Status of thesis

Title of thesis | Objective Assessment of Area and Erythema of Psoriasis Lesion Using Digital Imaging and Colourimetry

I, DANI IHTATHO ,

hereby allow my thesis to be placed at the Information Resource Center (IRC) of Universiti Teknologi PETRONAS (UTP) with the following conditions:

1. The thesis becomes the properties of UTP.
2. The IRC of UTP may make copies of the thesis for academic purposes only.
3. This thesis is classified as

[√] Confidential

[ ] Non-confidential

If this thesis is confidential, please state the reason:
Algorithm to be patented.

The contents of the thesis will remain confidential for 2 years.

Remarks on disclosure:
-

Endorsed by

Signature of Author

Desa Mundu RT.13 RW.07
45283 Indramayu, Indonesia

Date : 05/08/2008

Signature of Supervisor

Universiti Teknologi PETRONAS

Date : 5.08.2008

UNIVERSITI TEKNOLOGI PETRONAS

Approval by Supervisor (s)

The undersigned certify that they have read, and recommend to The Postgraduate Studies Programme for acceptance, a thesis entitled **"Objective Assessment of Area and Erythema of Psoriasis Lesion Using Digital Imaging and Colourimetry"** submitted by **(Dani Ihtatho)** for the fulfillment of the requirements for the degree of Master of Science in Electrical and Electronics Engineering.

Date 05/08/2008

Signature :

Main supervisor : Prof. Ir. Dr. Ahmad Fadzil M. Hani

Date : 5.08.2008

Signature :

Co-Supervisor :

Date :

TITLE PAGE

UNIVERSITI TEKNOLOGI PETRONAS

Objective Assessment of Area and Erythema of Psoriasis Lesion
Using Digital Imaging and Colourimetry

By

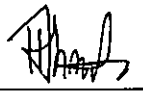
Dani Ihtatho

A THESIS
SUBMITTED TO THE POSTGRADUATE STUDIES PROGRAMME
AS A REQUIREMENT FOR THE
DEGREE OF MASTER OF SCIENCE
ELECTRICAL AND ELECTRONICS ENGINEERING
BANDAR SERI ISKANDAR,
PERAK

AUGUST, 2008

DECLARATION

I 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.

Signature : 

Name : DANI IHTATHO

Date : 05/08/2008

Acknowledgement

First and foremost, all praises and thanks are due to Allah, the almighty God, the source of my life and hope for giving me the strength and wisdom to succeed in life.

I am most grateful to my supervisor Professor Ahmad Fadzil M. Hani for giving me an opportunity to pursue a master degree. Many times, his patience and constant encouragement has steered me to be a better person.

I would like also express my gratitude to Puan Sri Dr. Suriya H. Hussein and Dr. Azura Affandi from Dermatology Department, Hospital Kuala Lumpur, for their effort in helping and providing me with the all data and guidance that I need for this research. My sincerity thanks also to postgraduate office staffs for their assistance during my study.

Special thanks also to my postgraduate research fellows Hermawan Nugroho and Nazr E Batool for serious discussions in research and entertaining chats in daily life.

At last and most importantly, I would like to thank my family for their open-mindedness and endless support. They are always close to my heart.

Abstract

Psoriasis is a non-contagious skin disease which typically consists of red plaques covered by silvery-white scales. It affects about 3% of world population. During treatment, dermatologists monitor the extent of psoriasis continuously to ascertain treatment efficacy. Psoriasis Area and Severity Index (PASI) is the current gold standard method used to assess the extent of psoriasis. In PASI, there are four parameters to be scored i.e., the surface area affected, erythema (redness), thickness and scaliness of the plaques. Determining PASI score is a tedious task and thus it is not used in daily clinical practice. In addition, the PASI parameters are visually determined and may result in intra-observer and inter-observer variations, even by experienced dermatologists. Objective methods in assessing area and erythema of psoriasis lesion have been developed in this thesis. Psoriasis lesion can be recognized by its colour dissimilarity with normal skin. Colour dissimilarity is represented by colour difference in CIELAB colour space, a widely used colour space to measure colour dissimilarity. Each pixel in CIELAB colour space can be represented by its lightness (L^*), hue (h_{ab}), and chroma (C_{ab}). Colour difference between psoriasis lesion and normal skin is analyzed in hue-chroma plane of CIELAB colour space. Centroids of normal skin and lesion in hue-chroma space are obtained from selected samples. Euclidean distances between all pixels with these two centroids are then calculated. Each pixel is assigned to the class of the nearest centroid. The erythema of psoriasis lesion is affected by degree of severity and skin pigmentation. In order to assess the erythema objectively, patients are grouped according to their skin pigmentation level. The L* value of normal skin which represents skin pigmentation level is utilized to group the patient into the three skin types namely fair, brown and dark skin types. Light difference (ΔL^*), hue difference (Δh_{ab}), and chroma difference (ΔC^*_{ab}) of CIELAB colour space between reference lesions and the surrounding normal skin are analyzed. It is found that the erythema score of a lesion can be determined by their hue difference (Δh_{ab}) value within a particular skin type group. Out of 30 body regions, the proposed method is able to give the same PASI area score as reference for 28 body regions. The proposed method is able to determine PASI erythema score of 82 lesions obtained from 22 patients objectively without being influenced by other characteristic of the lesion such as area, pattern, and boundary.

Abstrak

Psoriasis adalah sejenis penyakit kulit yang tidak berjangkit dan simptom – simptom tipikalnya ialah lepuhan plak merah yang diliputi sisik – sisik keputihan. Adalah dianggarkan sebanyak 3% populasi dunia menderita akibat psoriasis. Semasa rawatan, pakar kulit akan membuat pemerhatian secara berterusan untuk menentukan keberkesanan rawatan. Piawai terkini yang digunakan untuk mengkaji perkembangan psoriasis ialah kaedah Psoriasis Area and Severity Index (PASI). PASI akan menentukan skor daripada 4 parameter iaitu luas lepuhan, kemerahan, ketebalan, dan sisik pada plak. Walaupun begitu, PASI tidak dipraktikkan sehari-hari. Penentuan skor PASI mengambil masa yang panjang. Tambahan pula, 4 parameter ini ditentukan secara visual dan menghasilkan keputusan berbeza antara intra-pemerhati dan inter-pemerhati, malahan di kalangan pakar kulit berpengalaman. Objektif penyelidikan ini adalah menentukan PASI skor secara objektif, secara khususnya luas lepuhan dan kemerahan. Luas lepuhan akan diasingkan mengikut ketidaksamaan warna dengan kulit sihat. CIELAB colour space banyak digunakan untuk mengukur ketidaksamaan 2 warna. Ketidaksamaan warna diwakili dengan perbezaan warna pada CIELAB colour space. Perbezaan warna antara lepuhan dan kulit sihat akan dianalisis dengan hue-chroma plane pada CIELAB colour space. Pusat kulit sihat dan lepuhan pada hue-chroma plane akan dikira daripada sampel yang telah diasingkan secara manual daripada setiap imej yang masing- masing memberi jumlah pixel yang sama. Jarak Euclidean di antara semua pixel dengan kedua-dua pusat akan diukur. Setiap pixel akan dikelaskan mengikut jarak yang paling dekat. Dalam kajian ini pesakit akan dibahagikan kepada kumpulan mengikut tahap pigmentasi kulit. Nilai L* daripada kulit sihat akan digunakan sebagai rujukan untuk mengkategorikan pesakit kepada 3 kumpulan kulit iaitu; cerah, sawo matang, dan gelap. Dengan menganalisa ΔL^*, Δh_{ab}, and ΔC^*_{ab} daripada CIELAB colour space antara rujukan kelepuhan dan kulit sihat di sekelilingnya, adalah didapati bahawa skor kemerahan dapat ditentukan dengan Δh_{ab} di dalam kumpulan jenis kulit tertentu. Daripada 30 kes, metode ini mampu menghasilkan skor yang sama dengan referensi untuk 28 kes. Metode ini juga mampu menentukan skor erythema secara onjektif untuk 82 lepuhan yang didapatkan daripada 22 patient tanpa terpengaruh oleh karakteristik luka yang lain seperti luas, pola, dan garis tepi.

Table of Contents

List of Tables

List of Figures

CHAPTER 1: INTRODUCTION

Vision is one of five sensory systems that contributes 40% of the total sensory input to our brain [Lee, 2005]. Digital imaging is a system that aims to emulate the capability of human vision. It covers image acquisition, manipulation, analysis, storage, and display. The output of digital image analysis is usually being used as an input for decision making system. Nowadays, with the advance of imaging devices and hardware technology, digital imaging covers many areas including medical field.

1.1 BACKGROUND OF STUDY

Dermatology is one of the medical fields that has benefited from digital imaging. Image of the skin reflects pathological changes on and beneath the skin surface thus it is a vital source of information in dermatological diagnosis. Commonly, dermatologists assess the skin visually. Therefore, diagnosis is highly dependent on the dermatologists' experience and visual acuity. However, the human visual system may not have the accuracy and consistency in analyzing an object. In order to overcome these limitations, digital imaging is commonly used in dermatological diagnosis especially for telemedicine purposes [Maglogiannis and Kosmopoulos, 2003].

1.1.1 Digital imaging in dermatological diagnosis

Image acquisition is the first step in digital imaging system. The images can be captured either by film camera or by digital camera. The 35mm film cameras are able to produce images with resolution equivalent to about 3 megapixels of digital camera, providing enough information for our eye [Lee, 2005]. For further processing, the images are scanned to create the digital images. With the advance of digital imaging sensor technology, digital cameras can even produce a higher resolution image compared to film cameras. Since 2007, all digital single lens reflector (DSLR) cameras manufactured by various companies (Canon, Nikon, Olympus, and Sony) have minimum resolution of 10 megapixels [http://dpreview.com/]. Image sensor of DSLR camera is physically larger than that in digital compact camera, thus producing better quality images [Benamati, 2001]. With the same resolution, DSLR cameras produce image with lower noise than

digital compact camera. Besides the image resolution, another advantage of using digital camera is its convenience. The images are captured in digital format, which is very convenient for storage and further processing in computer. Moreover, the price of DSLR cameras is getting cheaper.

Digital image processing is a manipulation process of digital image. Manipulation is required in order to extract the information from an image for further analysis. Image processing can be implemented in general-purpose or specific-purpose computer. By using general-purpose computer, development and verification of an image processing algorithm can be easily performed. For commercial and real-time applications, specific-purpose computer is preferable due to its faster processing and smaller size [Vega-Rodríguez *et al.*, 2005].

Computer-aided diagnosis has become a main research area in dermatology during the past decade [Horsch, 2006]. It is used to assist dermatologist in interpreting the medical images for accurate and consistent diagnosis. The type and severity of a lesion are indicated by its shape, arrangement, distribution and colour [Numahara, 2001]. These are related to 2D, 3D, and colour information of a lesion. The 2D and colour information of a lesion can be obtained from the image taken by digital camera. For more accurate and consistent colour information, chromameter is preferably used. Chromameter is an instrument designed specifically for measuring colour by simulating characteristic of human visual system. It is commonly used in dermatological application for measuring skin and lesion colour [Fullerton *et al.*, 1996]. The advantage of chromameter over digital camera in measuring colour is that the measurement is not influenced by the surrounding lighting condition. The 3D information can be obtained either from several 2D images or from the image taken by a specific 3D camera.

1.1.2 Psoriasis lesion

Psoriasis is a chronic inflammatory skin disease which is caused by genetic fault where immune system is mistakenly triggered and producing skin cells quicker and thicker than normal. The skin often itches, and it may crack and bleed. Furthermore, it can cause permanent damage to the joints. This disease may occur on the entire body, especially on the elbows, knees, scalp, lower back, face, palms, and soles. It has been reported from

epidemiological studies around the world that the prevalence of psoriasis ranges from 0.05 to 11.8 % [Gordon and Ruderman, 2005; Neimann *et al.*, 2006; Cimmino, 2007]. In Malaysia, the prevalence of psoriasis ranges from 4 to 5.5 %. Since the disease is incurable, the prevalence of psoriasis cases is predicted to be increasing. Moreover, the disease can be inherited genetically [Gordon and Ruderman, 2005].

Besides physical effect, psoriasis also affects psychological aspect of the patients. Due to the appearance of the lesion, individuals with psoriasis are found to have low self-esteem. In some cases, it limits patients from doing their job responsibility and from their social interaction [National Psoriasis Foundation, 2008]. Despite of its appearance, psoriasis is non-contagious disease. It cannot be transferred from one person to another by physical contact.

There are five types of psoriasis, i.e. plaque, guttate, pustular, inverse, and erythrodermic. Plaque psoriasis is the most common form of psoriasis, which accounts for 80% of cases. It is characterized by circumscribed, thickened plaques that are marked by silvery scales. Guttate psoriasis which is mainly found on children and young adult, indicated by individual red spots on the skin. Pustular psoriasis is characterized by white pustules surrounded by red skin. Inverse psoriasis appears as a lesion which is very red and usually lack the scale associated with plaque psoriasis. Erythrodermic psoriasis involves the widespread inflammation and exfoliation (shedding) of the skin over most of the body surface. Psoriatic arthritis is a specific condition in which a person has both psoriasis and arthritis (joint inflammation). These psoriasis types are shown in Figure 1.1.

Although psoriasis is an incurable disease, there are many available treatments to control the symptoms of psoriasis. However, there is no single treatment that works for every case. Experimentation is required in order to find the best treatment for a particular patient. This includes combination of several treatments, changing dosage and rotation of treatments. During a treatment, dermatologist will monitor the extent of psoriasis continuously to ascertain the treatment efficacy.

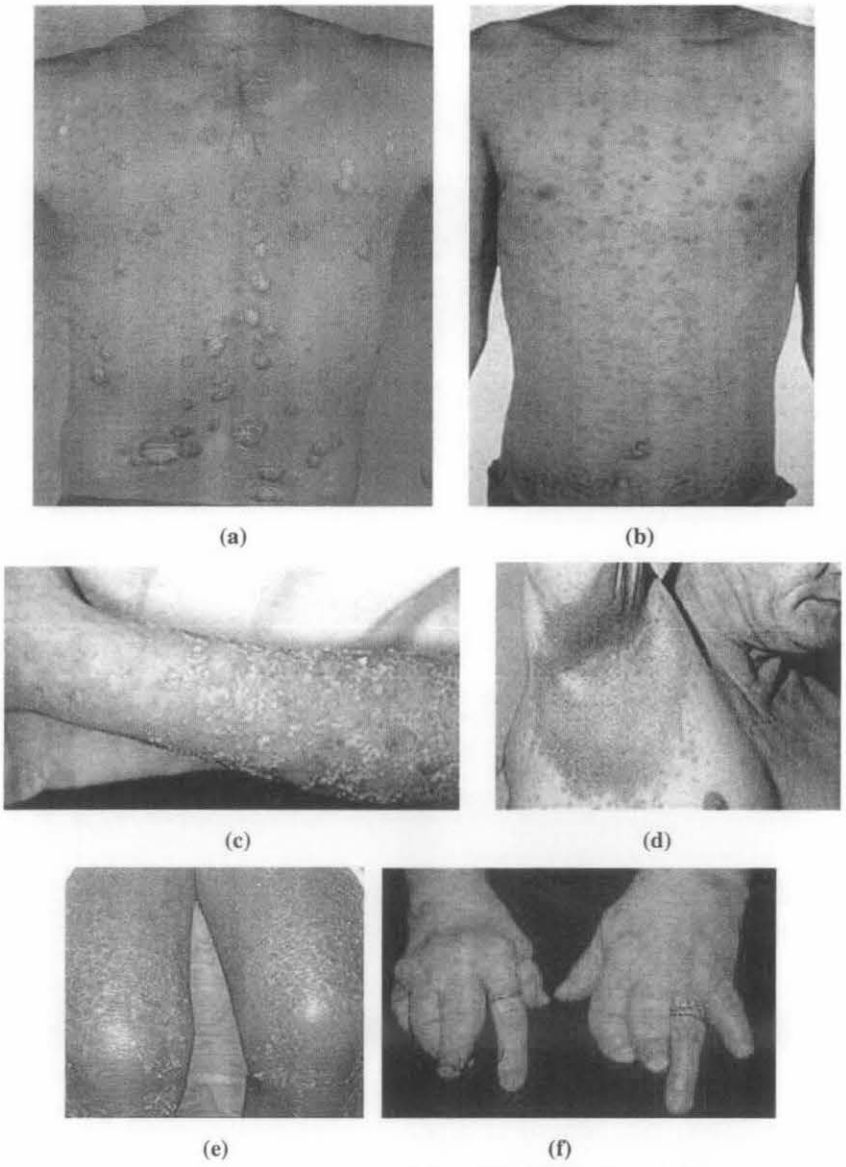


Figure 1.1 Samples of psoriasis types: (a) plaque, (b) guttate, (c) pustular, (d) inverse, (e) erythrodermic, and (f) psoriatic arthritis

The current gold standard method used to assess the extent of psoriasis is Psoriasis Area and Severity Index (PASI). PASI assesses four body regions, the head, trunk, upper extremities and lower extremities. For each region, the surface area involved, erythema (redness), thickness and scaliness of the plaques are determined. Each body regions are weighted differently to reflect their respective proportion of body surface area (BSA). The surface area affecting each region is calculated in terms of area percentage. It is graded by score 0 to 6 with 0 for no area affected and 6 for greater than 90 percent area

affected. The other three parameters are graded by score 0 to 4 with higher score indicates more severe condition.

The total PASI score ranges from 0 to 72; higher scores indicate more severe condition. It is now well established that 75% reduction in PASI score (PASI 75) is a clinically meaningful endpoint for clinical trials [Feldman and Krueger, 2005]. The treatment is considered effective if the PASI score is decreased by 75% from the initial score.

1.2 PROBLEM STATEMENT

Although PASI is the gold standard for evaluating the extent of psoriasis, it is not used in daily practice [Feldman and Krueger, 2005]. Assessing the four parameters of PASI manually is a tedious task and the result may not represent the actual condition of the lesions. The score of PASI area can be determined by just roughly estimating the percentage of lesion area visually. For better result, area assessment can be done by covering the patient with transparent plastic and drawing the border of lesion on the plastic as shown in Figure 1.2. The area of lesion is calculated from the lesion figure on the plastic by using 'matrix paper'. The percentage of lesion area is calculated as a ratio between lesion area and body surface area (BSA). The body surface area can be approximated from patient's height and weight. In some cases psoriasis are indicated by small and scattered lesions, which is hard for dermatologists to draw the border of the lesion on the plastic. Moreover, it is very tedious to calculate the area of this kind of lesion.

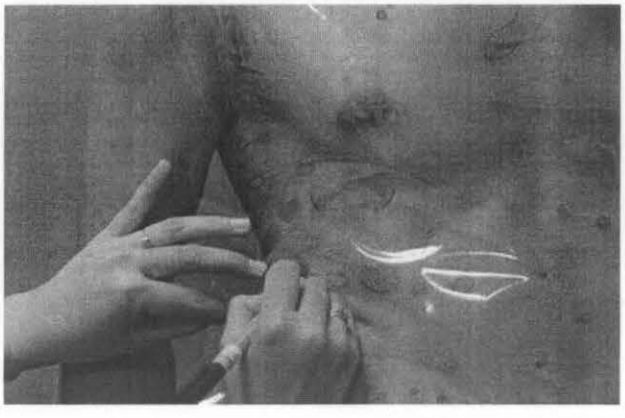


Figure 1.2 Measuring area of the lesions using plastic sheet (Courtesy of Hospital Kuala Lumpur)

Psoriasis lesion can appear in a wide variety of colour. It is affected by degree of severity and its original skin colour. 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 psoriasis lesion from skin with different level of pigmentation (low to high) are shown in Figure 1.3. On patients with low pigmentation, the lesion appears red whereas on those with high pigmentation, the lesion appears dark. On patients with medium pigmentation, the lesion appears less red than on patients with low pigmentation. As a result, the parameter of PASI erythema score cannot be generalized for all patients.

(a) (b) (c)

Figure 1.3 Typical appearances of psoriasis lesion from different skin colour: (a) fair skin (low pigmentation), (b) brown skin (medium pigmentation), and (c) dark skin (high pigmentation)

The thickness score is determined from tactile inspection on the lesion. Based on PASI standard, the thickness of psoriasis lesion is determined by examining the gradation of lesion edge. Although this is the convenient way, it does not reflect the actual thickness of the lesion. The thickness of the lesion on the border may not be the same with the thickness on the center. Moreover, it is very difficult to measure thickness of the lesion by using a ruler.

Based on PASI standard, the scaliness score of a lesion is affected by the area of lesion covered by the scale and the roughness of the scale. Area of the scale is assessed visually whereas roughness is assessed by tactile inspection. Roughness is a very subjective parameter.

Since the four parameters of PASI are manually determined, it may also result in inter-individual variations even by experienced dermatologists. Moreover, inconsistent PASI scoring by a single dermatologist may occur during repeated visits. Thus, objective and accurate evaluation of psoriasis lesion for PASI scoring is important in deciding the treatment efficacy, especially in clinical trials.

1.3 RESEARCH OBJECTIVE AND SCOPE OF WORK

The objective of this research is to develop a computer vision system to assess digital images and colourimetry data of psoriasis lesion for PASI parameters in particular the affected area and erythema. The type of psoriasis lesion which is being analyzed for this work is plaque psoriasis, since it is the most common form of psoriasis lesion. The affected area of lesion is analyzed based on digital images of the lesion. The erythema of lesion is analyzed based on colour measurement on the lesion.

The affected area of psoriasis lesion is calculated by assessing digital images. Based on PASI standard, images of face, anterior and posterior side from trunk and both left and right upper limbs and lower limbs were digitally photographed. In an image-based diagnosis system, image acquisition step plays an important role. The system should be able to capture images that represent actual condition of the skin. For monitoring purposes, the system should be able to capture reproducibility images [Maglogiannis and Kosmopoulos, 2003]. There are some issues in capturing consistent quality images of skin. The resolution of camera should be high enough to give detail information of the skin lesion. The noise of the camera image sensor should be as minimal as possible in order to produce an actual colour of the skin lesion. The lighting condition also should be set properly in order to avoid the appearance of spectral reflectance and shadows. For monitoring purposes, the position of the camera, patient, and light source should be constant for every image acquisition process. The above issues are addressed in this work. The score of PASI area is determined from the percentage of lesion area. The percentage of lesion area is a ratio between lesion areas over body surface area. The body surface area can be determined by segmenting the region belongs to human body from the region belongs to the background. The psoriasis lesion can be segmented from normal skin from its colour dissimilarity.

In assessing lesion erythema, colour samples of psoriasis lesion and normal skin are measured using Chromameter. Chromameter is a colourimeter instrument which is equipped with internal light source and photodetector that simulate physical characteristic of human visual system. This instrument produces higher accuracy and reproducibility since it is not affected by surrounding lighting condition [Draaijers *et al.*, 2004]. The erythema level of a lesion is determined by its dissimilarity level from the surrounding normal skin.

1.4 AN OVERVIEW OF THESIS STRUCTURE

This thesis is organized in six chapters including this introduction. In Chapter 2, the medical review of psoriasis is introduced. It covers explanation of psoriasis type, its symptoms, causes, and treatment. Psoriasis Area and Severity Index (PASI) as standard method for dermatologist in assessing severity of psoriasis also discussed in this chapter. Lastly, related works on assessing affected area and erythema of psoriasis lesion objectively are reviewed.

Chapter 3 describes basic theory of colour and vision covering physical characteristic of light source, object's reflectance, sensitivity of human visual system, and also CIE standard for these three parameters. CIEXYZ and CIELAB as colour spaces defined by CIE are presented. RGB as the widely used colour space in digital image is also presented in this chapter. Image processing techniques and data clustering that used in thesis are introduced in this chapter.

The approaches in solving the problem are discussed in Chapter 4. It begins with explanation of instruments for data acquisition, i.e. DSLR camera and Chromameter. Then, methods for calculating psoriasis lesion area and scoring degree of erythema are presented. The methods are applied on the datasets and the results are discussed in Chapter 5. This chapter also discussed about advantages and limitations of the proposed methods in assessing area and erythema of psoriasis lesion over visual assessment. Chapter 6 summarizes the achievements and contribution of this thesis and outlines several ideas based on our achievement for further work.

CHAPTER 2: LITERATURE REVIEW

In this chapter, medical backgrounds of psoriasis are described, covering the type of psoriasis, its causes, symptoms, and treatments. The gold standard for dermatologist in assessing the severity of psoriasis, namely Psoriasis Area and Severity Index (PASI) will be discussed in this chapter including its limitation. The related works in determining two PASI parameters (area and erythema) objectively are reviewed at the end of this chapter.

2.1 PSORIASIS

Psoriasis is a chronic inflammatory skin disease which affects people worldwide, regardless of age, sex and ethnicity. Chronic inflammatory means that there is simultaneous inflammation due to tissue destruction and regeneration. It is indicated by the appearance of red scaly patches on skin surface. These patches which are called plaques are areas of inflammation caused by excessive regeneration of skin cells. The disease may occur on the entire body, especially on the elbows, knees, scalp, lower back, face, palms, and soles. Although it does not bring about fatality, psoriasis usually causes discomfort to the people who have it. The skin often itches and it may crack and bleed. Moreover, if the plaques affect the joints, it can be disabling and cause permanent damage to the joints. Besides physical effect, psoriasis also affects psychological being of the patients. Individuals with psoriasis often feel frustrated and have low self-esteem. In some cases, it limits patients from doing their job responsibility and from their social interaction [National Psoriasis Foundation, 2008].

Although the cause of psoriasis is not fully understood, researchers found that it is related to the immune system [Fry, 2004]. Psoriasis triggers the immune system to produce skin cell at a faster rate. Normally, it takes 28 to 30 days for skin cells to mature before they are shed from skin surface. In psoriasis cases, skin cells mature in 3 to 4 days and accumulated on skin surface, producing visible lesions [National Psoriasis Foundation, 2008]. Despite of their appearance, psoriasis is a non contagious disease. It cannot be transferred from one person to another by physical contact. It has been reported from

epidemiological studies around the world that the prevalence of psoriasis ranges from 0.05 to 11.8 % [Gordon and Ruderman, 2005; Neimann *et al.*, 2006]. The majority of them have mild psoriasis, where psoriasis impact less than 3% of the body. It is found that the prevalence rate is higher in cooler region such as northern Europe. The prevalence of psoriasis in several regions is given in Table 2.1.

Table 2.1 Prevalence of psoriasis [Gordon and Ruderman, 2005; Neimann *et al.*, 2006; Cimmino, 2007]

Geographical area	Prevalence (%)
Arctic - Kasach'ye	11.8
Australia	2.3 - 2.6
Brazil	1.3
Canada	4.7
Caribbean	6
China	0.05 - 0.8
Croatia	1.5
Denmark	2.5 - 3.2
Egypt	3
Faroe Islands	2.8
Germany	6.5
India	0.7
Ireland	5.5
Italy	3.1
Japan	0.3 - 1.2
Kenya	3.5
Kuwait	3.1
Malaysia	4 - 5.5
Mali	0.05
Mexico	3
Nigeria	0.08 - 0.7
Norway	0.6 - 4.8
Paraguay	4.2
Scotland	4.8
South Africa	4.5
Spain	1.2 - 3.7
Sri Lanka	0.4
Sweden	2 - 2.3
Tanzania	3
Uganda	2.8
UK	1.5 - 1.6
USA	1.3 - 4.6
Venezuela	2
Yugoslavia	1.18

Genetically, a child has about 10% to 25% chance of having psoriasis if one parent has psoriasis and about 50% chance if both parents have psoriasis [Gordon and Ruderman,

2005]. About one third of those with psoriasis have at least one family member with the disease. However, some people with family history of psoriasis never get this condition. Research indicates that a genetic tendency needs to be triggered off by such things as injury, throat infection, certain drugs and physical and emotional stress. About 75% of patients developed psoriasis before age 40 [PsoriasisNet, 2007].

There are five types of psoriasis, each with unique appearance (what is seen) and symptom (what is felt by the patient): plaque, guttate, pustular, inverse, and erythrodermic. Generally, patients only have one type of psoriasis; however in some cases two or more types may occur at the same time. Psoriasis can also alter from one type to another such as from plaque to pustular. After one type of psoriasis disappears, another type may occur [National Psoriasis Foundation, 2008]. There is a specific condition in which a patient has both psoriasis and arthritis (a condition related to the joints). The most common symptom is inflammatory arthritis. This is called psoriatic arthritic.

2.1.1 Plaque psoriasis

Plaque psoriasis is the most common form of psoriasis, which accounts for 80% of cases [Fry, 2004]. The scientific name of this type of psoriasis is psoriasis vulgaris (vulgaris means common). It is characterized by circumscribed, thickened plaques that are marked by silvery scales, which occur most commonly on the elbows, knees, buttocks, scalp, and sites of local trauma. Additionally, patients often experience pain, itching, burning, and bleeding from the thickened lesions. An example of plaque psoriasis is shown in Figure 2.1.

Figure 2.1 Plaque psoriasis

2.1.2 Guttate psoriasis

Guttate psoriasis is the second most common form of psoriasis. It is found mainly in children and young adults [Fry, 2004]. The word guttate is derived from the Latin word *gutta,* meaning drop since the lesions are multiple, small (5-15 mm), round, or oval and drop-like in shape. This form of psoriasis resembles red, individual spots on the skin. These spots are not usually as thick as plaque lesions. Guttate lesions usually appear on the trunk and limbs. An example of guttate psoriasis is shown in Figure 2.2.

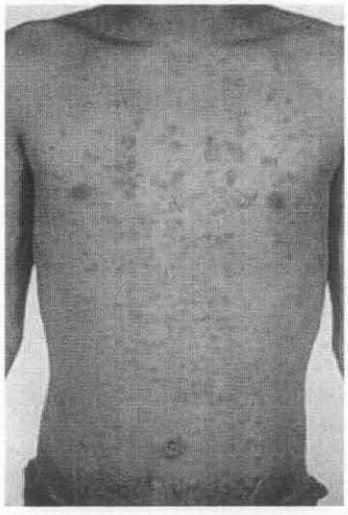


Figure 2.2 Guttate psoriasis

2.1.3 Pustular psoriasis

Pustular psoriasis is uncommon form of psoriasis which is primarily found in adults. It is characterized by white pustules (blisters of non-infectious pus) surrounded by red skin. The fluid in the pustules is not an infection or bacteria, and the pustules are not contagious. This type of psoriasis can occur in smaller areas on palm and soles (localized pustular psoriasis) or in widespread patches (generalized pustular psoriasis) [Fry, 2004]. Generalized pustular psoriasis can cause fever, chills, severe itching, weight loss and fatigue. An example of pustular psoriasis is shown in Figure 2.3.

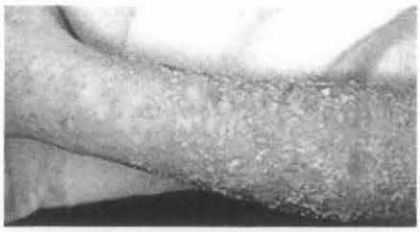


Figure 2.3 Pustular psoriasis

2.1.4 Inverse psoriasis

Inverse psoriasis is found in the armpits, groin, under the breasts, and in other skin folds around the genitals and the buttocks. This type of psoriasis first shows up as lesions that are very red and usually lack the scale associated with plaque psoriasis [Gordon and Ruderman, 2005]. It is aggravated by friction and sweat, and is vulnerable to fungal infections. Inverse psoriasis is more common and troublesome in overweight people and people with deep skin folds. An example of inverse psoriasis is shown in Figure 2.4.

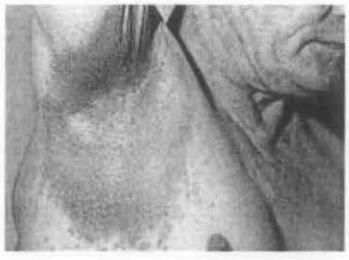


Figure 2.4 Inverse psoriasis

2.1.5 Erythrodermic psoriasis

Erythrodermic psoriasis is a form of psoriasis which involves the widespread inflammation and exfoliation (shedding) of the skin over most of the body surface. It may be accompanied by severe itching, swelling and pain [Fry, 2004]. This form of psoriasis can be fatal, as the extreme inflammation and exfoliation disrupt the body's ability to regulate temperature and for the skin to perform barrier functions. An example of erythrodermic psoriasis is shown in Figure 2.5.

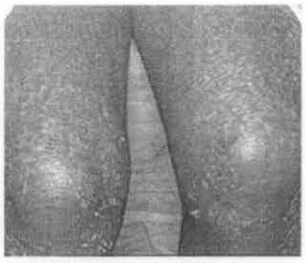


Figure 2.5 Erythrodermic psoriasis

2.1.6 Psoriatic arthritis

Psoriatic arthritis is a specific condition in which a person has both psoriasis and arthritis (joint inflammation). The joints affected may become tender, swollen and stiff. Without proper treatment, it can cause progressive joint damage that in the most serious cases may lead to permanent deformity. Approximately 10 percent to 30 percent of people with psoriasis develop psoriatic arthritis; with 80 percent of them develop psoriasis first [Gordon and Ruderman, 2005]. It seems to affect men at a slightly higher percentage than women. Psoriatic arthritis usually develops in people aged 30-50 years. However, it can develop in people of almost any age. An example of psoriatic arthritis is shown in Figure 2.6.

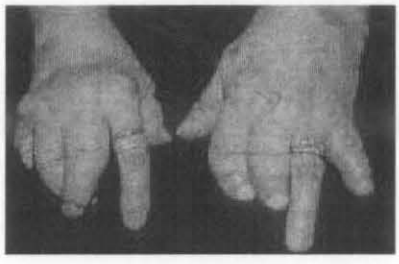


Figure 2.6 Severe psoriatic arthritis involving the finger joints. Several joints have deteriorated

2.2 TREATMENTS

Although there is currently no cure for psoriasis, there are a number of treatments available that can clear psoriasis symptoms for a period of time. Each treatment has advantages and disadvantages, and what works for one patient may not be effective for another. Board-certified dermatologists have the medical training and experience needed to determine the most appropriate treatments for each patient. During treatment, dermatologist will monitor the extent of psoriasis continuously to ascertain the treatment

efficacy [Pariser, 2003]. Psoriasis treatments can be divided into three categories: topical treatments, phototherapy treatments, and systemic treatments.

2.2.1 Topical treatments

Topical treatments (applied to the skin) are usually the first treatment in handling psoriasis. As mentioned before, psoriasis triggers skin cells to grow excessively. Topical treatments slow down or normalize that excessive cell reproduction and reduce inflammation (redness) associated with psoriasis. Topical corticosteroids are the most frequently prescribed medications for treating mild to moderate psoriasis. Low-potency corticosteroid ointments are usually applied on sensitive areas such as face and on widespread patches of damaged skin. Stronger corticosteroid ointments are applied on small areas of hands or feet with stubborn plaques. Topical corticosteroids are generally used on active outbreaks and not to be used for extended period, as psoriasis can return as bad or worse if this type of treatment is used for too long or in overly excessive quantities.

2.2.2 Phototherapy

It has long been recognized that daily, short, non-burning exposure to sunlight helped to clear or improve psoriasis. Sunlight contains many different wavelengths of light but only ultraviolet (UV) light that is useful for psoriasis treatment. Ultraviolet wavelengths are subdivided into UVA (315 - 380 nm), UVB (280 - 315 nm), and UVC (< 280 nm). UVA light is used along with psoralen (a light-sensitizing medication) in psoriasis treatment. This kind of treatment is called PUVA (Psoralen Ultra Violet A). UVA light penetrates deeper into the skin than does UVB light and psoralen makes the skin more sensitive to the effects of UVA exposure. PUVA is often used for more severe cases of psoriasis. More than 85% of patients report relief of disease symptoms with 20-30 treatments [eMedicineHealth, 2007]. Despite of its efficacy, PUVA has several side effects. The most common short-term side effects of oral PUVA are nausea, itching and redness of the skin. Long-term treatment increases risk of skin cancer, including melanoma, the most serious form of skin cancer. UVB phototherapy is extremely effective for treating moderate-to-severe plaque psoriasis. It is usually combined with

one or more topical treatments. Although not as effective as PUVA, narrow-band UVB is easier for people to undergo and may be safer over the long term.

2.2.3 Systemic

Systemic treatments (taken orally or by injection or infusion) are generally started when the above mentioned treatments have failed. They are generally reserved for people with severe psoriasis or psoriatic arthritis. The four most commonly prescribed systemic medications to treat psoriasis are Methotrexate, Ciclosporin, Acitretin and Hydroxycarbamide. Because of severe side effects, some of these medications are used for just brief periods of time and may be alternated with other forms of treatment. The current systemic medications are 'biologic drug', which are made from living human or animal proteins. Biologic drug works by blocking interaction between certain immune system cells. Although they're derived from natural sources rather than chemical ones, they have strong effects on the immune system. Their overall safety is still being evaluated and long-term side effects are not fully known.

2.3 PSORIASIS AREA AND SEVERITY INDEX (PASI)

As mentioned above, monitoring the extent of psoriasis is required to ascertain the treatment efficacy. It plays important role in finding the best treatment for particular patient. Every time patients visit dermatologist, the lesions are assessed and given scores according to predefined scoring criteria. From scores of sequential visits, dermatologist can determine the efficacy of treatment.

The current gold standard method for assessing the extent of psoriasis is Psoriasis Area and Severity Index (PASI). PASI assesses four body regions, the head, trunk, upper extremities and lower extremities. Each body regions are weighted differently to reflect their respective proportion of body surface area (BSA). For each region, the surface area affected, redness, thickness and scaliness of the plaques are determined [Fredriksson and Petterson, 1978]. The surface area affected of each region is calculated in terms of area percentage. Then, it is graded by score 0 to 6 with 0 for no area affected and 6 for greater than 90 percent area affected. The other three parameters are graded by score 0 to 4 with

higher score indicates more severe condition (Table 2.2). The total PASI score can be calculated as shown in Equation 2.1. The score ranges from 0 to 72.

$$\begin{aligned} \text{PASI} = 0.1\left(R_h + T_h + S_h\right)A_h + 0.2\left(R_u + T_u + S_u\right)A_u \\ +0.3\left(R_t + T_t + S_t\right)A_t + 0.4\left(R_l + T_l + S_l\right)A_l \end{aligned} \tag{2.1}$$

A = area (0 – 6), R = redness (0 – 4), T = thickness (0 – 4), S = scaliness (0 – 4), h = head, u = upper extremities, t = trunk, l = lower extremities.

