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Extraction and quantification of morphological and spectral features for improving the diagnostic accuracy of skin pathologies

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Abstract

Melanoma is one of the most often diagnosed cancers and fatal form of skin cancer. However, early detection can offer many effective treatment options. Clinical diagnosis and prognosis of melanoma is a field which remains a challenge for researchers. The study explains in detail the approaches involved for skin cancer diagnostic methods. One of the widely used methods to recognize the skin pathologies and distinguish the melanoma from normal skin is the ABCD Rule.

Specifically, this study proposes methods based on ABCD Rule, regarding the pre-processing of the input image, skin lesion segmentation and classification of nevus and malignant skin lesions and the extraction and quantification of morphological and spectral features of lesions. To implement this system, a code is performed in MATLAB environment for evaluating the four criteria **Asymmetry (A), Border (B), Color (C) and Diameter (D)** of a skin lesion. The obtaining features followed by the ABCD Rule are processed by calculating Total Dermoscopic Score (TDS) for detection benign and malignant skin lesions.

In this study, we deal also with a new type of optical imaging technology, hyperspectral imaging (HSI). As an emerging modality HSI holds great potential for objective cancer assessment and it is a noninvasive high-resolution imaging technique that assists researchers in making more accurate and objective diagnosis of skin cancers. We examine hyperspectral images over the spectral range of 400-880nm and obtain information about melanin content for the differentiation of various skin diseases and detect features such as border irregularity, asymmetry and diameter in different wavelengths, to categorize the images as melanoma or nonmelanoma.

In the end of this study, we quote the results which indicate whether our proposed approach is accurate and efficient in the segmentation of the lesion boundary and in the extraction of features of skin lesions and discuss the conclusions extracted for possible future work.

Chapter 1

Introduction about image techniques, image analysis and methods for diagnosing melanomas

Chapter 2

Information about the theoretical background of spectroscopy, spectral imaging, light spectrum and skin structure.

Chapter 3

This chapter presents the pre-processing stage which consists of techniques are used to ensure the segmentation of the lesion area and the healthy skin. This stage includes also the removal of artifacts and extraneous elements.

Chapter 4

This chapter provides information about segmentation stage and its methods.

Chapter 5

In this chapter we propose methods for skin lesion detection and feature extraction based on ABCD rule.

Chapter 6

In this chapter we analyze the results obtained from ABCD algorithm and give an outline of Classification methods. This chapter consists also the analysis of skin lesions in a different wavelength range and contain diagnostic information about skin's tissue pathology based on ABCD rule.

Chapter 7

In this chapter we discuss the conclusions that extracted and the possible future research directions on the problem.

Chapter 1

1. Introduction

Skin cancer is a common type of cancer that emerges from the skin and can be classified into melanoma and non-melanoma. Melanoma is the deadliest form of skin cancer affecting the human skin and can spread throughout the layers of the skin and spread to other parts of the body and may cause death. It arises from cancerous growth in pigmented skin area and progresses from the pigment-containing cells known as melanocytes. In the last few decades, the incidence of melanoma has increased significantly due to environmental factors, especially among white-skinned people who are exposed to the sun. More specifically, UV radiation causes unrepaired DNA damage to skin cells and finally can lead to skin cancer. As we read in a study from UK, about 86 percent of melanomas can be attributed to exposure to ultraviolet (UV) radiation from the sun.

Anyone can develop skin cancer, but some people who burn more easily can have a higher risk. Malignant melanoma is considered one of the most fatal forms of human skin cancers, which led to a raised mortality rate, because of its ability to spread widely to other parts of the body. According to reports, melanoma is considered the seventh most common malignancy in women and the sixth most common in men. Nevertheless, it is also the most treatable type of skin cancer if detected or diagnosed at an early stage. Approximately 197,700 cases of melanoma will be diagnosed in the U.S only in 2022. Of those, 97,920 cases will be noninvasive, restricted to the epidermis and 99,780 cases will be invasive, penetrating the epidermis into the skin's second layer. [5]

Melanoma detection is a crucial topic and several diagnostic systems have been proposed for this goal. In fact many researchers have been working on the image processing and have proposed computer vision techniques for skin cancer detection. One of the dermatologist's most popular imaging techniques is dermoscopy. The structure of the skin lesion becomes more visible for examination by magnifying the affected area. Dermoscopy can be a very useful tool to recognize whether a lesion is benign or malignant and can also recognize skin pathologies. Dermatologists can analyze the images in order to detect initial skin lesions and features that can observe in the skin lesions for early detection and effective treatment. Skin cancer is divided into three types : Melanoma, Basal Cell Carcinoma (BCC) and Squamous-cell carcinoma (SCC). BCC and SCC are less common in skin cancer and are known as nonmelanoma skin cancer. More specifically, BCC shows slow growth and damage on the surrounding tissues but doesn't lead to death . SCC is present as hard lump with a scaly top with scaly crusts and may form an ulcer. Melanoma can be recognized easily since it appears on the skin's surface. However, it is difficult for dermatologists to differentiate it from benign skin lesions. The main difference between them is that benign lesions cannot spread into additional tumors and they have a more structured structure than malignant ones. It is also important to refer that researchers are becoming increasingly concerned with this field since, some benign lesions can develop into melanoma. [4]

Image processing is a technique to extract useful information from images and can be implemented in early detection of melanoma by analyzing the features of images. One of the widely used methods to recognize the skin pathologies and distinguish the melanoma from normal skin is the ABCD rule . The choice of this rule is based on dermatology criteria: color, shape, irregularities and symmetry . As we found on studies, ABCD rule is very useful for skin moles with concerning changes including an increase in size, irregular edges, and change in color, itchiness, or skin breakdown. ABCD rule is also a reliable method which provides an objective and reproducible diagnosis of melanoma. Although, several approaches have been proposed to differentiate benign melanocytic lesions from malignant melanoma such as seven-point checklist, three-point checklist,

CASH algorithm and Menzies method. These methods are used to identify whether suspicious lesions might be melanoma and it is crucial for pathologists to make the final diagnosis. According to literature, some clinical photos can't be a reliable tool which provides an objective and diagnosis of melanoma since imaging conditions are usually not standardized. Low resolution, diverse lighting conditions and the presence of artifacts such as thick hairs , dots, bubbles , skin lines can affect the final result. [25]

1.1 Image Analysis

Image Analysis of melanoma has four different steps. Preprocessing Stage, Segmentation, Feature Extraction and classification. Each step has its difficulties and there are several methods in melanoma disease diagnosis which have been seen to evolve swiftly in recent years. In preprocessing Stage images are preparing for the main processing stage and for feature extraction. The segmentation of dermoscopic structures and the distinction between lesions type in dermoscopic images are considered one of the challenging issues, due to the containing of several artifacts such as uneven illumination or lightening reflection, hair, and presence of noise. Furthermore, the low contrast between the lesion and its surrounding skin, and the variegated coloring inside the affected lesion. The feature extraction is based on procedures employed by dermatologists in clinical routine diagnosis such as ABCD Rule and finally last step is classification. This part tries to answer whether a skin lesion is benign or malignant.

1.2 Thesis purpose

Our purpose is to extract and quantify the morphological and spectral features for improving the diagnostic accuracy of skin pathologies and the diagnosis of cutaneous melanomas. The morphological features studied are those of the ABCD (Asymmetry, Border, Color, Diameter) rule . ABCD rule was developed to facilitate the differentiation between benign and malignant melanocytic lesions according to the features of each image. Expert clinicians look for the presence of exclusive visual features to diagnose skin lesions correctly so we developed a method which had the following functions:

- The processing of the image and quantification of its morphological features
- The categorization of the risk of the image based on its characteristics in order to facilitate case management for the doctor and to inform the patient immediately.

To implement this system, a code is performed in MATLAB environment utilizing Image Processing Toolbox. Image Processing Toolbox provides a set of functions and applications for image processing, analysis, and visualization.

The discrete steps followed to process each image are as follows:

1. Pre-processing of the input image and removal of reflection artifacts and hairs from given images.

2. The segmentation of the image into two regions: that of the lesion and that of the remaining skin.

3. The calculation of the morphological characteristics of the lesion.

4. Classification

The second part of our study presents the important role of dermoscopy in the diagnosis of skin cancer. Purpose of this part is to extract the spectral features of images over the spectral range of 400-880nm and

provide crucial information for many clinical features of skin lesions such as asymmetry, color variegation, diameter and border irregularity in different wavelengths. In consequence we try to revisit the ABCD criteria with an analysis of the features of pigmented skin lesions s from UV to near-infrared spectral bands.

1.3 Methods for diagnosing Melanomas

Dermatologists use several medical diagnosis methods in order to diagnose melanoma skin cancer and other skin pathologies. Some of these methods are: 3-point checklist, 7-point checklist, Menzies method and ABCD rule.

1.3.1 3-point checklist

The three-point checklist was initially developed for non-experts as a skin cancer screening tool. The main purpose of it is to define whether the lesion being examined had to undergo a biopsy or not. It is also characterized for its high sensitivity for the diagnosis of melanoma in the hands of non-experts and thus can be very useful for the early detection of melanoma. According to this checklist, skin lesion has a high probability of malignancy if there are any two of the dermoscopic features, including:

- Asymmetry : Asymmetry of color and structures in one or two perpendicular axes. The contour or the shape of the lesion does not affect the result whether the lesion is defined as symmetric or not.
- Blue-white structures: Any type of blue and/or white colour, combination of bluewhite veil and regression structures
- Atypical network :Pigment network with thick lines and irregular holes.

This skin cancer tool is easy to learn and allow non-experts not to miss detection of melanomas. However, it is not a reliable method with specific features which can help dermatologists to provide an objective second opinion. [5]

1.3.2 7-point checklist

7-point checklist published in 1998 and represents one of the most and latest validated dermoscopic algorithms due to its high sensitivity and specificity, also when used by non-experts. It focuses on seven dermoscopic features in the pigmented skin lesion, which are divided into two groups: major and minor criteria. A skin lesion is considered to be melanoma according to 7-point checklist if there is a minimum total score of 3 criteria. The major criteria have score of 2 points and the minor criteria have 1 point as score. The major criteria are: blue-whitish veil, atypical pigment network and atypical vascular pattern. The minor criteria are: irregular pigmentation, radial or irregular streaks, globules and irregular spots, and regression patterns. To sum up, at least three or more dermoscopic criteria must be present in the skin lesion to classified as malignant melanoma and the lesion is classified as normal mole or nevus if a total score of less than three criteria is given. As we read in literature, the 7-point checklist is considered among the algorithms with the best sensitivity for the non-expert investigators. [12]

1.3.3 Menzies Method

The Menzies method is based on 11 features which are scored as present or absent for the purpose of distinguishing melanocytic lesions. These features are divided into two groups : negative and positive. For a melanoma to be diagnosed, none of the two “negative features” should be found and at least 1 of the 9 “positive features” must be present.

