Kappa, the agreement is almost perfect agreement.

5.3 Summary

The objective assessment of facial Acne Vulgaris using modified Global Acne Grading System (mGAGS) is applied on real data obtained from Hospital Kuala Lumpur (HKL). This assessment is applied on images of facial area which are forehead, nose, chin, right and left cheek of each patient.

In a few cases, acne images are under and over exposed. This is due to lighting condition in a small photography room in HKL. In order to correct this exposure, the illumination of images is adjusted and balanced. In data collection, the images are included non-skin objects such as hair, eyes and eyebrow. Therefore, the skin detection will separate the skin and non-skin region using the skin pixel value in YCbCr.

Then, the images are segmented using automated modified K-means clustering method. At the beginning, three to nine clusters are chosen to be clustered using modified K-means clustering. This modified K-means clustering give final result of minimum area of each cluster. Then, these minimum areas of each cluster are tested with feature selection in SVM classifier in order to get the cluster that has highest percentage of acne lesion. From that, the final result shows the best number of cluster and the best segmented cluster.

In order to measure the performance of the proposed segmentation method, the segmented images are compared with the reference segmented images. Reference segmented images are obtained by segmenting acne lesion manually from the digital images. ROC analysis is used to measure the performance of the proposed method. The acne lesion segmentation method is applied on 50 images with different levels of severity. For all the cases, the proposed method is able to achieve high sensitivity, specificity and accuracy.

Later on, the best segmented cluster is tested using feature extraction in order to determine the types of acne. Colour and diameter are the main features that are extracted to identify the types of acne which is papule, pustule or nodule cyst. The data from 50 patients are used in developing objective assessment of facial Acne Vulgaris using modified Global Acne Grading System (mGAGS). The patients are categorized into four groups according to their severity level, namely mild, moderate, severe and very severe groups. The grouping is required in order to incorporate the

types of acne lesion. 5 patients are classified into mild group, 19 patients are classified into moderate group, 20 patients are classified into severe and 6 patients are classified into very severe group.

The severity scores obtained from the proposed method are compared with the severity scores given by the dermatologists in order to evaluate the agreement between them. Therefore, the Kappa agreement test is used and as a result, Kappa value for forehead, right cheek, left cheek and chin are 0.81, 0.93, 0.93 and 0.83 respectively. With these value, Landis interpretation on Kappa designates that the value of 0.81 - 1.00 is almost perfect agreement. However, Kappa value for nose is 0.68 which is only reached substantial agreement.

Later on, the Acne grading obtained from the proposed method is compared with the Acne grading given by the dermatologists in order to evaluate the agreement between them. Again, the Kappa agreement test is used and as a result, Kappa value for Acne grading is 0.82 which is almost perfect agreement.

As a conclusion, we can conclude that the objective method is possible to replace the manual assessment of Acne Vulgaris lesion. Consequently, the proposed method has the potential to assess acne objectively and consistently.

CHAPTER 6
CONCLUSION

The objective assessment of facial acne vulgaris lesion has been done in this work. Results and findings of this work are discussed in this chapter. Contributions and future works are described at the end of chapter.

6.1 Conclusion

Acne is a common skin disease that affects 85% of adolescents at some time during their lives. Acne affects the areas of skin with densest population of sebaceous follicles which is face, the upper part of the chest and the back. The prevalence and severity of acne on the face, chest and back was 92%, 45% and 61% respectively. Generally, acne is presented in various types such as Acne Conglobata, Acne Excoriee, Acne Rosacea, Acne Cosmetica, Pomade Acne, Acne Fulminans, Acne Keloidalis Nuchae, Acne Chloracne, Acne Mechanica and Acne Medicamentosa. But acne vulgaris is common acne prevalent in 99% of the acne cases. The lesions evident in Acne Vulgaris are comedones, papules, pustules, nodules, cysts and in some cases, scarring.

There are two ways for treating the acne which are; using conventional treatment such as topical and oral and using therapy such as laser and light therapies. Before dermatologists prescribe the medication, they used standard acne assessment. The current gold standard method for assessing the severity of acne lesion is Global Acne Grading System (GAGS). GAGS assess forehead, right cheek, left cheek, nose, chin, chest and upper back. Since this research only focuses on facial area, we removed the non-facial area. Hence, we used modified Global Acne Grading System (mGAGS), since this grading system removes nonfacial areas (chest and upper back).

Each facial area is weighted differently with the factor for each location, based on surface area, distribution, and density of pilosebaceous units. For forehead, right and left cheek, the factor is 2, whereas for the nose and chin the factor is 1. On the other hand, each type of acne is weighted differently based on the severity. Among the lesions, nodule is most severe and its weighted is 4, follows with pustule, papule and comedone with 3, 2 and 1 respectively. Then the factor and severity are multiplied for each location in order to get local score for each location. Then the total of all local score shows the acne severity level mild, moderate, severe or very severe.