Table 2.2 PASI parameter scoring

Score	Area	Erythema	Scaliness	Thickness
0	0%	None	None	None
1	<10%	Slight pink	Fine scale	Slight plaque elevation
2	10% to <30%	Pink	Coarse scales with most lesions partially covered by scale	Moderate elevation with rounded or sloped edges
3	30% to <50%	Red	Coarse scales with almost all lesions covered and a rough surface	Marked elevation with marked sharp edges
4	50% to <70%	Dark red/ purple	Very coarse thick scales covering all lesions, very rough surface	Very marked elevation with very hard sharp edges
5	70% to <90%			
6	90% to 100%			

It is now well established that 75% improvement in PASI (PASI 75) is a clinically meaningful endpoint for clinical trials, and there is strong evidence demonstrating that 50% improvement in PASI (PASI 50) is also a clinically meaningful endpoint [Feldman and Krueger, 2005]. For example, Figure 2.7 shows pictures of a patient with plaque psoriasis along with the initial PASI score which is 37. The treatment is considered effective if the PASI score is decreased by 75% (PASI 75) from the initial score which becomes 9. Although PASI is the gold standard for evaluating the extent of psoriasis, it is not used in daily practice. Determining PASI score is a tedious task. Commonly, the four parameters are visually determined and may result in inter-individual variations, even by experienced dermatologists. During repeated visits by patients, inconsistent PASI scoring by a single dermatologist can occur. Several works have been conducted in order to overcome this limitation. They primarily aim to determine one of PASI parameter objectively and automatically [Roning *et al.*, 1999; Gomez *et al.*, 2003; Gomez *et al.*, 2004]. However, none of them cover all four parameters of PASI in one integrated system.

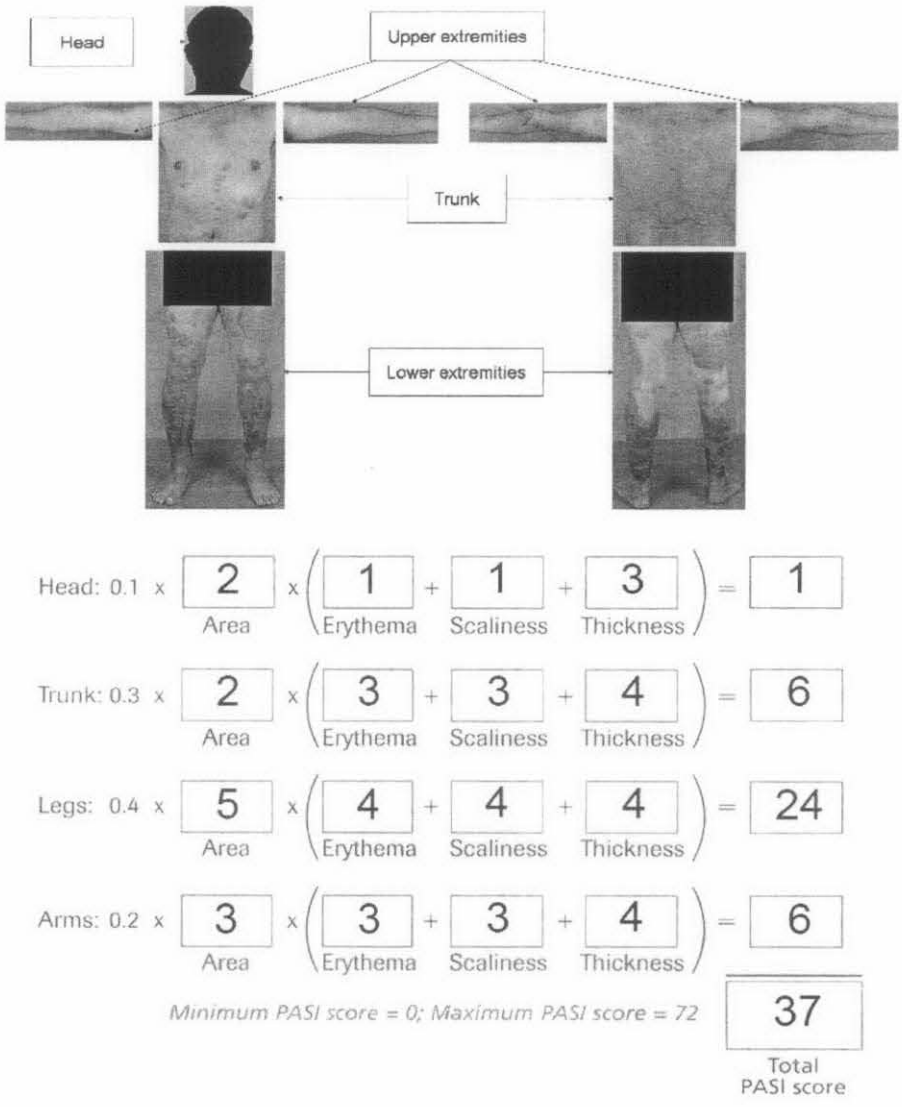


Figure 2.7 An example of PASI scoring

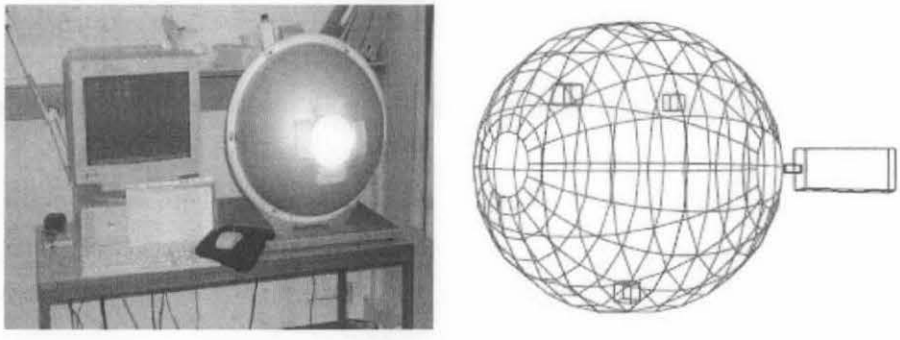
2.4 RELATED WORK

There have been many works conducted in assessing area and erythema of a lesion objectively. The area of lesion is assessed from digital images. Image acquisition is the important step in digital image system. There are several constrain 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 psoriasis lesion from the normal skin. Erythema of skin is affected by the interaction of light with the component beneath and on the skin. There are three different methods in measuring the erythema based on the interaction of light and skin.

2.4.1 Image Acquisition

The main concern in image acquisition system in dermatological application is its ability to produce images with consistent high quality. The quality of images is affected by the quality of the camera, lighting condition, and position of the patient [Maglogiannis and Kosmopoulos, 2003]. The resolution of the camera should be high enough to give detail of the lesion. 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 minimize specular reflection and shadow, Gomez developed an image acquisition system which consists of 3-chip CCD camera, an integrating sphere, and halogen light sources [Gomez *et al.*, 2003]. The sphere has two holes to place camera at one side and object (patient) at another hole. Three light sources were located inside the sphere in equilateral triangle configuration to produce completely diffused light to minimized specular reflection and shadow on the image being captured. Illustration of the system is shown in Figure 2.8.



(a) (b)

Figure 2.8 Image acquisition system: (a) image of the system, (b) position of light source inside the sphere [Gomez *et al.*, 2003]

The colour temperature of the light source should be within 2900 – 3300 Kelvin range, to optimize colour rendering ability. To improve colour rendering, light source with colour temperature near daylight (5300 – 6500 K) should be used [Maglogiannis and Kosmopoulos, 2003]. Moreover, the spectral energy distribution of light source should

uniform throughout all wavelength. Colour temperature and spectral energy distribution of light source are described more in Chapter 3.

2.4.2 Image analysis

With the goal of developing an objective method of estimating percentage of involved surface area on patient with psoriasis, Roning *et al.* developed method to segment psoriasis lesion from normal skin [Roning *et al.*, 1999]. To extract the lesion from normal skin, grayscale information is utilized. It is assumed that grayscale level of normal skin and psoriasis is distributed normally, creating bimodal histogram. First, the image is divided into small sub images. Variable thresholding are calculated based on bi-modality of small sub images. An iterative method using different size of small sub images is performed to take into account local and global information. In order to test reliability and accuracy of their system, they compare segmentation result of the system with reference segmentation. Reference segmentation was created by colouring manually the involved areas in the image. The error in all cases is less than 4%. Small psoriasis lesions are not detected by their system due to post-processing step. This problem can be minimized by adjusting post-processing parameter differently for each image.

Psoriasis lesion is indicated by red plaques and on some cases covered by silvery white scale. Taur *et al.* incorporate colour and texture information to segment psoriasis lesion [Taur *et al.*, 2002]. Colour information is obtained from hue and saturation component of RGB image. Fuzzy texture spectrum is extracted from grayscale image to provide texture information. It is based on relative gray levels between pixels in a small sub image. These two information are fed into Orthogonal Subspace Classifier to assign pixels into one of the two classes, psoriasis lesion or normal skin. Initially, small regions of psoriasis lesion and normal skin are selected manually from each image as samples. Then, colour and texture information are extracted from those regions to train the classifier. This technique was applied on two images and resulted in good lesion boundary as shown in Figure 2.9.

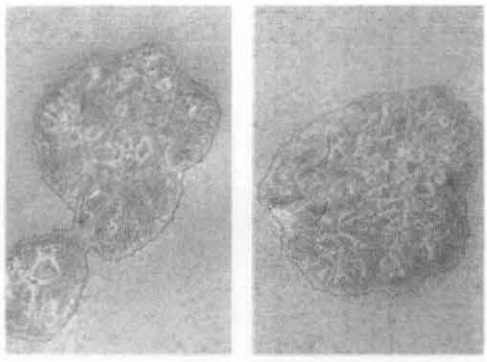
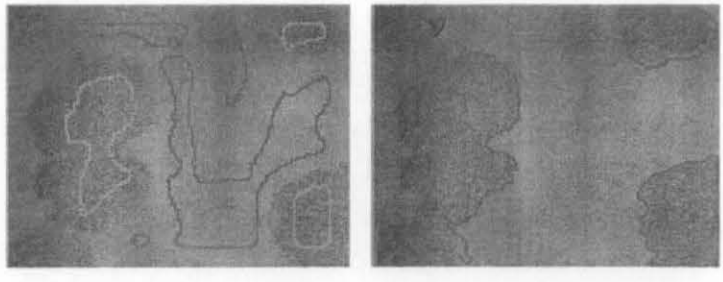


Figure 2.9 Result of segmentation using Orthogonal Subspace Classifier [Taur *et al.*, 2002]

Taur improved the system so that samples of psoriasis lesion and normal skin do not require to be selected manually [Taur, 2003]. It is assumed that pixels on homogenous region belong to a single class, psoriasis lesion or normal skin. Small window is passed through the image to detect homogeneity. Hue and saturation components of colour image and fuzzy texture spectrum of grayscale image are extracted from every pass to characterize homogeneity of that region. Several homogenous regions may exist, however only two types of homogenous region were required, psoriasis and normal skin region. Thus, homogenous regions are merged according to their similarity until there are only two types of homogenous regions. Once homogenous regions are detected, colour and texture feature are extracted from those regions to train neuro-fuzzy classifier. Typical result of homogenous region detection and segmented lesion are shown in Figure 2.10.



(a) **(b)**

Figure 2.10 (a) Typical result of homogenous region detection, (b) segmented lesion [Taur, 2003]

In order to find suitable features to discriminate psoriasis lesion from normal skin, Gomez *et al.* [Gomez *et al.*, 2003] analyzed RGB image using linear stepwise discriminant analysis. Trichromatic values and their logarithm are used in the analysis. From the experiment, the best linear combination is given by green and blue bands. The contrast

between psoriasis lesion and normal skin is increased in the |blue – green| image. Maletti [Maletti *et al.*, 2005] uses |blue – green| image along with red band image to registers and aligns digital image of psoriasis lesions within and between treatment session. The |blue – green| image is used to segment the lesion from normal skin, while red band image is used during the combined registration and alignment stage. Segmentation using |blue – green| image suffers from the appearance of shadows. Shadows which are appeared on the border of human limbs are mostly misclassified as lesion as shown in Figure 2.11.

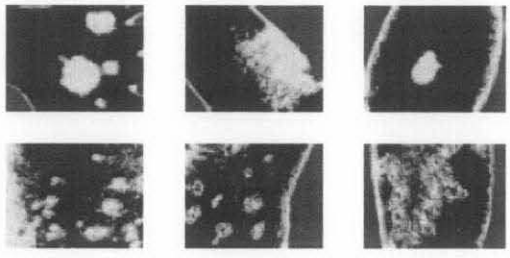


Figure 2.11 Segmented lesion from |blue - green| image [Gomez *et al.*, 2003]

Jailani *et al.* apply pre-processing, filtering, thresholding and post-processing step in segmenting psoriasis lesion [Jailani *et al.*, 2004]. Pre-processing step consists of intensity adjustment and histogram equalization. Gaussian filter, disk filter, and median filter are applied during filtering step. Thresholding step is not clearly defined in their paper. Post-processing step consists of closing, opening, and filled holes. This step removes noise as well as small lesion. Thus, their work concentrates only on big lesion.

There are five types of psoriasis, plaque, guttate, inverse, pustular, and erythrodermic. Normalization technique is applied on RGB and grayscale images to distinguish between plaque, guttate, and erythrodermic lesion [Jailani *et al.*, 2005]. The colour and gray component of psoriasis lesion are normalized by colour and gray component of normal skin from the same patient. The normalized image is obtained by following Equation 2.2. Blue and gray component provide significant information to discriminate the three types of psoriasis with the significant of mean difference at 0.05 levels.

$$(Lesion)_{normalized} = \frac{(Lesion)_{R,G,B,gray}}{(Skin)_{R,G,B,gray}} \tag{2.2}$$

Since skin lesions can appear in a wide variety of colour, segmentation based on selected colour is not effective. However, a lesion can be detected by colour gradation from its surrounding normal skin. This reason has motivated Xu *et al.* to use colour difference based on CIELAB colour space in segmenting skin cancer [Xu *et al.*, 1999]. In CIELAB, a colour is represented by three parameters, namely L*, a*, and b*. L* represents degree of lightness, a* represents degree of greenness to redness, and b* represents degree of blueness to yellowness (see Figure 2.12).

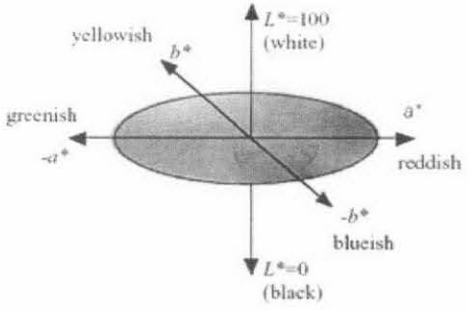
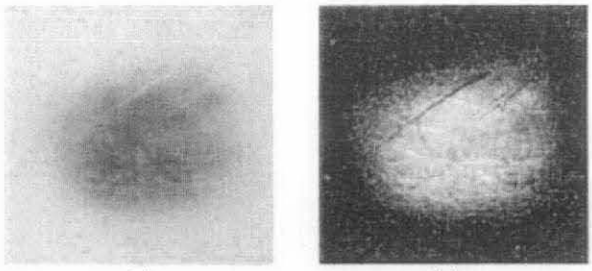


Figure 2.12 CIELAB colour space [Ohno, 2000]

Euclidean distance in CIELAB colour space is linear with perceptual colour difference. It is calculated as:

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{2.3}$$

For every image, a lesion is positioned in the center. Sample of normal skin colour is selected automatically from the four corner of the image. Median of L*, a*, and b* values is calculated from the sample to characterize normal skin colour. Median is chosen rather than mean in order to reduce bias of skin colour due to the appearance of hair on normal skin. Colour difference of pixels from normal skin colour is calculated. High colour difference is found at lesion region and small colour difference is found at normal skin region as shown in Figure 2.13.



(a) (b)

Figure 2.13 (a) an example of skin lesion, (b) image which its intensity is obtained from colour difference of the pixels from normal skin colour

Twenty images consists of 6 atypical lesion images, 7 benign lesion images, and 7 melanoma lesion images have been analyzed. Two surgeons, one dermatologist, and one bioengineer were involved in this research in order to segment the lesion manually from the image. Segmented lesions obtained manually were compared with those obtained from automatic method. Then, the sums of the two areas that did not overlap, a, and the sums of the two areas, b, are calculated. The error is represented as a ratio of the two areas $r = a/b$. Thus, the error ranges between 0 and 1. Variability between experts is also calculated using the above formula. It is found that the overall variation between experts is slightly higher than variation of automatic method with the four experts.

2.4.3 Erythema assessment

Skin erythema can be measured by applying three different methods. In the first method, erythema is measured by mean microvascular red blood cells under the skin using Laser Doppler Flowmeter. In the second method, it is measured from its absorbance and reflectance of either broad band or selected wavelengths in the visible range. In the third method, it is measured by analyzing tristimulus value of light reflected from skin structures [Lahti *et al.*, 1993; Fullerton *et al.*, 1996].

Erythema is affected by the number of blood cells under the skin. Laser Doppler Flowmeter (LDF) is the first erythema meter to be used in dermatological application. It measures capillary blood perfusion parameters, such as blood flow, velocity, and volume in real time. In order to measure these parameters, a small area of tissue which contains red blood and stationary tissue cells is illuminated by laser light. The light is randomly scattered by both cell types and is received by a detector (Figure 2.14). The moving

blood cells in the capillaries cause a Doppler shift to the incident light and fluctuation in the detector signal. The power spectrum of the detector signal is then converted into proportional flow, velocity, and volume of blood cells [Zografos *et al.*, 1992].

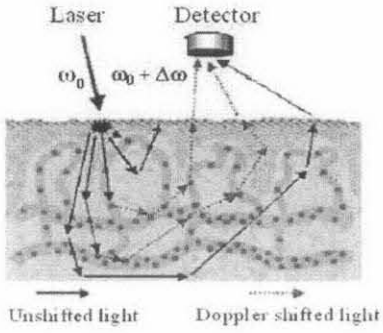


Figure 2.14 Principle of Laser Doppler Flowmeter

Hemoglobin and melanin are the most dominant pigments in the skin. Hemoglobin lies in the blood capillaries in the dermis and melanin lies in the keratinocytes and melanocytes of the epidermis. Hemoglobin absorbs much light at shorter wavelengths with the peak in the green wavelengths and absorbs very little at red wavelengths. Thus causing the blood is perceived as red colour. Melanin absorbs light of all wavelengths without any peak increasingly with shorter wavelengths. As the erythema increases, a greater amount of green light is absorbed and less is reflected. Based on these differences of melanin and hemoglobin in absorbance spectrum, Diffey *et al.* [Diffey *et al.*, 1984] suggested method to estimate melanin and erythema index using the following equation :

$$\begin{aligned} M &= \log_{10}\left(\frac{1}{\%\ \text{red reflectance}}\right) \\ E &= \log_{10}\left(\frac{1}{\%\ \text{green reflectance}}\right) - \log_{10}\left(\frac{1}{\%\ \text{red reflectance}}\right) \end{aligned} \tag{2.4}$$

The DermaSpectrometer is a narrow-band reflectometer that determines melanin (M) and erythema (E) index. It uses red and green LED (light emitting diode) to measure reflectance spectrum. The red light is centered at 655nm, with a half-width of 30nm and the green light is centered at 568, with a half-width of 30nm. The measured skin area is illuminated with the two light sources sequentially. A picture of DermaSpectrometer is shown in Figure 2.15.

Figure 2.15 The DermaSpectrometer (Cortex Technology, Hadsund, Denmark)

The colour of an object is affected by three components, light source, reflectance characteristic of the object, and colour vision of human. The international authority on light, illumination, colour, and colour spaces, CIE (Commission Internationale de l'Eclairage) has modeled the three components and created CIELAB colour space to describe colour perceived by human. Colour is described by three stimulus values, L*, a*, and b*. L* represents brightness varying from 0 to 100, a* represents degree of greenness-redness (negative values indicate green and positive values red) and b* represents degree of blueness-yellowness (negative values indicate blue and positive values yellow). Further details regarding CIELAB colour space is given in Chapter 3. Chromameter is a colorimeter instrument that measure colour in terms of CIELAB colour space. It consists of Xenon lamp that emits white light as a light source and 3 high-sensitivity silicone photocells as a detector of reflected light. The sensitivity of the photocells is adjusted to match sensitivity of human eye. A picture of Chromameter from Konica Minolta is shown in Figure 2.16.

Figure 2.16 Konica Minolta Chroma Meter CR-400 (Minolta, Osaka, Japan)

The three methods mentioned above have been used in dermatology to assess erythema. Two chromameters (Lange Micro Colour and Minolta Chromameter CR-200) and Laser Doppler Flowmeter (LDF) were used to quantify erythema and the results were compared with clinical scoring [Serup and Agner, 1990]. Eighteen volunteers aged 18 to 72 years were involved in the study. Erythema was elicited by the local irritant sodium lauryl sulphate. Total of 55 patch-test of erythema and 18 patch-test of normal skin were assessed using the two chromameters, LDF, and clinical scoring. The instruments assessed erythema and normal skin patches individually and also the differences between the two patches. Clinical scores were obtained by comparing erythema patch with normal skin patch from the same body region. The score ranges from 0 to 4, with 0 indicate no erythema and 4 indicate marked erythema of the whole test area. Results of comparison between erythema and normal skin patch showed a clear and highly significant increase in the a* values and a less clear decrease in L* values of chromameters and also significant increase in LDF values. Clinical scoring correlated positively with the increase in a* of both chromameters and increase in Laser Doppler flow. However, LDF is sensitive to physical activity of the patient during measurement, such as talking. Thus, consistency of this instrument is harder to achieve compare to chromameter. This phenomena also observed later by Lahti *et al.* [Lahti *et al.*, 1993].

Shriver and Parra compared two objective methods in determining skin and hair colour [Shriver and Parra, 2000]. They used two instruments, chromameter (Photovolt ColorWalk, UMM Electronics, Indianapolis) and DermaSpectrometer (Cortex Technology, Hadsund, Denmark) in their study. Eighty persons participated in their study with 55 of European ethnicity, 9 of African ethnicity, 7 of South Asians, and 9 of

East Asians. The skin colour samples were taken from unexposed skin (inner upper arm) and exposed skin (forehead) areas. The hair colour samples were taken only from individuals that did not colour or bleach their hair. They discovered a clear negative correlation between L* and M index such that as L* decreases (indicating less lightness and less reflectance), the M index increases (indicating higher melanin content in the skin) as shown in Figure 2.17 and Figure 2.18. Subjects of European ethnicity is found having the lightest skin (high L* and low M index) whereas subjects of African ethnicity have the darkest skin (low L* and high M index) and widest variance in pigmentation level.

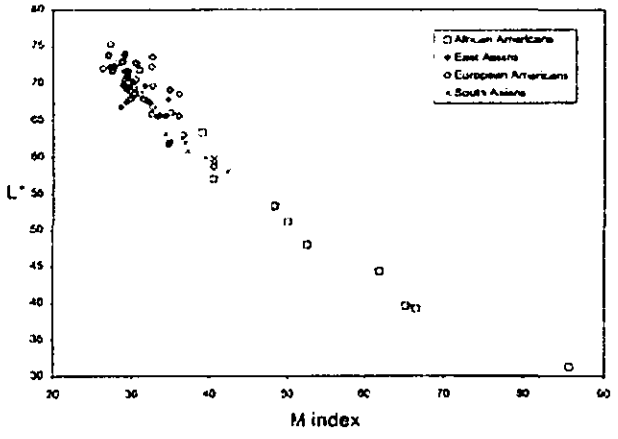


Figure 2.17 Relationship between L* and the M index for the inner arm region [Shriver and Parra, 2000]

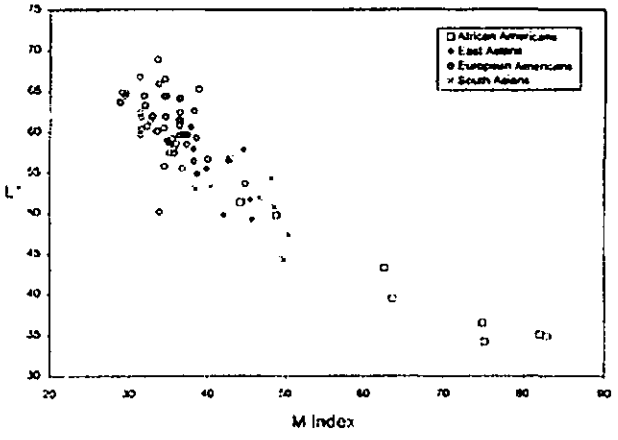


Figure 2.18 Relationship between L* and the M index for the forehead region [Shriver and Parra, 2000]

Both a* and E index have been used by dermatologist as indicators of skin erythemas [Diffey *et al.*, 1984; Serup and Agner, 1990; Takiwaki and Serup, 1994]. However, Shriver and Parra found that the relationship between a* and E index is complex and dependent on the level of pigmentation [Shriver and Parra, 2000]. A clear positive correlation between a* and E index is found only in persons with low melanin content (M < 40). In order to understand the phenomena above, they analyzed correlation between E and M index, and between a* and L*. A negative correlation between E and M index is observed in patients with high pigmentation level (M > 40) as shown in Figure 2.19. There is no correlation found in patients with low pigmented skin (M < 40). It indicates that E index is independent from M index, thus it becomes a good indicator of erythema in low pigmented skin. On the contrary, negative correlation between a* and L* is found in patients with low pigmentation level (L* > 60) as shown in Figure 2.20. Thus, a* is a good indicator of erythema for high pigmented skin.

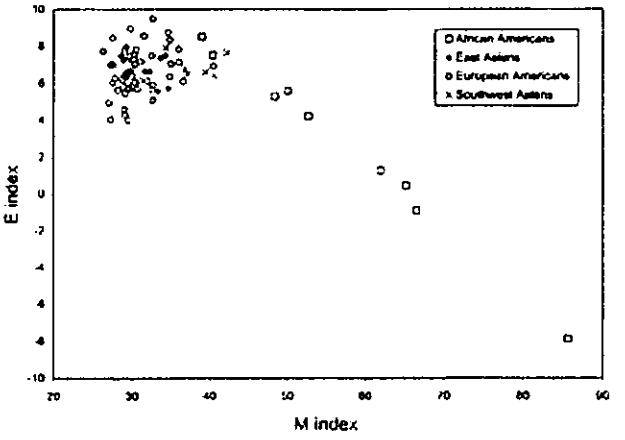


Figure 2.19 Relationship between E and M index for inner upper arm [Shriver and Parra, 2000]

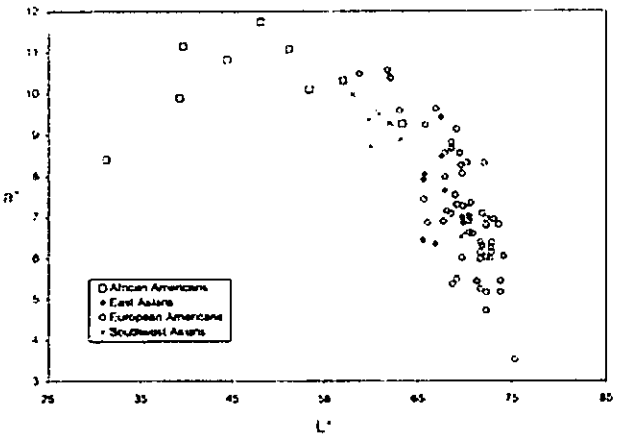


Figure 2.20 Relationship between L* and a* for inner upper arm [Shriver and Parra, 2000]

Draaijers *et al.* evaluated the reliability of visual assessment, Chromameter, and DermaSpetrometer in assessing colour of scar [Draaijers *et al.*, 2004]. Four observers assessed 49 scar areas on 20 different patients independently. Each observer rates the difference in pigmentation and vascularization of the scar compared to normal skin according to the Patient and Observer Scar Assessment Scale (POSAS). The score ranges from 1 to 10, the higher the score the worse the scar. In addition, observers also categorized the pigmentation type of the scar into normal, hypopigmentation, mixed pigmentation and hyperpigmentation, represented by score 0 to 3 respectively. Spearman's ρ correlation coefficient is calculated between visual assessment and instruments measurements. Correlation between visual assessment of vascularisation and Erythema index (E) and a* were significant but weak (r = 0.5 and 0.42, respectively). Correlation between visual assessment of pigmentation type and melanin index (M), L*, and b* were low (r = 0.32, 0.23, and 0.24, respectively).

The reliability of the measurements of DermaSpectrometer, Chromameter and of visual assessment were analysed by means of the intraclass correlation coefficient (ICC) with its 95% confidence interval [Draaijers *et al.*, 2004]. An ICC value of 0.7 is considered as reliable result. A single measure ICC was calculated based on a single measurement whereas the average measure ICC was based on the average measurements of four observers. Single measure ICC values of E and a* were comparable with single measure ICC value of visual assessment of vascularisation (r = 0.72, r = 0.75, and r = 0.76, respectively). The average measure ICC values for the three measurements above also showed a good reliability (r = 0.91, r = 0.92, and r = 0.93, respectively). Single measure

ICC values of M, L*, and b* were higher than visual assessment of pigmentation type (r = 0.94, r = 0.73, r = 0.89, and r = 0.59). For average measurements, ICC values of M, L*, and b* were still better than visual assessment (r = 0.98, r = 0.91, r = 0.97, and r = 0.85). Although quality of measurements of the instruments appeared comparable or better than visual assessment, more studies are necessarily required to consider this as 'gold standard' in assessing scar vascularisation and pigmentation.

2.5 SUMMARY

In this chapter an overview of psoriasis lesion was presented. Psoriasis was described as a skin disease which is related to malfunction of human immune system where skin cells are generated excessively fast. From the five types of psoriasis, it can be seen that the appearance of psoriasis lesion was indicated by inflamed, red, thick, and mostly scaly skin lesions. This disease affected worldwide population, regardless age, sex, and ethnicity. Psoriasis cannot be cured however the symptoms (the lesion) can be suppressed by applying several treatments. The treatments were ranging from the one that applied on skin surface such as lotion and exposed the lesion to UV light to oral medicine. It was observed that there is no universal treatment for every case. Thus, dermatologist should experiment using different treatments in order to find the best one for particular case. Monitoring the evolution of lesion becomes important in this process. Psoriasis Area and Severity Index (PASI) is the gold standard in assessing psoriasis lesion for monitoring purpose. Four parameters i.e. area involved, erythema (redness), thickness, and scaliness were used to characterize and score the lesion. Commonly, the four parameters were assessed visually which leads to subjective and inconsistent results. Thus, an objective method to determine the score objectively is required.

Many research works have been conducted with the aim to assess lesion area of psoriasis objectively. The main process was segmenting the lesion from normal skin. The first step in these works was acquiring digital images of psoriasis lesion. Mostly, the images were taken using camera that sensitive only to visible band. Multispectral camera which able to capture images up to 10 different spectral bands also used in order to obtain more information to remove noise such as hair and occlusion. Colour, grayscale, and texture information from images were utilized to distinguish psoriasis lesion from normal skin. It

is found that the appearance of shadows and occlusions could affect image analysis. From literature review, most of the methods only assess small area of human body. Furthermore, no one has tested their method on patients with different level of skin pigmentation.

Three different methods were commonly used to measure skin erythema quantitatively. Laser Doppler Flowmeter (LDF), the first erythema meter to be used in dermatological application measures blood flow, velocity, and volume underneath the skin in real time to determine its erythema. Yet the method produced lowest reproducibility compared to the other two methods. The second method based on equipment called DermaSpectrometer measures skin erythema based on light absorbance characteristic of melanin and haemoglobin, two dominant pigments in skin. The output is expressed as Erythema (E) and Melanin (M) index. The third method based on an instrument called Chromameter measures colour by modeling characteristic of light source, spectral reflectance of the object, and colour vision of human eye. Each colour is represented by three values i.e. L*, a*, and b* of CIELAB colour space. Quality of measurements of Chromameter and DermaSpectrometer were comparable to visual assessment. Both a* of Chromameter and E of DermaSpectrometer have been used as indicator of skin erythema. However, each of them has limitation. It has been reported that E is a good indicator of erythema only for low pigmented skin, whereas a* is a good indicator only for highly pigmented skin.

CHAPTER 3: COLOURIMETRY, IMAGE SEGMENTATION, AND PATTERN CLASSIFICATION

This chapter consists of basic theory and techniques that are used in this thesis. It starts from the basic theory of colourimetry, covering physical characteristic and quantitative parameters of light and our visual system. Colour spaces and image segmentation technique that are used in this thesis also discussed. Pattern classification as a way in categorizing data is described in the end of this chapter.

3.1 COLOUR AND VISION

The perception of colour occurs when light travels from the light source, reflects off the object, and arrives at our eyes and interpreted by our brain as sensation of colour. Thus, there are three components that affect the perceived colour of an object i.e. light source, the object itself, and human observer as illustrated in Figure 3.1.

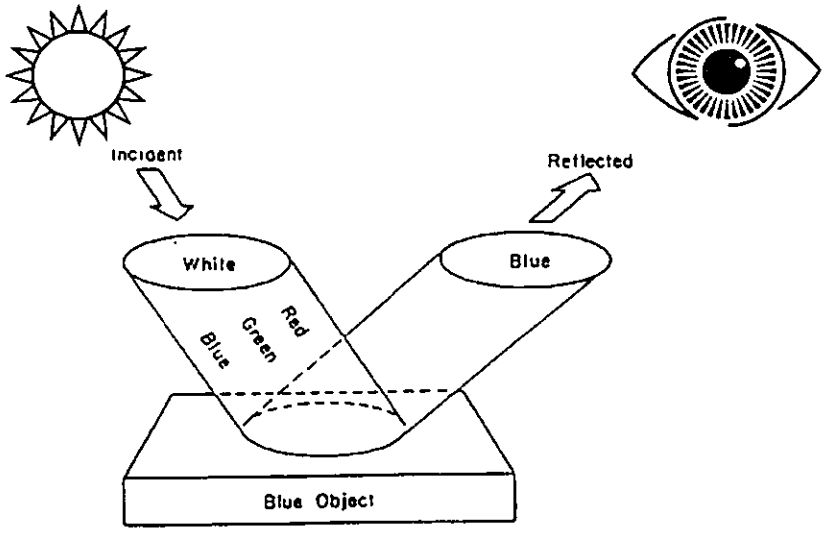


Figure 3.1 Three components that affect the appearance of a colour

3.1.1 Light source

Light is generally considered as an electromagnetic wave. Electromagnetic waves can be interpreted as propagating sinusoidal waves of varying wavelength or as massless materials propagating at the speed of light carrying packets of energy called photon. The

electromagnetic spectrum consists of gamma ray, X-ray, ultraviolet, visible light, infrared, microwaves, and radio wave. Gamma rays have highest frequency and shortest wavelength whereas radio waves have smallest frequency and longest wavelength as shown in Figure 3.2. Visible light is the only part of electromagnetic spectrum which can be perceived by human eye. Each spectrum can be utilized to produce an image.

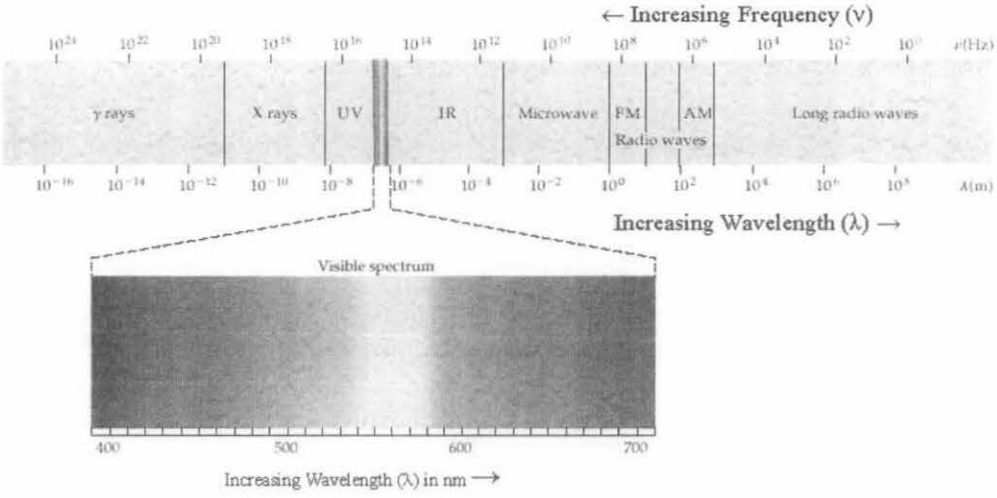


Figure 3.2 The electromagnetic spectrum arranged according to wavelength

3.1.2 Spectral energy distribution curve

As mentioned before, the perceived colour of an object is affected by the light source that illuminates the object. The perceived colour is actually a combination of colour of the light source and colour of the object. Light source colour can be described in terms of the relative amount of light emitted at each wavelength. This is plotted as the relative power at each wavelength and known as spectral energy distribution curve. Figure 3.3 shows the spectral distribution curves of three common light sources i.e. daylight, tungsten light, and fluorescent light.