Negative Features: Symmetry of Pigmentation Pattern and existence of a single color. The first feature consists of the symmetry of all pattern structures including color along any axis through the center of the skin lesion. As usually happens, the feature which make a skin lesion to classified as benign skin lesion is the presence of symmetry of the pigmentation pattern. When it comes to the second feature, presence of a single color is used to define the lesions as benign.

Positive Features: blue-whitish veil, multiple brown dots, pseudopods, radiated streaks, scar-like depigmentation, black dots and globules in the periphery of the lesion, multiple different colors (5 or 6), multiple blue-grey dots, and enlarged pigmentary network. These characteristics are utilized to determine the skin lesion as melanoma.

The existence of more than one single color and asymmetry in pattern are enough to make a skin lesion suspicious of melanoma . Suspect lesions displaying any of the 9 positive features for melanoma are considered to be melanoma unless proved otherwise. Menzies Method has been repeatedly shown to have the highest sensitivity for the diagnosis of melanoma compared to other published methods and has also a positive impact on the diagnosis of melanoma with small diameter. [14]

The main purpose of all proposed methods above is to distinguish the healthy skin lesion from the malignant melanomas. Even though these algorithms are easy tools, the are not always a reliable and objective way for a diagnosis. As we will see below, there are many difficulties when it comes to morphological characteristics of images. Nevertheless, the value of such methods is proven, since a trained dermatologist in conjunction with an assistive computer system based on these algorithms can provide a conclusion and detect early skin pathologies or a melanoma.

Chapter 2

Spectral features

2.Theoretical Background

As we already refer skin cancer is one of the most serious health problems which can be outfaced with early detection. On the other hand, with late diagnosis melanoma doesn't respond to treatment and can lead to death. Since early diagnosis is a such an important field of research, non-invasive imaging tools, such as dermoscopy have emerged and developed in recent years. These tools assist the screening process and boost diagnostic accuracy.

Spectral range of given images: 400 – 880nm

2.1 Imaging

Imaging is the science and technology of acquiring spatial and temporal data information from objects for the purpose of obtaining information. At this time, digital imaging is the most advanced and applicable method where data are recorded using a digital camera, such as a charged coupled device (CCD). The use of imaging in dermatological diagnosis is currently a very rapidly growing branch of medicine and computer science.

2.2 Spectroscopy

Spectroscopy is the study of the absorption and emission of light and other radiation by matter. Matter is comprised of atoms and empty space. It involves the splitting of light (or more precisely electromagnetic radiation) into its constituent wavelengths (a spectrum), which is done in much the same way as a prism splits light into a rainbow of colors. Recently, the definition of spectroscopy has been expanded to also include the study of the interactions between particles such as electrons, protons, and ions, as well as their interaction with other particles as a function of their collision energy.] Optical techniques are widely used for detection of early changes in human skin. Optical spectroscopy is another technology that is being established to aid in skin lesion diagnosis.

2.3 Spectometry

Spectrometry is the measurement of the interactions between light and matter, and the reactions and measurements of radiation intensity and wavelength. In other words, spectrometry is a method of studying and measuring a specific spectrum, and it's widely used for the spectroscopic analysis of sample materials. Essentially, spectrometry is the application of spectroscopy. Spectrometers measure the the wavelength and frequency of light, and allows us to identify and analyse the atoms in a sample we place within it. Light is passed from a source (which has been made incandescent through heating) to a diffraction grating (much like an artificial Fraunhofer line) and onto a mirror. As the light emitted by the original source is characteristic of its atomic composure, diffracting and mirroring first disperses, then reflects, the wavelength into a format that we can detect and quantify. [35]

2.4 Spectral Imaging (SI)

Spectral imaging combines spectroscopy and imaging. Each of these fields is well developed and is being used intensively in many fields including the life sciences. The combination of these two is, however, not trivial, mainly because it requires creating a three-dimensional (3D) data set that contains many images of the same object, where each one of them is measured at a different wavelength. This sort of data are known as Spectral Cubes. So, a spectral cube consists of the three dimensional projection of a great number of consecutive and registered sets of spectral images Specifically whereas imaging provides the intensity at every pixel of the image, I(x,y), a typical spectrometer provides a single spectrum, I(λ), so , a spectral image provides a spectrum at each pixel, I(x,y,λ). Over the years, different techniques have been applied, creating categories of Spectral Imaging: Multispectral Imaging and Hyperspectral Imaging. Spectral Imaging divided according to its spectral resolution, number of bands and how narrow the bands are, width, and contiguousness of bands. [35,36]

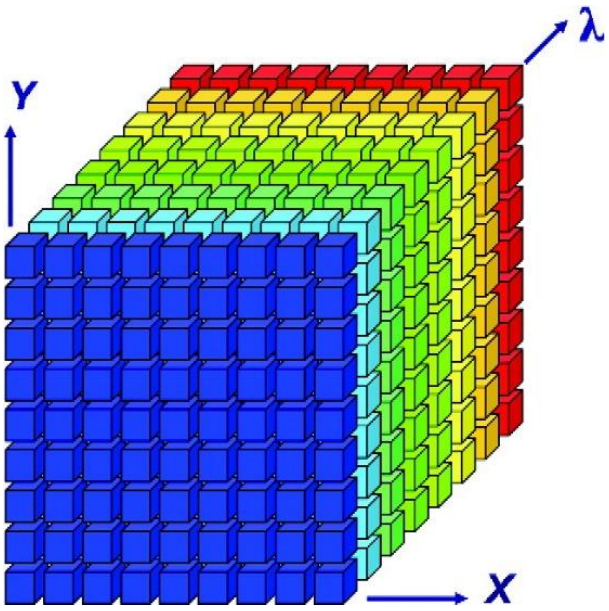


Fig 1.[36]

Description of a spectral image data set. Each point in the cube represents a single number and the spectral image is described as I(x,y,λ). It can be viewed either as an image I(x,y) at each wavelength λ, or as a spectrum I(λ) at every pixel (x,y).

2.5 Hyperspectral Imaging

Hyperspectral imaging (HSI) is a technique that analyzes a wide spectrum of light instead of just assigning primary colors (red, green, blue) to each pixel. The light striking each pixel is broken down into many different spectral bands in order to provide more information on what is imaged. The algorithms and the image processing methodologies associated with HSI are a product of military research, and were primarily used to identify targets and other objects against background clutter. In HSI, the unique color signature of an individual object can be detected. Unlike other optical technologies that can only scan for a single color, HSI is able to distinguish the full color spectrum in each pixel. [42]

2.6 Spectral Reflectance

Spectral Reflectance is the measure of the wavelength of the electromagnetic energy reflected from a surface in a given waveband to the energy incident in that waveband. The reflectance properties of an object depend on the material and its physical and chemical state, the surface roughness as well as the geometric circumstances (e.g. incidence angle of the sunlight).

2.7 Electromagnetic Spectrum

Electromagnetic spectrum is the entire distribution of electromagnetic radiation according to frequency f or wavelength λ. The electromagnetic spectrum comprises the span of all electromagnetic radiation and consists of many subranges, commonly referred to as portions, such as visible light or ultraviolet radiation. The entire electromagnetic spectrum, from the lowest to the highest frequency (longest to shortest wavelength), includes all radio waves , infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays. Nearly all frequencies and wavelengths of electromagnetic radiation can be used for spectroscopy. [37]

2.8 Visible Spectrum

The visible light spectrum is the section of the electromagnetic radiation spectrum that is visible to the human eye. A small portion of the electromagnetic spectrum, wavelengths from approximately 400 to 700 nm, is visible by human eyes. The spectrum of visible light is usually divided into three channels: red, green, and blue. Electromagnetic radiations with shorter wavelengths than visible are called ultraviolet (UV), X-rays or gamma rays progressively. Electromagnetic radiations with longer wavelengths than visible are called near infrared (NIR), microwaves or radio waves progressively. [38]

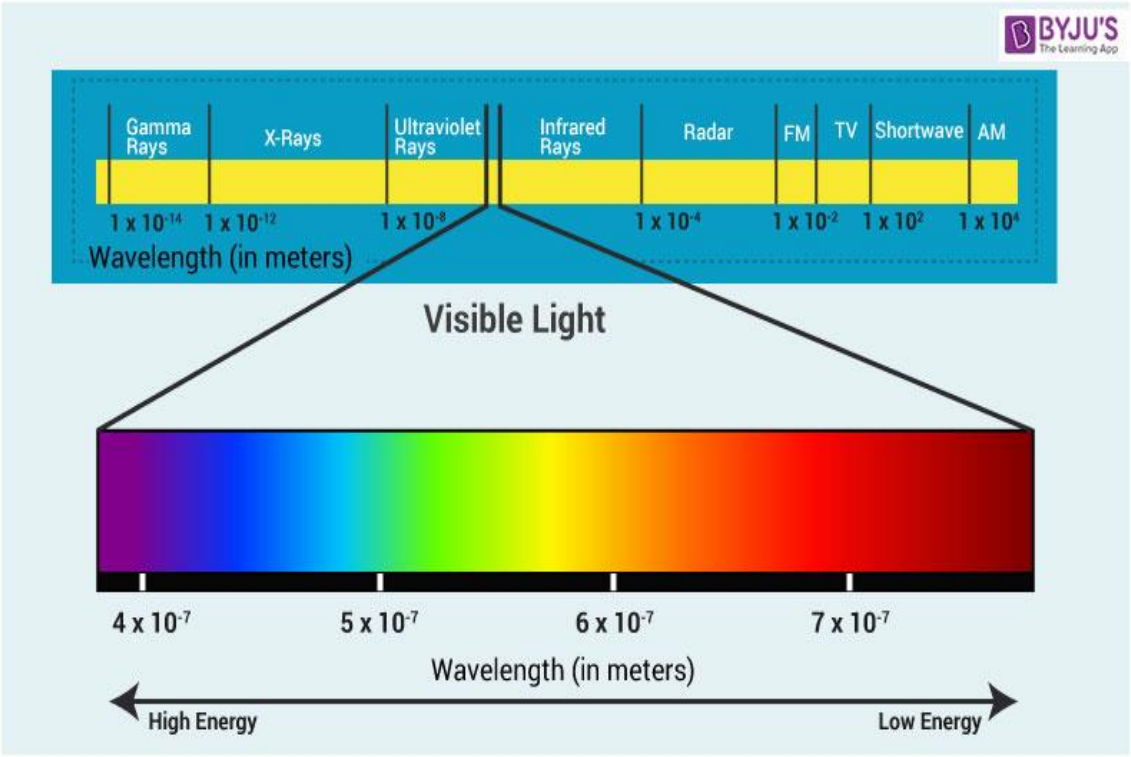


Fig 2. VISIBLE LIGHT DIAGRAM

2.9 Skin Structure

Human skin has a complex, multilayered structure and chemical composition. Generally, from outside to inside, human skin is composed into two layers, the dermis and the epidermis. The **dermis**, which is the layer of skin beneath the epidermis. It contains hair follicles, sweat glands, sebaceous glands, apocrine glands, lymphatic vessels, blood vessels, and nerve endings. The blood vessels provide nutrition for the epidermis and the dermis. Nerve endings can provide the sense of touch and heat. The **epidermis,** which is the exterior layer of skin. It does not contain blood vessels. It can be further divided into several sub-layers . The main type of cells in the epidermis are keratinocytes, melanocytes, Langerhans cells, and Merkels cells. Among these cells, melanocytes are the most important cells for skin spectroscopy, because they can synthesize melanin.