Although GAGS is the gold standard for assessing the acne vulgaris lesion, determining GAGS is a tedious task. Commonly, the types of acne are visually determined and may result in inter-individual and intra-individual variations, even by experienced dermatologists. The objective of this research is to develop a digital image analysis system to assess digital images and give consistent grading.

Consistency of digital image quality is essential to monitor the condition of the lesion. During image acquisition process, two light sources are used in order to create homogenous and diffused light to avoid the appearance of shadow and specular reflection. Green is selected as background colour since it has high contrast relative to the colour of human skin.

The first step in pre-processing is lighting compensation. This method was used to ensure the exposure of the images. The illumination of the images was extracted, normalized and averaged. Then, the average of images was compared with the minimum and maximum value to determine the images are under exposed, balanced or over exposed. After that, the illumination was corrected for under and over exposed.

The second step is skin detection where the aim is to separate the skin and non-skin region. The skin pixel is counted and results show that skin pixel is in the range of 10 to 35 for Cr components and -20 to 0 for Cb components. The skin pixel in between that range is considered as skin otherwise it is considered as non-skin. At this stage, acne and scar are still categorized as skin.

Final step in pre-processing is image conversion. The images are converted from RGB to CIE La*b*. Acne lesion can be recognized by its colour dissimilarity

with normal skin. The CIE La*b* colour space is widely used to measure any dissimilarity between colours.

Segmentation is done using automated modified k-means clustering. At the beginning, three to nine clusters are chosen to be clustered using modified K-means clustering. This modified K-means clustering give final result of minimum area of each cluster. Then, these minimum areas of each cluster are tested with feature selection in SVM classifier in order to get the cluster that has highest percentage of acne lesion. From that, the final result shows the best number of cluster and the best segmented cluster.

Later on, the best segmented cluster is tested using feature extraction in order to determine the types of acne. Colour and diameter are the main features that are extracted to identify the types of acne which is papule, pustule or nodule cyst.

Once the types of acne has been detected, it will be calculated using modified Global Acne Grading System (mGAGS) to determine the severity level such as mild, moderate, severe and very severe. This severity level is an indicator that dermatologist used to give the medication for treating the acne lesions.

6.2 Contribution and Direction for Future Works

The main contribution of this thesis is in the development of a system that is able to differentiate the types of acne and give acne grading objectively. The developed system can be applied on patients with various skin colours and has the potential to minimize variations of mGAGS due to inter- and intra-observer.

There are more than 25 different grading systems for assessment of acne severity that had been published in literature. The assessments are using lesion counting, photographic standard or both. Many research works have been conducted with the aim to view acne lesion clearly. However, there are no research works done with the aim to assess the acne grading objectively.

An initial study on segmentation using K-means clustering has been done. Segmentation is done in CIELAB colour space. In order to minimize misclassification due to shadow and reflectance area, only chrominance information (a* and b* of CIELAB colour space) is used to segment the lesion.

Acne lesions, scars and normal skin can be identified after segmentation and centroids of acne lesions, scars and normal skin are determined from selected sample. Euclidean distance of all pixels from each centroid is calculated. Each pixel is assigned to the class with minimum Euclidean distance. Results obtained show that the proposed method is comparable to the dermatologist visual approach (ground truth.

The techniques in segmentation and details of features will be used in determining acne grading. For acne cases, size and colour are the main features that are chosen in order to classify the types of acne.

All the complete grading system consisting of data acquisition, segmentation, classification and grading has been exhibited. Patients' data has been managed in Graphical User Interface (GUI). Results of mGAGS obtained show that the proposed method is comparable to the dermatologist manual assessment.

For future work:

- the data can be extended to the chest and back area. Therefore, the standard Global Acne Grading System (GAGS) can be used.
- develop an automated method to measure the size without using reference sticker
- develop an automated method to monitor disease progression over time.

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LIST OF PUBLICATIONS

Journals:

1. Ramli, R., Malik, A. S., Hani, A. F. M. and Jamil, A. (2012), Review Acne analysis, grading and computational assessment methods: an overview, *Skin Research and Technology 2012, 18:1-14*, doi: 10.1111/j.1600-0846.2011.00542.x (IF: 1.71)

2. Ramli, R., Malik, A. S., Hani, A. F. M. and Yap, B.B. (2011), EPSM-ABEC 2011 Conference, *Australasian College of Physical Scientists and Engineers in Medicine 2011 34:559-637. Springer*, doi 10.1007/s13246-011-0098-9 (IF: 0.561)

Conferences:

1. Ramli, R., Malik, A. S., Hani, A. F. M. and Yap, B.B. (2011), Segmentation of Acne Lesions using K-Means Clustering. *EPSM-ABEC Conference***,** 14-18 August 2011, Darwin, Northern Territory, Australia.