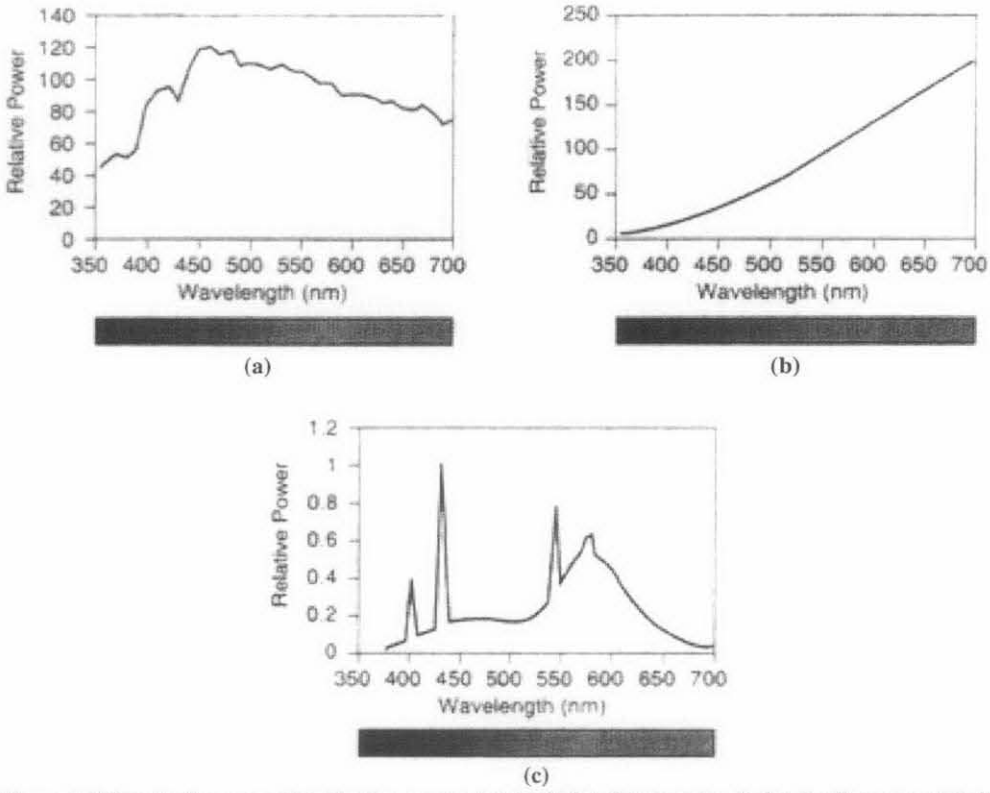


Figure 3.3 Spectral energy distribution curve: (a) daylight, (b) tungsten light, (c) fluorescent light

Daylight tends to have a well balanced light emission throughout the visible spectrum. The tungsten light emits an increasing amount of energy in the red part of the visible spectrum. The fluorescent light has some dominant peaks in the blue part of the spectrum. As a result, the colour of daylight is neutral, the colour of tungsten light is reddish, and the colour of fluorescent light is bluish. The perceived colour due to different light sources is shown in Figure 3.4. It can be seen that the colour of curtain which is illuminated by sunlight is neutral (white), the colour of the computer monitor is bluish, and the colour of book illuminated by tungsten light is yellowish.

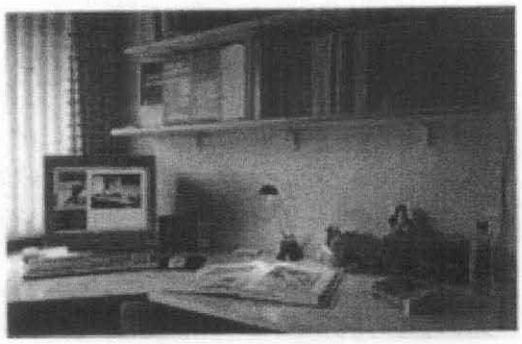


Figure 3.4 An example of different colour of light source

3.1.3 Colour temperature

The spectral energy distribution curve provides a complete and accurate form of expressing the quality of light from source. However, it is not the most convenient form to use. The "colour" of the light source cannot be interpreted directly from spectral energy distribution. Colour temperature is a simplified way to characterize the spectral properties of a light source. It follows Planckian black body radiators experiment as progressive heating of a piece of metal. As objects are heated, they get hotter and begin to glow and emit light from black to deep red until it become white. Colour temperature of a colour is defined as temperature of black body when the colour is appears. Colour temperature is measured on the absolute temperature scale that has units in Kelvin (K). In the colour temperature scale, lower colour temperatures are redder and higher colour temperatures are bluer as shown in Figure 3.5.

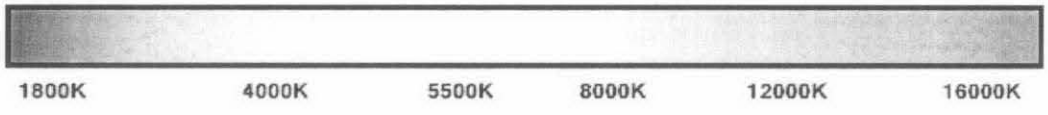


Figure 3.5 Colour temperature scale [Sharma, 2004]

3.1.4 CIE illuminant

The International Commission on Illumination (usually known as the CIE for its French-language name *Commission internationale de l'éclairage*) is the international authority on light, illumination, color, and color spaces. Over the years, the CIE has defined standards for a number of illuminants as shown in Table 3.1.

Table 3.1 CIE standard illuminant

Illuminant name	Type of light source	Colour temperature
Illuminant A	Tungsten lamp	2856
Illuminant B	Direct sunlight	4874
Illuminant C	Overcast sky	6774
D50	Direct sunlight	5000
D55	Sunlight with skylight	5500
D65	Overcast sky	6500
D75	"North sky" light	7500
Illuminant E	Hypothetical equi-energy illuminant	5400
Illuminant F11	Triband fluorescent light	4100

3.1.5 Sample spectrum

The colour of an object can be determined by its spectrum. Spectrum is a graph of an object's reflectance (or transmission) at each wavelength. As an object is illuminated with light source with different wavelengths, it absorbs some wavelengths and reflects some back. An apple would reflect only red part of the incident light and absorbs the rest. A perfect white object reflects all wavelengths whereas a perfect black object absorbs all. The spectrum is a plot of the relative amount of each wavelength being reflected by an object as shown in Figure 3.6.

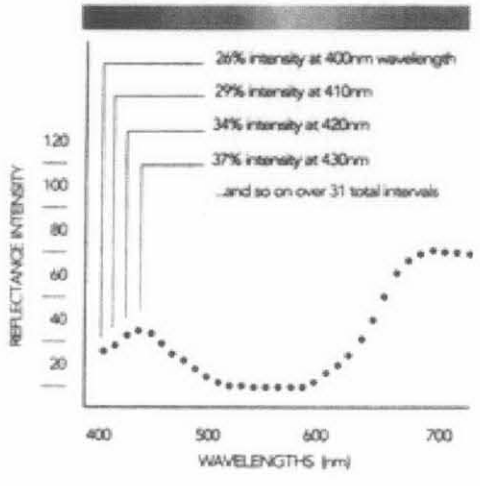
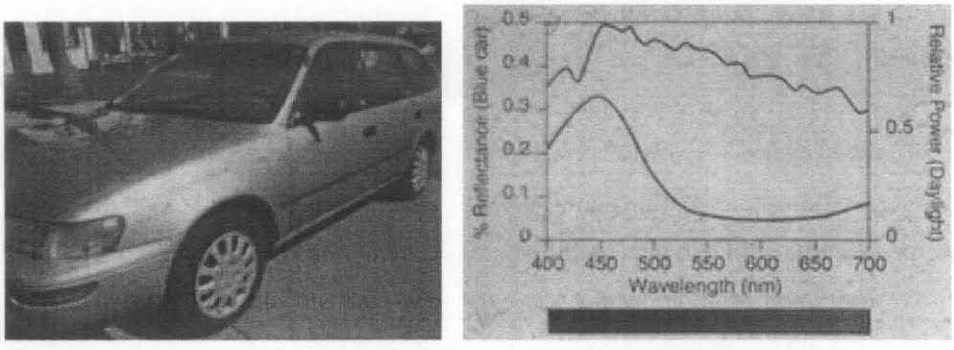


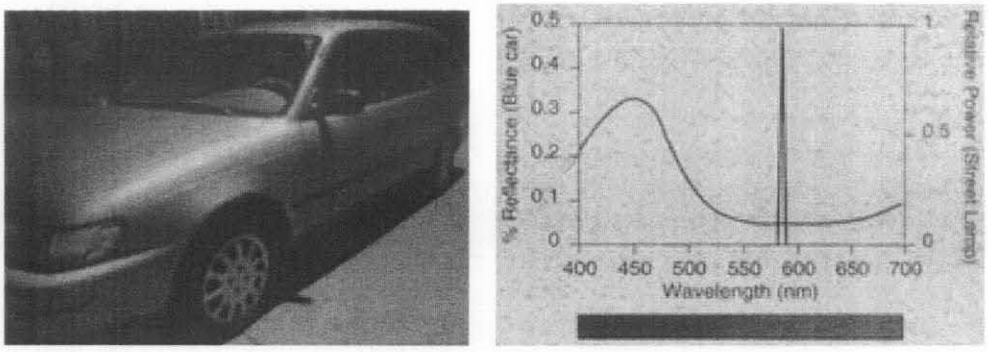
Figure 3.6 Reflectance spectrum of an object [Sharma, 2004]

It is also possible to measure spectrum of transmissive or emissive object. For transmissive object such as film transparencies, some of the wavelengths are absorbed and those that get through become the colour of the transparent object and form the transmission spectrum. For emissive object such as computer monitor, emissive spectrum can be determined by measuring wavelengths emitted by the monitor.

A single object can be perceived differently by our eyes under different light source. To illustrate this, the colour of a car viewed under daylight and streetlamp is shown in Figure 3.7(a) and (c) respectively. During the day, the car looks blue whereas under streetlamp it looks silver or dark gray. The car in this example is actually blue, thus its spectrum shows a high reflectance in the blue wavelengths. Under daylight condition, the car is illuminated by natural light which has a good spread radiation across the entire spectrum as shown in Figure 3.7(b). Radiation of blue wavelength (between 400 – 500 mm) incident the car and being reflected, whereas the others radiations are absorbed. Thus, it is perceived as blue. Streetlamp emits only narrow wavelengths in the green/red part of the spectrum as shown in Figure 3.7(d). When the car is illuminated by streetlamp, it received only green/red light and reflects only small amount of it. Thus, very little light returned to the observer, and as results the car looks silver or gray.



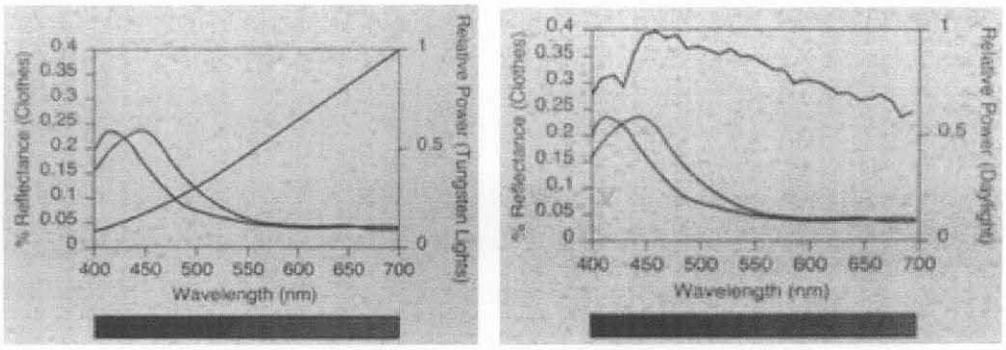
(a) (b)



(c) (d)

Figure 3.7 A single car under different lighting condition. (a) car under daylight, (b) spectral energy distribution of daylight (black line) and reflectance spectrum of car (blue line), (c) car under streetlamp, (d) spectral energy distribution of streetlamp (black line) and reflectance spectrum of car (blue line) [Sharma, 2004]

On the other hand, two different objects can be perceived having the same colour under one lighting condition but different under another lighting condition. This phenomenon is called metamerism. This situation commonly happens when a customer purchases a shirt and a trouser that appears matching in colour in the store, but looks different when worn outside. This phenomenon can be explained by looking at reflectance spectrum of the two objects and spectral energy distribution of the two light sources as shown in Figure 3.8. Assume that the light inside the store is tungsten light and the shirt and trouser having slightly different blue colour as can be seen from their reflectance spectrum in Figure 3.8(a). Tungsten light emits large amount of energy in red spectrum and only small amount in blue spectrum. Thus, the difference in blue spectrum is not highlighted. However, daylight consists of energy from the entire spectrum, including blue spectrum as shown in Figure 3.8(b). As a result, the difference in blue spectrum is obviously perceived by human eyes.



(a) (b)

Figure 3.8 Two objects illuminated by two different lighting conditions. (a) reflectance spectrum of the two objects (blue lines) and spectral energy distribution of tungsten light (black line), (b) reflectance spectrum of the two objects (blue lines) and spectral energy distribution of daylight (black line)

3.1.6 Human vision

The appearance of a colour is affected by three components called light source, object, and human observer. In the previous sections, spectral energy of a light source, spectral reflectance of an object and phenomena that could be explained by the interaction of the two have been described. The reflected signal will be received by the eyes and interpreted as sensation of colour by the brain.

There are two types of photoreceptor cells in the eye, i.e. rods and cones. They are named after their morphological shapes. The average number of rod and cone cells in human retina are 92 ± 15 million and 4.6 ± 0.45 million respectively [Curcio *et al.*, 1990]. Rod cells are responsible for vision in low-illuminated condition (scotopic vision) and cone cells are responsible for vision in high-illuminated condition (photopic vision). In the transition between the two conditions (mesopic vision), both receptor cells are responsible for the vision.

Monochromatic lights with equal power of different wavelength do not generate the same brightness or luminous sensation in our visual perception [Lee, 2005]. CIE luminous efficiency function describes the relative efficiency of light of various wavelengths in producing the luminous sensation. The luminous sensitivity peak of scotopic vision is at 507nm and the peak of photopic vision is at 555nm as shown in Figure 3.9.

Monochromatic light of wavelength at the peak requires less power to produce the same brightness as other monochromatic lights.

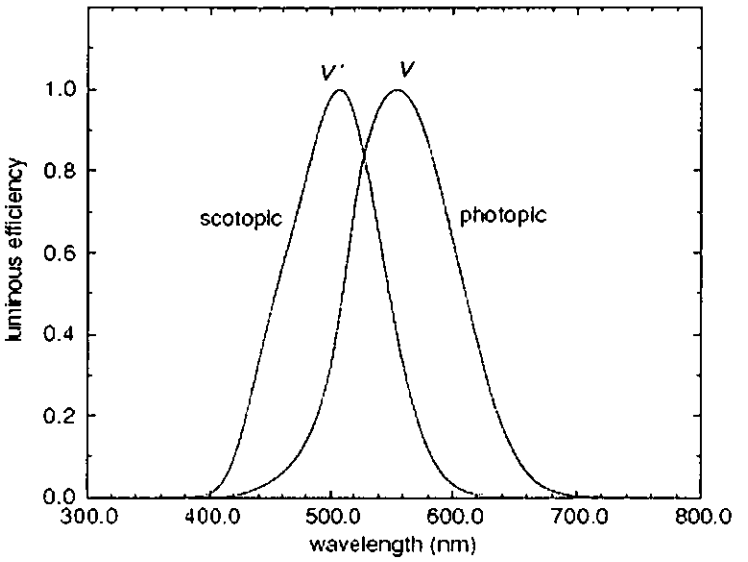


Figure 3.9 The CIE Luminous efficiency function for the photopic vision (V) and scotopic vision (V') [Lee, 2005]

There are three types of cone cells, each sensitive to the long (L), medium (M), and short (S) wavelengths as shown in Figure 3.10. Their sensitivity peaks occur at 566nm, 543nm, and 440nm, respectively [DeMarco *et al.*, 1992]. As can be seen, there are many areas of overlapped between L-cones and M-cones. The cones sum up the entire spectrum of incident wavelengths and reduce them to just three signals, one for each type of cones. This is called trichromatic vision and forms the foundation of how imaging devices work. Imaging device only need to set combination of the three colours to produce any colour. For example, consider to simulate a sunflower petal on a computer monitor. The monitor does not need to simulate the real spectrum of the flower. In fact, it just needs to simulate spectrum in the three regions as shown in Figure 3.11.

Once the photoreceptor cells are stimulated by the light, they send the received information to the brain. That information will be interpreted by the brain as sensation of colour. Since human visual process relies on interpretation, there is no quantitative method to know what colour is perceived by each person.

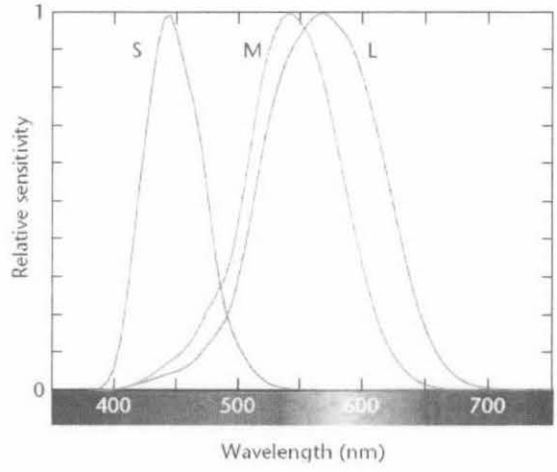


Figure 3.10 Normalized response spectra of human cone cells

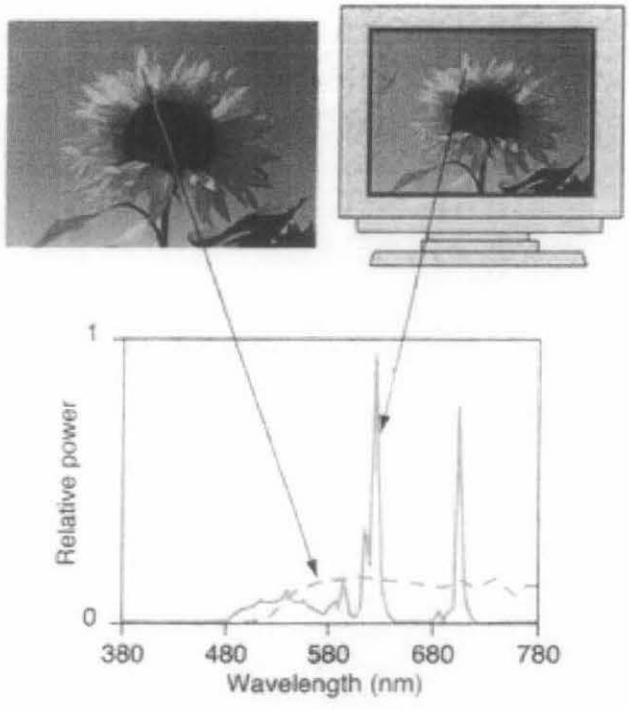


Figure 3.11 Trichromatic [Sharma, 2004]

3.1.7 CIE Standard Observer

Colour vision between individuals may be different and as people grow older, they may see colour differently. CIE standard observer is a mathematical way of representing the average colour vision of human population. It is obtained by performing colour matching

experiments that allows the trichromatic properties of human vision to be studied and characterized. In a typical colour matching experiment, an observer views a small circular field that is divided into two halves, as illustrated in Figure 3.12. One half of the circle is illuminated by a particular test colour whereas the other half is illuminated by the superposition of light from three independent sources. None of the independent sources can be matched by a mixture of the other two. The independent sources (usually red, green, and blue) are called primary colour.

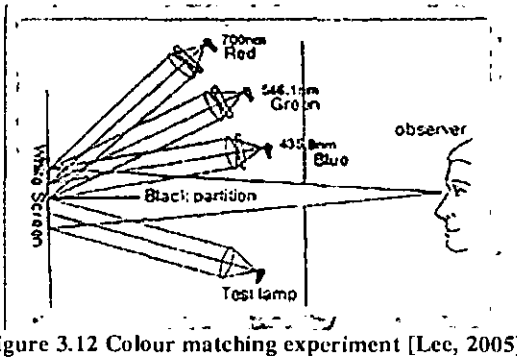


Figure 3.12 Colour matching experiment [Lee, 2005]

During the experiment, an observer adjusts the intensities of the three colour primaries until their combination appears to match the test colour. The intensities of the primaries required to produce the test colour are called the tristimulus values for each of the visible light. CIE has conducted the experiments by using three specific colour primaries (red = 700nm, green = 546.1nm, blue = 435.8nm) and test colours of monochromatic light for each of the visible light (from about 380 nm to about 740 nm). In 1931, CIE published the results as graphs called the color matching function as shown in Figure 3.13. Note that $\bar{r}(\lambda)$ and $\bar{g}(\lambda)$ are zero at 435.8 nm since the wavelength is equal to the blue primary colour, $\bar{r}(\lambda)$ and $\bar{b}(\lambda)$ are zero at 546.1 nm since the wavelength is equal to the green primary colour and $\bar{g}(\lambda)$ and $\bar{b}(\lambda)$ are zero at 700 nm, since the wavelength is equal to the red primary colour.

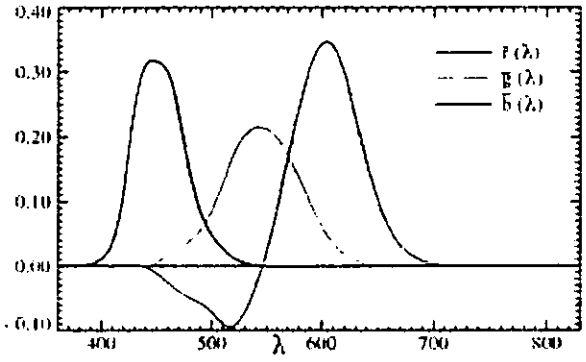


Figure 3.13 CIE 1931 RGB colour matching functions (http://wikipedia.org)

It can be seen from Figure 3.13 that some of the tristimulus values are negative. These result from the fact that some of those test colours cannot be matched by any combination of the three primaries. In these cases, light from one or more of the primaries is added to the light of the test colour. Light that is added to the test colour can be considered to have been subtracted from the mixture of the primaries.

Negative values of the tristimulus become a problem when designing spectrophotometer. This instrument measures object's spectral reflectance or transmittance. Since the $\bar{r}(\lambda), \bar{g}(\lambda)$, and $\bar{b}(\lambda)$ all have both positive and negative values, the instrument should have six channels, thus increasing its complexity and cost. Therefore, another primary sets was created such that their colour matching functions were all positive. Another consideration was that one of the colour matching functions would be the 1924 CIE standard photometric observer function. CIE standard photometric observer function is a luminous efficiency function for the photopic vision Figure 3.9.

The all-positive colour-matching functions, $\bar{x}(\lambda), \bar{y}(\lambda)$, and $\bar{z}(\lambda)$ were derived from $\bar{r}(\lambda), \bar{g}(\lambda)$, and $\bar{b}(\lambda)$ by following Equation 3.1.

$$\begin{bmatrix} \bar{x}(\lambda=380) \ldots \bar{x}(\lambda=780) \\ \bar{y}(\lambda=380) \ldots \bar{y}(\lambda=780) \\ \bar{z}(\lambda=380) \ldots \bar{z}(\lambda=780) \end{bmatrix} = \begin{bmatrix} 0.49000 & 0.31000 & 0.20000 \\ 0.17690 & 0.81240 & 0.01063 \\ 0.00000 & 0.01000 & 0.99000 \end{bmatrix} \cdot \begin{bmatrix} \bar{r}(\lambda=380) \ldots \bar{r}(\lambda=780) \\ \bar{g}(\lambda=380) \ldots \bar{g}(\lambda=780) \\ \bar{b}(\lambda=380) \ldots \bar{b}(\lambda=780) \end{bmatrix} \begin{bmatrix} n(\lambda=380) & & \\ & \ldots & \\ & & n(\lambda=780) \end{bmatrix} \tag{3.1}$$

The 1931 XYZ colour matching function is shown in Figure 3.14.

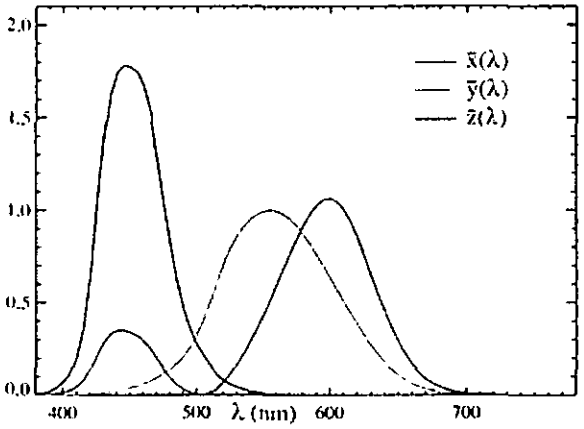


Figure 3.14 CIE 1931 XYZ colour matching function (http://wikipedia.org)

The XYZ tristimulus values for a given object that is illuminated by a light source can be calculated for the CIE Standard Colorimetric Observer by summing the products of these distributions over the wavelength range from 380 to 780 nm. This process is illustrated in Figure 3.15.

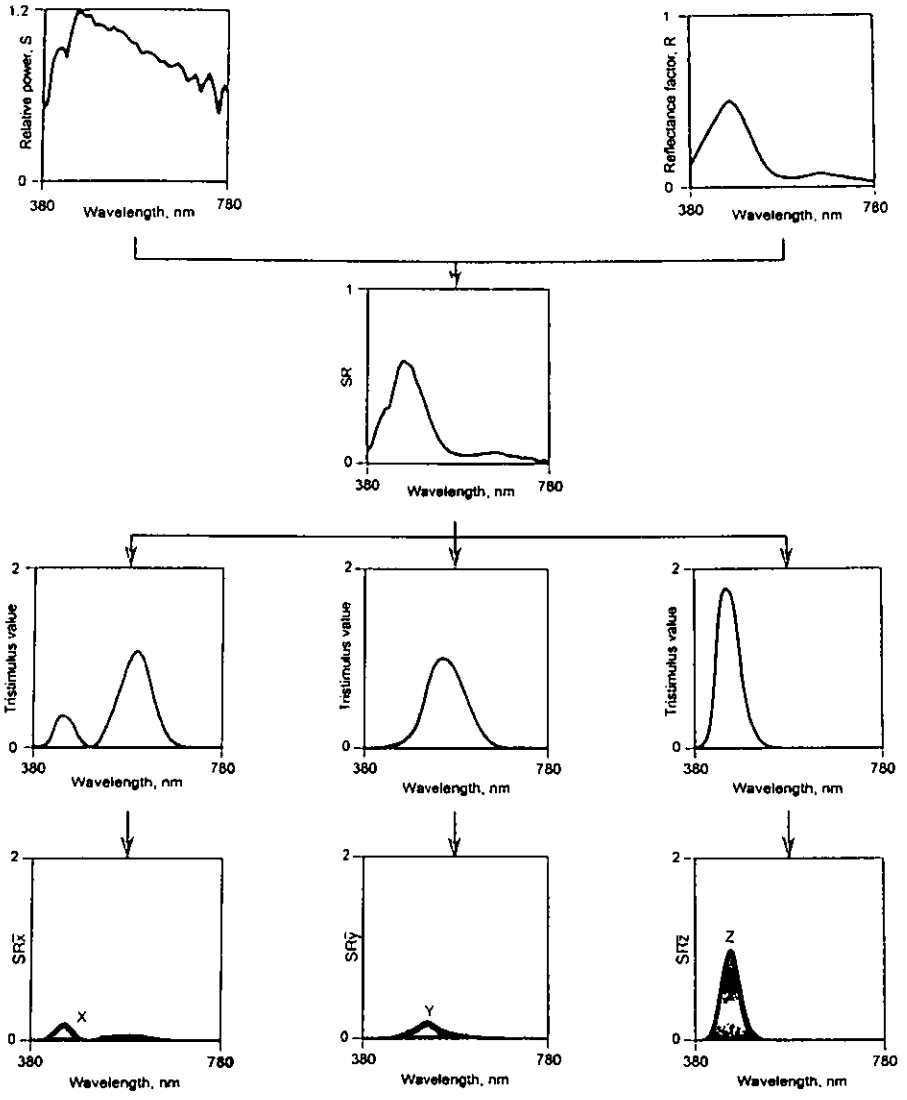


Figure 3.15 Derivation of XYZ tristimulus values [Sharma, 2004]

The calculations of X, Y, and Z are shown in

$$X = k \sum_{\lambda=380}^{780} S(\lambda) R(\lambda) \bar{x}(\lambda)$$

$$Y = k \sum_{\lambda=380}^{780} S(\lambda) R(\lambda) \bar{y}(\lambda)$$

$$Z = k \sum_{\lambda=380}^{780} S(\lambda) R(\lambda) \bar{z}(\lambda)$$

The terms X, Y, and Z are CIE tristimulus values; $S(\lambda)$ is the spectral power distribution of a light source; $R(\lambda)$ is the spectral reflectance of reflective object (or spectral transmittance of transmissive object); $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the colour matching functions of the CIE Standard Colourimetric Observer; and k is a normalizing factor. By convention, k is determined such that $Y = 100$ for a perfect white object [Giorgianni and Madden, 1998].

The CIEXYZ colour space was deliberately designed so that luminosity and chromaticity of a colour are separated. The chromaticity of a color was then specified by the two derived parameters x and y, two of the three normalized values which are functions of all three tristimulus values X, Y, and Z:

$$\begin{aligned} x &= \frac{X}{X+Y+Z} \\ y &= \frac{Y}{X+Y+Z} \\ z &= \frac{Z}{X+Y+Z} = 1-x-y \end{aligned} \tag{3.2}$$

As a result, the complete description of the colour of a spectrum is given by the values of x, y, and Y. These three numbers provide an alternative to using the values of X, Y, and Z. A plot of y versus x is called chromaticity diagram as shown in Figure 3.16. The horseshoe-shaped outline is the spectrum locus, which is a line connecting the points representing the chromaticity of the spectrum colours. The lower portion of the spectrum locus is bounded by a straight line that connects the blue and red ends of the spectrum locus, known as purple line. Hues along this line are not produced by any single wavelength of light, but rather, result from the mixture of red and blue light. The chromaticity coordinates of all physically possible colour stimuli lie within the area defined by the spectrum locus and the purple line.

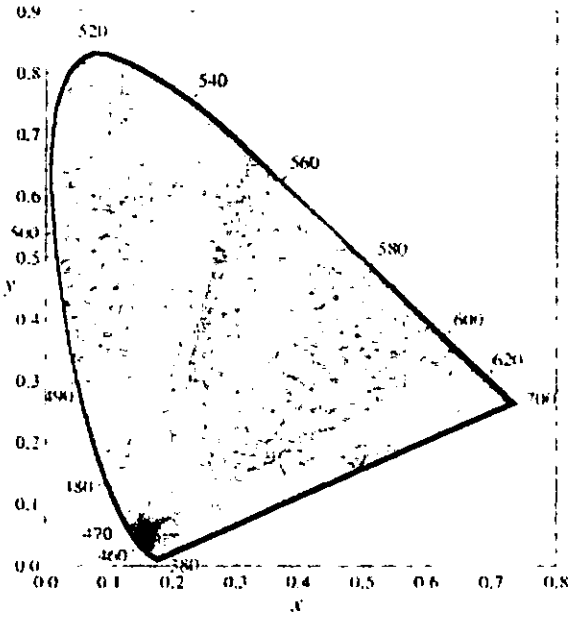


Figure 3.16 Chromaticity diagram (http://wikipedia.org)

Chromaticity diagram as shown in Figure 3.16 is useful in colour management. It is possible to predict the hue and saturation of a sample under a specific illuminant. First, the x, y coordinates of both illuminant and object should be calculated. A straight line is drawn, starting from the illuminant through the object to the locus edge. Hue is the wavelength where the line intersects the locus. Saturation can be determined by calculating distance of the illuminant to the sample (a) and the sample to the locus (b). Saturation is defined as $a/(a+b)$ as shown by sample (A) in Figure 3.17. Referring to Figure 3.17, if the sample lies between the illuminant and purple line, the hue is the complementary dominant wavelength (B). It is also possible to predict the hue of a sample under different illuminant as given by (C) in Figure 3.17. Combination of two colours can be described by chromaticity diagram. Result of combination between two colours will be on the line connecting the two samples as shown by D in Figure 3.17.

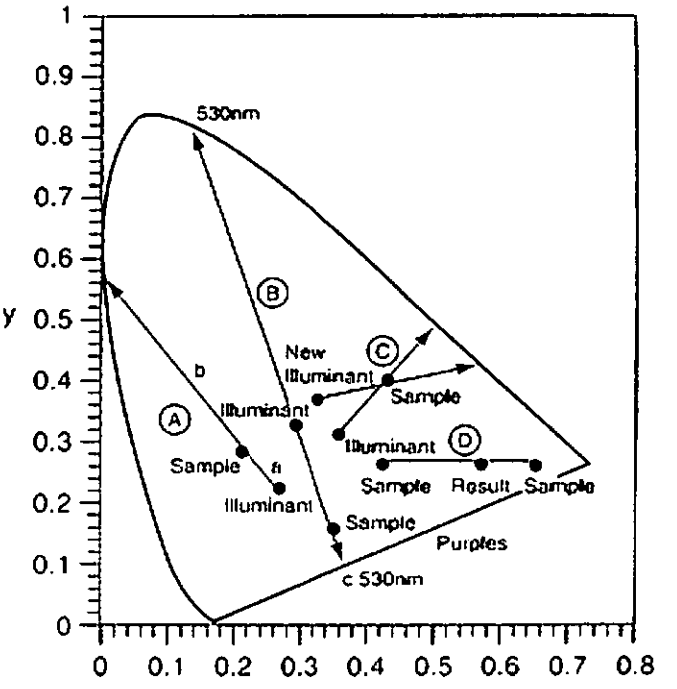


Figure 3.17 Colour calculation using chromaticity diagram

3.2 COLOUR SPACE

Colour space is designed to facilitate the specification of colours in standard way. Within a colour space, every colour is defined by their coordinate. RGB (Red Green Blue) 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.

3.2.1 RGB

As has been mentioned in Chapter 3.1.6, 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.

RGB colour space is based on Cartesian system where red, green, and blue values are at three corners; cyan, magenta, and yellow are at three other corners as shown in Figure 3.18. Cyan is obtained by adding green and blue, magenta is obtained by adding red and blue, yellow is obtained by adding red and green. Black is at the origin and white is at the corner farthest from the origin. The grayscale extends from black to white along the line joining these two points.

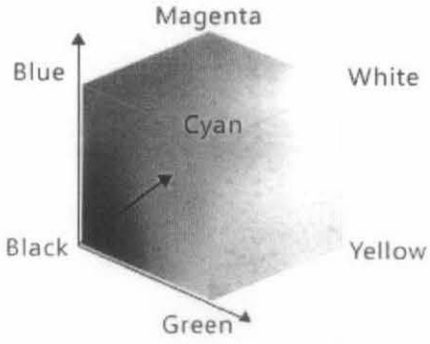


Figure 3.18 RGB colour space (http://msdn2.microsoft.com)

Images represented in the RGB colour space consists of three component images, one for each primary colour. The number of bits used to represent each pixel in this colour space is called the pixel depth. Consider an RGB image with 8-bit for each primary colour; each pixel is therefore 24 bits. Thus there are $(2^8)^3 = 16{,}777{,}216$ possible colours.

RGB is used in both specifying and storing the colour information in imaging devices. Digital camera captures and stores the image in RGB format. Most of digital camera use CCD (Charged Coupled Device) sensor to capture the image. CCD is a semiconductor device that converts optical information into electrical information [Peterson, 2001]. The surface of CCD consists of smaller region called pixels or picture elements. When light strike CCD surface, electrons are released from the pixels and captured by "electron-collecting bins". The number of released electrons is proportional with the intensity of incident light. In order to capture colour image, Bayer mask is used over CCD as light filter [Bayer, 1976]. It consists of red, green, and blue filter where the number of green

filter is twice than red or blue filter as shown in Figure 3.19. This proportion reflects the sensitivity of human eyes which are more sensitive to green colour than red and blue.

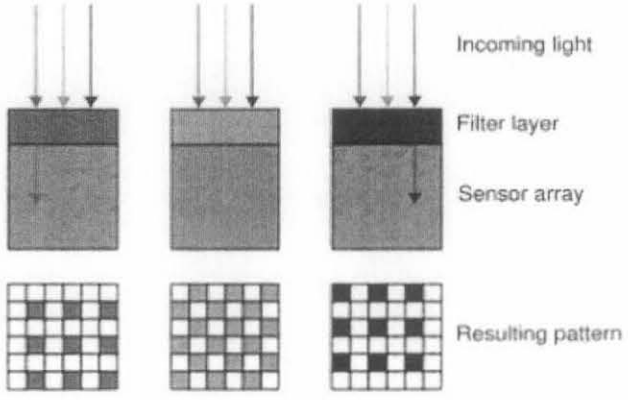


Figure 3.19 Bayer's mask filter (http://wikipedia.org)

3.2.2 CIELAB

As has been explained in section 3.1.7, CIEXYZ colour space was derived from colour matching experiment to approximate human vision. However, it is not perceptually uniform with human vision. This phenomena was found by MacAdam from his experiment [MacAdam, 1942]. The experiment involved observer to view two different colours. The first colour was fix (test colour), whereas the second one was adjustable. The observer was asked to match the two colours. The matching experiment was done at 25 test colours. All of the matches done by the observer lie on ellipses on chromaticity diagram as shown in Figure 3.20. The ellipses, called MacAdam ellipses, are the region which contains colours which are indistinguishable by human vision. The size and orientation of the ellipses are not uniform and depends on the position of the test colour. This finding initiates to the creation of uniform colour space. It is expected that the same amount of change in uniform colour space should produce the same visual colour change.