Skin optics, i.e. the manner in which skin reflects and transmits light of different colors, or wavelengths, is determined by the inherent optical properties of the skin layers. Each of these layers has different inherent optical properties, primarily due to differences in the concentration of melanin, blood, and keratin between them.

The radiation first interacts with the surface of the skin and then penetrates inside, but it usually cannot reach the subcutaneous tissue. Thus, the skin surface, the epidermis, and the dermis are three main aspects that been studied in skin spectroscopy. The optics of skin is dependent on the wavelength and the dose of the incident light. The spectrum from 0.25 to 3 μm (including UV, VIS and IR) are the interesting areas for our project. [39-40]

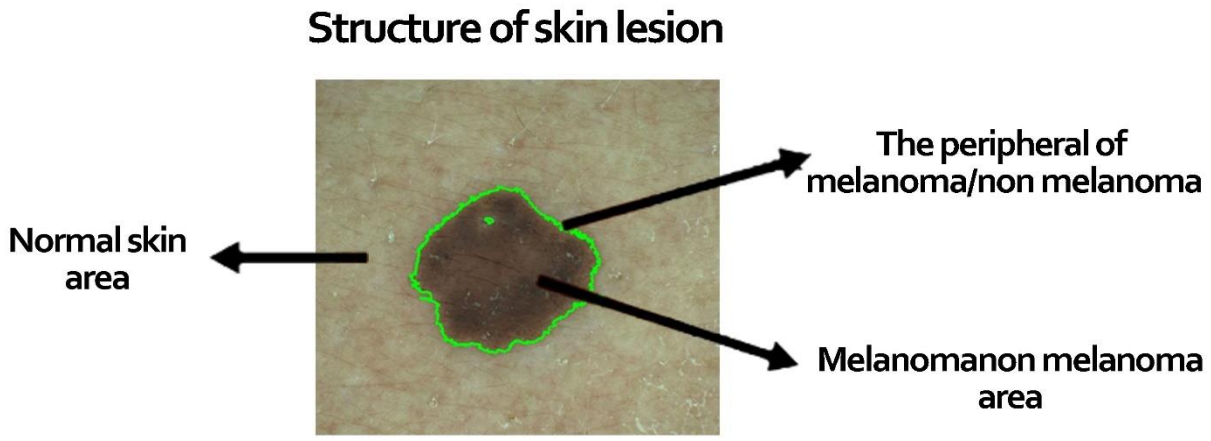
2.10 Malignant melanoma

As we have referred above , melanoma is usually observed as a dark spot on the epidermal (outer) layer of the skin. It is the fast-growing cancer cells that have the ability to spread over the surrounding tissue of the body. The malignant melanoma is caused due to UV radiation and damages the DNA indirectly. The free radical and the reactive oxygen species are the two leading causes of DNA damage. The detection of melanoma skin cancer in the early stage will be very useful to cure it and safeguard the life of the affected individuals. Skin pathologies detection and evaluation of the sub-type and stage of development of the lesion investigated is still a significant area for investigation.

2.11 Dermoscopy

Dermoscopy is a potent but at the same time very simple technique used for clinical visual inspection of a skin lesion. It plays an important role in the diagnosis of skin cancer. The dermoscope is a hand- held device consisting of a magnifying lens, a non-polarized light source, a transparent plate and a liquid medium between the device and the skin so that skin reflections can be avoided. Modern dermoscope do not use this liquid medium, instead, it uses polarized light that eliminates the skin reflection. The main advantage of using polarized light is, it provides better visualization in deeper skin structures whereas for non-polarized the information will be only on the superficial layer of skin . The observation is performed by the eye of a trained dermatologist and often a digital camera is attached for image recording. This technique is usually used for determining whether a lesion is benign or malignant and pathologies such as Melanoma, Basal Cell Carcinoma (BCC), Seborrheic Keratosis, vascular lesions and Dermatofibroma can be diagnosed. Especially for the case of pigmented lesions, several diagnostic methodologies have been developed based on the morphological characteristics revealed by dermoscopic images. Dermoscopy plays a crucial role in

distinguishing the melanoma cells from benign cells with the help of various diagnostic tools such as the tool that we apply , ABCD rule. [34,36, 41]



Chapter 3

3. Stages and Techniques

This section represents the pre-processing stage. We introduce you to the techniques which are required for designing the skin cancer detection system. We have classified the whole process into three sections of Image Enhancement, Image Restoration and Hair Removal. In the first two processes, all the steps with its beneficial techniques to enhance the skin cancer images and also the useful filters to remove the noise and smoothing the images have been explained. In the last step we apply DullRazor method to remove thick hairs from the region of interest of skin.

Dataset

We examined images with 2 skin lesions. The pixel dimension of each skin lesion image is 1900 × 3000 × 3 in RGB (Red, Green, Blue) color space. The input RGB color images consist of M x N x 3, where M and N are the number of rows and columns, respectively. The default color space is RGB with wide variety of intensities and skin color. We also had to examine these skin lesions in the wavelength range of 400 nm - 880 nm.

Pre-processing stage

Dermatologists can achieve an early detection of the skin tumor by studying the medical history of the patient, and also by examining the lesion in term of edge, shape, texture and color. Before such an examination, it is necessary to start with pre-processing and segmenting the skin tumor image. There are technical difficulties concerning the image segmentation in term of variations of the brightness, presence of artifacts, such as air bubbles and hair and the variability of edges. [21] So, it is necessary to remove all unwanted pixels and enhance the images to exact results for improving the diagnostic accuracy of skin pathologies. The pre-processing methods are used to ensure the segmentation of the lesion area and extract the features correctly which leads to high accuracy in diagnosis. Pre-processing stage includes three steps (**Image Enhancement** , **Image Restoration**, **Hair Removal**) [1]

The total framework of techniques followed in preprocessing stage of medical image processing is illustrated in Fig. 3.

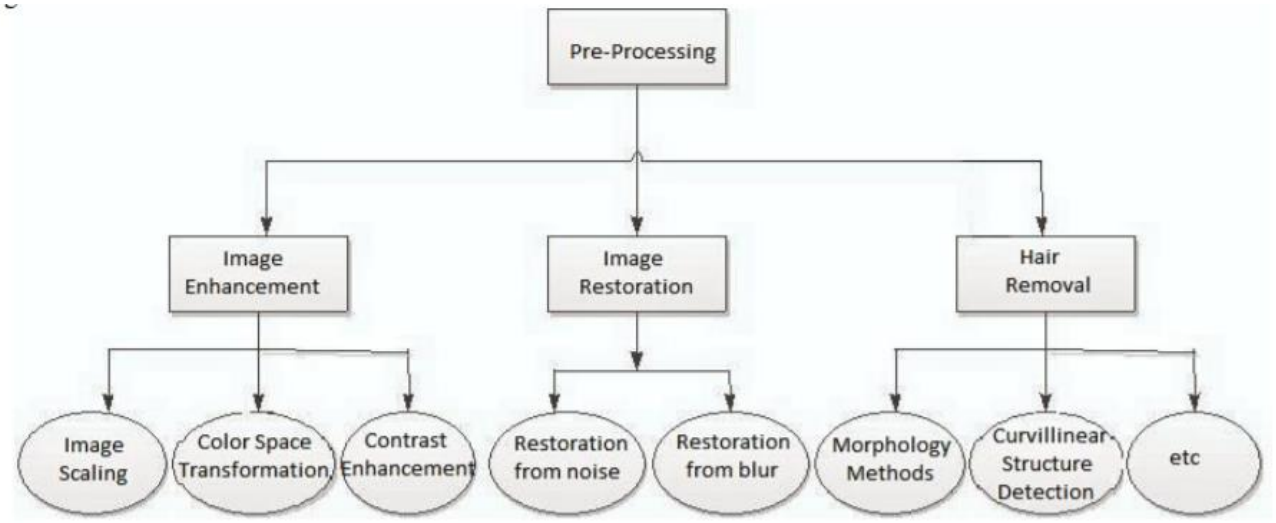


Fig 3. Total framework of preprocessing in Skin detection systems

3.1 Image enhancement

3.1.1 Image Scaling

Image Scaling playing a crucial role in Pre-Processing Stage. Sometimes the image database consists of images from different source and the size of the images is different, too. So , the first step of the procedure we have to follow is to resize the image in order to have the fixed width pixels but variable size of height. [28]

3.1.2 Contrast enhancement

A dermoscopic image may contain artifacts, such as hair, ruler markings, air bubbles and uneven illumination. Because of them and non uniform lighting conditions during image acquisition step, dermoscopic image can have non-uniform background as well as low contrast. To reduce the effect of above factors, several enhancement techniques can be used in to improve the low contrast of the image and for removing artifacts. [8] Contrast enhancement plays a vital role in increasing the quality of an image. In medical purposes, non-Linear contrast enhancement techniques are commonly used , such as Histogram Equalization (HE).

Image histogram is the representation of the distribution of the intensity values across the image and one of the most valuable tools for the processing of digital images. Histogram can give us crucial information about the image, X-axis represents the intensity value of the image from 0 to 255 and the y- axis represents the number of photo-elements that contains each intensity respectively.

To improve the low contrast between the lesion and the skin, contrast limited adaptive **histogram equalization** (HE) has been used. It is a technique used to improve the local contrast of an Image instead of improving contrast of whole image. **Histogram equalization** is a method to increase the contrast of an image and through this process we manage to distribute the intensity over the pixels of the image. Images with skin lesions always show two areas: the area of the lesion and the rest area of the skin.This technique has the advantage of using local information instead of using the entire image and is also useful for images with

both background and foreground are bright or both dark. Thus, techniques that increase color contrast are very useful for segmentation stage.

The following images are an example where the result of this filter to the histogram of the image can be observed.