2. Ramli, R., Malik, A. S., Hani, A. F. M. and Yap, B.B. (2011), Identification of Acne Lesions, Scars and Normal Skin for Acne Vulgaris cases**,** *National Postgraduate Conference (NPC 2011),* 19-20 September 2011, Universiti Teknologi Petronas, Perak, Malaysia.
   Award: Certificate of Recognition (Special Mention Award)

3. Ramli, R., Malik, A. S., Hani, A. F. M. and Yap, B.B. (2011), Segmentation of Acne Vulgaris Lesions, *2011 International Conference on Digital Image Computing: Techniques and Applications (DICTA 2011),* 6-8 December 2011, Noosa, Queensland, Australia.

Exhibition:

1. Assessment of Facial Acne Vulgaris in 30th Science and Engineering Design Exhibition (SEDEX30), 8-9 August 2012, Universiti Teknologi Petronas, Perak, Malaysia
   Award: Silver Medal

Patent:

1. Digital Assessment of Facial Acne Vulgaris. File: July 2013. Intellectual Property Corporation of Malaysia (myIPO)

APPENDIX A

PATIENT INFORMATION SHEET

Study Title: Studies on automated acne analysis.

Doctor: Dr. Felix Yap Boon Bin

Researchers: Roshaslinie Ramli
Jawad Humayun

Institution address:

1. Department of Dermatology/Outpatient Department
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   Bandar Seri Iskandar
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INTRODUCTION

You are invited to participate in a study conducted by the Department of Dermatology Hospital Kuala Lumpur, Outpatient Department Hospital Kuala Lumpur and Universiti Teknologi PETRONAS. This is because you have a condition called acne. As a potential research subject, you have the right to know the consequences of participating in this study. The following information explains the possible benefits and risks of being in the study to help you make a decision about participation. Your participation in this study is strictly voluntary and you have no obligations to participate whatsoever.

It is important that you read this document thoroughly and discuss any queries with your doctor or anyone else you prefer before agreeing to participate. Your signature, dated, on the consent form is required before the researchers can perform study procedures on you.

PURPOSE OF THE STUDY

Acne is a common skin disease. It is a significant health and socioeconomic issue. It causes people with acne often experience low self-esteem and feel socially withdrawn. It is a difficult condition to assess the acne. Since assessment of acne is time consuming and tedious. In this study, we aim to build a new computational method for doctors to assess your acne condition in a more objective way.

WHO WOULD THIS STUDY INVOLVE

This study will involve patients who had been diagnosed to have acne condition.

WHAT WILL HAPPEN TO THE PARTICIPANTS AND THE INFORMATION OBTAINED IN THIS STUDY?

Photographs will be taken from DSLR and Multispectral camera. Acne condition usually appears on face, back and upper chest. So the patients having such condition on back and upper chest may also have to expose these areas in front of camera. You may be asked to move your head in a few positions in order to get a good photograph. We assure you that this data is being collected solely for the research purpose and your identity will not be disclosed anywhere else. The information obtained in this study will be analyzed and the results will help us in the management of patients with acne in the future. All medications and other treatment for your acne will be continued as usual.

POTENTIAL BENEFITS OF THE STUDY

The results of this study may be able to help doctors to assess your acne condition faster and consistently through computerized methods. Your participation may contribute to the way doctors assess or examine acne in the future.

POTENTIAL RISKS OF THE STUDY

This study will involve taking photographs through DSLR and Multispectral cameras of your face, back and upper chest only. There are no expected risks, discomfort and radiation that could cause long term consequences associated with the study. The procedure and risk for taking the images from above mentioned equipment is same like taking photographs from ordinary camera.

VOLUNTARY PARTICIPATION

Participation in this study is strictly voluntary. If you decide to participate in the study, you are expected to comply with the study requirements. You are allowed to withdraw from the study at any time without penalty or loss of benefits to which you

are otherwise entitled. We will be interested to know if the reason for withdrawal is due to adverse events experienced.

CONFIDENTIALITY

All information given by you are confidential. Reports prepared on the study will not include your name or other identification. Information and records may be reviewed by the Institutional Review Board (IRB)/Ethics Committee (EC) and other regulatory authorities to determine the accuracy of the reported data and/or to protect your safety and welfare.