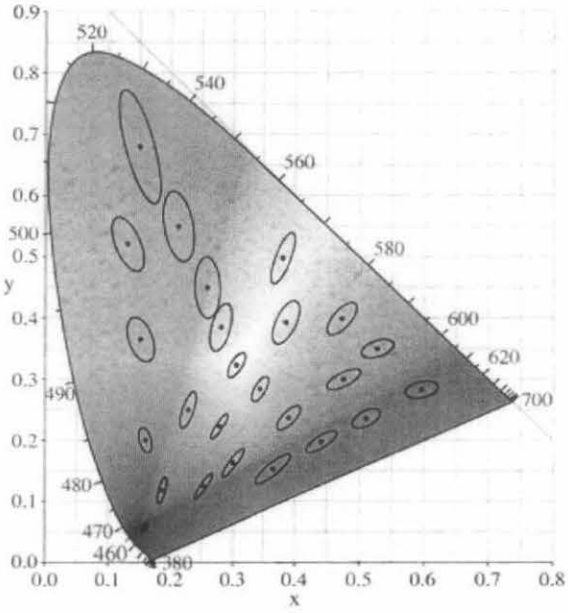


Figure 3.20 MacAdam ellipses (http://wikipedia.org)

In 1976, CIE proposed CIELAB colour space as a perceptually linear colour space. It is transformed from CIEXYZ colour space in order to map MacAdam ellipses into circles of the same radius. Although it is found later that CIELAB is not succeed in making MacAdam ellipses truly circles of uniform radius, it is the only colour space that is nearly linear with human vision [Braun *et al.*, 1998]. The tristimulus values in CIELAB colour space are L*, a*, and b*. As shown in Figure 3.21, L* represents degree of lightness ranging from 0 to 100, a* represents degree of redness-greenness (negative values for greenness and positive values for redness), and b* represents degree of yellowness-blueness (negative values for blueness and positive values for yellowness) [Plataniotis and Venetsanopoulos, 2000; Sharma, 2004; Lee, 2005].

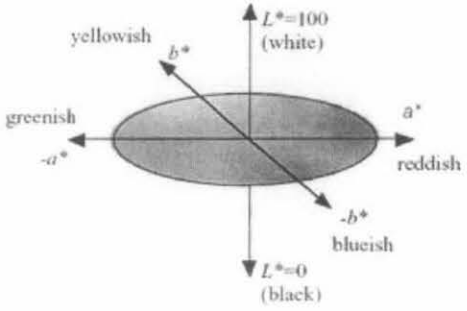


Figure 3.21 CIELAB colour space [Ohno, 2000]

CIELAB colour space is derived from CIEXYZ by following Equation 3.3.

$$\begin{aligned} L^* &= 116(Y/Y_n)^{1/3} - 16 \\ a^* &= 500\left[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}\right] \\ b^* &= 200\left[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}\right] \end{aligned} \tag{3.3}$$

CIEXYZ colour space is derived from RGB by following Equation 3.4.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{3.4}$$

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. 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 [Pascale, 2003].

While CIELAB is linear with human visual system, colour is not described in terms of L*, a*, and b* values. Instead, it is described by its hue, saturation, and brightness. Hue is a colour attribute that describes a pure colour such as pure yellow, orange, red, etc. Saturation defines the purity of a colour, whereas brightness is the intensity of a colour. The three parameters are represented in CIELAB colour space as hue, chroma, and L*. Chroma represents the purity of a colour in comparison with the brightness of white reference under the same illumination [Sangwine and Horne, 1998]. Hue and chroma can be derived from CIELAB by following Equations 3.5 and 3.6 respectively.

$$h_{ab} = \tan^{-1}\left(b^*/a^*\right) \tag{3.5}$$

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \tag{3.6}$$

3.3 OTSU'S THRESHOLDING

Image segmentation is a process in image processing to extract information from an image. It is performed by segmenting an image into one or several regions which are homogenous with respect to some image feature [Otsu, 1979]. Thresholding is one of the common techniques in image segmentation process. It transforms the input image *f* into a binary image *g* as follows:

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

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).

Selecting the threshold value is essential in image thresholding. One way to select the threshold is by analyzing the image histogram. Histogram contains information of the number of pixels that have certain grey value. Consider a grayscale image with bright object on dark background as shown in Figure 3.22. The histogram of this image as shown in Figure 3.23 is a bimodal distribution with clear separation, indicates high contrast between the object and background. The distribution on the right belongs to the object whereas the distribution on the left belongs to the background. In order to segment the object from background, threshold value should be selected from the valley of the histogram. It can be determined either manually or automatically.

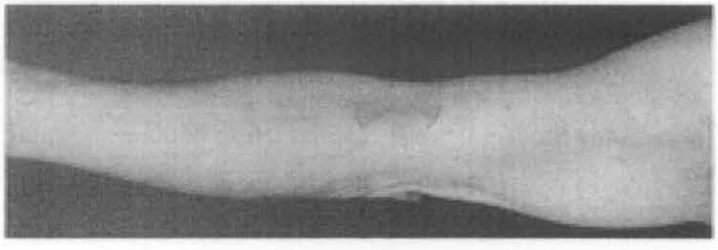


Figure 3.22 Bright object on dark background

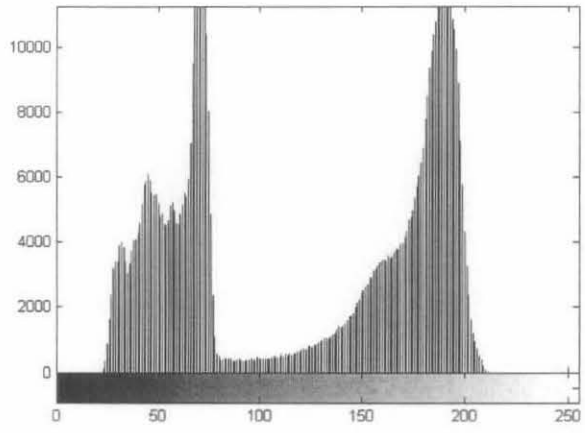


Figure 3.23 Histogram of an image with bright object on dark background

Otsu's thresholding method determines threshold value of an image with bimodal histogram automatically. The threshold value is obtained from statistical properties of the image histogram [Otsu, 1979]. Consider a histogram of an image with L grey levels. The number of pixels for each grey level x is represented by p_x. Assume that this image is segmented into two regions, namely object and background by selecting threshold value at t. Pixels that belong to background are:

$$\theta(t) = \sum_{x=1}^{t} p_x \tag{3.7}$$

Pixels that belong to the object are:

$$1-\theta(t) = \sum_{x=t+1}^{L} p_x \tag{3.8}$$

The mean of grey level value of the background pixels and the object pixels respectively are:

$$\mu_b = \frac{\sum_{x=1}^{t} xp_x}{\sum_{x=1}^{t} p_x} = \frac{\mu(t)}{\theta(t)} \tag{3.9}$$

$$\mu_o = \frac{\sum_{x=t+1}^{L} xp_x}{\sum_{x=t+1}^{L} p_x} = \frac{\sum_{x=1}^{L} xp_x - \sum_{x=1}^{t} xp_x}{1-\theta(t)} = \frac{\mu-\mu(t)}{1-\theta(t)} \tag{3.10}$$

Where

$$\mu(t) \equiv \sum_{x=1}^{t} xp_x \tag{3.11}$$

and μ is the mean of grey level value over the whole image, defined by:

$$\mu \equiv \frac{\sum_{x=1}^{L} xp_x}{\sum_{x=1}^{L} p_x} \tag{3.12}$$

The variances of the two regions are:

$$\sigma_b^{\,2} \equiv \frac{\sum_{x=1}^{t} (x-\mu_b)^2 p_x}{\sum_{x=1}^{t} p_x} = \frac{1}{\theta(t)} \sum_{x=1}^{t} (x-\mu_b)^2 p_x \tag{3.13}$$

$$\sigma_o^{\,2} \equiv \frac{\sum_{x=t+1}^{L} (x-\mu_o)^2 p_x}{\sum_{x=t+1}^{L} p_x} = \frac{1}{1-\theta(t)} \sum_{x=t+1}^{L} (x-\mu_o)^2 p_x \tag{3.14}$$

The variance of all pixels in the image:

$$\sigma_T^{\,2} = \sum_{x=1}^{L} (x-\mu)^2 p_x$$

This can be split into:

$$\sigma_T^2 = \sum_{x=1}^{t} (x-\mu)^2 p_x + \sum_{x=t+1}^{L} (x-\mu)^2 p_x \tag{3.15}$$

Substituting statistical parameters of the two regions into the above equation, the variance of all pixels becomes:

$$\begin{aligned}\sigma_T^2 &= \sum_{x=1}^{t} (x-\mu_b+\mu_b-\mu)^2 p_x + \sum_{x=t+1}^{L} (x-\mu_o+\mu_o-\mu)^2 p_x \\ &= \sum_{x=1}^{t} (x-\mu_b)^2 p_x + \sum_{x=1}^{t} (\mu_b-\mu)^2 p_x + 2\sum_{x=1}^{t} (x-\mu_b)(\mu_b-\mu) p_x \\ &+ \sum_{x=t+1}^{L} (x-\mu_o)^2 p_x + \sum_{x=t+1}^{L} (\mu_o-\mu)^2 p_x + 2\sum_{x=t+1}^{L} (x-\mu_o)(\mu_o-\mu) p_x\end{aligned} \tag{3.16}$$

Then substitute Equations 3.7, 3.8, 3.12, and 3.14 into the above equation

$$\begin{aligned}\sigma_T^2 &= \theta(t)\sigma_b^2 + (\mu_b-\mu)^2\theta(t) + 2(\mu_b-\mu)\sum_{x=1}^{t}(x-\mu_b)p_x + (1-\theta(t))\sigma_b^2 \\ &+ (\mu_o-\mu)^2\theta(t) + 2(\mu_o-\mu)\sum_{x=t+1}^{L}(x-\mu_b)p_x\end{aligned} \tag{3.17}$$

From Equation 3.9,

$$\sum_{x=1}^{t}(x-\mu_b)p_x = \sum_{x=1}^{t} x p_x - \sum_{x=1}^{t}\mu_b p_x = \mu_b\theta(t) - \mu_b\theta(t) = 0$$

Then Equation 3.17 becomes

$$\begin{aligned}\sigma_T^2 &= \underbrace{\theta(t)\sigma_b^2 + (1-\theta(t))\sigma_o^2}_{\text{within-class variance}} + \underbrace{(\mu_b-\mu)^2\theta(t) + (\mu_o-\mu)^2(1-\theta(t))}_{\text{between-class variance}} \\ &\equiv \sigma_W^2(t) + \sigma_B^2(t)\end{aligned} \tag{3.18}$$

The term $\sigma_W^2(t)$ is defined as within-class variance and $\sigma_B^2(t)$ is defined as between-class variance. The segmented regions should be as compact as possible, i.e. $\sigma_W^2(t)$ is as small as possible and $\sigma_B^2(t)$ is as large as possible. Suppose that $\sigma_B^2(t)$ is considered in selecting t. By substituting Equations 3.9 and 3.10 into $\sigma_B^2(t)$ part of Equation 3.18

$$\begin{aligned}
\sigma_B^2(t) &= (\mu_b - \mu)^2\theta(t) + (\mu_o - \mu)^2(1-\theta(t)) \\
&= \left[\frac{\mu(t)}{\theta(t)} - \mu\right]^2 \theta(t) + \left[\frac{\mu - \mu(t)}{1-\theta(t)} - \mu\right]^2 (1-\theta(t)) \\
&= \frac{[\mu(t) - \mu\theta(t)]^2}{\theta(t)} + \frac{[\mu - \mu(t) - \mu + \mu\theta(t)]^2}{1-\theta(t)} \\
&= \frac{[\mu(t) - \mu\theta(t)]^2[1-\theta(t)] + \theta(t)[-\mu(t) + \mu\theta(t)]^2}{\theta(t)[1-\theta(t)]} \\
&= \frac{[\mu(t) - \mu\theta(t)]^2}{\theta(t)[1-\theta(t)]}
\end{aligned} \tag{3.18}$$

Once t value has been selected, the interclass variance $\sigma_B^2(t)$ can be calculated. The optimal threshold value is t that gives maximum $\sigma_B^2(t)$. Graphical plot of interclass variance versus t of image in Figure 3.22 is shown in Figure 3.24. The maximum interclass variance occurs at t = 118. Thus, by selecting t = 118 as threshold, binary image that separates object from the background is obtained as shown in Figure 3.25.

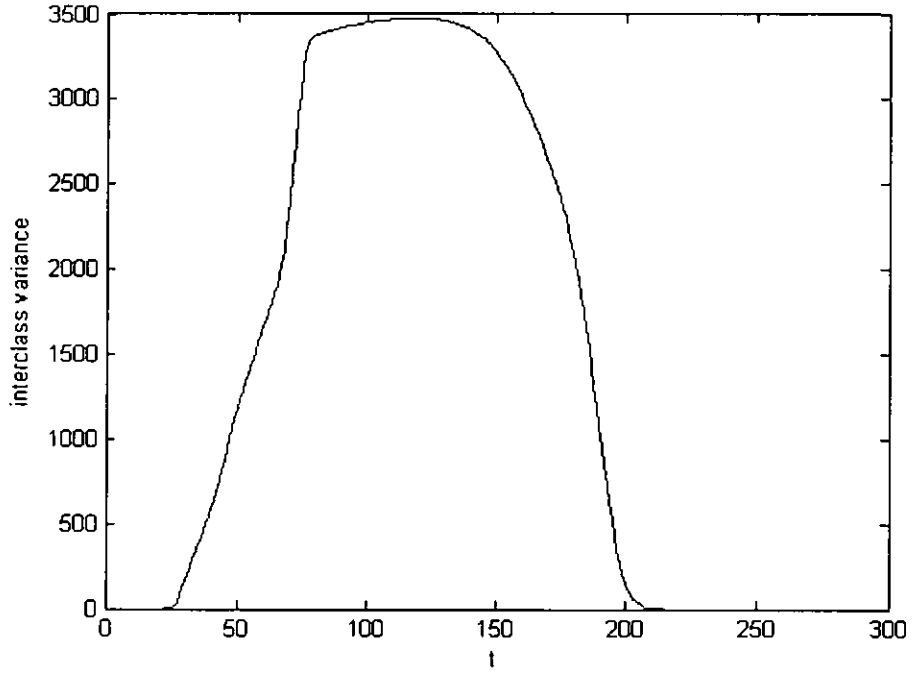


Figure 3.24 Graphical plot of interclass variance over t

Figure 3.25 Result of Otsu's thresholding on image in Figure 3.22

3.4 PATTERN CLASSIFICATION

Pattern classification is a process to classify data (pattern) into some group based on either a priori knowledge or on statistical information extracted from the data. The data in each group share some common features. Figure 3.26 shows general procedure of pattern classifier.

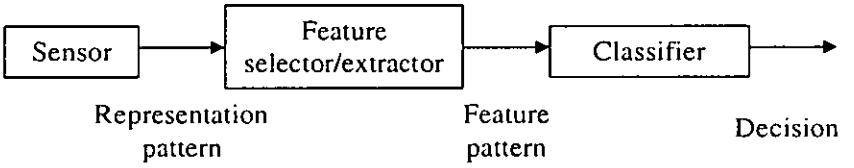


Figure 3.26 Pattern classifier [Webb, 1999]

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 [Jain *et al.*, 1999]. There are three objectives of feature selection/extraction in pattern classifier: improving the prediction performance of the classifier, increasing efficiency in learning task, and providing a better understanding of the underlying process that generated the data [Guyon and Elisseeff, 2003].

The classifier component will classify the data into several classes according to the features given by feature selector/extractor. There are two types of classification, namely supervised classification (discrimination) 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.

3.4.1 Feature selection

As has been mentioned before, feature classification aims to find subset of significant features from the original features to be used in classifier. Significance means that the features can be used to discriminate data one class from the other. Mean and standard deviation are the most often used criteria to select the discriminative features. The standard deviation of a feature for data belongs to a class should be as small as possible. On the other hand, the mean of features for data from different class should be separated as much as possible. These two parameters are included in measuring the discrimination coefficient of a feature. The discrimination coefficient of feature *f* for class A and B is defined by Equation 3.19.

$$S_{AB}(f) = \frac{|\mu_A(f) - \mu_B(f)|}{\sigma_A(f) + \sigma_B(f)} \tag{3.19}$$

μ_A and μ_B are the mean values of feature *f* for class A and B respectively whereas σ_A and σ_B represent standard deviation. High value of S_{AB} indicates good discriminative ability of feature *f* for the two classes.

The goodness of a feature in classification also can be measured by its correlation. A good feature has high correlation with the data's class but has low correlation with other variable. A linear correlation coefficient (r) between two random variables (X, Y) is calculated using Equation 3.20.

$$r = \frac{\sum_i (x_i - \mu_x)(y_i - \mu_y)}{\sqrt{\sum_i (x_i - \mu_x)^2}\sqrt{\sum_i (y_i - \mu_y)^2}} \tag{3.20}$$

μ_X and μ_Y are the mean values of X and Y respectively. The value of r ranges from -1 to 1, positive values indicates positive correlation whereas negative values indicate negative linear correlation. If X and Y are maximally positively correlated, r is 1; if X and Y are maximally negatively correlated, r is -1; if X and Y are uncorrelated, r is 0.

3.4.2 K-means clustering

Clustering is the unsupervised classification of a data set into several groups (clusters). Based on membership of each data, clustering can be classified into hard clustering and fuzzy clustering. A hard clustering algorithm divides data into distinct clusters, where each data element belongs to exactly one cluster. In fuzzy clustering, data elements can belong to more than one cluster and defined by membership levels. A fuzzy clustering becomes a hard clustering when each data element is assigned to the cluster with the largest membership level.

The most commonly used and simplest hard clustering algorithm is *k*-means clustering. It is popular due to its easy implementation and time complexity. The algorithm is composed of the following steps:

1. Choose cluster centers
2. Assign each data to the nearest cluster center
3. Recalculate the new cluster centers
4. Repeat the two previous steps until convergence criterion is met

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 3.21.

$$J = \sum_{i=1}^{c} \left(\sum_{k, x_k \in G_i} \left\| x_k - v_i \right\|^2 \right) \tag{3.21}$$

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 3.22.

$$v_i = \frac{1}{|G_i|} \sum_{k, x_k \in G_i} x_k \tag{3.22}$$

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

An example of k-means clustering on data which is represented by two features (x_1 and x_2) is shown in Figure 3.27. The three initial cluster centers are chosen randomly, indicated by pink dots. Their associated Voronoi tessellations are indicated by pink line number 1. The new cluster centers are calculated based on the points in each of the three Voronoi cells. The algorithm converges after the third iteration. The final cluster centers and their Voronoi tessellations are denoted by red dots and lines respectively.

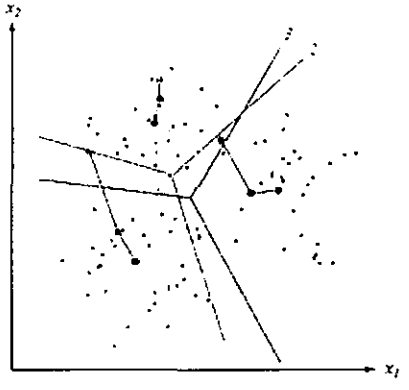


Figure 3.27 Trajectories for the means of the k-means clustering procedure applied to two-dimensional data [Duda *et al.*, 2001]

Performance of k-means clustering algorithm depends on the initial positions of cluster centers. This algorithm is sensitive to the selection of the initial partition and may

converge to a local minimum if the initial cluster centers is not properly chosen [Jain *et al.*, 1999]. Figure 3.28 shows seven two-dimensional data. If A, B, and C are chosen as the initial cluster centers, the classification will end up with three clusters as indicated by ellipses. However, if A, D, and F are chosen as the initial cluster centers, it ends up with the final clusters which are indicated by rectangles. The latter clusters are the best solution for this case since they yield global minimum of objective function.

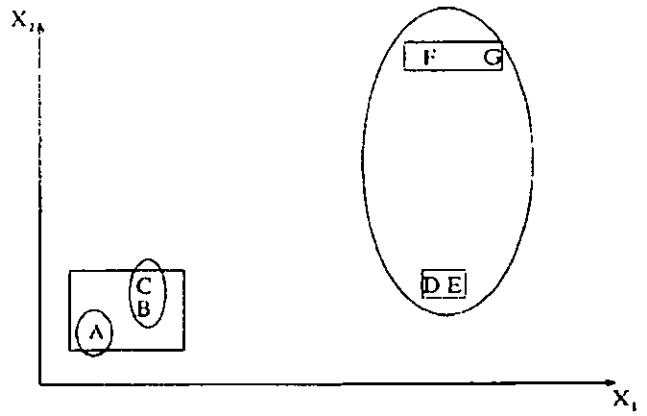


Figure 3.28 Sensitivity of k-means to the initial cluster centers [Jain *et al.*, 1999]

3.5 SUMMARY

In Chapter 3, the basic theory of colourimetry, colour space, Otsu's thresholding technique, and pattern classification are discussed. The above mentioned techniques are used in assessing area and erythema of psoriasis lesion in this thesis.

The appearance of a colour is affected by light source, object, and human vision. CIE as the International Commission on Illumination standardized the three components. Light source can be represented by its spectral energy distribution or by its colour temperature. Spectral energy distribution represents the relative amount of light emitted at each wavelength, providing a complete and accurate form of expressing the quality of light from source. Colour temperature is a simplified way to characterize the spectral properties of a light source. Colour temperature of a colour is defined as temperature of back body when the colour is appears. The colour of an object can be determined by its spectrum. Spectrum is a graph of an object's reflectance (or transmission) at each

wavelength. Human vision is characterized by CIE Standard Observer. It is mathematical way of representing the average colour vision of human population. Colourimetry instrument is designed to measure colour of an object quantitatively. The measurement is carried out by simulating spectral energy distribution of the light source, spectral reflectance of the object, and colour vision of human eyes. In this thesis, colourimetry instrument is utilized to measure colour of psoriasis lesion.

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. Thresholding is one of the common techniques in image segmentation process. Threshold value is determined by analyzing the image histogram. Otsu's thresholding technique determined the threshold value from statistical properties of the image histogram. This technique works well for images with bimodal histogram.

Pattern classification is used in this work to analyze characteristic of data obtained from colourimetry instrument. The objective is to select the best set of features that gives high discriminatory ability.

CHAPTER 4: OBJECTIVE ASSESSMENT OF PSORIASIS LESION AREA AND ERYTHEMA

In this chapter, the approaches in developing objective methods for area and erythema PASI assessment of psoriasis lesion are discussed. The equipments set-up and data acquisition process are described in this chapter. For area assessment, images of patient covering head, trunk, upper extremities, and lower extremities are digitally photographed. Psoriasis lesion is segmented from each image by analyzing colour difference with normal skin. For erythema assessment, colour of psoriasis lesion is measured by using chromameter. Degree of erythema is analyzed from colour difference between a lesion and the surrounding normal skin.

4.1 IMAGING EQUIPMENTS

4.1.1 Digital Camera

In order to determine the area PASI score, skin areas having psoriasis on patient's body must be determined. For this purpose, images of the face, anterior and posterior side from trunk and upper limbs and lower limbs are digitally photographed for each patient. The Nikon DSLR D100 shown in Figure 4.1 is used to capture the images. The camera has CCD sensor with 3008 x 2000 pixels resolution.

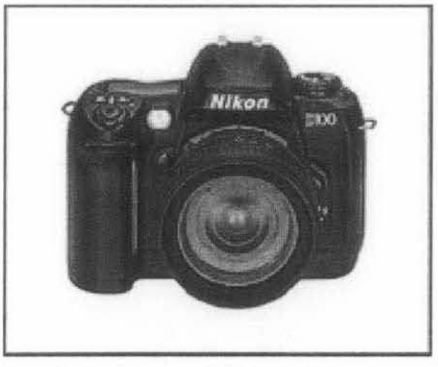


Figure 4.1 Nikon DSLR D100

Due to its larger physical sensor size, images captured by a Digital Single Lens Reflector (DSLR) camera are of a higher quality than images obtained by ordinary digital compact

camera. With the same resolution, the pixel size of DSLR is bigger than those of compact camera allowing better image capture. An illustration of a digital camera sensor size is shown in Figure 4.2. The largest size of digital camera sensor is 36mm by 24mm, equivalent to the size of analog camera film (Full frame sensor). Sensor size of Nikon DSLR D100 is indicated by blue line (APS-C sensor) and sensor size of digital compact camera is indicated by green line (1/2.5" sensor).

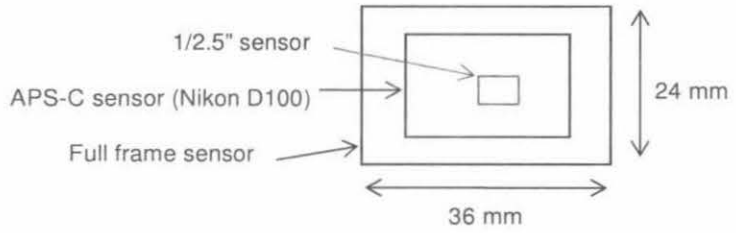
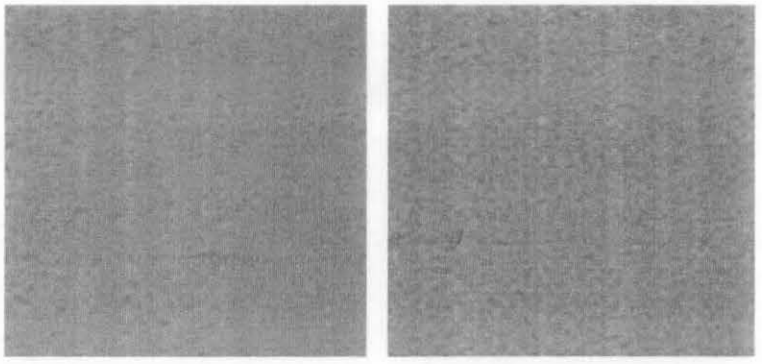


Figure 4.2 Digital camera sensor size

Each pixel on the CCD sensor contains light sensitive photodiodes that convert the incoming light (photons) into an electric signal. The quality of a pixel is affected by the number of photodiodes within it. Larger pixel size means more photodiodes resulting in higher signal to noise ratio [Benamati, 2001]. An example of images taken using large sensor and small sensor camera is shown in Figure 4.3.



(a) (b)

Figure 4.3 Images taken using (a) large sensor camera, (b) small sensor camera [http://dpreview.com/]

4.1.2 Chromameter

For evaluating PASI erythema score, Konica Minolta chromameter CR-400 is used to measure colour samples of psoriasis lesion and normal skin. The chromameter is

equipped with an internal light source and a photodetector that simulate the CIE Standard Observer function. During measurement, the chromameter probe is placed on the object surface as shown in Figure 4.4. The chromameter probe is designed to block light from outside, so that the object is illuminated only by the built-in light. The light reflected by the object is then captured by photodetector and transformed to tristimulus value of CIE XYZ colour space. Before conducting any colour measurement, a white calibration process is performed. This step is performed by measuring the colour of white calibration plate as shown in Figure 4.4.

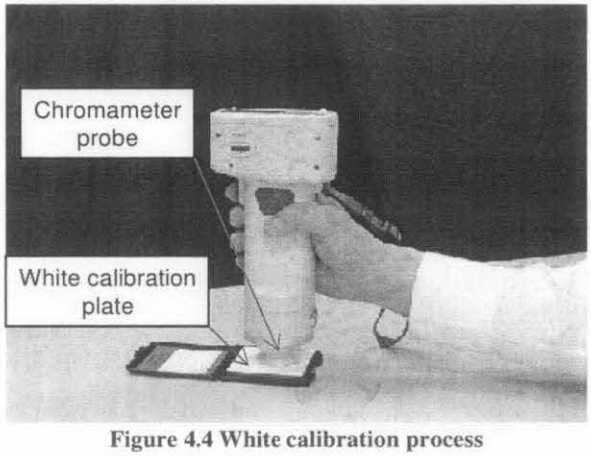


Figure 4.4 White calibration process

4.2 DATA ACQUISITION

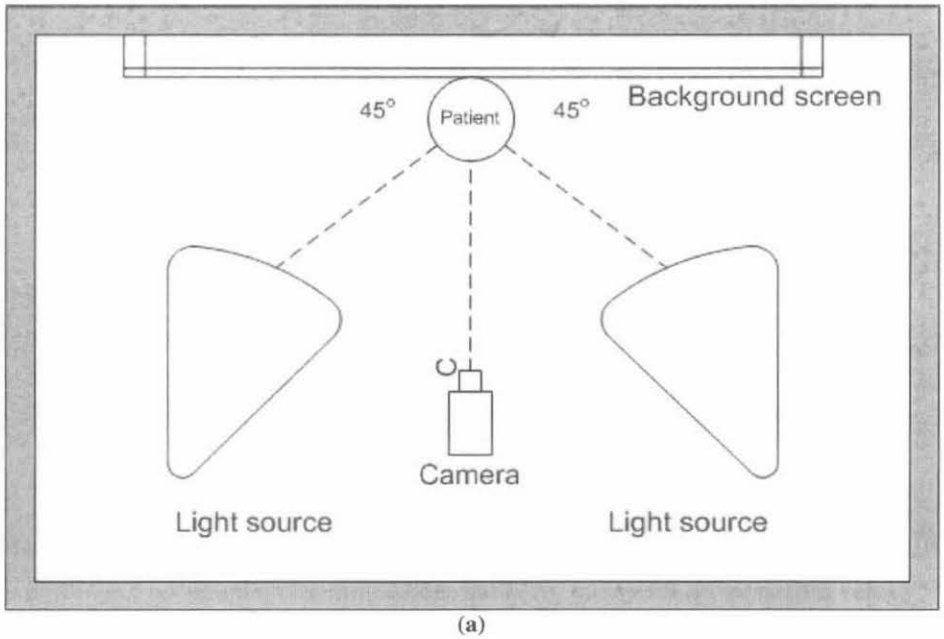
4.2.1 2D images

The main concern of digital image acquisition in dermatological application is the consistency of image quality [Maglogiannis and Kosmopoulos, 2003]. Consistency is essential for monitoring condition of the lesion. In order to capture images with consistent quality, equipment and environmental conditions should be considered.

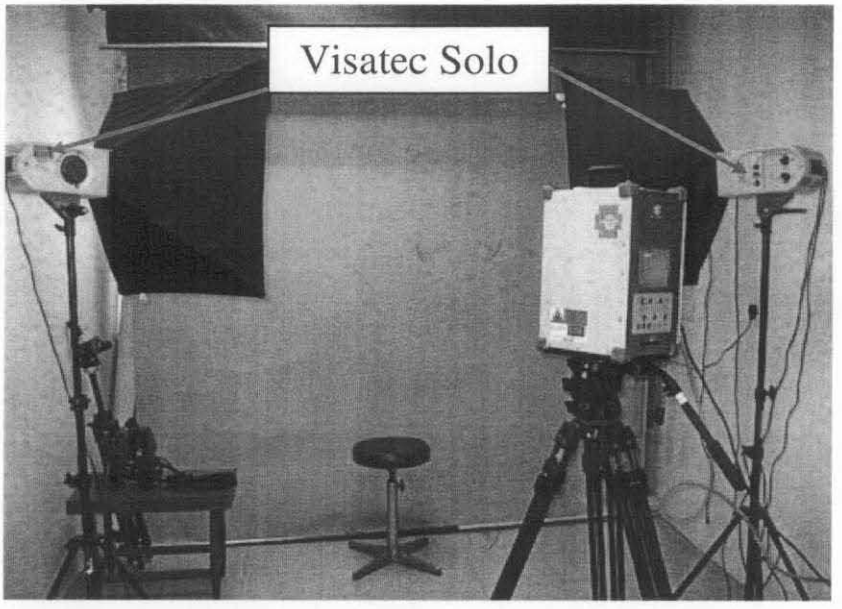
Light sources should be arranged to create homogenous and diffused light in order to avoid the appearance of shadow and specular reflection. In this work, two light sources are positioned so that the light is transmitted at an angle approximately 45^{o} with respect to the patient and the camera is positioned at 0^{o} as depicted in Figure 4.5(a). The light sources used are Visatec Solo 400, a halogen 150 W lights source as shown in Figure

4.5(b). They are covered by softboxes in order to produce diffused light as shown in Figure 4.5(c).

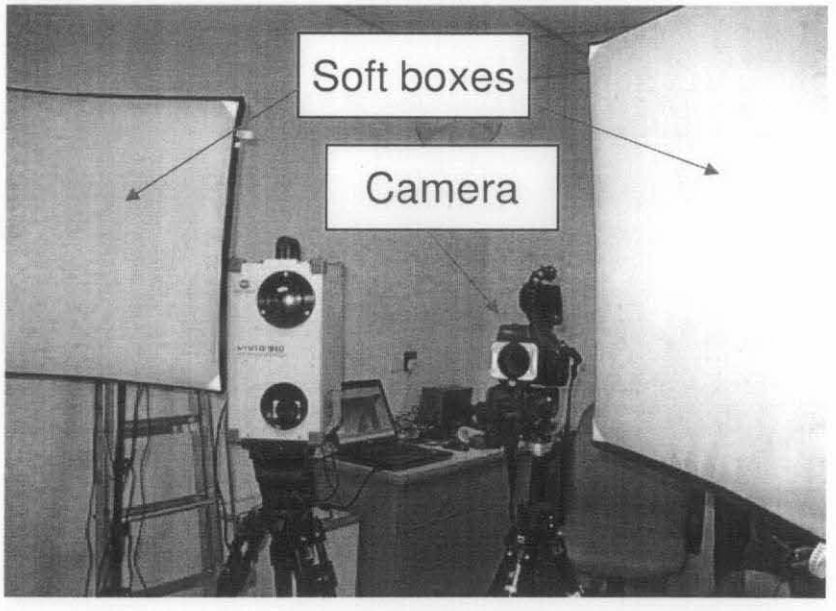
The background colour is selected so that it has high contrast relative to the colour of human skin. By having high contrast, background can be easily segmented from the image. Red is found to be the most dominant colour of human skin [Maletti *et al.*, 2005]. In CIELAB colour space, the a* axis represents degree of redness to greenness with positive values represent red and negative values represent green. Thus, by using green colour for the background it is expected that pixels belonging to the human skin will have positive values and pixels belonging to the background will have negative values for the CIE a* band.



(a)



(b)



(c)

Figure 4.5 2D image acquisition setup : (a) Layout, (b) Visatec Solo 400, (c) Softboxes

Based on the PASI standard, images of face, anterior and posterior side from trunk and both left and right upper extremities and lower extremities were digitally photographed for each patients. Sample images from a patient are shown in Figure 4.6. The image of the face is digitally edited for privacy reasons.

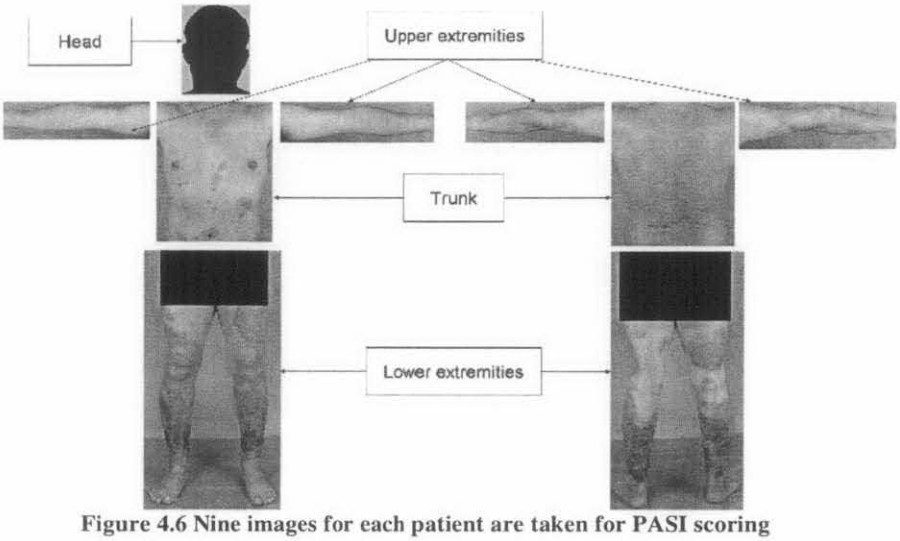


Figure 4.6 Nine images for each patient are taken for PASI scoring

4.2.2 Skin and lesion colour

Samples of skin and lesion colour are obtained from each body region (head, trunk, upper extremities, and lower extremities). The chromameter can be used either standalone or by connecting to a computer. The standalone mode gives advantage when portability is required or there is limited space to carry out measurements. However, in standalone mode the chromameter only store up to 1,000 measurements. The chromameter can be attached to a data processor as shown in Figure 4.7. The data processor is able to store up to 2,000 measurements and is equipped with built-in high speed printer.

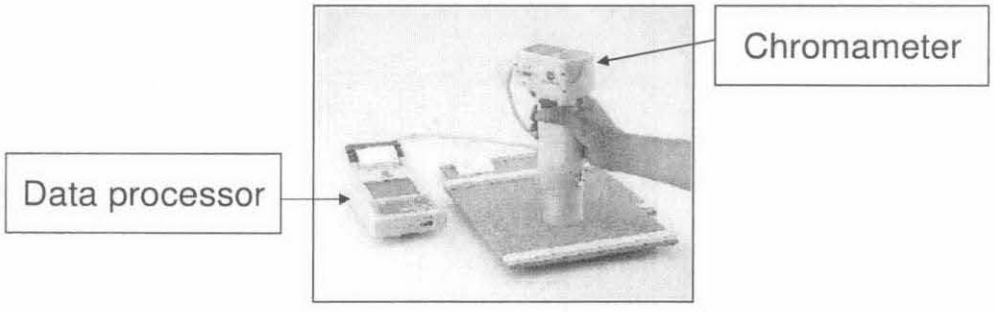


Figure 4.7 Chromameter connected to data processor during measurement

A specific software is required to interface the chromameter with a computer called SpectraMagic developed by Konica Minolta. In this mode, measurements by the chromameter can be stored in computer directly. Thus, the number of measurements is

only limited by storage capacity of the computer. A screenshot of SpectraMagic is shown in Figure 4.8. SpectraMagic is equipped with a feature that can visualize coordinate of a colour in CIELAB colour space and to calculate colour difference between two colours.