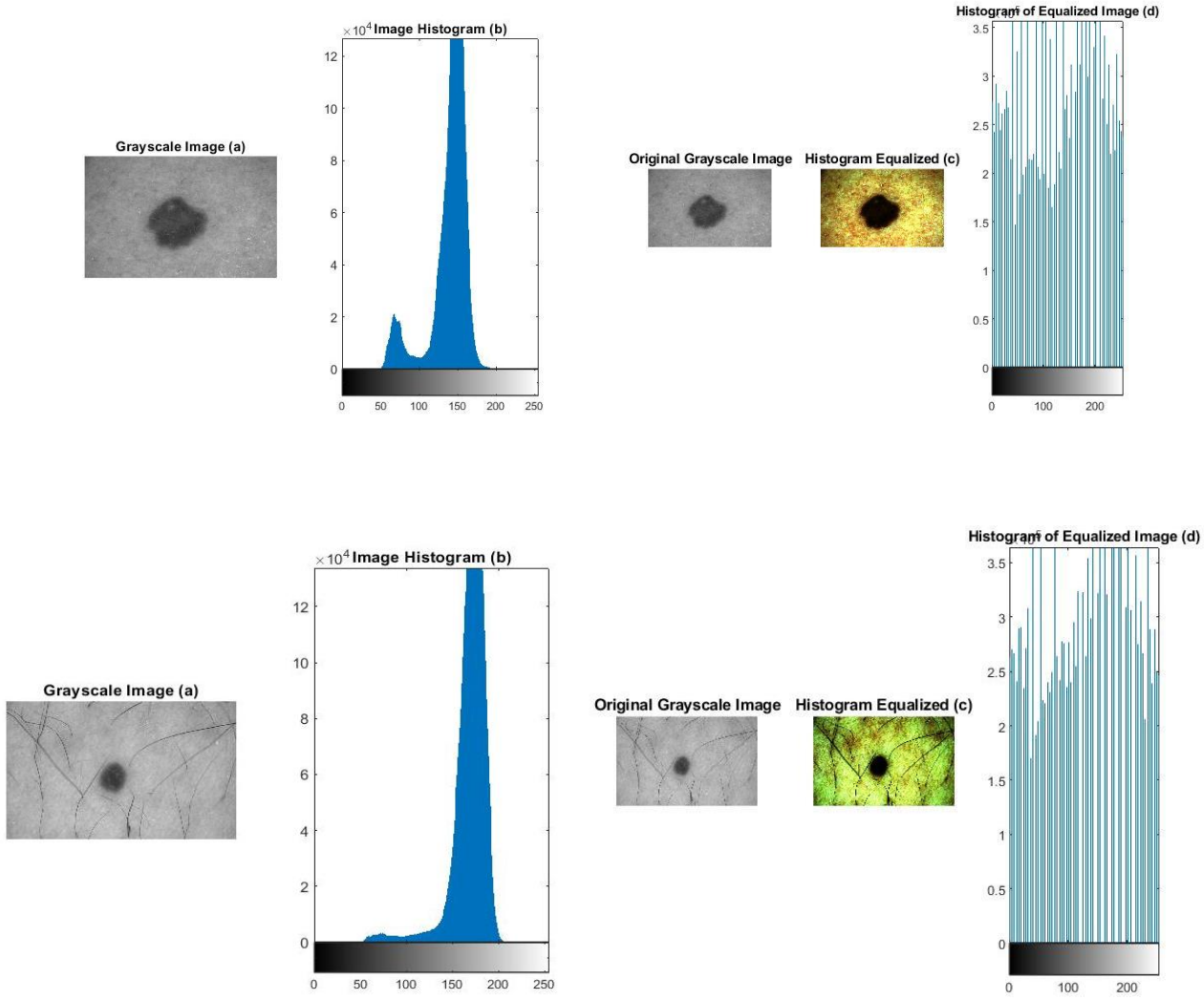


Fig 4. (A)INPUT GRAYSCALE IMAGE, (B)HISTOGRAM OF THE OUTPUT IMAGE, (C) OUTPUT IMAGE BY THE HISTOGRAM EQUALIZATION TECHNIQUE, (D) HISTOGRAM OF THE OUTPUT IMAGE [25]

Histogram equalization replaces the output image with uniform distribution of pixel and it flattens and stretches the image. [29]

3.1.3 Color Space Transformation

In the case of digital image processing, there are many known preprocessing techniques, one of them is **Color Space Transformation.** Images in (RGB) color space need to be transformed to other color spaces that separates the color component from the intensity component for image processing or analysis. Since RGB color space has some limitation in high level processing, other color space representations have been developed. The commonly used color spaces are HSV(where H represents hue, S represents saturation, and V represents value in the cylindrical coordinate system), which imitate the human visual perception of color,

Y'UV (where Y' represents luminance, and U and V represent the chromaticity components in the Cartesian system), and LAB (where L represents lightness, and A and B represent the chromaticity components in the Cartesian system) , which has been proposed to provide uniformity [1] [27]. Note that the use of the CIEL*a*b* and CIEL*u*v* color spaces requires careful calibration of the acquisition device, a step that seems to be frequently neglected in the literature. Since the purpose in images of skin cancer detection systems is to obtain the high-level variations between intensities to detect the edges of lesions, it would be optimal to convert the image into gray scale. Conversion into gray scale offer better results when it comes to image contrast, construction of heightmap ,emphasis on color features. The conversion is done per pixel with elementary functions that are available and it also important to clarify that by the conversion of the pixels, the colors of images are not actually changed, in fact the way that they are encoded in computer's memory is changed. [1]

3.2 Image Restoration

The idea of image restoration is to minimize the noise and blurring image from a degraded image by various atmospheric defects. The image degradation can happen by various defects such as imperfection of imaging system, bad focusing, motion and etc. which make an image usually noisy or blur. [1]

3.2.1 Restoration from noise

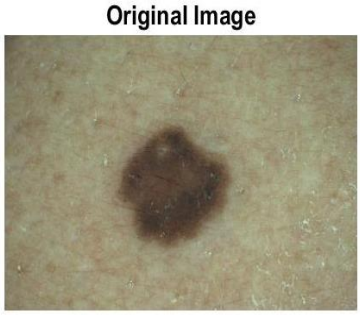
Image denoising is an important step in preprocessing of images. The essential property of a good image denoising method is to suppress the noise as well as preserving the edges. There are many existing methods for de-noising an image. [30] The basic methods can be classified as Spatial Filtering and Transform Domain Filtering. Spatial filtering such as Mean filters, Median filters, Wiener filter include neighborhood and a predefined operation which change the grey value of each pixel according to the pixel values of square neighborhood centered at that pixel. In this project we applied the following filters [1] :

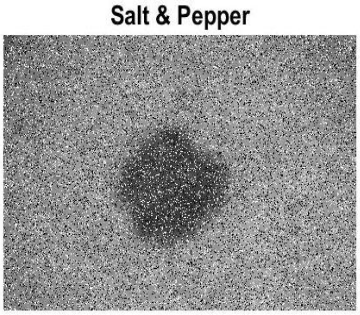
Median Filter

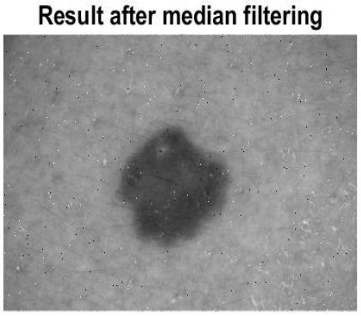
The median filter is one of the most common smoothing filters in the literature and one of the most accurate filtering techniques used in image processing. The median filter considers each pixel in the image in turn and looks at its nearby neighbors to decide whether it is representative of its surroundings. Instead of simply replacing the pixel value with the mean of neighboring pixel values, it replaces it with the median of those values. The median is calculated by first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel being considered with the middle pixel value.[31]

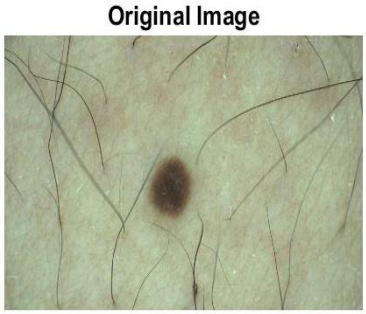
In general, the median filter allows a great deal of high spatial frequency detail to pass while remaining very effective at removing noise on images.

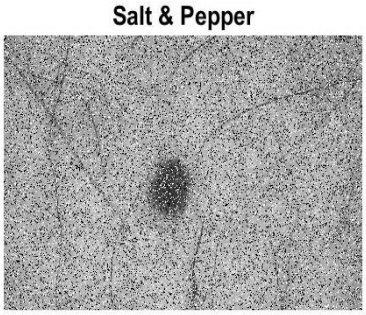
One of the major problems with the median filter is that it is relatively expensive and complex to compute. To find the median it is necessary to sort all the values in the neighborhood into numerical order and this is relatively slow, even with fast sorting algorithms such as quicksort.

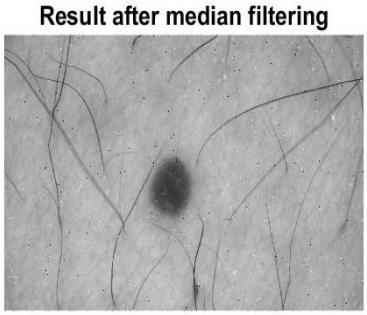








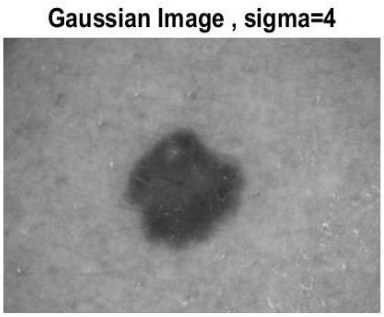


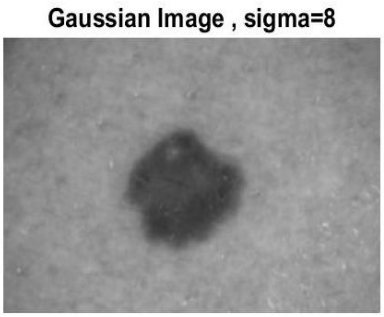


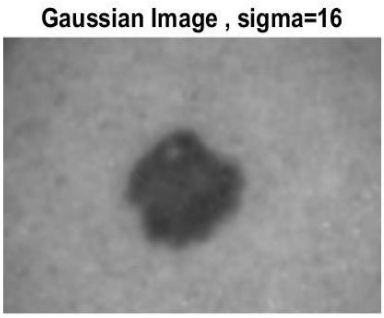
It is noticed that noise is not eliminated and some residual noise which depicting some hair traces remained. As studies referred such noise can adversely affect the segmentation quality.