STUDY COSTS/COMPENSATION

This research does not require any payment from you and neither will you get paid or receive any rewards for your participation. The cost of your acne treatment will remain the same whether you participate in this research or not. This research does not provide compensation for any problems that may occur.

TREATMENT OF STUDY RELATED INJURY

In the event that you suffer an injury or side effects or complications that is a direct consequence of the study, the attending doctor will be notified and you will be managed appropriately in Hospital Kuala Lumpur.

ETHICAL REVIEW

This study has been reviewed and approved by the Medical Research & Ethics Committee, Ministry of Health Malaysia.

CONTACT NUMBERS

If you have any enquiries regarding the study or experience any side effects of the study, please contact

Dr. Felix Yap Boon Bin

Dermatology Clinic Hospital Kuala Lumpur

03-5555259 or 03-5556687

APPENDIX B

CONSENT AND PHOTOGRAPHY REQUEST FORM

Study Title: Studies on automated acne analysis.

I have read the information on the research project stated above and have been given the explanation by a doctor about the purpose of this document. I understand that I retained the absolute right over the information given and I have the absolute right to withdraw from the study at any time.

I _____ IC Number:_____, give my consent for joining this research and photographs to be taken, as indicated above, of the said patient and for the photographs to be used by the research and academic purposes only.

I understand that the research authorities will, to the best of their ability, protect my identity in the event that the photographs are reproduced in the teaching sessions, academic discussions/meeting and medical/scientific journals.

Patient/Person giving consent

Name : _____

Signature : _____

Identity Card : _____

Date : _____

Tel : _____

Requesting Researcher

Name : _____

Signature : _____

Identity Card : _____

Date : _____

Tel : _____

Requesting Doctor

Name : _____

Signature : _____

Identity Card : _____

Date : _____

Tel : _____

APPENDIX C

COHEN'S KAPPA (K) COEFFICIENT

❖ Right Cheek

Table A Measure of agreement using Kappa coefficient between dermatologist and proposed algorithms in acne severity for right cheek

		DERMATOLOGIST					
		0	1	2	3	4	TOTAL
PROPOSED METHOD	0	0	0	0	0	0	0
	1	0	1	0	0	0	1
	2	0	0	10	1	0	11
	3	0	0	0	30	1	31
	4	0	0	0	0	7	7
	TOTAL	0	1	10	31	8	50

Pr (a) = 48 : 50 = 0.96

Dermatologist gives score 0	:	0	:	50	=	0
Proposed method gives score 0	:	0	:	50	=	0
Both give score 0	:	0	x	0	=	0
Dermatologist gives score 1	:	1	:	50	=	0.02
Proposed method gives score 1	:	1	:	50	=	0.02
Both give score 1	:	0.02	x	0.02	=	0
Dermatologist gives score 2	:	10	:	50	=	0.2
Proposed method gives score 2	:	11	:	50	=	0.22
Both give score 2	:	0.2	x	0.22	=	0.04
Dermatologist gives score 3	:	31	:	50	=	0.62
Proposed method gives score 3	:	31	:	50	=	0.62
Both give score 3	:	0.62	x	0.62	=	0.38

Dermatologist gives score 4	:	8	:	50	=	0.16
Proposed method gives score 4	:	7	:	50	=	0.14
Both give score 4	:	0.16	x	0.14	=	0.02

Then, Pr (e) = 0 + 0 + 0.04 + 0.38 + 0.02 = 0.44

Therefore, $\text{Kappa} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} = \frac{0.96 - 0.44}{1 - 0.44} = 0.93$

Hence, the Kappa value for right cheek is 0.93 and Landis interpretation on Kappa designates that the value of 0.81 - 1.00 is almost perfect agreement.

- Left Cheek

Table B Measure of agreement using Kappa coefficient between dermatologist and proposed algorithms in acne severity for left cheek

		DERMATOLOGIST					
		0	1	2	3	4	TOTAL
PROPOSED METHOD	0	0	0	0	0	0	0
	1	0	0	0	0	0	0
	2	0	0	10	1	1	12
	3	0	0	0	30	0	30
	4	0	0	0	0	8	8
	TOTAL	0	0	10	31	9	50

Pr (a) = 48 : 50 = 0.96

Dermatologist gives score 0	:	0	:	50	=	0
Proposed method gives score 0	:	0	:	50	=	0
Both give score 0	:	0	x	0	=	0

Dermatologist gives score 1	:	0	:	50	=	0
Proposed method gives score 1	:	0	:	50	=	0
Both give score 1	:	0	x	0	=	0