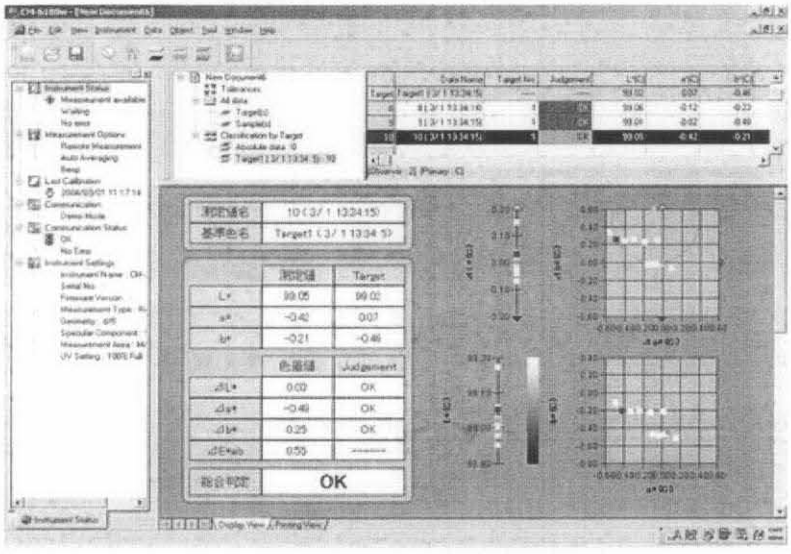


Figure 4.8 Screenshot of SpectraMagic

In this work, the chromameter is always connected to the computer for colour measurement. This mode is preferable since it is easier to record the patient's name and body region from which the colour sample is obtained.

4.3 ASSESSMENT OF PSORIASIS LESION AREA

4.3.1 Region of Interest (ROI) segmentation

In each image, the appearance of background is inevitable as shown in Figure 4.11a. When calculating body surface area, the background should be excluded. By using green colour for the background it is expected that pixels belonging to the ROI (human skin) will have positive values and pixels belonging to the background will have negative values for the CIE a* band. However in preliminary tests, it is found that skin areas bordering the background can have negative values of a* as shown in Figure 4.9. These areas are not well illuminated due to the curvature of human body limbs. Therefore, selecting a* = 0 as threshold value will not give accurate segmentation.

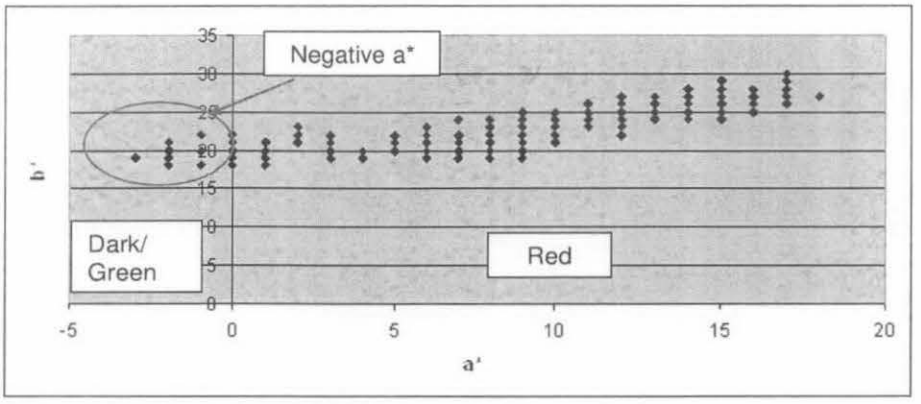


Figure 4.9 Distribution of skin colour of Patient 1 on a*, b* plane

However, histogram of the CIE a* band shows bimodality with clear separation as shown in Figure 4.10. This allows effective thresholding on this band using Otsu's method [Otsu, 1979]. Result of ROI segmentation is shown in Figure 4.11(b).

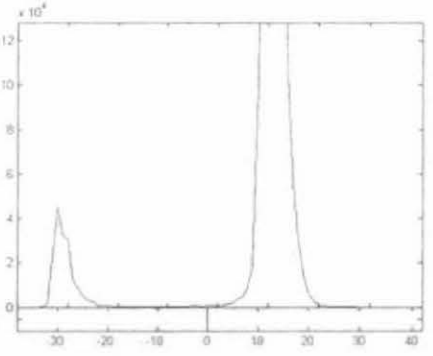
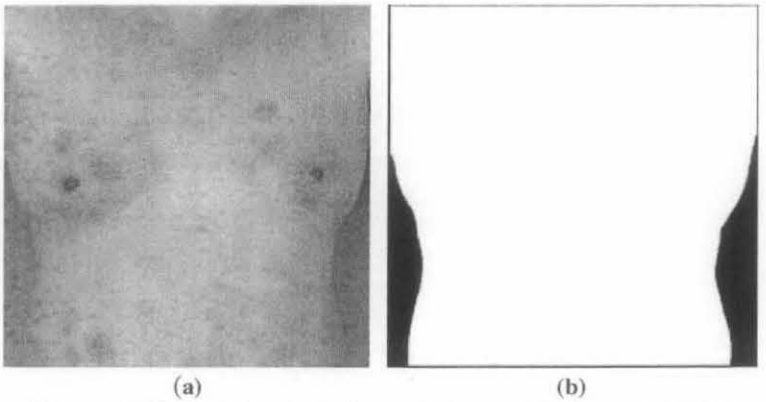


Figure 4.10 Histogram of trunk image



(a) (b)

Figure 4.11 Patient 1: (a) anterior trunk image, (b) Segmented ROI

The segmented region is considered as Region of Interest (ROI), since it consists of normal skin and psoriasis lesion and thus represents the total body surface area.

4.3.2 Psoriasis lesion segmentation

Once the background has been excluded from each image, the next step is to segment psoriasis lesion from normal skin. Psoriasis can appear in a wide variety of colours. It is affected by original colour of normal skin and extent of psoriasis lesion. Therefore, segmentation based on a selected colour will not be effective [Xu *et al.*, 1999]. However, psoriasis lesion can be recognized by its colour dissimilarity with normal skin. The CIELAB colour space is widely used to measure dissimilarity between two colours [Sharma, 2004]. Colour dissimilarity is represented by colour difference in CIELAB colour space. The smaller the colour difference between two colours, the more similar the two colours are. As discussed in Section 3.2., due to human visual system in discriminating colour, each pixel in CIELAB colour space can be represented by its lightness (L^*), hue (h_{ab}), and chroma (C_{ab}). Colour difference (ΔE) between two colours in CIELAB colour space is determined by

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta h_{ab}{}^2 + \Delta C^{*}_{ab}{}^2} \tag{4.1}$$

The term ΔL^* is the lightness (L^*) difference between two colours, Δh_{ab} is the hue difference between two colours, and ΔC^*_{ab} is the chroma difference between two colours. For example, Figure 4.12 shows 2 different pixels having different colours (P_1 and P_2). P_1 is represented by L^*_1, h_{ab1}, and C_{ab1} whereas P_2 is represented by L^*_2, h_{ab2}, and C_{ab2}. The ΔL^*, Δh_{ab}, and ΔC^*_{ab} are calculated as

$$\Delta L^* = \left| L^*_1 - L^*_2 \right|$$
$$\Delta h_{ab} = \left| h_{ab1} - h_{ab2} \right|$$
$$\Delta C^*_{ab} = \left| C^*_{ab\,1} - C^*_{ab\,2} \right|$$

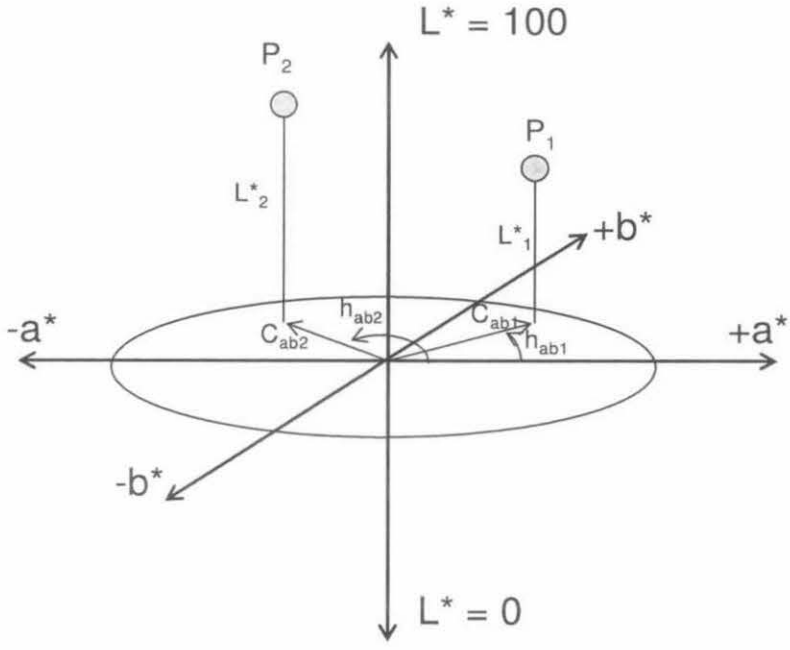


Figure 4.12 Illustration of colour difference between two colours in CIELAB colour space

Normal skin colour of a single person is not uniform since some regions are exposed to the sun more often than the other region. The exposed skin is usually darker than the unexposed skin. Figure 4.13 shows an example of exposed and unexposed skin.

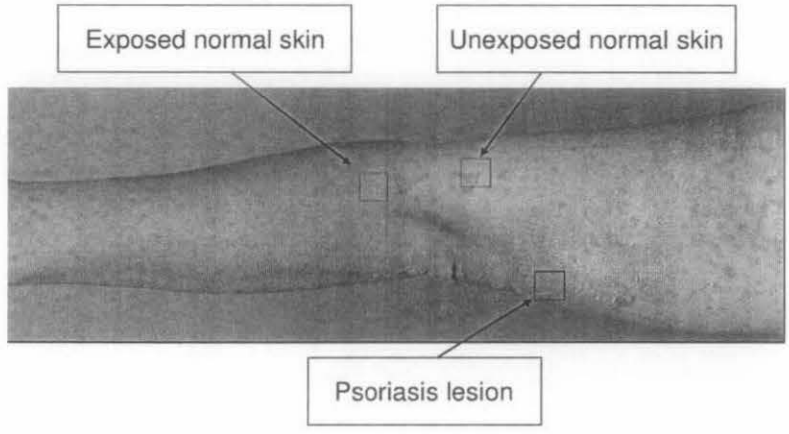


Figure 4.13 Colour of psoriasis lesion, exposed and unexposed normal skin

Samples of unexposed normal skin, exposed normal skin, and lesion are indicated by red, green, and blue squares respectively as shown in Figure 4.13. Average values of L^*, h_{ab}, and C^*_{ab} of these sample types are given in Table 4.1. These values are required to

calculate colour differences (ΔE) between the three regions. The lightness (L^*) of unexposed normal skin is higher than the exposed normal skin and the lesion. It means that the unexposed normal skin is brighter than the other two regions. The hue (h_{ab}) of unexposed normal skin is higher than the exposed normal skin and the lesion. The exposed normal skin has the highest chroma (C^*_{ab}). It is interpreted as the colour of exposed normal skin is more saturated than the other two regions.

Table 4.1 The L*, hue, chroma of lesion, exposed, and unexposed normal skin

	L*	h_{ab}	C^*_{ab}
Unexposed normal skin	66.0267	63.8789	30.6567
Exposed normal skin	50.9367	58.7711	41.4911
Lesion	43.5833	44.0289	29.3400

The ΔL^*, Δh_{ab}, ΔC^*_{ab}, and ΔE between the three sample types are shown in Table 4.2.

Table 4.2 Colour difference between lesion, unexposed, and exposed skin

	ΔL^*	Δh_{ab}	ΔC^*_{ab}	ΔE
unexposed – exposed normal skin (ΔE_{ue})	15.0900	5.1078	-10.8344	19.2661
unexposed normal skin – lesion (ΔE_{ul})	22.4434	19.8500	1.3167	29.9910
exposed normal skin – lesion (ΔE_{el})	7.3534	14.7422	12.1511	20.4708

Since the objective of this work is to segment psoriasis lesion from normal skin, the exposed and unexposed areas of the normal skin should be considered as the same object type. Thus, it is expected that colour difference (ΔE) between unexposed and exposed normal skin (ΔE_{ue}) to be significantly smaller than colour differences between exposed / unexposed and lesion (ΔE_{el}& ΔE_{ul}). However, results from Table 4.2 show that ΔE_{ue} is quite similar to ΔE_{el}. Colour difference between unexposed and exposed normal skin is mainly due to their ΔL^* values as shown in Table 4.2. Visually, the difference between exposed and unexposed skin is mainly due to their lightness. In order to minimize the difference between unexposed and exposed skin, ΔL^* is excluded from colour difference formula. In other words, only chrominance information is incorporated in colour difference formula as given in Equation 4.2. The new colour differences between the three samples are given in Table 4.3. By excluding L* from calculation, colour difference between unexposed and exposed normal skin (ΔE_{ue}) is significantly smaller

than colour difference between exposed/unexposed normal skin and lesion (ΔE_{el}& ΔE_{ul}). Thus, for segmenting psoriasis lesion from normal skin, only hue and chroma are analyzed. By excluding L*, the two colours are represented by two points on hue-chroma plane as shown in Figure 4.14.

$$\Delta E = \sqrt{\Delta h_{ab}{}^2 + \Delta C_{ab}^{*\,2}} \tag{4.2}$$

Table 4.3 Colour difference (ΔE) between the three samples by excluding L*

	ΔE
unexposed – exposed normal skin	11.9781
unexposed normal skin - lesion	19.8936
exposed normal skin - lesion	19.1045

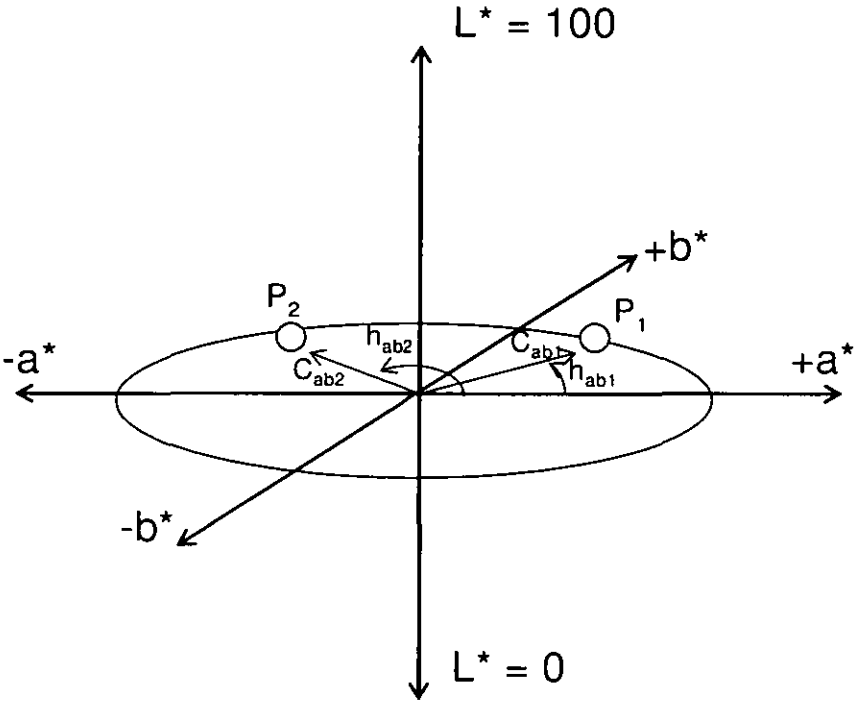


Figure 4.14 Illustration of colour difference between two pixels by excluding L*

Colour difference (ΔE) can therefore be used as a parameter to determine whether a pixel belongs to normal skin or lesion. It is essentially the Euclidean distance between two

pixels in hue-chroma plane. Classification based on Euclidean distance can be done by k-means method. Initially, centroids of normal skin and lesion in hue-chroma space are selected randomly. Euclidean distances between all pixels with these two centroids are calculated. Each pixel will be assigned to the class with minimum distance. Once all pixels have been classified, the objective function as given in Equation 3.19 is calculated. If the objective function does not meet predefined threshold, the new centroids are recalculated. The iteration will stop when convergence criterion is met. An example of segmentation result using k-means is shown in Figure 4.15. The result shows that this technique can segment the lesion from normal skin properly. Area of lesion is smaller than area of normal skin. It is indicated by the histogram of normal skin and psoriasis lesion pixels in hue-chroma plane as shown in Figure 4.16. It shows that there are two modalities which the bigger one belongs to normal skin and the smaller one belongs to psoriasis lesion. K-means method is able to separate the two modalities correctly.

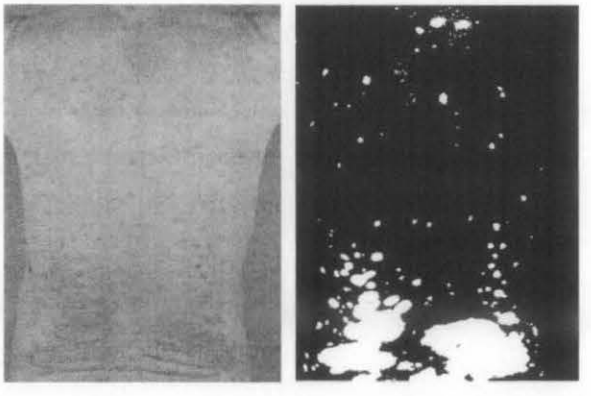


Figure 4.15 Correct segmentation using k-means clustering

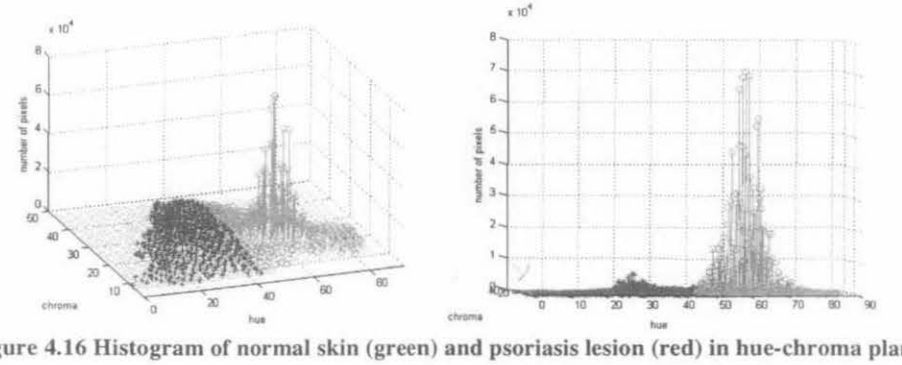


Figure 4.16 Histogram of normal skin (green) and psoriasis lesion (red) in hue-chroma plane

Another example of segmentation using k-means is shown in Figure 4.17. Unlike the previous example, this result shows oversegmentation where lesions are segmented correctly but some areas of normal skin are also classified as lesion. Histogram of normal skin and psoriasis lesion pixels in hue-chroma plane is shown in Figure 4.18. The histogram is dominated by pixels of normal skin whereas pixels of lesion do not create a peak. This is reflected in the Figure 4.17 that the area of lesion is significantly smaller compared to the area of body surface. When there are great differences in the number of samples in different cluster, k-means will split a large cluster and distribute it to the smaller cluster [Shihab, 2000; Duda *et al.*, 2001]. As a result, some pixels that actually belong to the normal skin will be categorized as pixels of lesion.

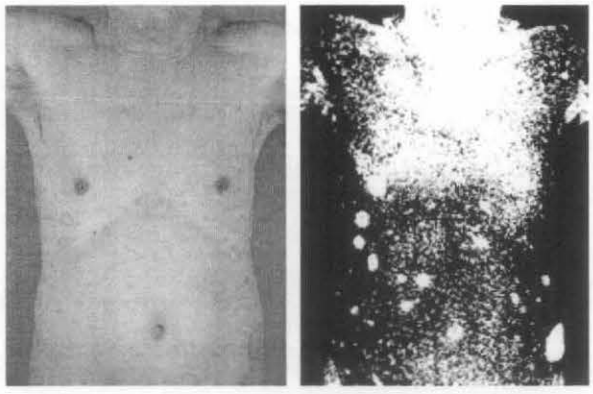


Figure 4.17 Oversegmentation using k-means clustering

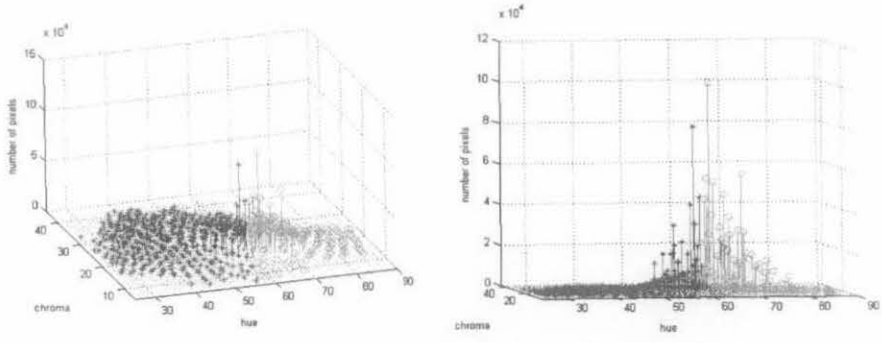


Figure 4.18 Histogram on normal skin (green) and psoriasis lesion (red) in hue-chroma plane

In order to avoid the above problem, the centroids of normal skin and psoriasis lesion are predetermined. The centroids are calculated from selected samples of normal skin and psoriasis lesion which are segmented manually from each image, giving equal amount of

pixels. Centroids of normal skin and lesion classes are calculated using the following formula:

$$h_O = \frac{1}{N}\sum_{i=1}^{N} hue_i, c_O = \frac{1}{N}\sum_{i=1}^{N} chroma_i \tag{4.3}$$

N = number of pixels from samples

Euclidean distances of all pixels from the two centroids are calculated. Each pixel is assigned to the class with minimum distance. An example of segmentation result is shown in Figure 4.19. It is significantly better than the result in Figure 4.17, where only small amounts of normal skin are misclassified as lesion. From the histogram in Figure 4.20, it can be noticed that the whole 'hill' belongs to one cluster, i.e. normal skin.

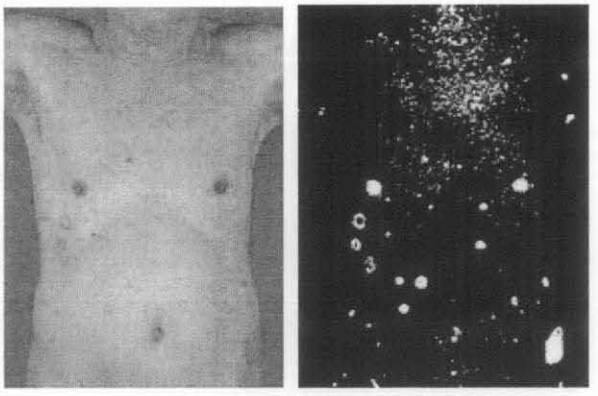


Figure 4.19 Result of segmentation

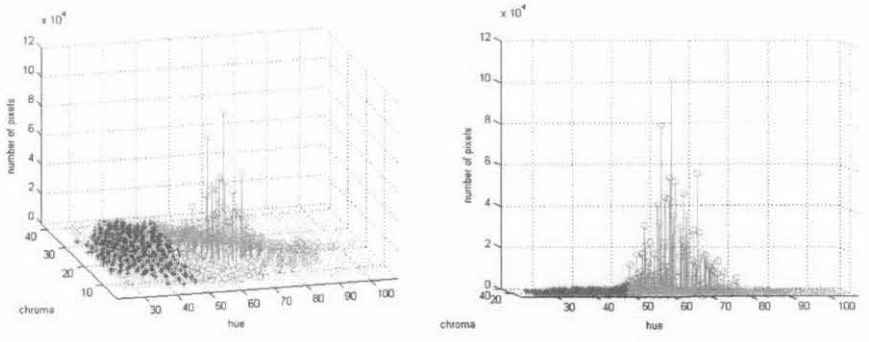


Figure 4.20 Histogram of segmentation

Once body surface area and lesion area are obtained, area percentage of psoriasis lesion can be calculated as:

$$\text{Area percentage} = \frac{\text{lesion area}}{\text{body surface area}} \times 100\% \quad (4.4)$$

Referring to Table 4.4, score for PASI area is determined.

Table 4.4 PASI Area Score

Area	Score
0%	0
<10%	1
10% to <30%	2
30% to <50%	3
50% to <70%	4
70% to <90%	5
90% to 100%	6

4.4 ASSESSMENT OF PSORIASIS LESION ERYTHEMA

As described in Chapter 2, DermaSpectrometer and Chromameter are commonly used to measure erythema. DermaSpectrometer measured erythema of skin based on light absorbance characteristic of melanin and hemoglobin, two dominant pigments in skin. The output is expressed as Erythema (E) and Melanin (M) index. Chromameter is an instrument which measures colour by modeling characteristic of light source, spectral reflectance of the object, and colour vision of human eye. Each colour is represented by three values i.e. L*, a*, and b* of CIELAB colour space. Both a* of Chromameter and E of DermaSpectrometer have been used as indicator of skin erythema. However, they are dependent on the level of pigmentation. For low pigmented skin, E is a good indicator of erythema whereas a* is a good indicator for highly pigmented skin. In this work, the dataset consists of thirty three patients with different level of pigmentation. The aim of this work is to develop a quantitative method in assessing erythema which is independent with pigmentation level.

Psoriasis lesion can appear in a wide variety of colour. It is affected by degree of severity and its original skin colour. The skin colour is related to the degree of skin pigmentation. Low, medium, and high pigmented skins are indicated by fair, brown, and dark skin colours respectively. From observation on the dataset, there are 3 typical appearances of psoriasis lesion as shown in Figure 4.21. It can be noticed that the appearance of the

lesion is related to the skin colour. The colour of lesions on patients with bright skin colour is red whereas that on patients with dark skin colour is dark purplish. The colour of lesions on patients with brown skin colour is dark red. Therefore, patients should be grouped according to their skin pigmentation level in order to assess the erythema objectively. By grouping the patients, bias in measuring erythema due to the skin colour is eliminated.

(a) (b) (c)

Figure 4.21 Three typical appearances of psoriasis lesion on different skin colour: (a) fair skin (low pigmentation), (b) brown skin (medium pigmentation), and (c) dark skin (high pigmentation)

Pigmentation level is inversely linear with the L* value [Shriver and Parra, 2000]. Thus, it can be utilized to group the patients according to their skin pigmentation level. The sample of normal skin for each patient is taken from the trunk region. This region is expected to represent the original colour of normal skin since it is covered by the clothes most of the time. The range of L* values of particular skin group is selected so that all patients within the group have similar appearances of psoriasis lesion. Seven patients with L* value ranges from 37 to 47 are classified into dark skin group, fifteen patients with L* value ranges from 57 to 65 are grouped into fair skin group, and eleven patients with L* value ranges from 48 to 56 are categorized into brown skin group. Figure 4.22 shows a chart of L* values of patients from fair, brown, and dark skin group.

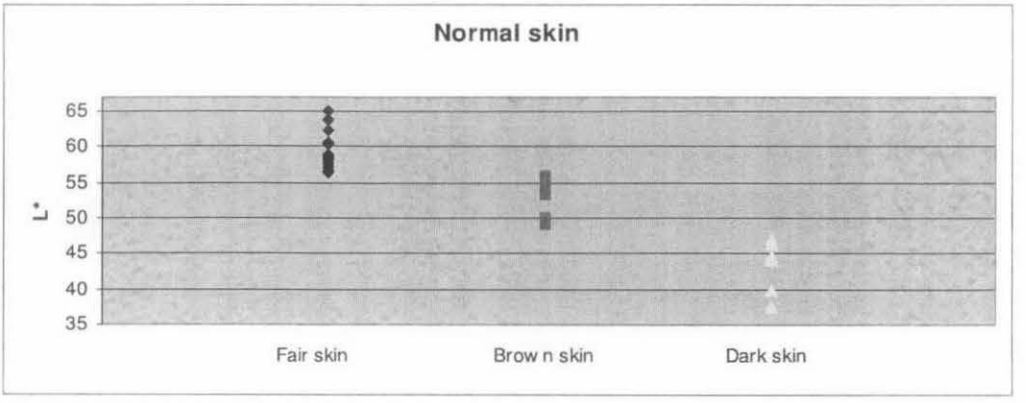


Figure 4.22 Skin group according to L* value

In developing a method to assess the erythema objectively, references of lesion with different erythema score are required. The references are obtained from selected lesions by dermatologists. For each patient, two dermatologists select one representative lesion, each from head, trunk, upper extremities, and lower extremities regions. Both of them independently assess the lesion to determine PASI score. It is possible that a lesion is given different scores by them. Therefore, only lesions which are given the same score by the two dermatologists are taken as references.

In assessing the erythema, dermatologists compare colour of a lesion with colour of the surrounding normal skin. To incorporate that, ΔL*, Δh_{ab}, ΔC^*_{ab} values between the lesion and normal skin in CIELAB colour space is calculated. The three features are sorted according to their discriminative ability. The two most discriminative features are taken in the analysis. Mean and standard deviation are the most often used criteria to select the discriminative features [Markiewicz and Osowski, 2006]. The discrimination coefficient of feature *f* for class A and B is defined by Equation 4.5.

$$S_{AB}(f) = \frac{|\mu_A(f) - \mu_B(f)|}{\sigma_A(f) + \sigma_B(f)} \tag{4.5}$$

μ_A and μ_B are the mean values of feature *f* for class A and B respectively whereas σ_A and σ_B represent standard deviation. In this work, the features are ΔL*, Δh_{ab}, ΔC^*_{ab} and the classes are the erythema scores. High value of $S_{AB}(f)$ indicates good discriminative ability of feature *f* for the class A and B.

4.5 SUMMARY

This chapter describes development of objective method in assessing area and erythema of psoriasis lesion. The development starts from selection of instruments for data acquisition until the analysis of the data. For area assessment, 2D images of each patient covering head, trunk, upper extremities, and lower extremities are digitally photographed. Position of the camera, light sources, and patient are arranged in order to produce images with consistent high quality. PASI area score is determined from area percentage of psoriasis lesion. The area percentage is ratio between lesion area and body surface area. Body surface area is calculated from the image by segmenting the background. Green is selected as colour of the background since it is contrast with human skin colour. Lesion area is calculated by segmenting psoriasis lesion from normal skin. The segmentation is based on colour difference between normal skin and psoriasis lesion in CIELAB colour space.

For erythema assessment, colour of normal skin and psoriasis lesion are measured by chromameter. The colour is represented by L*, hue, and chroma of CIELAB colour space. Degree of erythema is analyzed by calculating colour difference between normal skin and psoriasis lesion.

CHAPTER 5: RESULTS AND DISCUSSION

The methods for objective assessment of psoriasis lesion area and erythema 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 DATASET

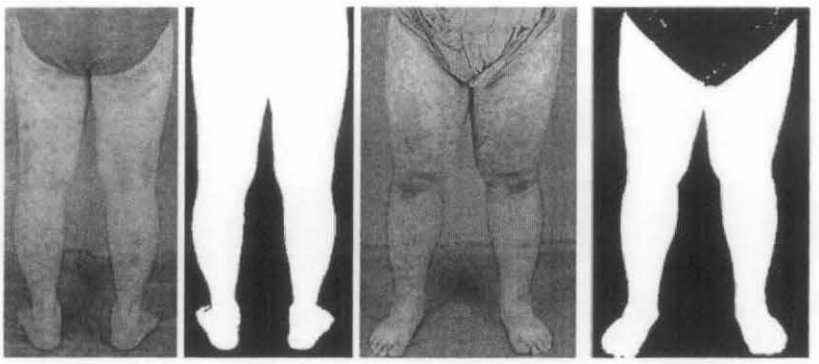
Data is obtained from patients with plaque psoriasis. Thirty three patients were recruited from Dermatology Department, Hospital Kuala Lumpur. All patients are male with age above 18 years old and do not have any other type of psoriasis or dermatological diseases. The patients comprises of people having skin with various levels of pigmentation ranging from low (fair skin) to high (dark skin). All patients have been informed the nature and aims of the study and have given their written informed consent.

5.2 REGION OF INTEREST (ROI) AND LESION SEGMENTATION

The proposed segmentation method is applied on 33 patients of 3 skin types; fair, brown, and dark (See Appendix A). Out of 33 patients, 8 patients are selected as references for calculating the accuracy of the proposed segmentation method.

5.2.1 Cloth colour

Patients only wear their underwear during photography session for 2D image acquisition. However, the colour of underwear for photography is not standardized. As a result, cloth in one image is segmented as background whereas in another image is classified as region of interest (ROI) as shown in Figure 5.1. On the other hand, the green background on the floor and the wall are perfectly segmented as one object despite of their slightly different appearance. For PASI scoring, it is required that the cloth is excluded from ROI.



(a) (b) (c) (d)

Figure 5.1 Effect of cloth colour in ROI segmentation: (a) cloth colour similar with the skin colour, (b) segmented ROI of image (a), (c) cloth colour similar with the background colour, (d) segmented ROI of image (c)

Histograms of images in Figure 5.1(a) and (c) in a* band of CIELAB colour space are shown in Figure 5.2(a) and (b) respectively. It is observed that the histogram in Figure 5.2(a) consists of four significant peaks. The peak on the most left represents the green background on the wall whereas the peak next to it represents the green background on the floor. The distribution of pixels due to the cloth is represented by the rightmost peak. The small peak next to it represents distribution of pixels due to the skin. By minimizing the intra-class variance of the pixels distribution, Otsu's thresholding method yields threshold value at a* = -7. Thus, the green background (the wall and floor) are segmented as background whereas the cloth and skin areas are segmented as ROI as shown in Figure 5.1(b).

The cloth colour in Figure 5.1(c) is observed to be similar to the colour of the background. Therefore, the distribution of pixels due to the cloth lies near the distribution of green background as shown in Figure 5.2(b). Threshold value obtained from Otsu's method for this image is at a* = -7, resulting the cloth to be segmented as background as shown in Figure 5.1(d). To be able to segment the cloth as background, it should have similar colour with the background.

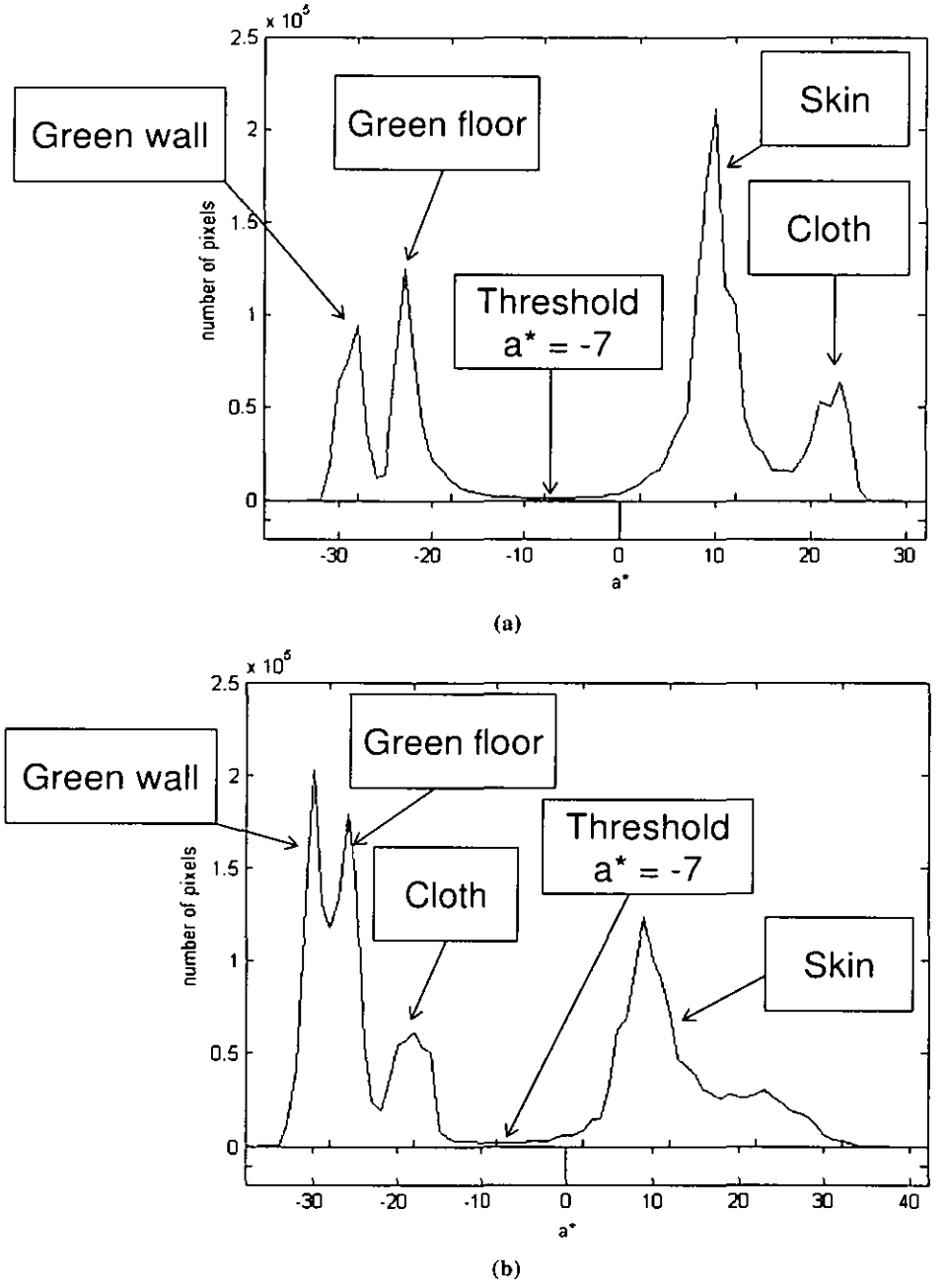


Figure 5.2 Histogram of images in Figure 5.1 in a* band of CIELAB colour space

5.2.2 Misclassified object

In some cases, non-lesion objects such as lips, eyes, eyebrow and nipples are misclassified as psoriasis lesion. This is due to the colour of these non-lesion objects are

not similar with the colour of normal skin. An example of misclassified objects is given in Figure 5.3. In this case, lips, eyes and eyebrow are misclassified as psoriasis lesion as shown in Figure 5.3(b). The distributions of pixels belong to normal skin, psoriasis lesion, and lips in hue-chroma plane are shown in Figure 5.4. The distribution of pixels belong to the lips is overlapped with distribution of the lesion pixels. Therefore, lips are misclassified as lesions.