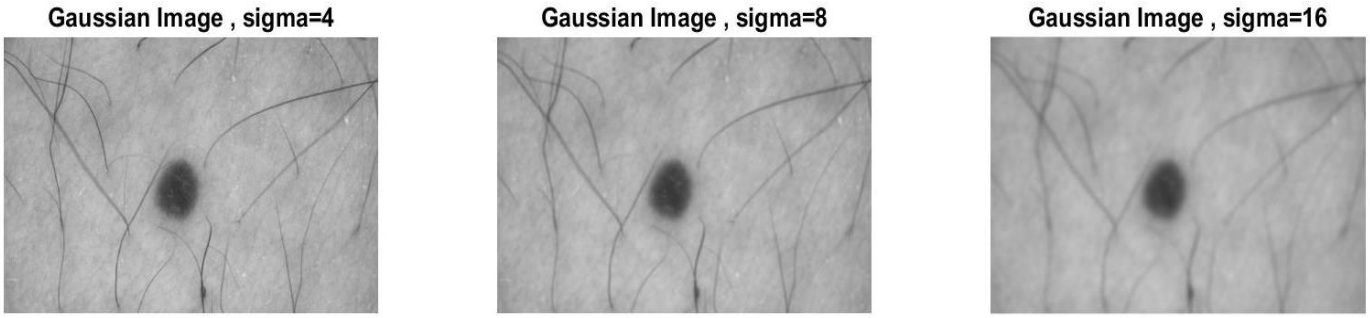
Gaussian filtering

Gaussian filter is used to remove unwanted pixels such as hair and air bubbles , that negatively affect the information in the image , by replacing unwanted pixels by averaging the pixels of the adjacent pixels. The Gaussian is a low-pass filter which removes the noise level and insignificant details by blurring the image. It is used to reduce or eliminate noise and enhance images [4]. In this step we observe that smoothing images using the Gaussian method produces a blurry image. The degree of smoothing is determined by the standard deviation in Gaussian. Sigma is the Gaussian filter's standard deviation expressed in pixels. As can be observed, smoothing reduce details in the image and noise of image or artifact level. Although, this filter can affect segmentation quality.









Images after gaussian filter.

As can be observed by images, most details within the lesion and some details in the background have been suppressed, while variations from the lesion to the background and from the background to the lesion have been enhanced.

3.2.2 Restoration from blur

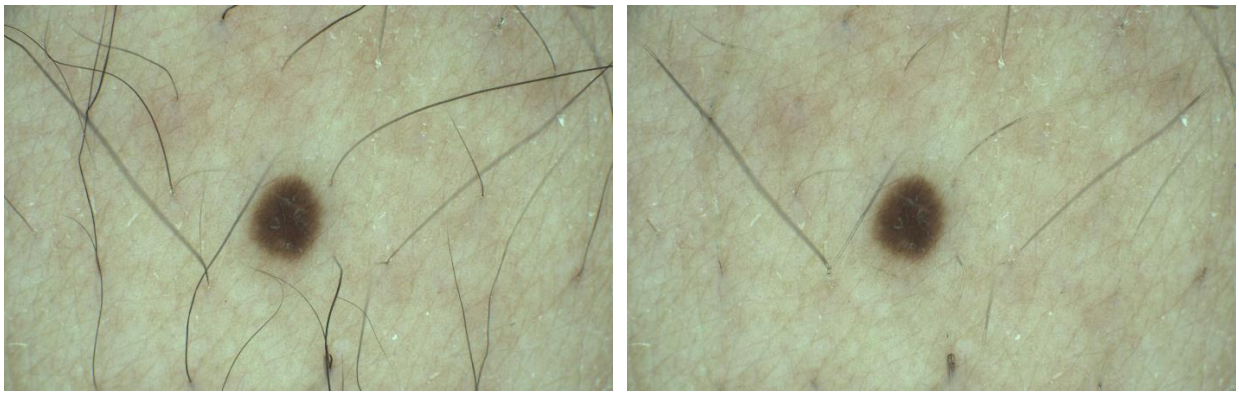
Blur is a kind of image degradation which owe to the imperfect formation process of an image. It occurs by bad focusing or motion between original image and camera.[1] As studies referred, Wiener filter has been applied as one of the most powerful and common de-blurring technique which also remove the noise as well. In this project it wasn't necessary to use Wiener deconvolution to deblur images.

3.3 Hair Removal

Dermoscopy images often contain artifacts such as such as black frames, ink markings, rulers, air bubbles, as well as intrinsic cutaneous features that can affect border detection such as blood vessels, hairs, and skin lines. These artifacts and extraneous elements complicate the border detection procedure, which results in loss of accuracy as well as an increase in computational time. For images including thick hairs with color hue similar to that of the lesion which was not removable by the filters above, a specific hair removal technique called **DullRazor** is applied. DullRazor is an artefact removal pre-processing program which consists of three basic steps: **(1)** identifying the dark hair locations; **(2)** replacing the hair pixels by the nearby non-hair pixels; and **(3)** smoothing the final result. DullRazor is a pre-processing step that helps the automatic segmentation program to achieve a satisfactory result despite the hair interference. Without it, the hairy images could not have been used for any further analysis [6] . Hair detection and removal is a topic that is still being explored. Hair occlusion can cause segmentation algorithms to perform badly due to confusion between hair and mole borders. Hence, the removal of hair is an important pre-processing step in such systems. DullRazor cannot remove light colored or thin hairs. Some other ways to detect and remove hair are: the morphological closing operator to enhance hair and applied a statistical threshold to detect the hair regions utilized the concept of non-linear-PDE based diffusion which proposed in this study [32]. Other way proposed by Abbas [33]. According to this study hairs are detected by a derivative of Gaussian method and subsequently enhanced by a morphological technique which are inpainted by a fast marching method. An alternative strategy for artifact removal is an iterative algorithm based on the lightness component of the HSL (Hue-Saturation-Lightness) color space, which is proposed by Celebi [3].As we can consider hair removal received

the most attention in the literature. [50] In this project we apply the most popular hair detection method, DullRazor .

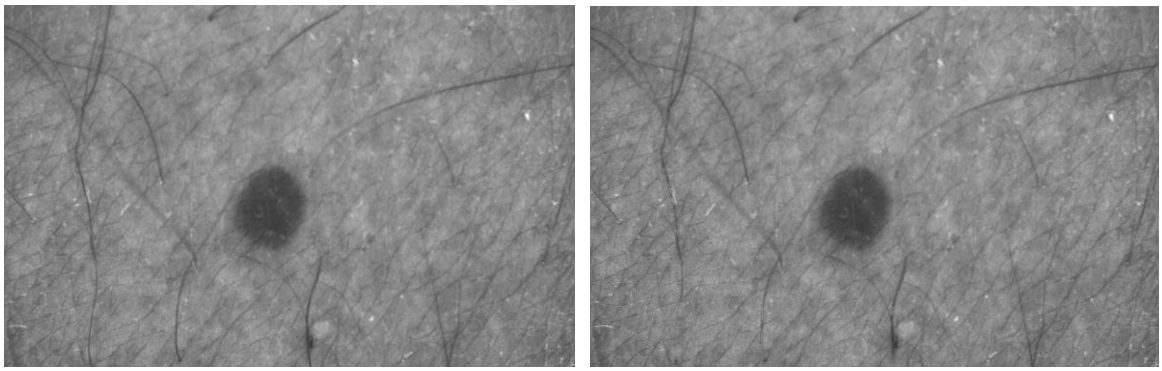
Results of hair removal by the DullRazor technique



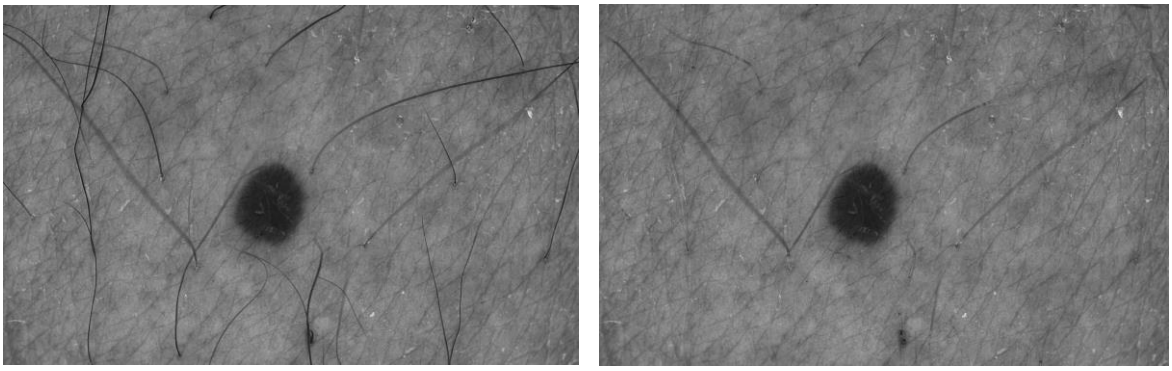
(A) ORIGINAL IMAGE (B) IMAGE AFTER REMOVAL OF HAIR-DULLRAZOR

At the end of pre-processing step of skin cancer detection system, the resulting images are distinguishable from those initial images and almost are ready to feed the segmentation stage.

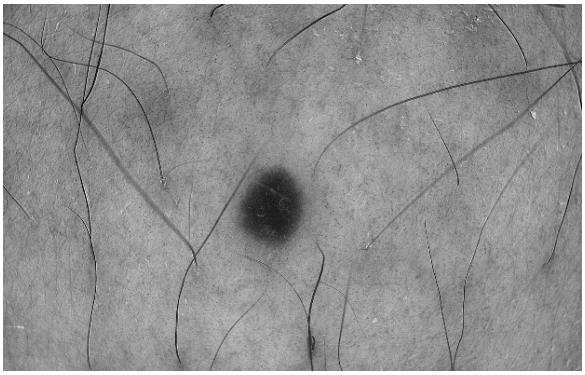
As for the thick hair removal, we use DullRazor for images with wavelengths of 400, 460, 540, 640, 780 and 880 nm.