Dermatologist gives score 2	:	10	:	50	=	0.2
Proposed method gives score 2	:	12	:	50	=	0.24
Both give score 2	:	0.2	x	0.24	=	0.05
Dermatologist gives score 3	:	31	:	50	=	0.62
Proposed method gives score 3	:	30	:	50	=	0.6
Both give score 3	:	0.62	x	0.6	=	0.37
Dermatologist gives score 4	:	9	:	50	=	0.18
Proposed method gives score 4	:	8	:	50	=	0.16
Both give score 4	:	0.16	x	0.14	=	0.03

Then, Pr (e) = 0 + 0 + 0.05 + 0.37 + 0.03 = 0.45

Therefore, $\text{Kappa} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} = \frac{0.96 - 0.45}{1 - 0.45} = 0.93$

For left cheek, the Kappa value is 0.93 and similar to the Kappa value of right cheek. Landis interpretation on Kappa designates that the value of 0.81 - 1.00 is almost perfect agreement.

- Nose

Table C Measure of agreement using Kappa coefficient between dermatologist and proposed algorithms in acne severity for forehead

		DERMATOLOGIST					
		0	1	2	3	4	TOTAL
PROPOSED METHOD	0	0	0	0	0	0	0
	1	12	16	0	0	0	28
	2	0	0	11	0	0	11
	3	0	0	0	8	0	8
	4	0	0	0	0	3	3
	TOTAL	12	16	11	8	3	50

Pr (a) = 38 : 50 = 0.76

Dermatologist gives score 0	:	12	:	50	=	0.24
Proposed method gives score 0	:	0	:	50	=	0
Both give score 0	:	0.24	x	0	=	0
Dermatologist gives score 1	:	16	:	50	=	0.32
Proposed method gives score 1	:	28	:	50	=	0.56
Both give score 1	:	0.32	x	0.56	=	0.18
Dermatologist gives score 2	:	11	:	50	=	0.22
Proposed method gives score 2	:	11	:	50	=	0.22
Both give score 2	:	0.22	x	0.22	=	0.05
Dermatologist gives score 3	:	8	:	50	=	0.16
Proposed method gives score 3	:	8	:	50	=	0.16
Both give score 3	:	0.16	x	0.16	=	0.03
Dermatologist gives score 4	:	3	:	50	=	0.06
Proposed method gives score 4	:	3	:	50	=	0.06
Both give score 4	:	0.06	x	0.06	=	0

Then, Pr (e) = 0 + 0.18 + 0.05 + 0.03 + 0 = 0.26

Therefore, $\text{Kappa} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} = \frac{0.76 - 0.26}{1 - 0.26} = 0.68$

However, the Kappa value is 0.68 and Landis interpretation on Kappa designates that the value of 0.61 - 0.80 is substantial agreement. This Kappa value is low due to no acne in 12 patients' nose where is given by dermatologist but detected as comedone by proposed method.

❖ Chin

Table D Measure of agreement using Kappa coefficient between dermatologist and proposed algorithms in acne severity for chin

		DERMATOLOGIST					
		0	1	2	3	4	TOTAL
PROPOSED METHOD	0	0	0	0	0	0	0
	1	6	7	0	0	0	13
	2	0	0	8	0	0	8
	3	0	0	0	23	0	23
	4	0	0	0	0	6	6
	TOTAL	6	7	8	23	6	50

Pr (a) = 44 : 50 = 0.88

Dermatologist gives score 0	:	6	:	50	=	0.12
Proposed method gives score 0	:	0	:	50	=	0
Both give score 0	:	0.12	x	0	=	0
Dermatologist gives score 1	:	7	:	50	=	0.14
Proposed method gives score 1	:	13	:	50	=	0.26
Both give score 1	:	0.14	x	0.26	=	0.04
Dermatologist gives score 2	:	8	:	50	=	0.16
Proposed method gives score 2	:	8	:	50	=	0.16
Both give score 2	:	0.16	x	0.16	=	0.03
Dermatologist gives score 3	:	23	:	50	=	0.46
Proposed method gives score 3	:	23	:	50	=	0.46
Both give score 3	:	0.46	x	0.46	=	0.21
Dermatologist gives score 4	:	6	:	50	=	0.12
Proposed method gives score 4	:	6	:	50	=	0.12
Both give score 4	:	0.06	x	0.06	=	0.01

Then, Pr (e) = 0 + 0.04 + 0.03 + 0.21 + 0.01 = 0.29

Therefore, $\text{Kappa} = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} = \frac{0.88 - 0.29}{1 - 0.29} = 0.83$

Finally, the Kappa value for right cheek is 0.83 and Landis interpretation on Kappa designates that the value of 0.81 - 1.00 is almost perfect agreement.