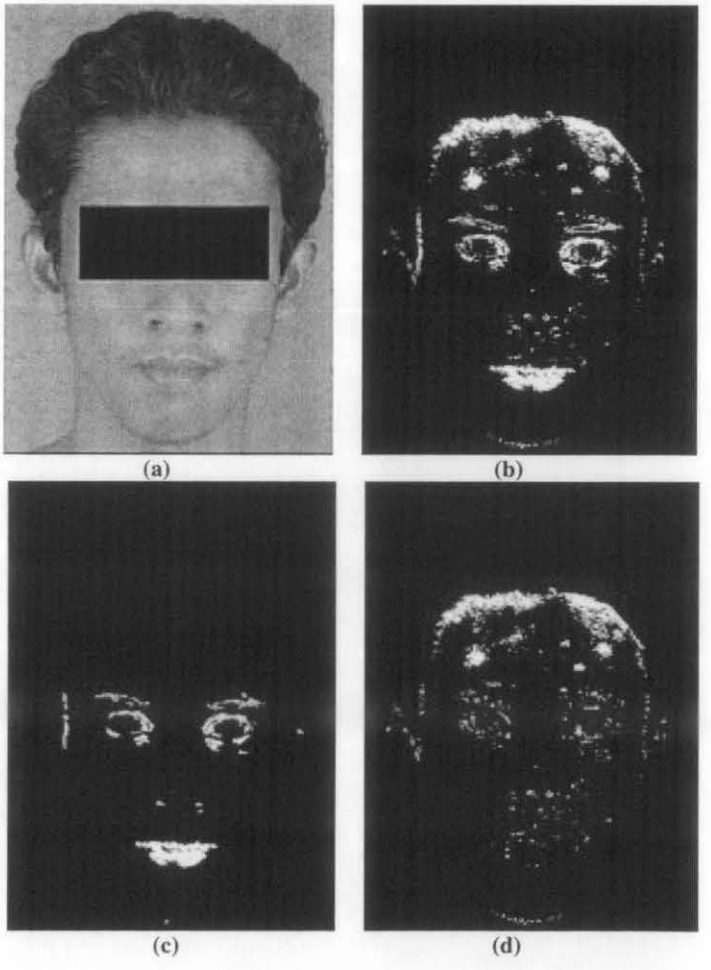


Figure 5.3 Misclassified object : (a) Original image (edited for privacy reasons), (b) segmented lesion, (c) non-lesion objects misclassified as lesions, (d) segmented lesion after correction

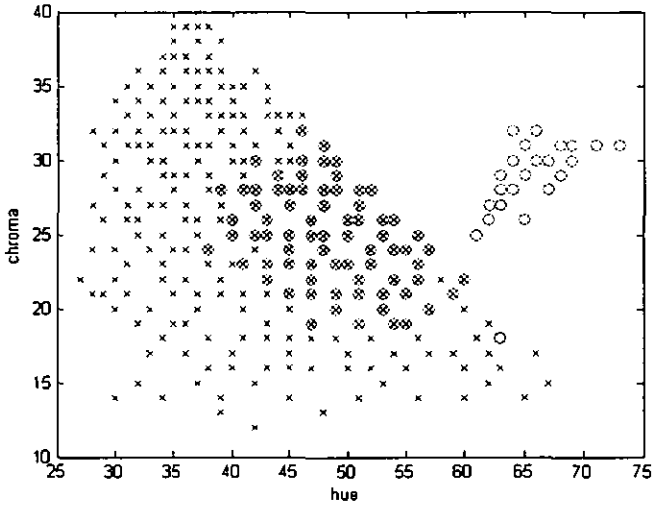


Figure 5.4 Distribution of pixels belong to normal skin (green circle), psoriasis lesion (red circle), and lips (blue cross) in hue-chroma plane

In order to exclude the misclassified objects from the segmented image, all pixels belong to that objects should be selected first. These objects are composed from subset of connected pixels. In a digital image, two pixels are connected if they have the same value and they are neighbours. In binary image, usually the observed pixels are those with value of 1. Neighbourhood relationship between two pixels is related to their adjacency. There are 2 types of adjacency, namely 4-adjacency and 8-adjacency. A pixel at coordinate (x,y) is 4–adjacent with the pixels at coordinate $(x+1,y)$, $(x-1,y)$, $(x,y+1)$, and$(x,y-1)$. A pixel at coordinate (x,y) is 8–adjacent with the pixels at coordinate $(x+1,y)$, $(x-1,y)$, $(x,y+1)$, $(x,y-1)$, $(x-1,y-1)$, $(x+1,y-1)$, $(x-1,y+1)$, and $(x+1,y+1)$. The illustrations of the connected pixels are given in Figure 5.5. All pixels with value 1 in Figure 5.5(a) are connected since they have the same value and are 4-adjacent neighbour. All pixels with value 1 in Figure 5.5(b) are connected since they have the same value and are 8-adjacent neighbour.

2 patients which are having healed lesion areas. The examples of healed lesions from the two patients are shown in Figure 5.7(a) and Figure 5.7(c). For PASI scoring, healed lesions are categorized as healthy skin by the dermatologists. As seen from Table 5.1, the colour difference (refer to Equation 4.2) between normal and healed skin (ΔE_{nh}) is found to be relatively smaller than the colour difference between normal skin and lesion (ΔE_{nl}). Using this observation, the proposed method is able to detect healed lesion as normal skin due to the colour similarity as shown in Figure 5.7(b) and Figure 5.7(d).

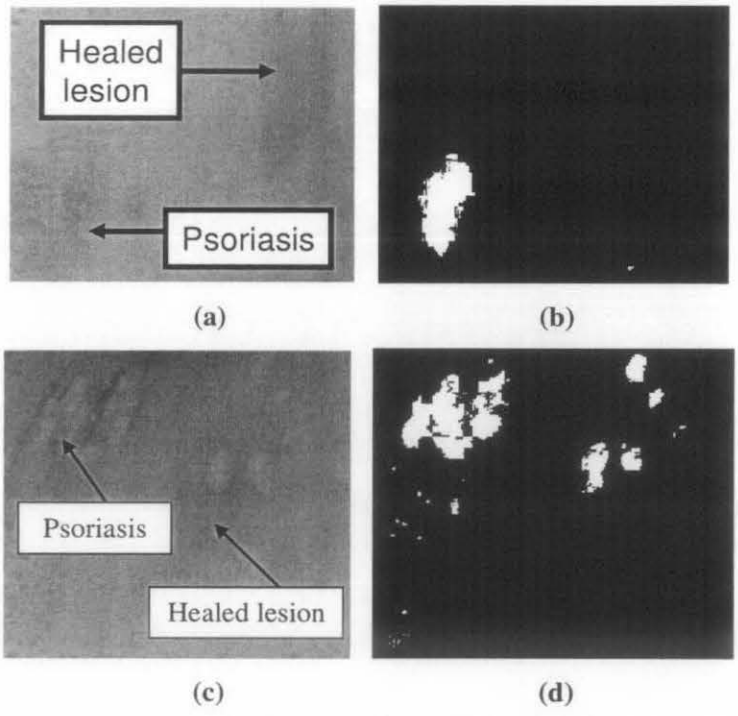


Figure 5.7 Patient A: (a) healed lesion and psoriasis lesion, (b) segmented lesion Patient B : (c) healed lesion and psoriasis lesion, (d) segmented lesion

Table 5.1 Colour difference between normal skin - healed skin and between normal skin - lesion

	Patient A	Patient B
Normal skin – healed skin (ΔE_{nh})	14.3198	4.6378
Normal skin – lesion (ΔE_{nl})	25.0262	16.3484

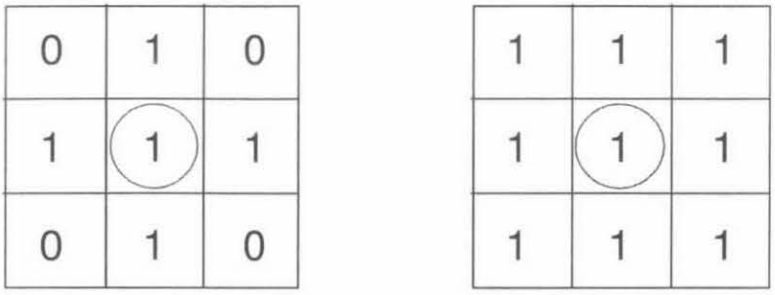


Figure 5.5 Pixel neighbourhood relationship: (a) 4-neighbours, (b) 8-neighbours

By selecting several pixels manually from the misclassified objects, all pixels belong to these objects can be selected as shown in Figure 5.3(c). Once all the misclassified objects are selected, they are subtracted from the segmented image to obtain the correct segmented image as shown in Figure 5.3(d).

Another example of misclassification is shown in Figure 5.6. In this case, nipples are misclassified as psoriasis lesions (indicated by red circles).

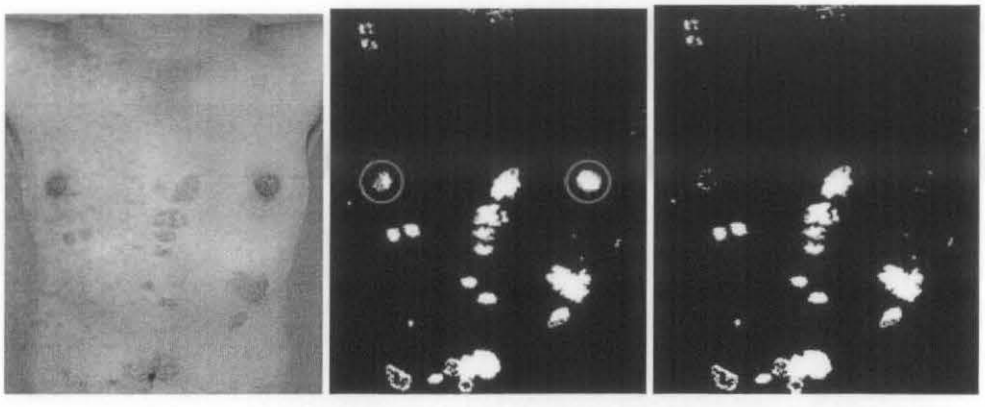


Figure 5.6 Misclassification : (a) Original image, (b) Segmented image with nipples are misclassified, (c) Segmented image after correction

5.2.3 Healed lesion

During treatment, lesions can vanish gradually and the healed lesion usually appears darker in contrast to the healthy skin but having similar hue. Out of 33 patients, there are

5.2.4 Performance

The segmented images are compared with the reference images to measure the performance of the proposed lesion segmentation method. Reference images are obtained by segmenting lesion area manually from the digital images as benchmark. True positive rate (hit rate) and false positive rate (false alarm rate) are used to measure the performance of the proposed method. True positive rate and false positive rate are calculated by following Equation 5.1 and 5.2 respectively [Fawcett, 2006]:

$$True\ positive\ rate = \frac{True\ positive}{Total\ positives} \tag{5.1}$$

$$False\ positive\ rate = \frac{False\ positive}{Total\ negatives} \tag{5.2}$$

True positive is the area which is categorized as lesion by reference segmented images and also by the proposed method. False positive is the area which is categorized as normal skin by reference segmented images but categorized as lesion by the proposed method. Total positive and total negative are the areas categorized by reference segmented images as psoriasis lesion and normal skin respectively.

The proposed lesion segmentation method is applied on images of 8 patients; 3 patients with fair skin colour, 3 patients with brown skin colour, and 2 patients with dark skin colour (See Appendix A). The selection of patients is based on the clarity of lesion border to ensure minimal error in manual segmentation. The true positive rates and false positive rates achieved by the segmentation method are given in Table 5.2. Receiver operating characteristics (ROC) graph of the proposed segmentation method, a plot between true positive and false positive rate is shown in Figure 5.8. A good classifier has high true positive rate and low false positive rate. In ROC graph, a good classifier occupies the upper left triangle region. Any classifier in the lower right triangle region performs worse than random guessing [Fawcett, 2006]. For all the cases, the proposed method is able to achieve high true positive rate and low false positive rate.

Table 5.2 True positive and false positive rate of proposed segmentation method

Patient			True positive rate	False positive rate
Fair skin	1	head	0.893272906	0.060786586
		trunk	0.919652127	0.011796215
		upper extremities	0.740601968	0.00582003
		lower extremities	0.624775015	0.005743971
	2	head	0.545653922	0.029111095
		trunk	0.71341745	0.011351823
		upper extremities	0.810782655	0.053785879
		lower extremities	0.622656649	0.067309141
	3	head	0.612275886	0.006770989
		trunk	0.597684159	0.000999643
		lower extremities	0.4818064	0.002180482
Brown skin	4	head	0.574802668	0.054743888
		trunk	0.577099867	0.012470869
		upper extremities	0.805125169	0.004949275
		lower extremities	0.651117596	0.037802529
	5	head	0.180835054	0.028120896
		trunk	0.823364745	0.021793967
		upper extremities	0.820810977	0.038362472
		lower extremities	0.636790092	0.057480193
	6	head	0.78225293	0.038210102
		trunk	0.925633164	0.022865533
		upper extremities	0.872479163	0.012463471
		lower extremities	0.791666291	0.290959001
Dark skin	7	head	0.930354034	0.015558056
		trunk	0.700059517	0.015136761
		upper extremities	0.81678339	0.014716715
		lower extremities	0.488336565	0.050871974
	8	trunk	0.569114134	0.005115261
		upper extremities	0.61609634	0.001895096
		lower extremities	0.71197034	0.014354486

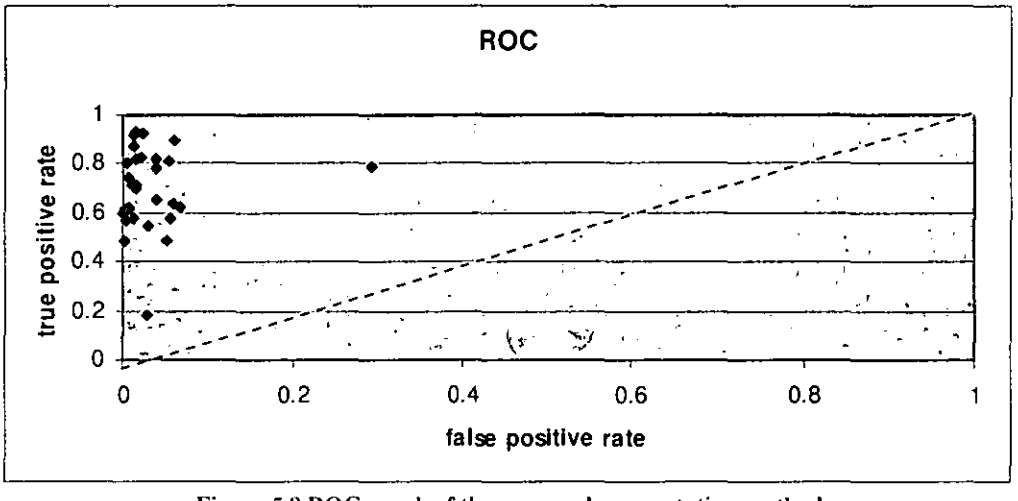


Figure 5.8 ROC graph of the proposed segmentation method

Comparisons between the lesion area percentages and PASI area scores (A) obtained from dermatologist, reference images, and the proposed method are given in Table 5.3. The lesion area percentages obtained from reference images are taken as benchmark. The dermatologist determined the area percentage by visual estimation. It is observed that the area percentages estimated by the dermatologist are significantly different from the area percentages obtained from reference images. As a result, some PASI area scores given by the dermatologist are different from the scores obtained from reference images (18 out of 30, shaded boxes in column Dermatologist of Table 5.3). The errors in the head region are relatively smaller compared with the errors of other regions. This is due to the small area of head region which is easier for dermatologist to estimate the lesion area percentage. The proposed method gives the same PASI area scores as reference images except for two cases (shaded in column Proposed method of Table 5.3).

Images of lower extremities region of Patient 5 and Patient 6 are given in Figure 5.9 and Figure 5.10 respectively. It can be seen that the proposed method segments less area of lesions than the actual area. The lesions on calves are covered by thin scales which occupy the same region as normal skin in hue-chroma plane. Therefore, these regions are misclassified as normal skin. As a result, the area of lesions segmented by the proposed method is smaller than the references.

Table 5.3 Lesion area percentage and PASI area score (A) given by dermatologist, reference, and proposed method

Patients			Reference		Dermatologist		Proposed method	
			Area (%)	A	Area (%)	A	Area (%)	A
Fair skin	1	head	6.62	1	5	1	8.28	1
		trunk	6.69	1	30	3	5.89	1
		upper extremities	4.7	1	15	2	4.23	1
		lower extremities	7.41	1	45	3	7.64	1
	2	head	1.43	1	2	1	1.36	1
		trunk	2.71	1	10	2	3.1	1
		upper extremities	7.6	1	25	2	9.27	1
		lower extremities	7.68	1	20	2	9.29	1
	3	head	1.15	1	1	1	1.1	1
		trunk	0.2	1	5	1	0.26	1
		lower extremities	0.52	1	5	1	0.6	1
Brown skin	4	head	1.13	1	5	1	3.87	1
		trunk	4.82	1	30	3	3.53	1
		upper extremities	1.76	1	10	2	1.68	1
		lower extremities	6.66	1	40	3	7.42	1
	5	head	2.33	1	10	2	3.36	1
		trunk	10.37	2	40	3	10.43	2
		upper extremities	21.4	2	40	3	18.02	2
		lower extremities	30.48	3	30	3	17.77	2
	6	head	17.16	2	20	2	13.58	2
		trunk	48.12	3	60	4	45.89	3
		upper extremities	36.75	3	50	4	34.85	3
		lower extremities	56.68	4	60	4	31.62	3
Dark skin	7	head	1.22	1	3	1	1.21	1
		trunk	6.38	1	25	2	6.51	1
		upper extremities	11.5	2	40	3	13.62	2
		lower extremities	23	2	50	4	14.72	2
	8	trunk	0.94	1	1	1	1.1	1
		upper extremities	3.86	1	5	1	2.78	1
		lower extremities	5.01	1	20	2	5.02	1

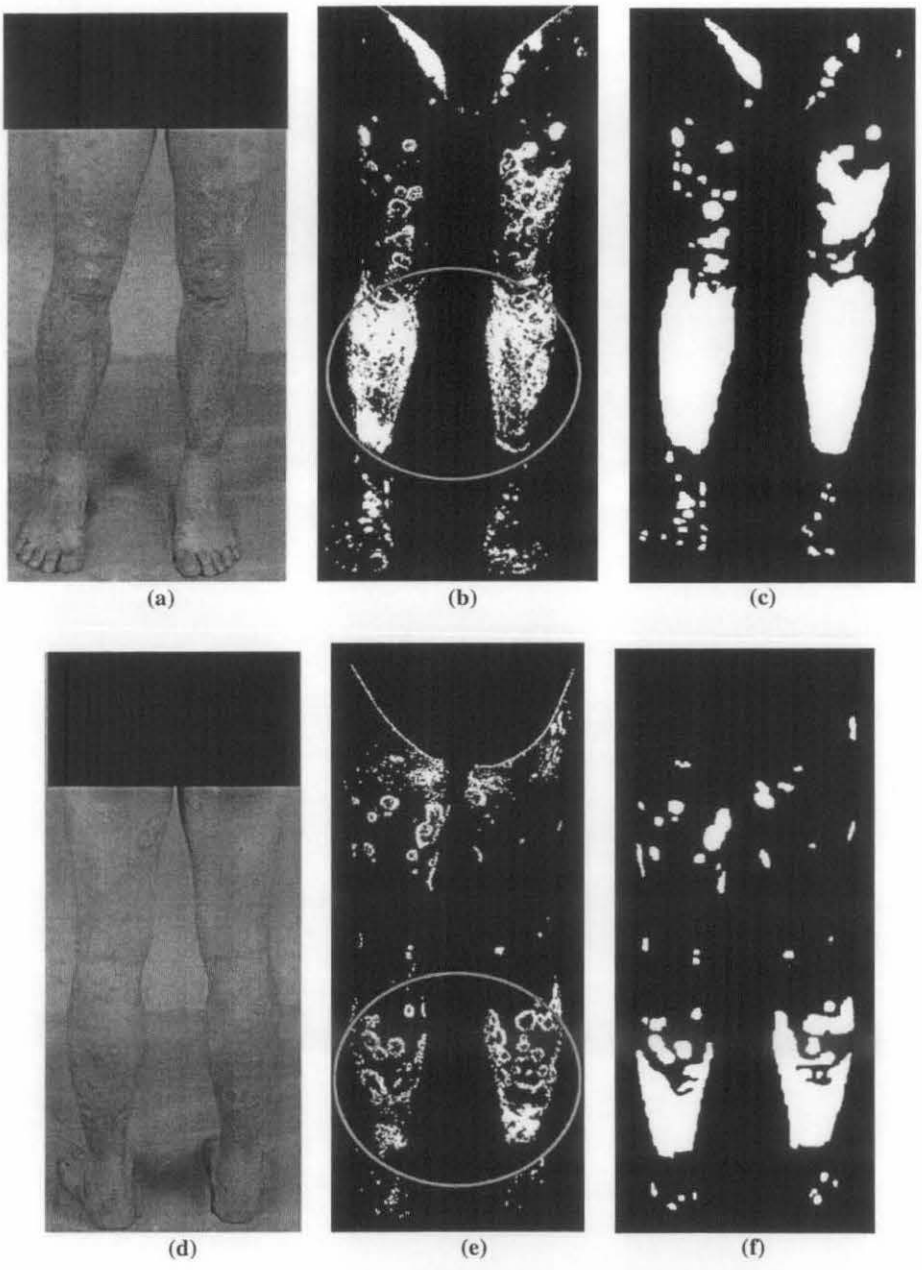


Figure 5.9 Lower extremities of Patient 5: (a) anterior, (b) segmented lesion of image (a), (c) reference lesion of image (a), (d) posterior, (e) segmented lesion of image (d), (f) reference lesion of image (d)

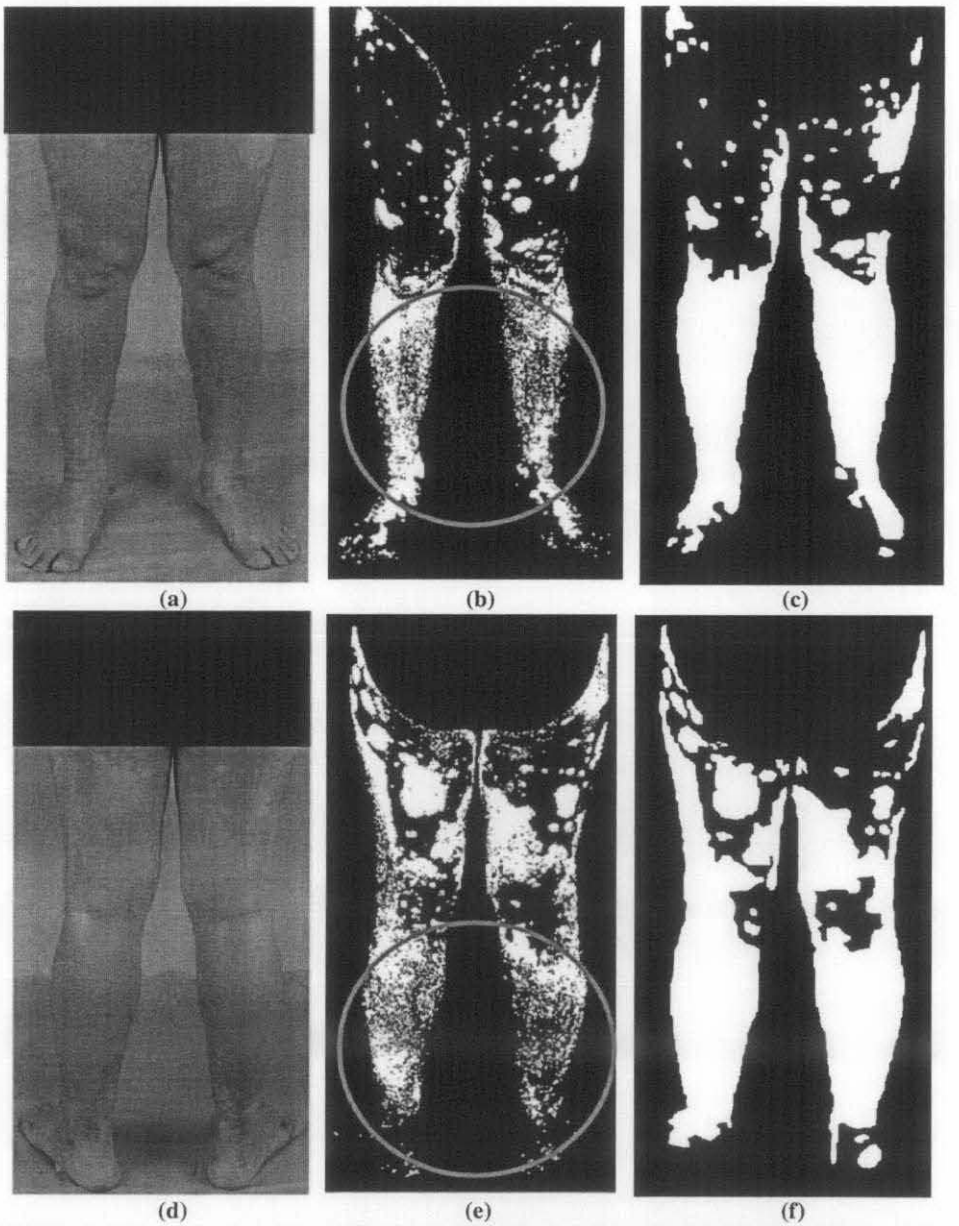


Figure 5.10 Lower extremities of Patient 6: (a) anterior, (b) segmented lesion of image (a), (c) reference lesion of image (a), (d) posterior, (e) segmented lesion of image (d), (f) reference lesion of image (d)

5.3 PASI ERYTHEMA SCORE

Data from 22 patients are used in this work; 10 patients from fair skin group, 8 patients from brown skin group, and 4 patients from dark skin group (See Appendix B, C, D, and E). For each patient, erythema of psoriasis lesion from head, trunk, upper extremities, and lower extremities are assessed twice for PASI erythema scores by two

dermatologists. The interval between the first and second assessment is around 15 to 30 minutes. This is to incorporate the intra-individual variations and inter-individual variations. During that period, the dermatologists were doing other activities whereas the patient was assessed by using chromameter. A total of 82 lesions are obtained because some patients do not have lesion on particular body region.

During the investigation only 16 patients are assessed twice by the two dermatologists and the remaining 6 patients assessed once (four patients from fair skin group and two patients from dark skin group). However, due to lack of reference lesions the data from these six patients are taken as reference too.

From the 22 patients, there are 38 lesions that are given the same erythema score by the two dermatologists. These lesions are taken to be the reference for erythema scoring as they are not affected by inter-observer variations. The reference lesions consist of 15 lesions for fair skin group, 16 lesions for brown skin group, and 7 lesions for dark skin group. Reference lesions for fair skin group consist of 6 lesions with score 1, 8 lesions with score 2, and 1 lesion with score 3. Reference lesions for brown skin group consist of 8 lesions with score 1, 5 lesions with score 2, and 3 lesions with score 3. Reference lesions for dark skin group consist of 5 lesions with score 1, and 2 lesions with score 2.

The lightness difference (ΔL^*), hue difference (Δh_{ab}), chroma (ΔC^*_{ab}) between reference lesions and the surrounding normal skin are calculated. Discrimination coefficient (refer to Equation 3.19) is calculated to determine the suitability of the three above features in discriminating lesions with different scores. Discrimination coefficient of each feature within a particular skin group is shown in Table 5.4. For fair and brown skin group, discrimination coefficients are calculated between lesions with score 1 and 2 (S_{12}), score 2 and 3 (S_{23}), and score 1 and 3 (S_{13}) are calculated. For dark skin group, only discrimination coefficient between lesions of scores 1 and 2 (S_{12}) is calculated. As can be seen from Table 5.4, Δh_{ab} and ΔL^* are the two most discriminative features for fair and brown skin group. This is well suited with the visual observation that the appearance of lesion from fair and brown skin groups differs in colour and is darker than the normal skin. For dark skin group, the most discriminative features are Δh_{ab} and ΔC^*_{ab}. Visually, the brightness of normal skin and psoriasis lesion from dark skin group are low. Thus,

ΔL^* is not a good feature in discriminating the lesion. The two most discriminative features are being used in assessing the erythema score for each skin colour group.

Table 5.4 Discrimination coefficients of fair, brown, and dark skin group

Group	Discrimination coefficient	ΔL^*	Δh_{ab}	ΔC^*_{ab}
Fair skin (low pigmentation)	S_{12}	0.7473	1.1263	0.0277
	S_{23}	0.5971	0.382	0.575
	S_{13}	1.5377	1.2847	1.1622
Brown skin (medium pigmentation)	S_{12}	0.1635	0.5187	0.1373
	S_{23}	0.8364	0.9642	0.1812
	S_{13}	1.8646	1.6768	0.0498
Dark skin (high pigmentation)	S_{12}	0.1433	1.3414	0.4035

5.3.1 Fair skin group

Plot of Δh_{ab} and ΔL^* values of reference lesions from fair skin group is shown in Figure 5.11. It can be noticed that lesions with lower score lie on the lower value of Δh_{ab} axis, whereas lesions with higher score lie on the higher value. However, there is a lesion with score 2 which lies near lesion with score 3 as indicated by blue ellipse in Figure 5.11.

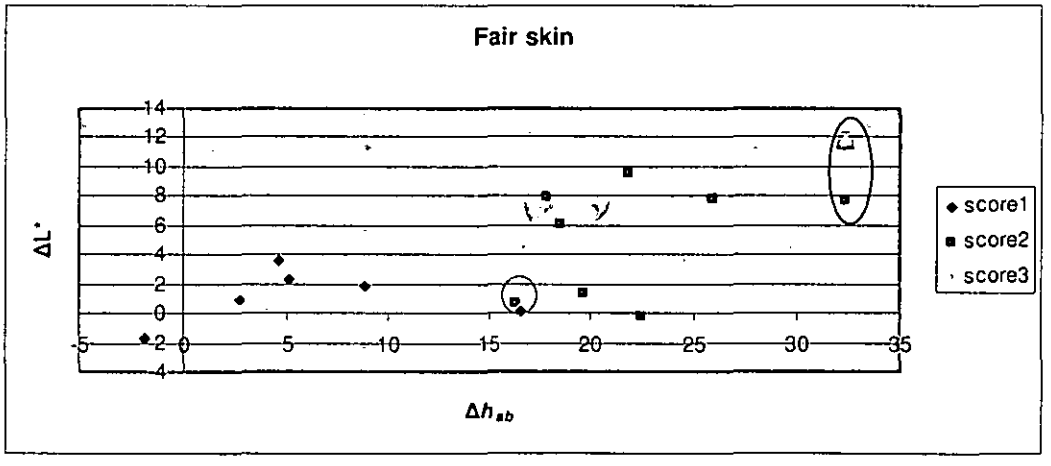
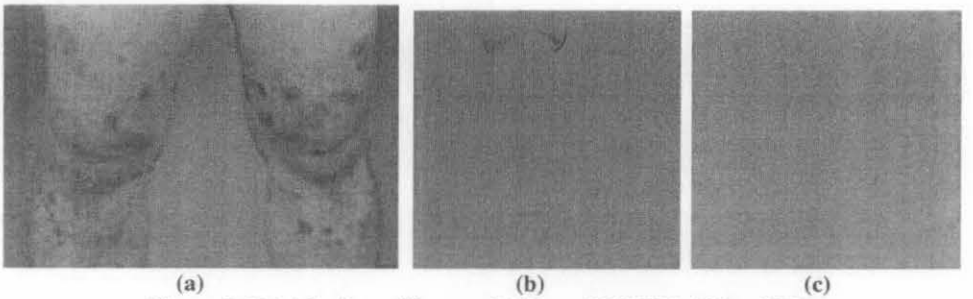


Figure 5.11 Reference lesions from fair skin group

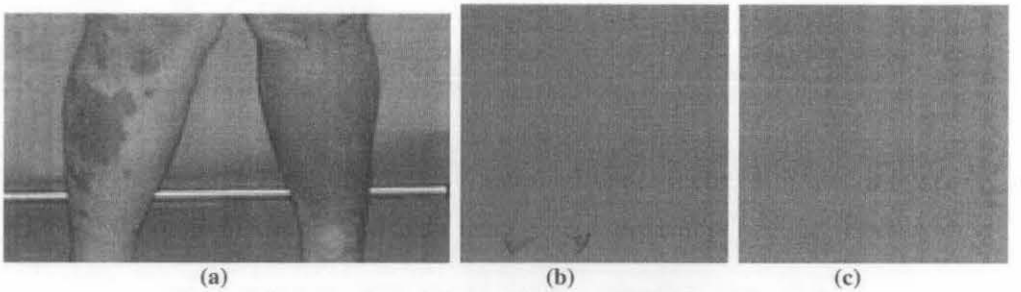
Images of lesions with score 2 and 3 as indicated by blue ellipse in Figure 5.11 are shown in Figure 5.12(a) and Figure 5.13(a). The colours of lesions and normal skins as read by chromameter are shown in Figure 5.12(b), Figure 5.12(c), Figure 5.13(b), and Figure 5.13(c). Despite of similar appearance, the lesion in Figure 5.12(a) scored lower than the lesion in Figure 5.13(a). Since the area of lesions in Figure 5.12(a) is smaller and more

scattered than those in Figure 5.13(a), dermatologists are inclined to give a lower score. Therefore, lesion in Figure 5.12(a) and Figure 5.13(a) are categorized as lesion with score 3.



(a) (b) (c)

Figure 5.12 (a) Lesion with score 2 (Δh_{ab} = 32.35488, ΔL^* = 7.73), Colour read by chromameter: (b) Lesion, (c) normal skin



(a) (b) (c)

Figure 5.13 (a) Lesion with score 3 (Δh_{ab} = 32.30569, ΔL^* = 11.8), Colour read by chromameter: (b) Lesion, (c) normal skin

Image of lesion with score 2 as indicated by red circle in Figure 5.11 is shown in Figure 5.14. Sample of lesion colour was taken from the lesions which are covered by the scales. As a result, the colour sample of this lesion does not show the actual colour of lesion beneath the scales. Thus, this lesion cannot be considered as references.

Figure 5.14 Lesion covered by scales

Once the PASI erythema scores of reference lesions have been adjusted, boundaries between lesions with different score in Δh_{ab} – ΔL^* plane can be determined. The

boundaries are perpendicular with Δh_{ab} axis and separate the nearest lesions from different score in the middle as shown in Figure 5.15.

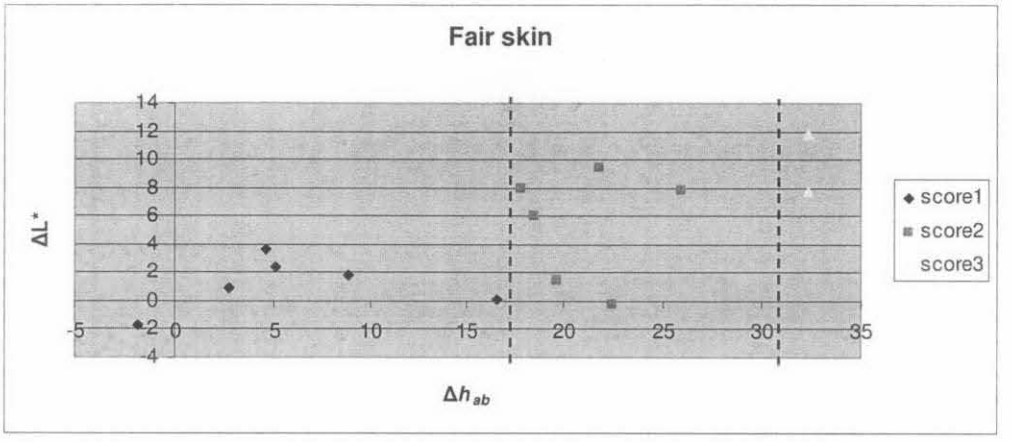


Figure 5.15 Reference lesions from fair skin group after proper adjustment

5.3.2 Brown skin group

Reference lesions of patients from brown skin group are plotted in Figure 5.16. The trend of lesion distribution in this group is similar with that in fair skin group. Image of lesion with score 2 as indicated by green circle in Figure 5.16 is shown in Figure 5.17(a). The colours of this lesion and the surrounding normal skin measured by using chromameter are shown in Figure 5.17(b) and (c) respectively. The two colours are quite similar, however large area of lesion as seen in Figure 5.17(a) seems to influence dermatologists to give a higher score. Thus, lesion in Figure 5.17(a) is categorized as lesion with score 1.