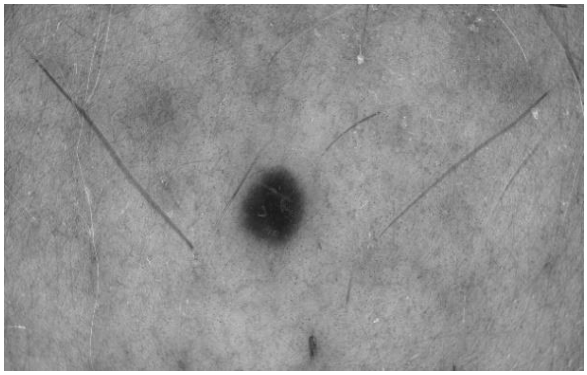
(A) Image 400nm With Hair *(B) Image 400nm With Hair After DullRazor*



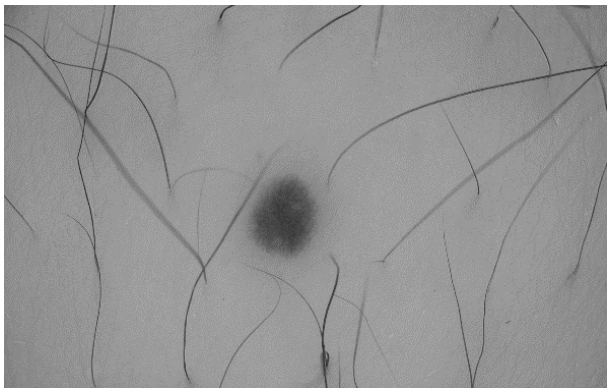
A) Image 460nm With Hair *(B) Image 460nm With Hair After DullRazor*



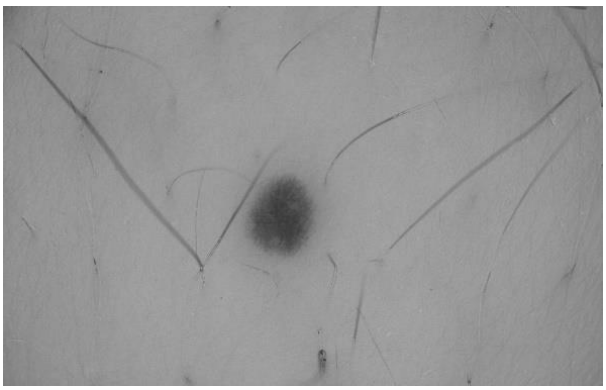
A) Image 540nm With Hair



B) Image 540nm With Hair After DullRazor



A) Image 640nm With Hair



(B) Image 640nm With Hair After DullRazor

Chapter 4

1. Segmentation

The purpose of image segmentation stage is to separate the background and the region of interest by converting the image to binary and depict the area of interest. This stage is dominant for our implementation, since the binary image is used for extracting the most features from the ABCD rule. Segmentation is essential in image analysis because it facilitates the methods processing of the next steps. In the analysis of medical images, the segmentation is necessary. If segmentation is effective, the next steps in image processing are more accurate and efficient. Medical image analysis requires segmentation of images in the areas of interest. With the correct segmentation process, the correct results are obtained from the interest pixels. There are many methods and algorithms for image segmentation. [4] Correct measurement of image characteristics for diagnosis of melanoma first needs a proper detecting of lesions. It is significant that lesion boundaries are determined accurately so that measurements, like maximum diameter, asymmetry, irregularity of the boundaries and existence of colors can be accurately calculated. Image Segmentation is a difficult procedure due to several reasons such as low contrast between the lesion and the surrounding skin , irregular and fuzzy lesion borders, artifacts such as skin lines, air bubbles and hairs and variegated coloring inside the lesion. To resolve these problems, several segmentation algorithms have been developed. We can classify these into the following categories which are : edge- based , contour-based, thresholding-based ,region-based and artificial-intelligence based methods .

Segmentation methods can be categorized also as contextual or non-contextual. The non-contextual are independent of spatial relationships between features in an image and group pixels together on the basis of

some global attribute, e.g. grey level or color. Contextual techniques additionally utilize these relationships, e.g. group together pixels with similar grey levels and close spatial locations.

4.1 Thresholding methods: In this category approaches aim at comparing visual feature values for single or group of pixels in the dermoscopic image with threshold values. Thresholding is one of the simplest non-contextual segmentation techniques. With a single threshold, it transforms a greyscale or color image into a binary image considered as a binary region map , which can be further processed to filter out outliers, to fill small holes, or to select the largest connected component. Thresholding is classified into two Global Thresholding and Local Thresholding.

4.1.1 Global thresholding method is used when there the intensity distribution between lesion and skin are very distinct and we have to apple one threshold to the entire image. When the differences between the region of interest and the background are very distinct, a single value of threshold can simply be used to differentiate both objects apart. Thus, in this type of thresholding, the value of threshold T depends solely on the property of the pixel and the grey level value of the image. One most common used global thresholding methods is Otsu method. This method face problems when there is an overlap of the modes of the two regions.

4.1.2 Local Thresholding method is used when a threshold is calculated for each pixel, so we have to apply different threshold values to different regions of the image. The threshold which is calculated based on some local statistics such as range, variance, or surface-fitting parameters of the neighborhood pixels. It can be approached in different ways such as background subtraction, means and standard derivation of pixel values, and local image contrast. Some disadvantages of the local thresholding techniques are region size dependent, individual image characteristics, and time consuming.

4.2 Edge and contour-based methods

Algorithms in this group detect the edges between the regions using edge operators and contour based methods involve the detection of object contours using curve evolution techniques. In edge-based segmentation, all pixels are initially labelled as either being on an edge or not, then non-edge pixels which form connected regions are allocated to the same category. Edge labelling may be: manual, by using a computer mouse to control a screen cursor and draw boundary lines between regions or automatic, by using an edge-detection filter.

Contours are boundaries designed for the area of interest required in an image. Contour is a collection of points that undergoes interpolation process. The interpolation process can be linear, splines and polynomial. Edge and contour-based methods are inappropriate when it comes to images including thick hairs and air bubbles and if the transition between the lesion and the surrounding skin is smooth. [43]

4.3 Region-based methods

These type of segmentation algorithms operate iteratively by grouping together pixels which are neighbors and have similar values and attributes such as brightness, features, color and splitting groups of pixels which are dissimilar in value. Connectivity is used to identify which pixels are neighbors. A variance for each property can be defined. The region growth stops when a pixel outside of this variance is encountered. From the analysis of the literature it can be noted that, region-based algorithms are prone to over-segmentation when the skin or lesion regions are textured or when the interior of the lesion exhibit multi-colored areas. [7,21,43]

4.4 Artificial Intelligence based methods

Techniques based on artificial intelligence (AI) have also been proposed for the image segmentation of skin lesions, in which the image pixels are classified as belonging to the ROIs or to the background of the images. These techniques may be combined among themselves, or with other traditional image processing techniques, in order to improve segmentation performance.

Segmentation method	Technique
Edge-based	Edge detectors
Thresholding-based	Otsu's thresholding
	Fuzzy logic
	Renyi's entropy
	Adaptive thresholding
	Iterative thresholding
	Ensemble
	Statistics
Region-based	Region growing
	Statistical region merging
	Iterative stochastic region merging
AI-based	Neural networks
	Evolutionary computation
	Fuzzy logic
	k-means clustering
Active contour-based	Adaptive snake
	Gradient vector flow
	Level set
	Region-based active contour algorithm
	Active contour without edges
	Expectation-maximization level set
Other methods	Hill-climbing algorithm
	Dynamic programming

Fig 1. Segmentation methods
Figure from article [9]

Chapter 5

In this chapter the proposed method is described in detail for tackling the problem of melanoma detection and the feature extraction.

5. Techniques

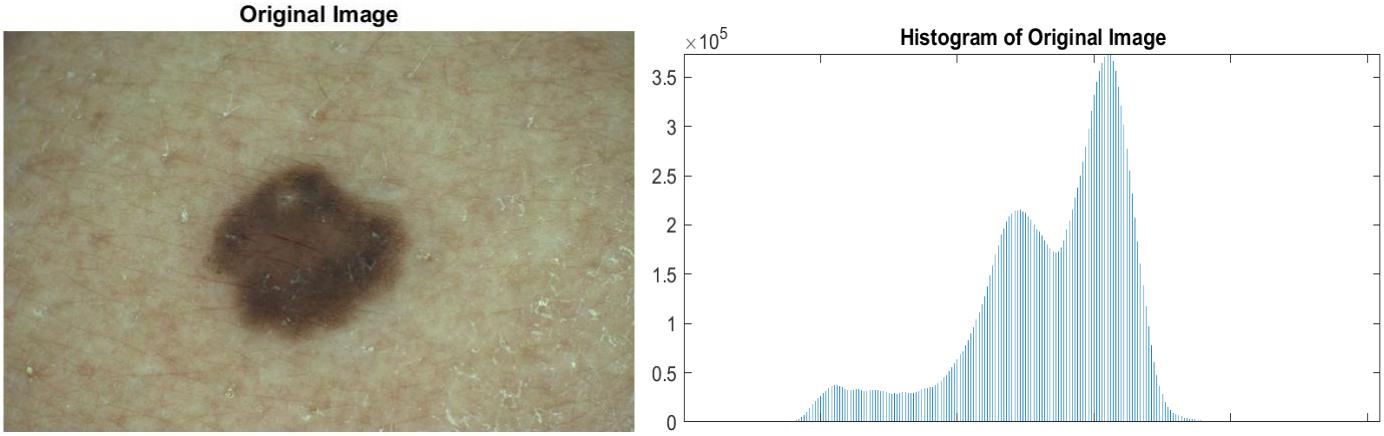
To do a classification of given skin lesions and distinguish melanoma from benign lesions, we begin by isolating the lesion from healthy skin that surrounds each color image using segmentation methodologies.

5.1 Otsu method

Otsu's algorithm, proposed by Nobuyuki Otsu, is a segmentation technique which searches for a threshold that minimizes the intra-class variances of the segmented image and can achieve good results when the histogram of the original image has two distinct peaks, one belongs to the background, and the other belongs to the foreground or the signal. The Otsu's threshold is found by searching across the whole range of the pixel values of the image until the intra-class variances reach their minimum. As it is defined, the threshold determined by Otsu's method is more profoundly determined by the class that has the larger variance, be it the background or the foreground. As such, Otsu's method may create suboptimal results when the histogram of the image has more than two peaks or if one of the classes has a large variance . [7,44,45]

Otsu algorithm

First of all we tried to adapt Otsu algorithm. In this method it is presumed that it considers that there are two classes of pixels that are foreground pixels (skin lesion) and background pixels of the image (healthy skin). The optimum thresholding is calculated by distinguishing the two classes so that the minimum class variance can be obtained. As the algorithm described we had to draw the histogram of the digital image and calculate the various intensity levels and initialize ω_i (0) and μ_i (0), then we had to calculate all possible threshold values , calculate $\sigma_b{}^2$ for all threshold value and finally choose the threshold which relates to maximum of $\sigma_b{}^2$. [45]



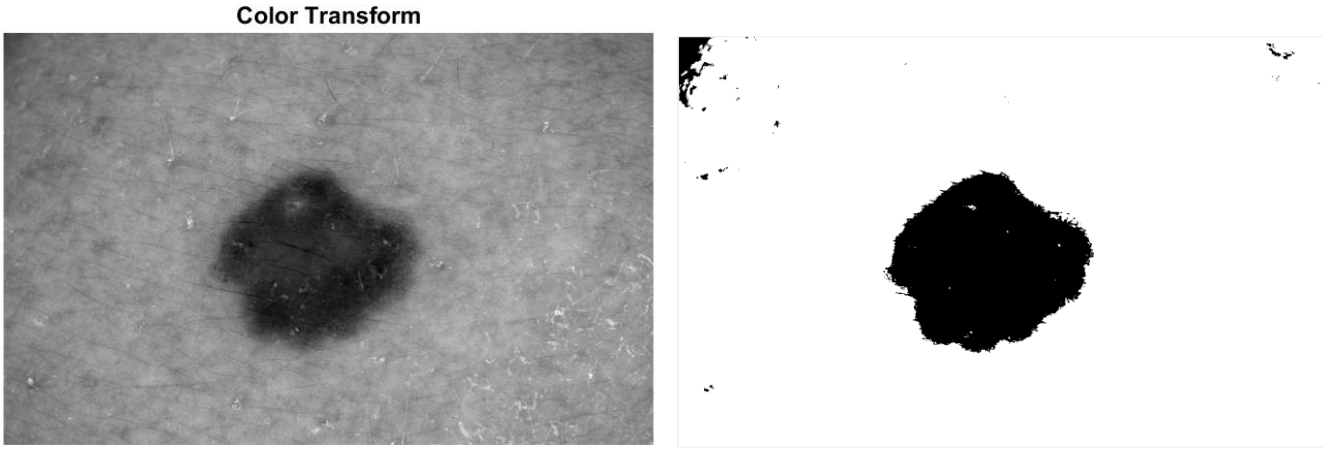
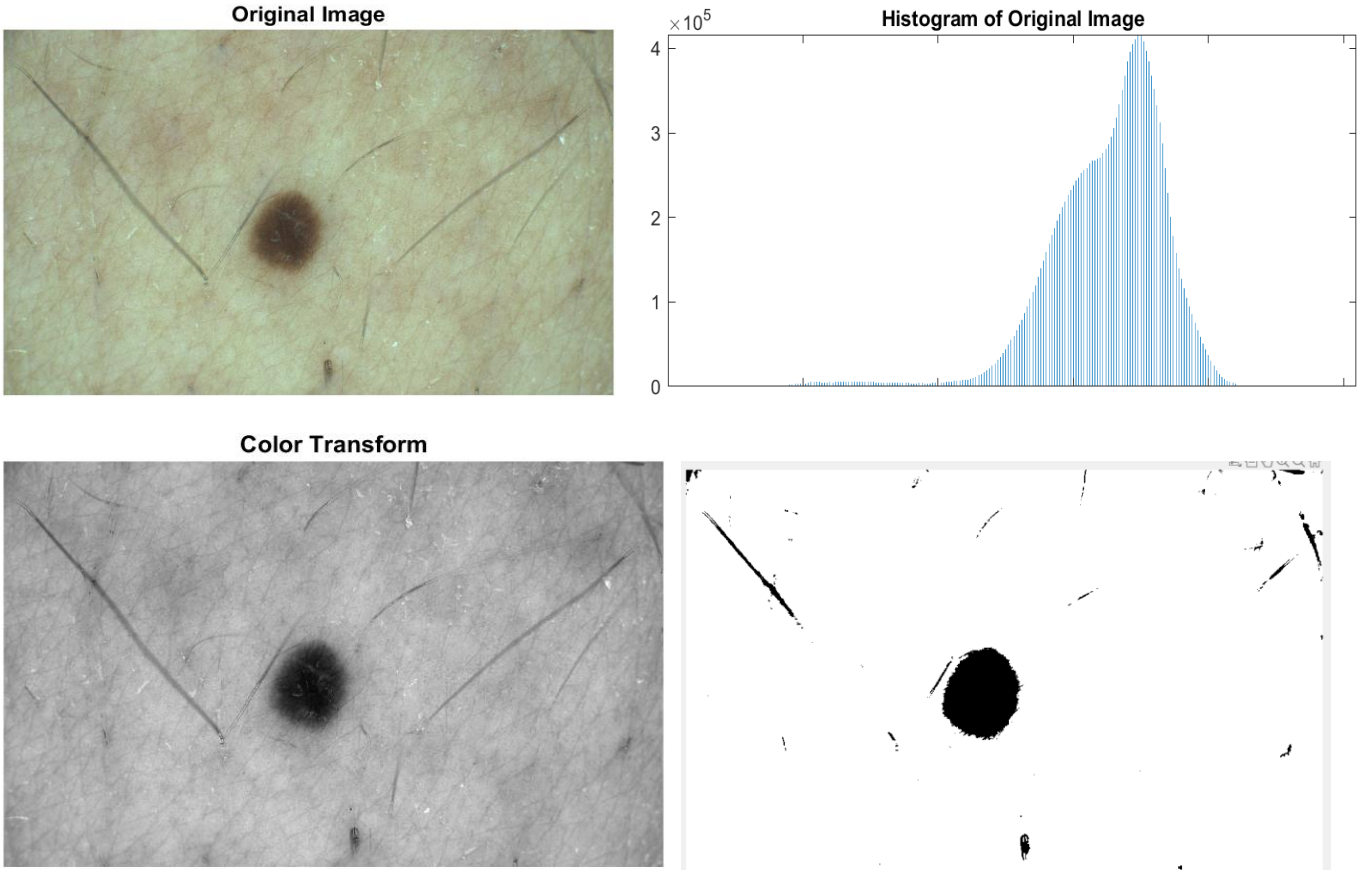


Fig 2-3. Otsu's thresholding methods seek to find a threshold t that minimizes within-class scatter for the two classes and two variances between-class scatter characterized by the deviation of the class means from the overall expected value T.



The result of Otsu's segmentation method is affected from the noise and intensity variations due to skin's repetitive texture and hair that exists in the image. As we referred above such segmentation method face problems when there is an overlap of the modes of the two regions. The results of this segmentation method for the first image are better but it is difficult to define true region boundaries in order to extract other features of skin lesion. Although, as we already know, the construction of the binary mask is the most important part of the process.

Segmentation

In our project we apply boundary tracing algorithms, and we use functions from the image processing toolbox in order of clear segmentation of the lesion area from the background skin. The boundary tracing algorithm is used to extract the region of interest from an image. This algorithm is used to find edges, this function looks for places in the image where the intensity changes rapidly, using one of these two criteria. The fist one is the places where the first derivative of the intensity is larger in magnitude than some threshold. The second one refers to places where the second derivative of the intensity has a zero crossing.

The feature extraction method is focusing on the way to get information from color space. The goal of the skin lesion segmentation process is to generate a binary mask providing an accurate separation between the lesion area and the surrounding healthy skin. The mask can be used for extracting information about the border irregularity, asymmetry and diameter.

5.2 Process

The segmentation method that we apply is performed in a MATLAB environment. MATLAB is a programming and computing platform with a useful and easy-to-use Image Processing Toolbox. Image Processing Toolbox provides a set of functions and applications for image processing, analysis, and visualization. There are many functions available for image analysis, image segmentation, image enhancement, noise reduction, geometric transformations, and image registration. In this project, a program has been developed using this Toolbox and all relevant algorithms are discussed below. One of the benefits also of using MATLAB is that functions may act on large arrays of data rather than simply single scalar numbers. Most pictures are represented as two dimensional arrays, or matrixes, in which each matrix element corresponds to a single pixel in the exhibited image. A single dot on a computer monitor is commonly referred to as a pixel.

First of all we apply optimal weight selection for converting RGB to gray level, in order to have better results in contrast between the lesion and the skin. Accordingly, high contrast image also results in more accurate segmentation. Then we use **imclearborder** (I) to suppresses structures in image (I) that are lighter than their surroundings and that are connected to the image border. We use also this function to clear the image border. For grayscale images, imclearborder tends to reduce the overall intensity level in addition to suppressing border structures. As a next step, we apply the function **bwareafilt** (BW,range) to extract the largest object from the binary image BW. Bwareafilt is a function from the image processing toolbox that accepts a binary image and determines unique objects in this image, as an output we get a binary image with area of skin lesion. After that we use the function **imfill** which is used to fill the holes in the input binary image. A hole is considered a group of background pixels inside the edges. We also use the function **regionprops** which is used to measure a set of properties for each labeled region in label image.

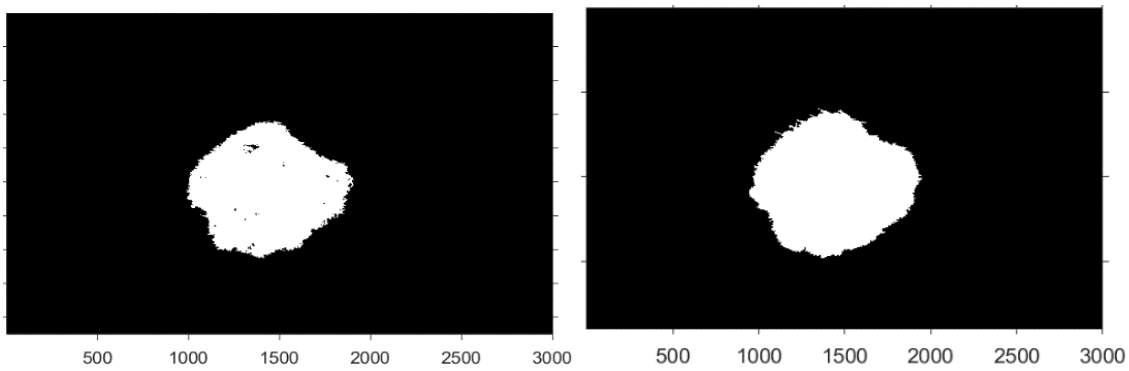
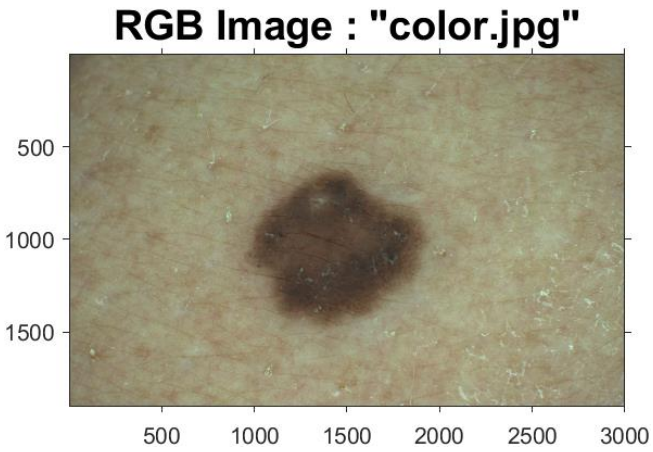
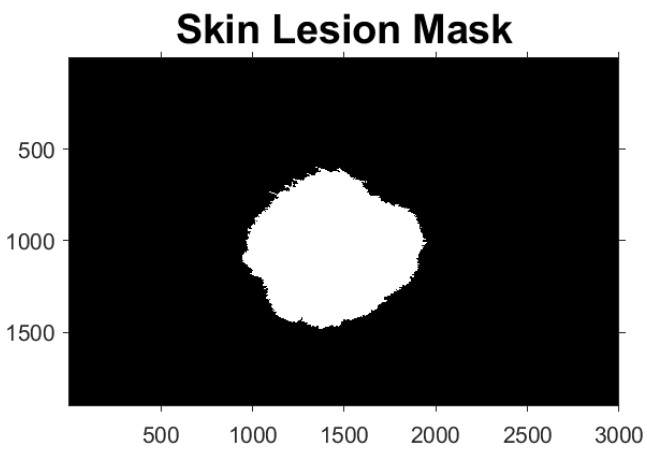