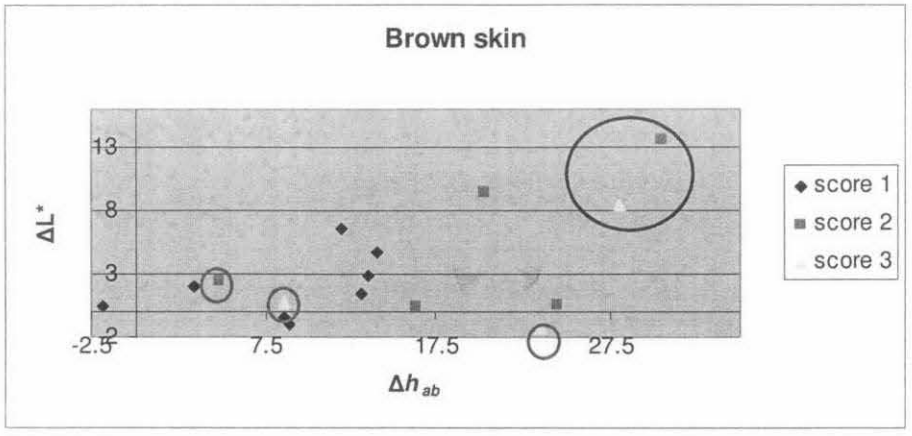
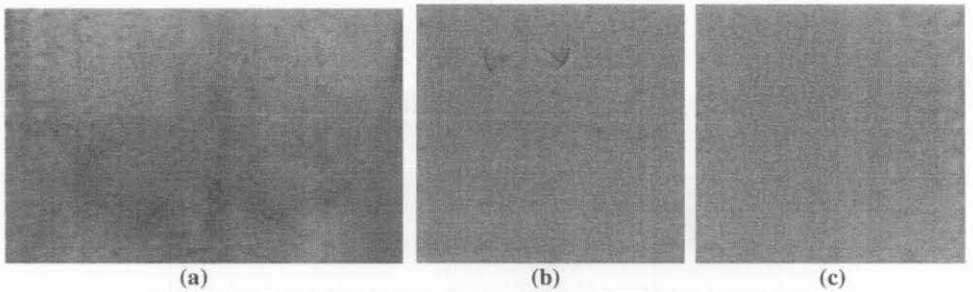


Figure 5.16 Reference lesions from brown skin group



(a) (b) (c)

Figure 5.17 (a) Lesion with score 2 (Δh_{ab} = 4.69906, ΔL* = 2.41), colour read by chromameter : (b) lesion, (c) normal skin

Images of lesion as indicated by two red circles in Figure 5.16 are shown in Figure 5.18. Samples of lesion colour were taken from the lesions which are covered by the scales. As a result, the colour samples of these lesions do not show the actual colour of lesion beneath the scales. Thus, these lesions cannot be considered as references.

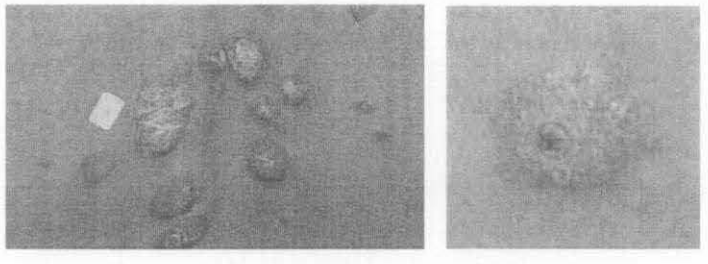


Figure 5.18 Lesions which are covered by scales

Images of lesion with score 2 and 3 as indicated by blue circle in Figure 5.16 are shown in Figure 5.19(a) and Figure 5.20(a) respectively. These two lesions are given different scores, however the Δh_{ab} and ΔL* of these two lesions are similar. By looking at the

position of the lesions in Figure 5.16, it is clear that lesion in Figure 5.19(a) is supposed to be categorized as lesion with score 3.

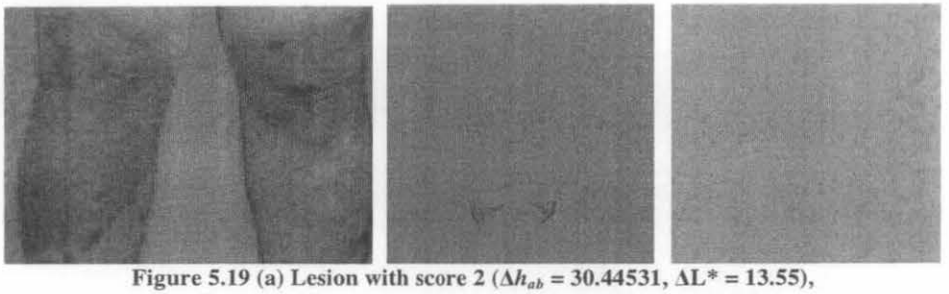


Figure 5.19 (a) Lesion with score 2 (Δh_{ab} = 30.44531, ΔL^* = 13.55), Colour read by chromameter: (b) Lesion, (c) normal skin

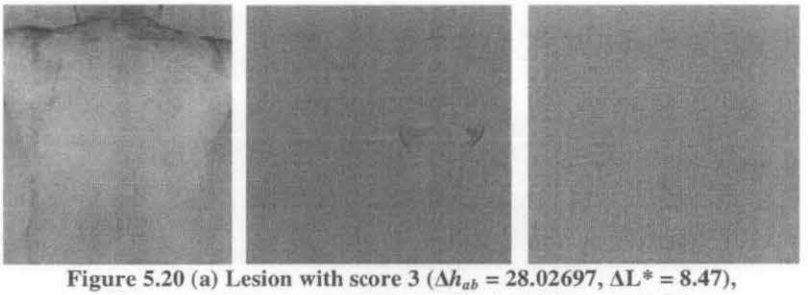


Figure 5.20 (a) Lesion with score 3 (Δh_{ab} = 28.02697, ΔL^* = 8.47), Colour read by chromameter: (b) Lesion, (c) normal skin

Boundaries between lesions with different score are indicated by black dashed line in Figure 5.21.

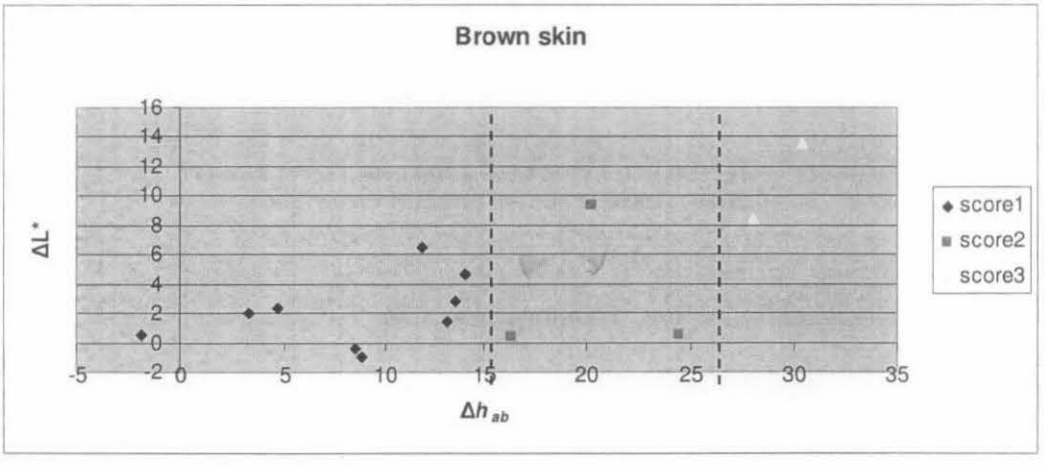


Figure 5.21 Reference lesions of brown skin group after proper adjustment

5.3.3 Dark skin group

Reference lesions of patients from dark skin group are plotted in Figure 5.22. For this group, there is no reference for lesion with score 3. The distribution of lesions with score 1 and 2 is spread in Δh_{ab} axis without any overlap. Boundaries between lesions with different score are indicated by black dashed line.

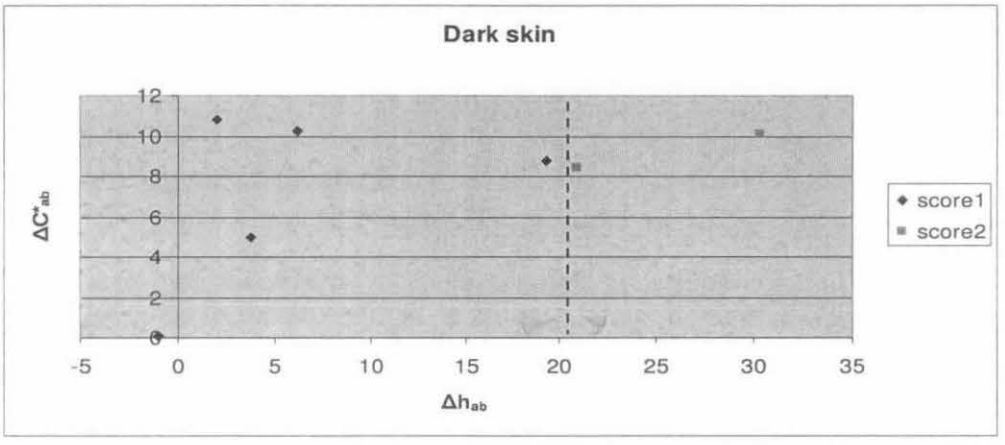


Figure 5.22 Reference lesions of dark skin group

5.3.4 Analysis

As mentioned before, the dermatologists determine PASI erythema score by comparing colour of the lesion with the surrounding normal skin. In other words, they determine the erythema score from the colour ratio of a lesion with the normal skin. High erythema score is indicated by high colour ratio. Results from the proposed method also shows that characteristics of lesion erythema from the three skin colour groups are positively linear with Δh_{ab} (refer to Figure 5.15, Figure 5.21, Figure 5.22). Therefore, PASI erythema scores of patients from the three skin colour group can be analyzed as a single dataset. Instead, the scores are organized according to the body region from where the scores are obtained. PASI erythema scores from 22 patients given by subjective (dermatologists) and objective (computer) methods are shown in Table 5.5. For each dermatologist, the average score of the 1st assessment and the 2nd assessment for each case is calculated. The average scores are used to assess the inter-observer variation. The intra-observer variations are analyzed only from the lesions which are assessed twice. The lesions

which are only assessed once are excluded from the analysis (grey shaded in Table 5.5, column Dermatologist 1 and Dermatologist 2).

Table 5.5 PASI erythema scores given by the subjective (dermatologists) and objective (computer) methods

	Dermatologist 1			Dermatologist 2			Computer
	1st assessment	2nd assessment	Average	1st assessment	2nd assessment	Average	
head	1	-	-	1	-	-	1
	1	-	-	2	-	-	2
	2	-	-	2	-	-	2
	1	-	-	1	-	-	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	2	1	1.5	2	1	1.5	2
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	2	1	1.5	1
trunk	2	-	-	2	-	-	2
	3	-	-	2	-	-	3
	2	-	-	3	-	-	2
	2	-	-	1	-	-	1
	1	-	-	1	-	-	1
	2	2	2	1	2	1.5	1
	2	2	2	2	2	2	2
	2	2	2	2	1	1.5	2
	2	2	2	2	2	2	1
	2	2	2	2	2	2	2
	3	3	3	2	3	2.5	2
	3	3	3	3	3	3	1
	3	3	3	3	3	3	2
	3	3	3	3	3	3	3
	2	2	2	2	2	2	1
	1	1	1	2	2	2	1
	4	4	4	3	3	3	2
	2	2	2	3	3	3	2
	3	3	3	2	2	2	2
	1	1	1	2	2	2	1
	2	2	2	3	2	2.5	1
arm	1	-	-	2	-	-	2
	2	-	-	1	-	-	2
	2	-	-	3	-	-	2
	2	-	-	3	-	-	2
	1	-	-	1	-	-	1
	2	-	-	2	-	-	2
	2	1	1.5	1	1	1	1
	2	2	2	1	1	1	2

	2	2	2	1	1	1	1
	2	2	2	2	1	1.5	1
	2	2	2	2	2	2	2
	3	3	3	2	3	2.5	1
	2	3	2.5	2	2	2	3
	3	2	2.5	3	2	2.5	2
	1	1	1	1	1	1	1
	2	1	1.5	2	1	1.5	1
	3	2	2.5	2	2	2	2
	2	2	2	2	2	2	2
	1	1	1	1	1	1	1
	1	1	1	2	2	2	1
	2	2	2	3	2	2.5	1
leg	2	-	-	3	-	-	3
	2	-	-	2	-	-	2
	4	-	-	2	-	-	3
	3	-	-	3	-	-	3
	1	-	-	1	-	-	1
	2	-	-	2	-	-	2
	2	2	2	2	1	1.5	1
	2	2	2	3	2	2.5	3
	3	3	3	2	2	2	2
	3	3	3	2	2	2	2
	3	3	3	2	2	2	2
	3	3	3	3	3	3	3
	2	2	2	2	2	2	2
	3	2	2.5	2	2	2	3
	3	3	3	3	2	2.5	2
	1	2	1.5	1	2	1.5	2
	1	1	1	1	2	1.5	2
	3	4	3.5	3	3	3	2
	2	2	2	2	2	2	3
	2	2	2	2	2	2	2
	1	1	1	2	1	1.5	1
	2	2	2	3	2	2.5	1

The objective method (computer) gives the same score with reference lesions except for five cases (Table 5.5, column Computer). These five lesions are already discussed in section 5.3.1 and 5.3.2.

The consistency of each dermatologist and the agreement between the two dermatologists are calculated in order to measure the intra- and inter-observer variation respectively. The consistency of each dermatologist is calculated as a ratio of the number of cases which are given the same score twice with the total number of cases. The agreement between two dermatologists is calculated as a ratio of the number of cases given the same score by the two dermatologists with the total number of cases. The agreement between a single dermatologist and the computer is calculated as a ratio of the number of cases given the same score by the dermatologist and computer with the total number of cases.

The consistencies and agreements of the two dermatologists and the computer are shown in Table 5.6.

Table 5.6 The consistencies and agreements of the two dermatologists and computer

	Consistency		Agreement		
	D1	D2	D1 & D2	D1 & C	D2 & C
Head	92.86	85.71	92.86	92.86	85.71
Trunk	100	75	43.75	43.75	25
Arm	66.67	66.67	40	40	46.67
Leg	81.25	56.25	31.25	25	37.5
Average	**85.25**	**70.49**	**50.82**	**49.18**	**47.54**

On average, the consistency of Dermatologist 1 (D1) is greater than the consistency of Dermatologist 2 (D2). It can be concluded that Dermatologist 1 is more consistent than Dermatologist 2 in giving PASI erythema score. However, this does not mean that Dermatologist 1 gives correct score more often than Dermatologist 2. The agreements between the two dermatologists (D1 & D2) range from 31.25 to 92.86 %, with the average is 50.82%. The agreement on head region is higher than the other regions. Observations of images in the dataset show that lesions that appear in the head region are similar (less variations) and are usually have less or no scales. Therefore, the dermatologists are able to assess the lesion erythema accurately. On the contrary, the lesions that appear in other body regions are more varied. In regions such as elbow, back, knees, and legs, the lesions are covered by thick scales. In these cases, the dermatologists are unable to assess the lesion erythema accurately. This difficulty causes variation between both dermatologists, thus the agreement is low (see Table 5.6, column D1 & D2).

The agreements between each dermatologist and computer (D1 & C, D2 & C) range from 25 to 92.86 %. On average, the agreement between Dermatologist 1 and computer (D1 & C) is slightly higher than the agreement between Dermatologist 2 and computer (D2 & C). This is because Dermatologist 1 has a higher consistency compared to Dermatologist 2. The agreements between each dermatologist and computer for head region are higher than the other regions (grey shaded in Table 5.6). The computer system is developed based on the references from the two dermatologists (refer to Section 5.3). As explained before, the agreement between the two dermatologists for head region is high. As a result, the agreements between each dermatologist and the computer for head region are also high.

5.4 SUMMARY

The objective assessment of psoriasis lesion area and erythema assessment for PASI scoring are applied on real data obtained from Hospital Kuala Lumpur. Objective assessment of psoriasis lesion area is applied on images that cover most of the skin surface of each patient. The main tasks are to extract region of interest (ROI) and segment psoriasis lesion from each image. In order to obtain images that cover most of the skin surface, during photography session patient only wear their underwear. For PASI scoring, underwear should not be considered as region of interest (ROI). However, in some cases the underwear is misclassified as ROI. This is due to the underwear colour is more similar with the skin colour than with the background colour. Therefore, it is suggested that patient should wear underwear with similar colour with the background.

During treatment, lesions can vanish gradually and the healed lesions usually appear darker in contrast to the healthy skin. For PASI scoring, the healed lesions are categorized as healthy skin. The proposed method was able to segment the healed lesion as healthy skin due to the colour similarity with healthy skin.

In some cases, non-lesion objects such as lips, eyes, eyebrow and nipples are misclassified as psoriasis lesion. This is due to the fact that colour of these non-lesion objects are not similar with the healthy skin colour. In order to correct this error, misclassified region should be excluded from segmented lesion images. First, the misclassified regions should be selected first by utilizing pixel neighborhood relationship. Then these regions are subtracted from the segmented lesion images.

In order to measure the performance of the proposed lesion segmentation method, the segmented images are compared with the reference segmented images. Reference segmented images are obtained by segmenting lesion area manually from the digital images. True positive rate (hit rate) and false positive rate (false alarm rate) are used to measure the performance of the proposed method. The lesion segmentation method was applied on images of 8 patients with different skin colour. For all the cases, the proposed method is able to achieve high true positive rate and low false positive rate.

The lesion area percentages and PASI area scores of 8 patients given by dermatologist, reference images, and the proposed method are compared. The lesion area percentages and PASI area scores obtained from reference images are considered as benchmark. For most of the cases, the lesion area percentages estimated by the dermatologist are significantly different from the percentages calculated from reference images. Therefore, the PASI area scores also different (18 out of 30). Only for two cases the proposed method gives different score with reference images (2 out of 30). The error occurs due to some lesions are covered by scales which occupy the same region as normal skin in hue-chroma space. These lesions are misclassified as normal skin.

The data from 22 patients are used in developing objective assessment of psoriasis lesion erythema. The patients are categorized into three groups according to their skin colour, namely fair skin, brown skin, and dark skin groups. Ten patients are classified into fair skin group, eight patients are classified into brown skin group, and four patients are classified into dark skin group.

For each skin colour group, reference lesions are obtained from two dermatologists. Reference lesions are the lesions which are given the same PASI erythema scores by the two dermatologists. The ΔL^*, Δh_{ab}, ΔC^*_{ab} between reference lesions and the surrounding normal skin are calculated. Discrimination coefficient is calculated to determine the suitability of the three above features in discriminating lesions with different erythema scores. It is found that Δh_{ab} and ΔL^* are the most discriminative features for fair and brown skin group whereas Δh_{ab} and ΔC^*_{ab} are the most discriminative features for dark skin group. These two most discriminative features are used in assessing the erythema score of reference lesions for each skin colour group. It is found that the erythema score of a lesion can be distinguished by their Δh_{ab} value within a particular skin type group.

PASI erythema scores obtained from the proposed method are compared with the scores from the two dermatologists. It is found that each dermatologist is inconsistent in giving the scores (intra-observer variation). The variation of lesion appearance causes variation between both detmatologists (inter-observer variation) in giving the scores. Therefore, the agreement between the two dermatologists in giving the scores is also low (50.82 %). Therefore, objective method is required to assess the erythema of psoriasis lesion. The proposed method has the potential to assess erythema objectively and consistently

without being influenced by other characteristic of the lesion such as area, pattern, and boundary.

CHAPTER 6: CONCLUSIONS

Objective assessment of area and erythema of psoriasis 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 DISCUSSION

Psoriasis is a chronic inflammatory skin disease which affects people worldwide, regardless of age, sex and ethnicity. Although there is currently no cure for psoriasis, there are a number of treatments available that can clear psoriasis symptoms for a period of time. During treatment, dermatologist will monitor the extent of psoriasis continuously to ascertain the treatment efficacy [Pariser, 2003]. The current gold standard method for assessing the extent of psoriasis is Psoriasis Area and Severity Index (PASI). PASI assesses four body regions, the head, trunk, upper extremities and lower extremities. Each body regions are weighted differently to reflect their respective proportion of body surface area (BSA). For each region, the surface area affected, redness, thickness and scaliness of the plaques are determined [Fredriksson and Petterson, 1978].

Although PASI is the gold standard for evaluating the extent of psoriasis, it is not used in daily practice [Feldman and Krueger, 2005]. Determining PASI score is a tedious task. Commonly, the four parameters are visually determined and may result in inter-individual and intra-individual variations, even by experienced dermatologists. These variations were observed during the course of this research in particular in the assessment of psorasis area and erythema scores. The objective of this research is to develop a digital image analysis system to assess digital images and colourimetry data of psoriasis lesion for the determination of PASI parameters in particular, the affected area and erythema. The type of psoriasis lesion which is being analyzed for this work is plaque psoriasis, since it is the most common form (80%) of psoriasis lesion. The affected area of the lesion is determined based on digital images of the four body regions, the head, trunk, upper extremities and lower extremities. The erythema of lesions for each body region is analyzed based on colour measurement obtained from a chromameter.

Consistency of digital image quality is essential for monitoring 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.

Segmentation of region of interest (ROI) which consist of normal skin and psoriasis lesion is done by applying Otsu's threshold method on a* band images. Based on PASI standard, pelvis region should not be included as ROI. During image acquisition process, patients are required to cover pelvis area. However, the colour of the cloth covering the pelvis is not standardized. Cloth which has similar colour with background is segmented as background whereas that which has similar colour with skin is segmented as ROI. Therefore, in order to obtain correct segmentation, cloth colour should be the same or similar with the background colour.

Psoriasis can appear in a wide variety of colours. However, psoriasis lesion can be recognized by its colour dissimilarity with normal skin. The CIELAB colour space is widely used to measure dissimilarity between two colours [Sharma, 2004]. Colour dissimilarity is represented by colour difference in CIELAB colour space. The colour difference between two similar colours is small and vice versa. Due to human visual system in discriminating colour, each pixel in CIELAB colour space can be represented by its lightness (L^*), hue (h_{ab}), and chroma (C_{ab}). The L^* is excluded from colour difference formula in order to minimize the difference between exposed and unexposed normal skin. Therefore, colour difference between psoriasis lesion and normal skin is analyzed in hue-chroma plane of CIELAB colour space. Initially, centroids of normal skin and lesion in hue-chroma space are calculated from selected samples which are segmented manually from each image, giving equal amount of pixels. Euclidean distances between all pixels with these two centroids are calculated. Each pixel is assigned to the class of the nearest centroid. This technique can segment the lesion from normal skin properly.

In some cases, non-lesion objects such as lips, eyes, eyebrow and nipples are misclassified as psoriasis lesion. This is due to the colour of these non-lesion objects are

not similar with the colour of normal skin. In order to obtain correct segmentation, the misclassified objects should be excluded from the segmented image. By utilizing pixel neighbourhood relationship, misclassified objects can be selected and then subtracted from the segmented image.

During treatment, lesions can vanish gradually and the healed lesion usually appears darker in contrast to the normal skin. For PASI scoring, the healed lesions are categorized as normal skin. Colour difference between normal skin and healed lesion is smaller than the colour difference between normal skin and lesion. Therefore, the proposed method is able to segment the healed lesion as normal skin due to smaller colour difference.

The performance of the lesion segmentation method is determined by comparing segmented images with reference segmented images. Reference segmented images are obtained by manually segmenting lesion area from the digital images. True positive rate (hit rate) and false positive rate (false alarm rate) are used to measure the performance of the proposed method. The lesion segmentation method was applied on images of 8 patients which consist of 3 patients with fair skin colour, 3 patients with brown skin colour, and 2 patients with dark skin colour. For all the cases, the proposed segmentation method achieves high true positive rate and low false positive rate. The proposed method gives the same PASI area score as reference (28 of 30 cases). The error occurs due to some lesions are covered by scales which occupy the same region as normal skin in hue-chroma space. These lesions are misclassified as normal skin.

The erythema of psoriasis lesion is affected by degree of severity and its original skin colour. The skin colour is related to the degree of skin pigmentation. Low, medium, and high pigmented skins are indicated by fair, brown, and dark skin colours respectively. From observation on the dataset, there are 3 typical appearances of psoriasis lesion (refer to Figure 4.21). It can be noticed that the appearance of the lesion is related to the skin colour. The colour of lesions on patients with fair skin colour is red whereas that on patients with dark skin colour is dark purplish. The colour of lesions on patients with brown skin colour is dark red. Therefore, it is required to group the patients according to their skin pigmentation level in order to assess the erythema objectively. By grouping the patients, bias in measuring erythema due to the skin colour can be eliminated. The L*

value of normal skin which represents skin pigmentation level is utilized to group the patient into the three skin types namely fair, brown and dark skin types.

For each skin types, reference lesions are obtained from two dermatologists. Reference lesions are the lesions which are given the same PASI erythema score by the two dermatologists. By analyzing the lightness difference, ΔL^*, hue difference, Δh_{ab}, and chroma difference, ΔC^*_{ab} between reference lesions and the surrounding normal skin, it is found that the erythema score of a lesion can be accurately determined by the hue difference, Δh_{ab} value within a particular skin type group. The higher scores are indicated by the higher Δh_{ab} value. The PASI erythema scores of 22 patients given by the proposed method are compared with the scores given by the two dermatologists. It is found that each dermatologist is inconsistent in giving the scores (intra-observer variation). The variation of lesion appearance causes variation between both detmatologists (inter-observer variation) in giving the scores. Therefore, the agreement between the two dermatologists in giving the scores is also low (50.82 %). Therefore, objective method is required to assess the erythema of psoriasis lesion. Since the proposed method uses chromameter in measuring the lesion colour, it has the potential to assess erythema objectively and consistently without being influenced by other characteristic of the lesion such as area, pattern, and boundary.

Colour measurement of psoriasis lesion by using chromameter should be carried out properly. During colour measurement, the chromameter probe is placed on the lesion surface. The chromameter measures the average colour of the lesion which is covered by the probe. Therefore, the size of the lesion should be larger than the size of chromameter probe (Ø = 8mm). Otherwise, the chromameter will measure the average colour of lesion and the surrounding normal skin. In order to obtain the actual lesion colour, measurement should be done on the lesion which is not covered by scales.

6.2 CONTRIBUTION AND FUTURE WORKS

The main contribution of this thesis is in the development of a system that is able to determine two parameters of PASI score objectively, namely the affected area and erythema. The developed system can be applied on patient with various skin colours and has the potential to minimize variations of PASI score due to inter- and intra-observer.

Many research works have been conducted with the aim to assess lesion area of psoriasis objectively. However, most of them only assess small area of human body. The methods also suffer from the appearance of shadows and specular reflectance. The areas of shadow and reflectance are misclassified as lesion area. An initial study on calculating percentage of psoriasis lesion on human body has been done (Paper 1 in List of Publications). 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. Chroma differences between all pixels with the normal skin sample pixels are calculated. Otsu's thresholding method is applied on histogram of the chroma differences in order to classify all pixels into normal skin and lesion region.

Psoriasis can appear in a wide variety of colours. It is affected by original colour of normal skin and extent of psoriasis lesion. However, psoriasis lesion can be recognized by its colour dissimilarity with normal skin. Hue and chroma of CIELAB are analyzed in order to classify all pixels into normal skin and lesion region (Paper 2). Centroids of normal skin and psoriasis in the hue-chroma space 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. The study involves patients from three different ethnic origins having different skin tones. Results obtained show that the proposed method is comparable to the dermatologist visual approach. However, centroids of normal skin and psoriasis lesion in hue-chroma plane must be calculated for each patient (local centroids). The possibilities of using global centroids to segment psoriasis lesion has been observed (Paper 3). Patients are grouped according to their skin complexion (fair, medium, and dark). For each group, the centroids of four body regions (head, trunk, arm, and leg) are calculated from normal skin and lesion samples of all patients in the group. Results obtained show that the segmentation using global centroids are comparable with using local thresholding.

As has been discussed, non-lesion objects such as lips, eyebrows, eyes, and nipples are misclassified as psoriasis lesion. For future work, in order to improve the accuracy of lesion segmentation method, these objects can be classified as normal skin manually.

This can be done by selecting regions containing these objects manually from the image before segmentation. These regions are then classified as normal skin.

An initial work on modelling colour of psoriasis lesion has been done. The colour of psoriasis lesion is modeled by hue (H), saturation (S), and value (V) of HSV colour space (Paper 4). Correlation coefficient between HSV parameters of lesion references with PASI erythema score is calculated. Among the three parameters, hue and saturation are the two most correlated parameters with PASI erythema scores (Paper 5). Since colour of psoriasis lesion is also affected by colour of the normal skin, skin pigmentation level is incorporated in determining erythema level of a lesion. Patients are grouped according to their skin pigmentation level (high, medium, and high) and analyzed within particular skin pigmentation group. Therefore, the proposed method can be used on patients with any skin pigmentation levels. The erythema level is determined by comparing colour of psoriasis lesions with the surrounding normal skin. Reference lesions obtained from two dermatologists are used in developing the system in order to minimize intra- and inter-observation variation (Paper 6).

In determining PASI erythema score, the threshold value of hue for each skin colour group is derived from the reference lesions. However, in this work there are only small numbers of reference lesion for patient from dark skin group. A larger number of reference lesions are required in order to obtain more accurate threshold value.

REFERENCES

B. E. Bayer (1976). Color Imaging Array. U. S. Patent. 3,971,065.

B. L. Benamati (2001). In the Search of the Ultimate Image Sensor. Photonics Spectra.

G. J. Braun, M. D. Fairchild and F. Ebner (1998). Color Gamut Mapping in a Hue-Linearized CIELAB Color Space. IS&T/SID 6th Color Imaging Conference, Scottsdale.

M. A. Cimmino (2007). "Epidemiology of psoriasis and psoriatic arthritis." Reumatismo 59: 19-24.

C. A. Curcio, K. R. Sloan, R. E. Kalina and A. E. Hendrickson (1990). "Human photoreceptor topography." The Journal of Comparative Neurology 292: 497-523.

P. DeMarco, J. Pokorny and V. C. Smith (1992). "Full-spectrum cone sensitivity functions for X-chromosome-linked anomalous trichromats." Journal of the Optical Society of America 9: 465-1476.

B. L. Diffey, R. J. Oliver and P. M. Farr (1984). "A portable instrument for quantifying erythema induced by ultraviolet radiation." British Journal of Dermatology 111(6): 663–672.

L. J. Draaijers, F. R. H. Tempelmana, Y. A. M. Botmanb, R. W. Kreis, E. Middelkoop and P. P. M. v. Zuijlen (2004). "Colour evaluation in scars: tristimulus colorimeter, narrow-band simple reflectance meter or subjective evaluation?" Burns 30: 103-107.

R. O. Duda, P. E. Hart and D. G. Stock (2001). Pattern Classification. Canada, John Wiley & Sons, Inc.

T. Fawcett (2006). "An introduction to ROC analysis." Pattern Recognition Letters 27: 861-874.

S. R. Feldman and G. G. Krueger (2005). "Psoriasis assessment tools in clinical trials." Annals of the Rheumatic Diseases 64: 65-68.

T. Fredriksson and U. Petterson (1978). "Severe psoriasis--oral therapy with a new retinoid." Dermatologica 157: 238-244.

L. Fry (2004). An Atlas of Psoriasis. London, Taylor and Francis.

A. Fullerton, T. Fischer, A. Lahti, K. -P.Wilhelm, H. Takiwaki and J. Serup (1996). "Guidelines for measurement of skin colour and erythema." Contact Dermatitis 35: 1-10.

E. J. Giorgianni and T. E. Madden (1998). Digital Color Management:Encoding Solutions. Massachusetts, Addison Wesley Longman, Inc.

D. D. Gomez, J. M. Carstensen, B. Ersboll, L. Skov and B. Bang (2003). Building an Image-Based System to Automatically Score Psoriasis. Proceedings of the 13th Scandinavian Conference in Image Analysis: 557-564.

D. D. Gomez, B. Ersboll and J. M. Carstensen (2004). Automatic Scoring of the Severity of Psoriasis Scaling. Proceedings of the Irish Machine Vision and Image Processing Conference: 204-209.

K. B. Gordon and E. M. Ruderman (2005). Psoriasis and Psoriatic Arthritis, An Integrated Approach. Berlin, Springer-Verlag.

I. Guyon and A. e. Elisseeff (2003). "An introduction to Variable and Feature Selection." Journal of Machine Learning Research 3: 1157-1182.

A. Horsch (2006). Picture of Health: Advances in Medical Image Processing. Patient Care.

http://dpreview.com/.

R. Jailani, H. Hashim and M. N. Taib (2005). Normalization Techniques for Psoriasis Skin Lesion Analysis. Asian Conference on Sensors and The International Conference on New Techniques in Pharmaceutical and Biomedical Research Kuala Lumpur, Malaysia.

R. Jailani, H. Hashim, M. N. Taib and S. Sulaiman (2004). Border Segmentation on Digitized Psoriasis Skin Lesion Images. Proceedings of the 2004 IEEE Region 10 Conference. 3: 596- 599.

A. K. Jain, M. N. Murty and P. J. Flynn (1999). "Data Clustering : A Review." ACM Computing Surveys 31(3): 264-323.

A. Lahti, H. Kopola, A. Harila, R. Myllylii and M. Hannuksela (1993). "Assessment of skin erythema by eye, laser Doppler flowmeter, spectroradiometer, two-channel erythema meter and Minolta chroma meter." Archives of Dermatological Research 285: 278-282.

H.-C. Lee (2005). Introduction to Color Imaging Science. New York, Cambridge University Press.

D. L. MacAdam (1942). "Visual sensitivities to color differences in daylight." Journal of the Optical Society of America 32: 247.

I. Maglogiannis and D. I. Kosmopoulos (2003). "A system for the acquisition of reproducible digital skin lesions images." Technology and Health Care 11(6): 425–441.

G. Maletti, B. Ersboll and K. Conradsen (2005). "A combined alignment and registration scheme of lesions with psoriasis." Information Sciences 175: 141–159.

T. Markiewicz and S. Osowski (2006). Data mining techniques for feature selection in blood cell recognition. European Symposium on Artificial Neural Networks, Bruges, Belgium.

A. L. Neimann, S. B. Porter and J. M. Gelfand (2006). "The Epidemiology of Psoriasis." Expert Review of Dermatology 1(1): 63-75.

T. Numahara (2001). "From the Standpoint of Dermatology." Digital Color Imaging in Biomedicine: 67-72.

Y. Ohno (2000). CIE Fundamentals for Color Measurements. IS&T NIP16 Conference: 540-545.

N. Otsu (1979). "A Threshold Selection Method from Gray-Level Histograms." IEEE Transactions on Systems, Man, and Cybernetics 9: 62-66.

D. M. Pariser (2003). "Management of Moderate to Severe Plaque Psoriasis With Biologic Therapy." Managed Care 12: 36-44.

D. Pascale (2003). A Review of RGB Color Spaces from xyY to R'G'B'. Montreal, Canada, The BabelColor Company.

C. Peterson (2001). "How It Works: The Charged-Coupled Device, or CCD." Journal of Young Investigators(1).

K. N. Plataniotis and A. N. Venetsanopoulos (2000). Color Image Processing and Applications. Berlin, Springer-Verlag.

PsoriasisNet. (2007). "http://www.skincarephysicians.com/psoriasisnet/."

J. Roning, R. Jacques and J. Kontinen (1999). Area Assessment of Psoriatic Lesions based on Variable Thresholding and Subimage Classification. Proceedings of the Vision Interface'99: 303-311.

S. J. Sangwine and R. E. N. Horne (1998). The Colour Image Processing Handbook. Cambridge, Chapman & Hall.

J. Serup and T. Agner (1990). "Colorimetetric quantification of erythema -- a comparison of two colorimeters (Lange Micro Color and Minolta Chroma Meter CR-200) with a clinical scoring scheme and laser-Doppler flowmetry." Clinical and Experimental Dermatology 15: 267-272.

A. Sharma (2004). Understanding Color Management. New York, Thomson Delmar Learning.

A. I. Shihab (2000). Fuzzy Clustering Algorithms and Their Application to Medical Image Analysis. Department of Computing. London, University of London. Doctor of Philosophy.

M. D. Shriver and E. J. Parra (2000). "Comparison of Narrow-Band Reflectance Spectroscopy and Tristimulus Colorimetry for Measurements of Skin and Hair Color in Persons of Different Biological Ancestry." American Journal of Physical Anthropology 112: 17-27.

H. Takiwaki and J. Serup (1994). "Measurement of color parameters of psoriatic plaques by narrow-band reflectance spectrophotometry and tristimulus colorimetry." Skin Pharmacol 7: 145-150.

J. S. Taur (2003). "Neuro-Fuzzy Approach to the segmentation of Psoriasis Images." Journal of VLSI Signal Processing 35: 19 - 27.

J. S. Taur, C. W. Tao, C. C. Chen and C. W. Yang (2002). Segmentation of Psoriasis Vulgaris Images Using Orthogonal Subspace Techniques. The Seventh Conference on Artificial Intelligence and Applications: 667-671.

M. A. Vega-Rodríguez, J. M. Sánchez-Pérez and J. A. Gómez-Pulido (2005). "Recent advances in computer vision and image processing using reconfigurable hardware." Microprocessors and Microsystems 29(8-9): 359-362

A. Webb (1999). Statistical Pattern Recognition. New York, Arnold.

L. Xu, M. Jackowski, A. Goshtasby, D. Roseman, S. Bines, C. Yu, A. Dhawan and A. Huntley (1999). "Segmentation of skin cancer images." Image and Vision Computing 17: 65-74.

G. C. Zografos, K. Martis and D. L. Morris (1992). "Laser Doppler flowmetry in evaluation of cutaneous wound blood flow using various suturing techniques." Annals of Surgery 215(3): 266-268.

List of Publications

1. Dani Ihtatho, M. H. Ahmad Fadzil, M. A. Azura, H. H. Suraiya, "Area Assessment of Psoriasis Lesion for PASI Scoring" Proceeding of the International Conference on Biotechnology Engineering 2007 (ICBioE'07) p751-757, Kuala Lumpur, Malaysia

2. Dani Ihtatho, M. H. Ahmad Fadzil, M. A. Azura, H. H. Suraiya, "Area Assessment of Psoriasis Lesion for PASI Scoring" Proceeding of the 29th Annual International Conference of the IEEE EMBS 2007 p3446-3449, Lyon, France

3. Dani Ihtatho, M. H. Ahmad Fadzil, M. A. Azura, H. H. Suraiya, "Automatic PASI Area Scoring" Proceeding of the International Conference on Intelligent and Advanced Systems 2007 (ICIAS2007), Kuala Lumpur, Malaysia.

4. Dani Ihtatho, M. H. Ahmad Fadzil, " Modeling Psoriasis Lesion Colour for PASI Erythema Scoring" Proceeding of the National Postgraduate Conference on Engineering, Science, and Technology 2008 (NPC2008), Tronoh, Malaysia

5. M. H. Ahmad Fadzil, Dani Ihtatho, " Modeling Psoriasis Lesion Colour for PASI Erythema Scoring" accepted at the 3rd International Symposium on Information Technology 2008, Kuala Lumpur, Malaysia.

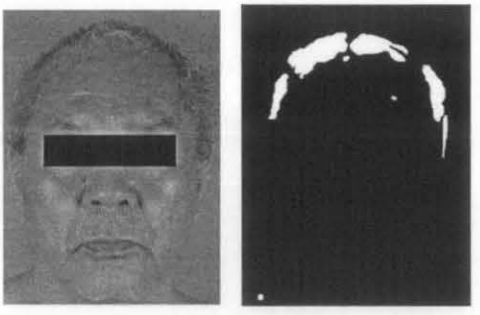
6. M. H. Ahmad Fadzil, Dani Ihtatho, " Objective Assessment of Psoriasis Erythema for PASI Scoring" accepted at the 30th Annual International Conference of the IEEE EMBS 2008, Vancouver, Canada.

APPENDIX A

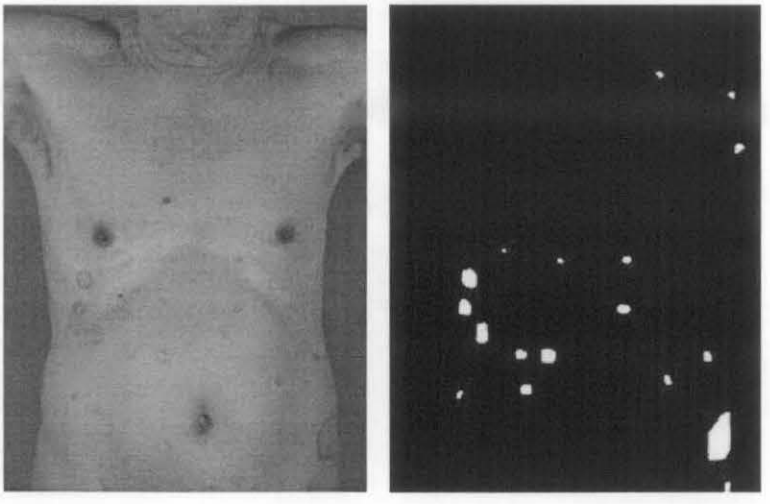
ORIGINAL AND REFERENCE IMAGES FOR LESION AREA SEGMENTATION

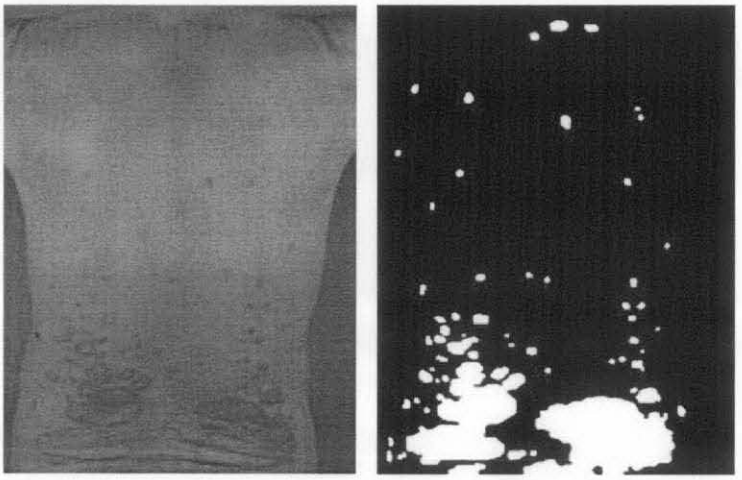
The rest of the images are available in the CD.

Patient from fair skin group

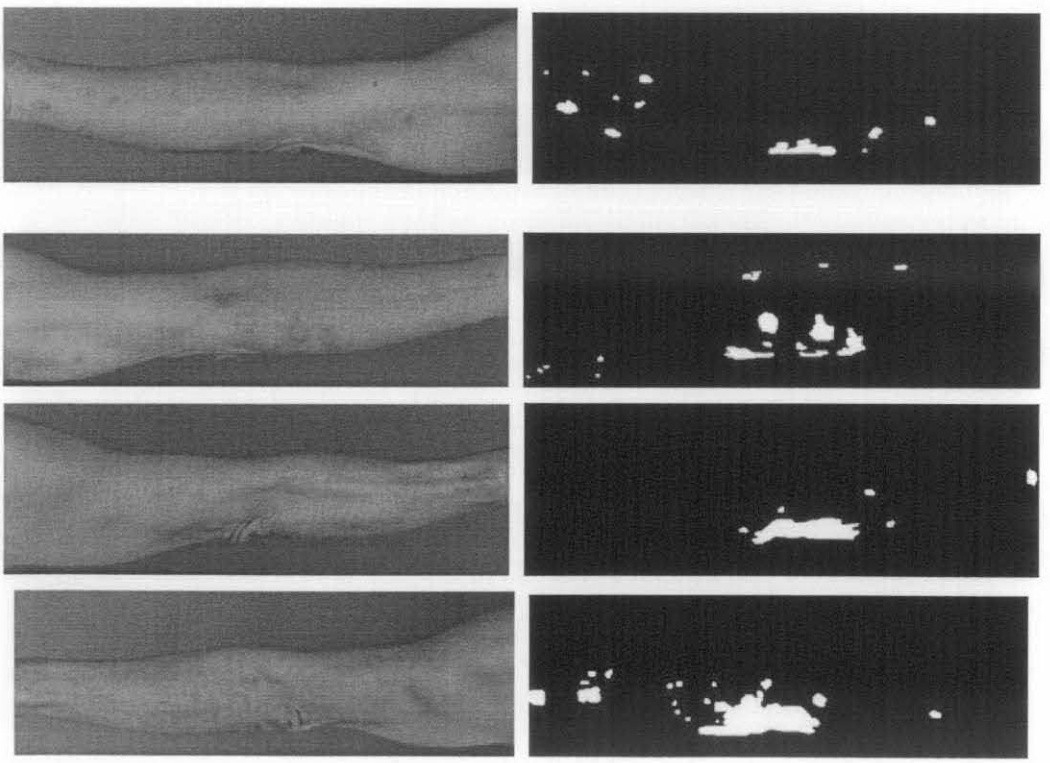


(a) Head region

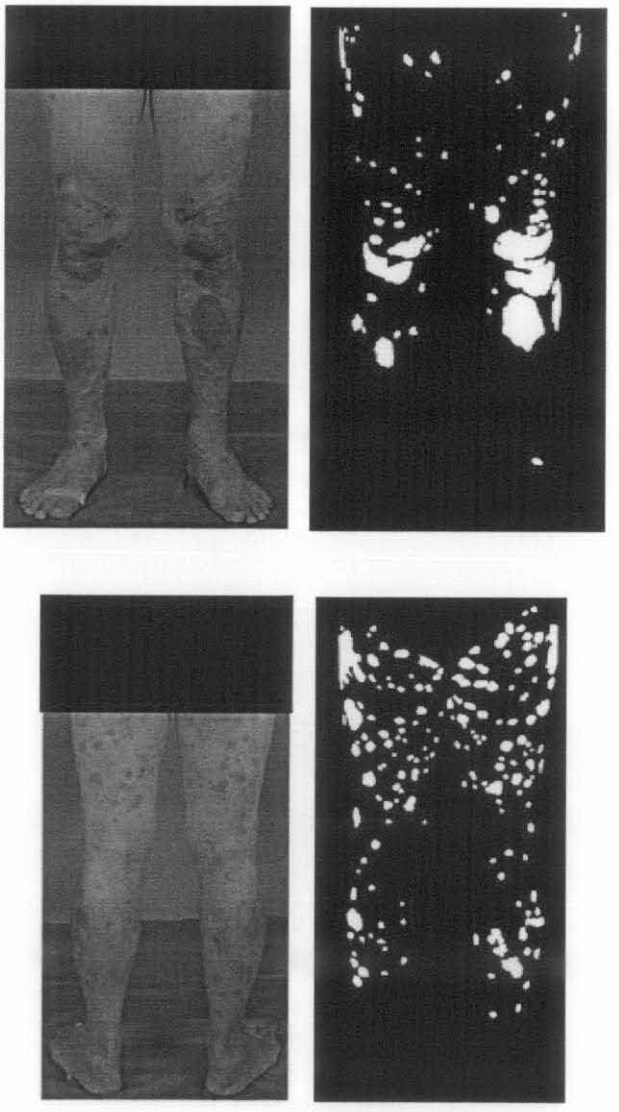




(b) Trunk region

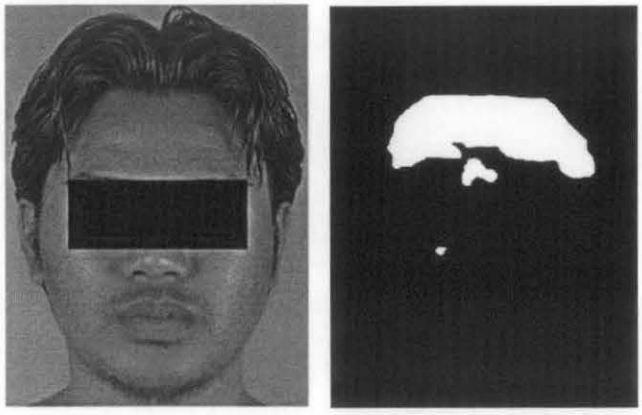


(c) Upper extremities region

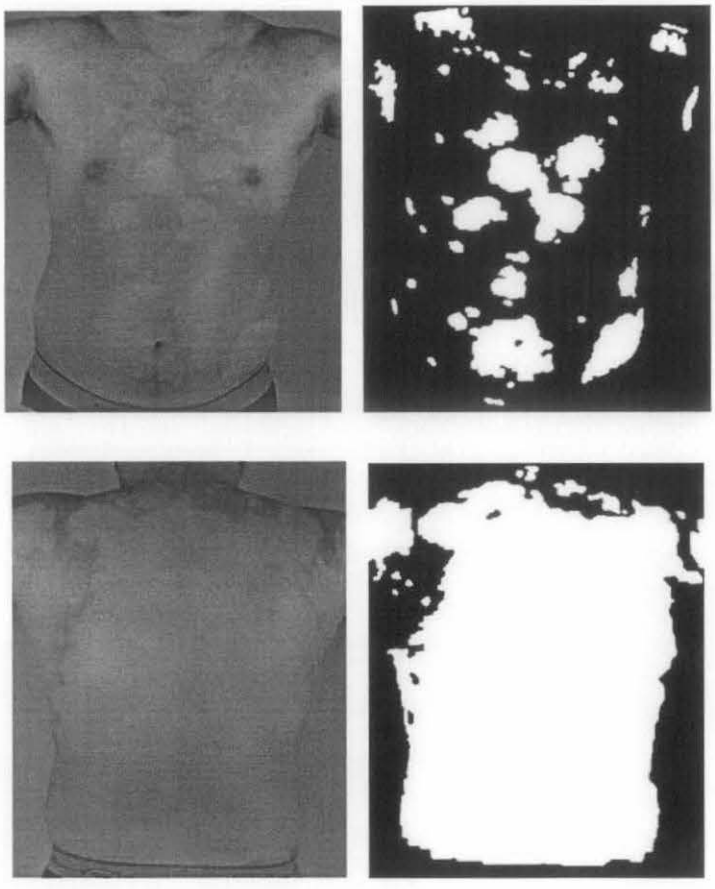


(d) Lower extremities region

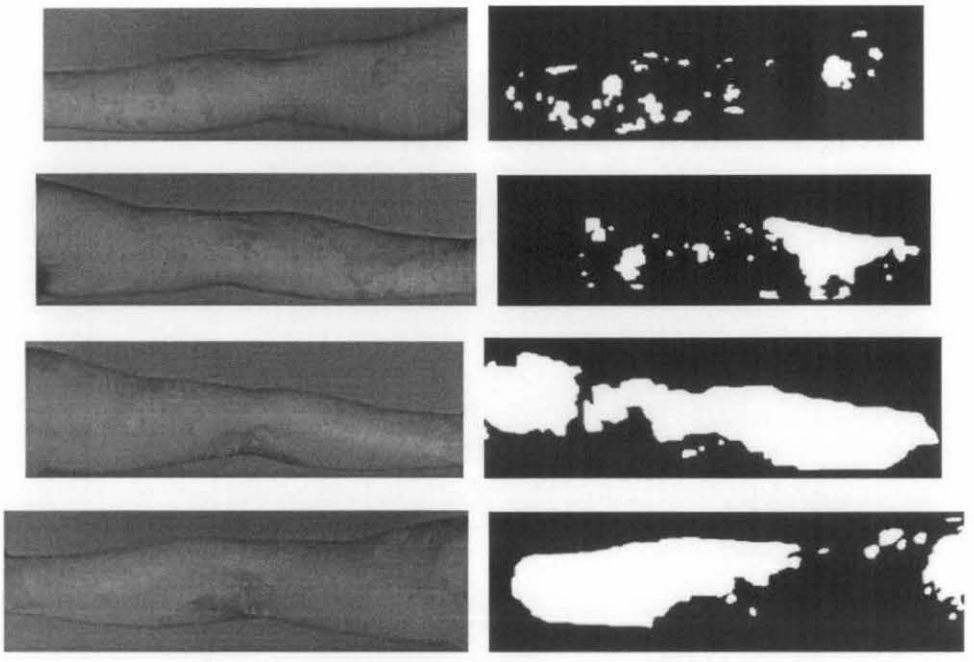
Patient from brown skin group



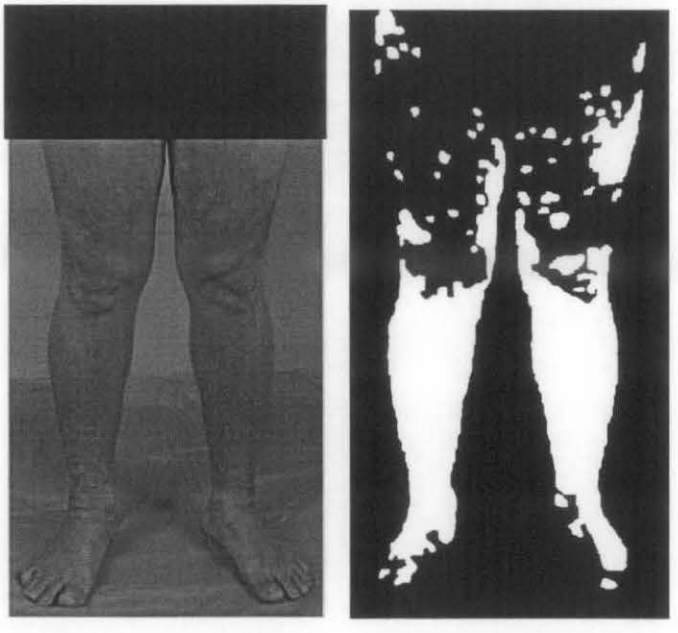
(a) Head region

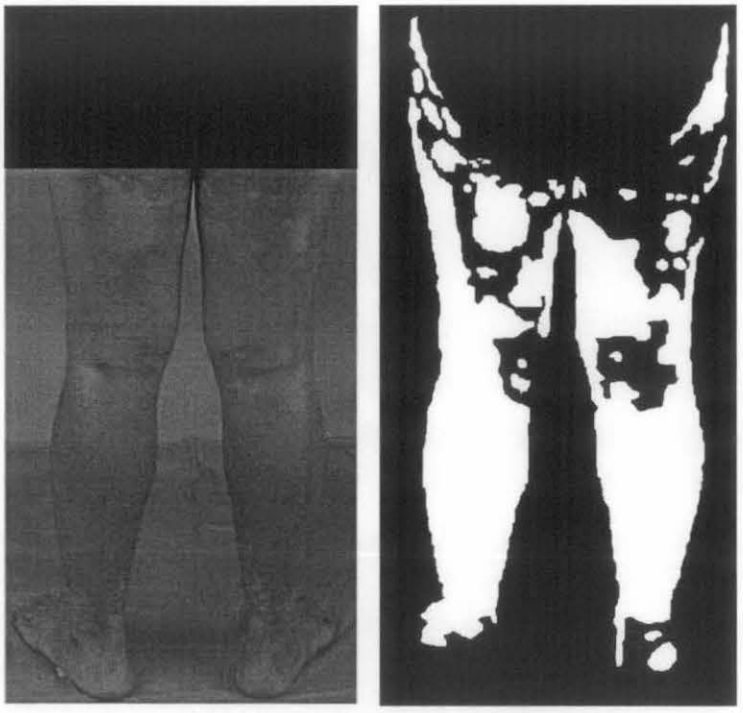


(b) Trunk region



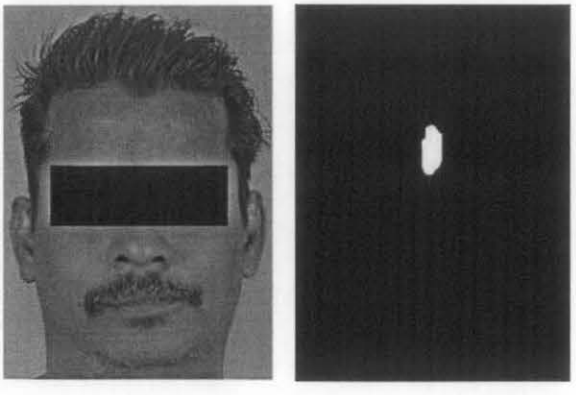
(c) Upper extremities region



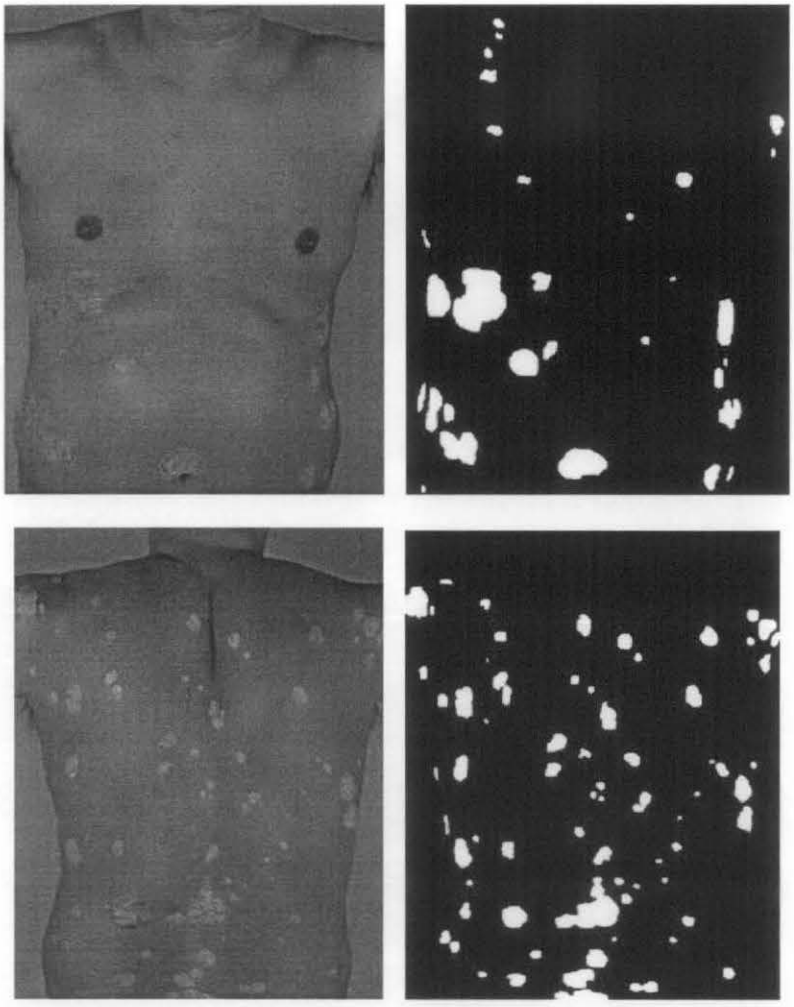


(d) Lower extremities region

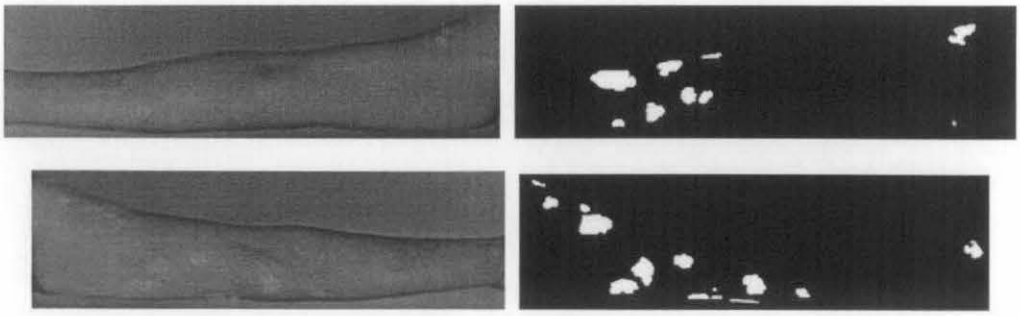
Patient from dark skin group

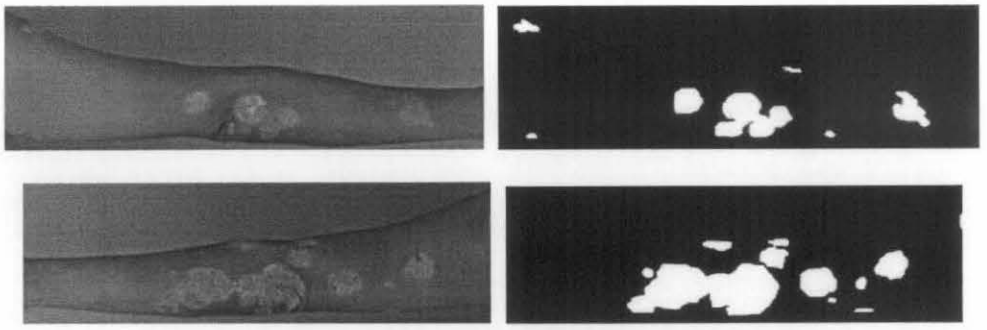


(a) Head region

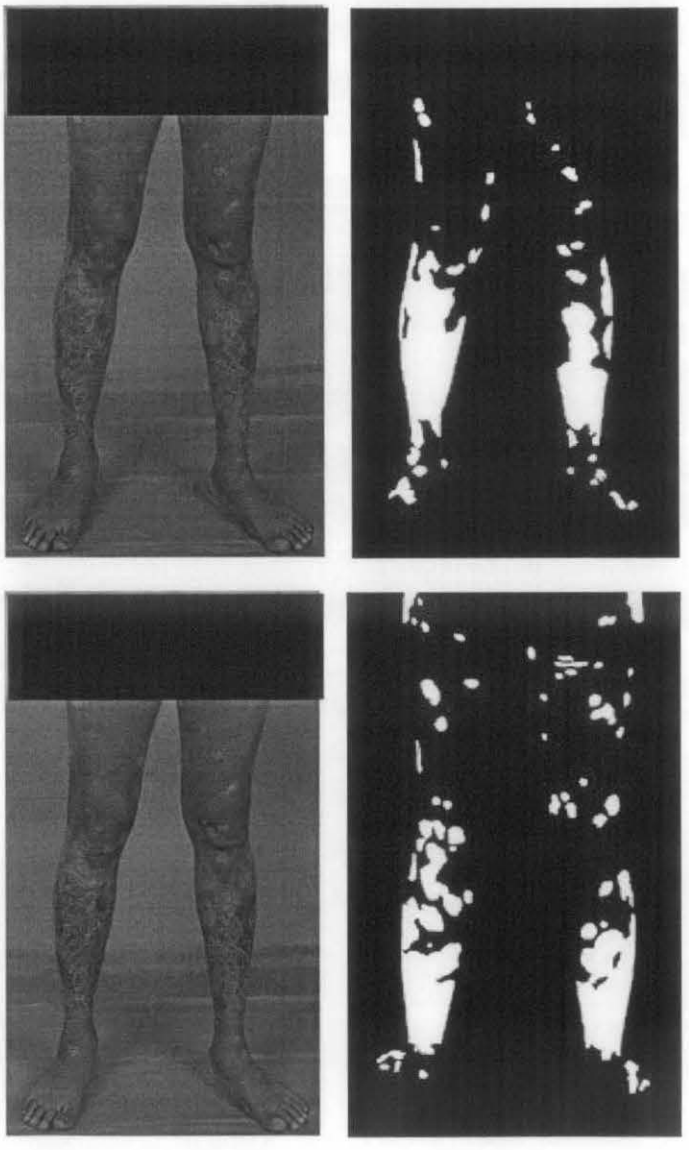


(b) Trunk region





(c) Upper extremities region



(d) Lower extremities region

APPENDIX B

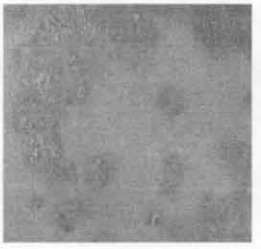
IMAGES OF PSORIASIS LESION FOR ERYTHEMA ASSESSMENT

The rest of the images are available in the CD.

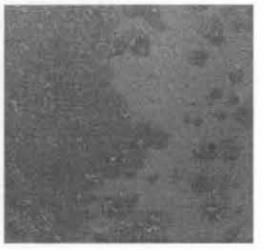
Patient from fair skin group

Head region

Trunk region



Upper extremities region



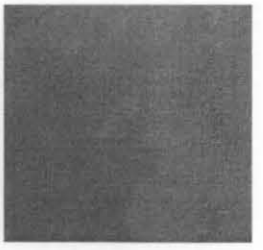
Lower extremities region

Patient from brown skin group

Head region

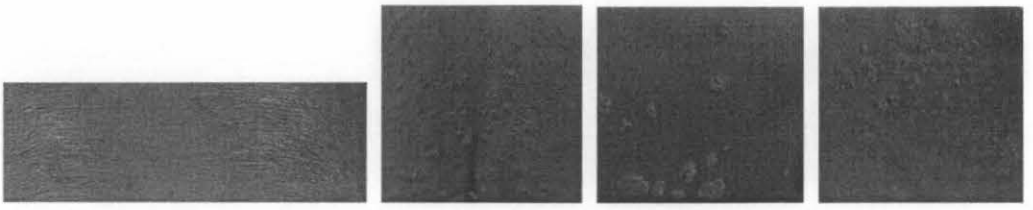
Trunk region

Upper extremities region



Lower extremities region

Patient from brown skin group



Head region | **Trunk region** | **Upper extremities region** | **Lower extremities region**

APPENDIX C

THE LIGHTNESS DIFFERENCE (ΔL*), HUE DIFFERENCE (Δh_{ab}), AND CHROMA DIFFERENCE (ΔC^*_{ab}) OF LESIONS FROM FAIR SKIN GROUP

Patient	Body region	ΔL*	Δh_{ab}	ΔC^*_{ab}
1	Upper extremities	3.47	24.30	1.19
	Lower extremities	7.97	32.33	2.14
2	Head	-1.70	-1.83	0.80
	Trunk	7.86	25.97	-5.22
	Upper extremities	0.39	12.93	-1.90
	Lower extremities	7.50	21.61	-6.40
3	Head	6.29	21.01	-4.53
	Trunk	11.95	35.91	-5.35
	Upper extremities	6.69	19.30	-1.85
	Lower extremities	9.83	32.34	-10.47
4	Head	1.43	19.67	5.84
	Trunk	5.98	29.83	2.33
	Upper extremities	1.04	24.88	2.34
	Lower extremities	7.73	32.35	0.48
5	Head	2.36	5.15	0.14
	Trunk	7.21	13.87	3.19
	Upper extremities	0.92	12.54	0.50
	Lower extremities	5.98	6.00	-2.44
6	Head	0.91	2.72	-0.28
	Trunk	6.06	18.47	8.53
	Upper extremities	9.32	23.08	2.94
	Lower extremities	9.41	33.04	2.51
7	Trunk	18.17	27.61	-0.21
	Upper extremities	2.72	14.08	-1.11
	Lower extremities	7.02	20.78	-7.15
8	Head	0.13	16.57	0.77
	Trunk	0.74	16.29	1.48
	Lower extremities	8.08	28.08	-2.69
9	Head	-1.70	-1.83	0.80
	Trunk	7.86	25.97	-5.22
	Upper extremities	0.39	12.93	-1.90
	Lower extremities	7.50	21.61	-6.40
10	Head	3.62	4.61	-1.30
	Trunk	13.08	26.44	-9.33
	Upper extremities	-0.21	22.48	-0.66
	Lower extremities	11.80	32.31	-4.89

APPENDIX D

THE LIGHTNESS DIFFERENCE (ΔL*), HUE DIFFERENCE (Δh_{ab}), AND CHROMA DIFFERENCE (ΔC^*_{ab}) OF LESIONS FROM BROWN SKIN GROUP

Patient	Body region	ΔL*	Δh_{ab}	ΔC^*_{ab}
1	Head	2.01	3.32	2.24
	Trunk	0.78	8.57	10.34
	Upper extremities	-3.31	5.65	8.37
	Lower extremities	0.41	16.29	9.26
2	Head	0.50	-1.85	-0.09
	Trunk	-1.28	23.50	9.23
	Upper extremities	0.93	40.46	7.63
	Lower extremities	6.58	32.54	6.30
3	Head	1.22	18.79	0.53
	Trunk	8.47	28.03	1.14
	Upper extremities	-1.26	21.45	0.04
	Lower extremities	-3.07	17.56	-2.48
4	Head	-0.95	8.86	4.31
	Trunk	2.41	4.70	3.09
	Upper extremities	6.51	11.88	8.40
	Lower extremities	8.61	20.51	5.45
5	Head	-0.36	8.53	1.82
	Trunk	3.67	12.52	2.67
	Upper extremities	-0.68	10.09	0.69
	Lower extremities	12.11	19.86	4.84
6	Trunk	5.40	26.01	0.33
	Upper extremities	1.82	22.57	0.43
	Lower extremities	-0.42	25.75	0.01
7	Head	1.43	13.09	5.13
	Trunk	5.33	22.77	4.71
	Upper extremities	0.50	24.45	1.38
	Lower extremities	13.55	30.45	-2.52
8	Head	4.70	14.03	2.18
	Trunk	3.81	16.05	2.15
	Upper extremities	2.82	13.51	2.20
	Lower extremities	9.39	20.25	-1.32

APPENDIX E

THE LIGHTNESS DIFFERENCE (ΔL*), HUE DIFFERENCE (Δh_{ab}), AND CHROMA DIFFERENCE (ΔC^{*}_{ab}) OF LESIONS FROM DARK SKIN GROUP

Patient	Body region	ΔL*	Δh_{ab}	ΔC^{*}_{ab}
1	Head	-0.55	-0.96	0.05
	Trunk	7.16	14.33	11.73
	Upper extremities	4.92	2.01	10.83
	Lower extremities	8.12	6.15	10.22
2	Trunk	0.06	19.32	8.77
	Upper extremities	3.11	20.85	8.42
	Lower extremities	5.02	30.35	10.11
3	Head	4.22	3.80	4.99
	Trunk	-1.17	17.72	7.71
	Upper extremities	-1.19	16.80	6.79
	Lower extremities	0.42	8.25	8.86
4	Head	-2.89	-1.14	-1.44
	Trunk	-0.53	1.85	13.34
	Upper extremities	2.94	5.87	6.18
	Lower extremities	12.44	2.02	15.52

APPENDIX F

MATLAB CODE FOR LESION SEGMENTATION

```
clear
clc
% centroid of healthy skin
cx1 = 59; cy1 = 34;
% centroid of lesion
cx2 = 36; cy2 = 28;
% calculate the nearest distance
gbr = imread('1.jpg');                    % read original image
rgbkelab = makecform('srgb2lab');
lab_uint = applycform(gbr,rgbkelab);
lab_dbl = lab2double(lab_uint);
L = round(lab_dbl(:,:,1));
a = lab_dbl(:,:,2);
b = lab_dbl(:,:,3);
[baris,kolom] = size(L);
satu = ones(baris,kolom);
%=========================================
a_uint = lab_uint(:,:,2);
level = graythresh(a_uint);
kulit = im2bw(a_uint,level);
kulit = imfill(kulit,'holes');
kulit_asli = kulit;
%=========================================
idx_roi = find(kulit == 1);
L_roi = L(idx_roi);

min_L_roi = min(L_roi);
mean_L_roi = mean(L_roi);
max_L_roi = max(L_roi);

jarak_min = abs(L_roi - min_L_roi);
jarak_mean = abs(L_roi - mean_L_roi);
jarak_max = abs(L_roi - max_L_roi);

deket_min = min(jarak_min,jarak_mean);
deket_max = min(jarak_max,jarak_mean);

idx_item = find(jarak_min == deket_min);
idx_item = idx_roi(idx_item);
idx_putih = find(jarak_max == deket_max);
idx_putih = idx_roi(idx_putih);

gbr_item = zeros(baris,kolom);
gbr_item(idx_item) = 1;
gbr_putih = zeros(baris,kolom);
gbr_putih(idx_putih) = 1;

kulit = kulit - gbr_item - gbr_putih;
kulit = bwareaopen(kulit,10000,8);
idx_kulit = find(kulit == 1);
idx_bg = find(kulit == 0);
```

```
%=========================================
chroma = round(sqrt(a.^2 + b.^2));
chroma = round(chroma);

n_kulit = size(idx_kulit,1);
hue = zeros(baris,kolom);
for i = 1:n_kulit
    if (a(idx_kulit(i)) == 0) & (b(idx_kulit(i)) == 0)
        hue(idx_kulit(i)) = 0;
    elseif (a(idx_kulit(i)) == 0) & (b(idx_kulit(i)) > 0)
        hue(idx_kulit(i)) = 90;
    elseif (a(idx_kulit(i)) == 0) & (b(idx_kulit(i)) < 0)
        hue(idx_kulit(i)) = -90;
    elseif (a(idx_kulit(i)) < 0) & (b(idx_kulit(i)) < 0)
        hue(idx_kulit(i)) = atand(abs(b(idx_kulit(i))./a(idx_kulit(i))))
- 180;     % 3rd quadrant
    elseif (a(idx_kulit(i)) > 0) & (b(idx_kulit(i)) < 0)
        hue(idx_kulit(i)) = 0 -
atand(abs(b(idx_kulit(i))./a(idx_kulit(i))));      % 4th quadrant
    elseif (a(idx_kulit(i)) < 0) & (b(idx_kulit(i)) > 0)
        hue(idx_kulit(i)) = 180 -
atand(abs(b(idx_kulit(i))./a(idx_kulit(i))));       %2nd quadran
    else
        hue(idx_kulit(i)) =
atand(abs(b(idx_kulit(i))./a(idx_kulit(i))));            %1st quadran
    end
end
hue = round(hue);

%=========================================
hue_kulit = hue(idx_kulit);
chroma_kulit = chroma(idx_kulit);
%=========================================
jarak_hue1 = (hue_kulit - cx1).^2;
jarak_chroma1 = (chroma_kulit - cy1).^2;
jarak1 = sqrt(jarak_hue1 + jarak_chroma1);

jarak_hue2 = (hue_kulit - cx2).^2;
jarak_chroma2 = (chroma_kulit - cy2).^2;
jarak2 = sqrt(jarak_hue2 + jarak_chroma2);

deket = min(jarak1,jarak2);
idx_deket1 = find(jarak1 == deket);
idx_deket1 = idx_kulit(idx_deket1);
idx_deket2 = find(jarak2 == deket);
idx_deket2 = idx_kulit(idx_deket2);
hasil1 = zeros(baris,kolom);
hasil1(idx_deket1) = 1;
hasil2 = zeros(baris,kolom);
hasil2(idx_deket2) = 1;
artifact = bwselect(hasil2,8);
bw_akhir = hasil2 - artifact;
AreaLuka = sum(sum(bw_akhir))
AreaKulit = sum(sum(kulit_asli))

persen = (AreaLuka/AreaKulit)*100

figure,imshow(bw_akhir)
```

```
% =============
% CALCULATE ROC
% =============
ref = imread('1ref.jpg');            % read reference image
ref_bw = im2bw(ref);
AreaLukaRef = sum(sum(ref_bw));
%
temp = and(bw_akhir,ref_bw);          % true positive
tp = sum(sum(temp))
kulit_sehat = xor(kulit_asli,ref_bw);

bw_sehat = xor(satu,bw_akhir);
bw_sehat = and(bw_sehat,kulit_asli);
temp = and(kulit_sehat,bw_sehat);
tn = sum(sum(temp))                   % true negative
ROI = sum(sum(kulit_asli))
accuracy = ((tp+tn)/(ROI))*100
```