Fig.4 Example of filling the holes by using imfill

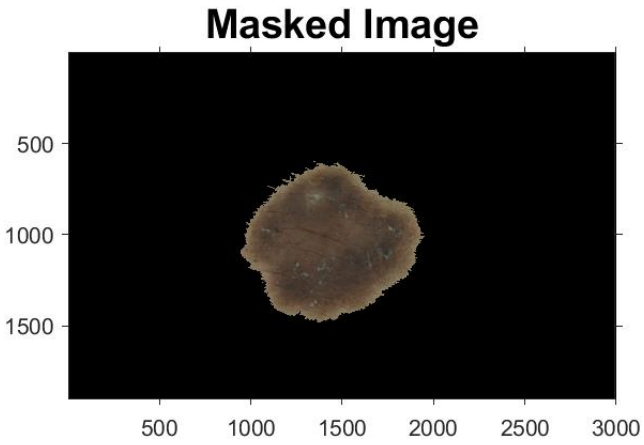
As a result of this procedure, we create a mask for the image with pixel values of 1 indicating image pixels that belong to the ROI and pixel values of 0 indicating image pixels that are part of the background. According to all these steps we got a segmented image and its mask.



(A)

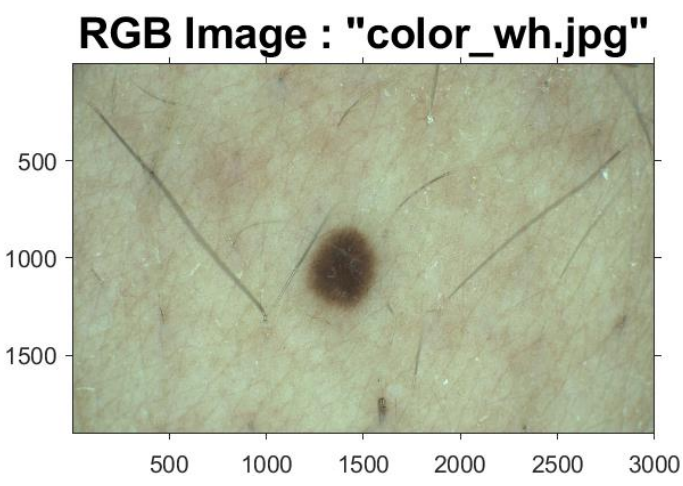


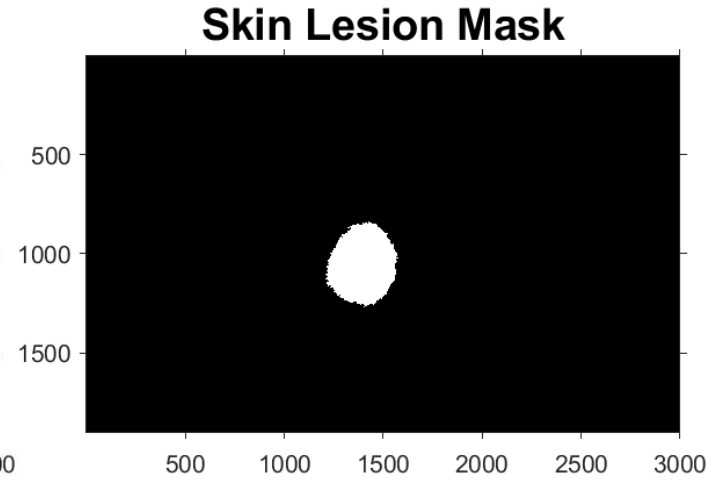
(B)

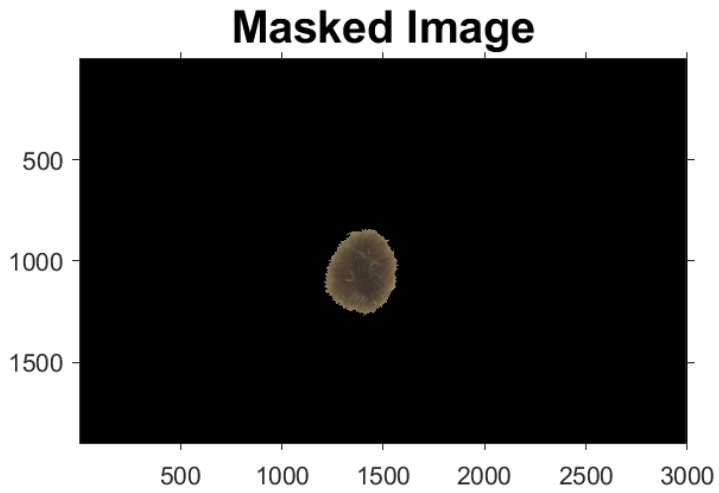


(C)

Fig.5-6 Examples of image Segmentation using Matlab's environment







5.3 Hybrid Lesion Detection

We also apply Tyler L. Coye's script for the segmentation of skin lesion [10]. This algorithm is an improved version of a previous skin lesion segmentation algorithm that he developed by applying iterative canny edge to the image mask. As he noted this change has the added benefit of improving contour matching between the mask and original lesion. This algorithm is also a novel approach to lesion segmentation. The techniques used are Iterative Median Filtering , 2-D Wavelet Transformation, Otsu Thresholding on individual dwt2 levels , morphological closing and Iterative Canny Edge (novel method applied to this type of problem). This algorithm has a different way of calculation the threshold level. It is typical to divide the sum of threshold levels by '4' but Tyler L. Coye decided to divide by '2' in order to have better results for segmentation .

5.3.1 Edge Detection

An edge is a set of connected pixels that lie on the boundary between two regions. An image can be segmented by detecting those discontinuities. As we already mention edge detection technology has been developing rapidly and plays an increasingly important role in image analysis. Edge detection is used to locate boundaries such as line and curve in the image. The image outline is important for accurate diagnosis because many features such as border irregularity and asymmetry are calculated from border. The most traditional edge detection operators are Sobel and Laplace operator , that accorded to the gray value changes of each pixel neighborhood and used the changes of the first order or the second order directional derivative in mathematical methods to detect the edge. As we read these operators have disadvantages as discontinuity on the edge of cell images, interference edge and losing of cell image details, despite of their simple structures.

Canny Edge

There are two important points in image edge detection. The first one is reducing the impact of noise effectively and the other point is selecting the threshold objectively and correctly. Iterative algorithm which is based on Canny operator calculate the optimal dual-threshold and refine the detected edge image with mathematical morphology. It uses the analysis and the calculation of each pixel's gray value of the image itself to select the high and low thresholds. Iterative algorithm make the average of the minimum and maximum gray values through the histogram as the initial threshold. Secondly, use the initial threshold to divide all the gray values into two parts. As we observe it can suppress noise effectively, and is able to obtain the best segmentation threshold , which is good ready for subsequent processing of the image. [46]

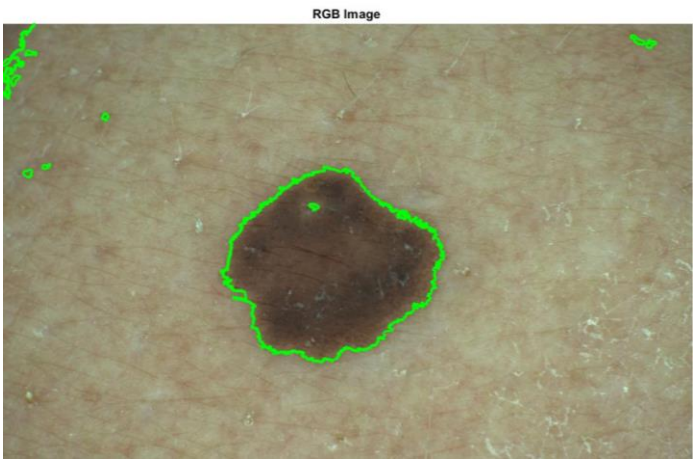
Convert via PCA

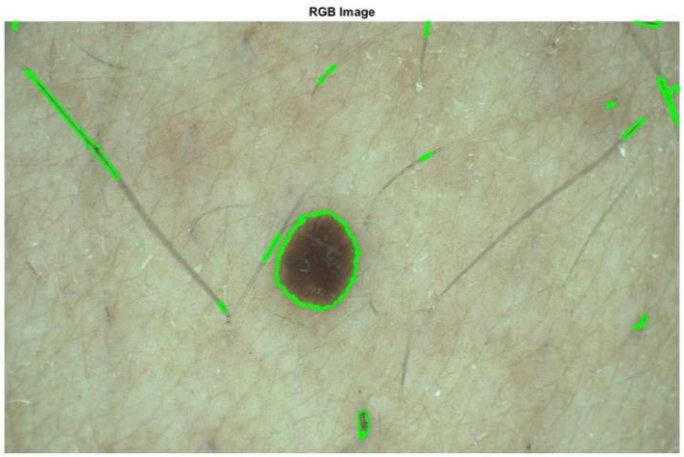
The primary difference between RGB and grayscale images is the number of color channels that the image has. An RGB image has three color channels: Red, Green and Blue while a grayscale image has only a single color channel. Image compression is a technique that minimizes the size in bytes of an image while keeping as much of the quality of the image as possible. It is applied to reduce the cost of the image when storing and transmitting. PCA (principal component analysis) is one of the dimensionality reduction techniques that can be used to compress images.[47]

Wavelet Analysis - Morphological Filters

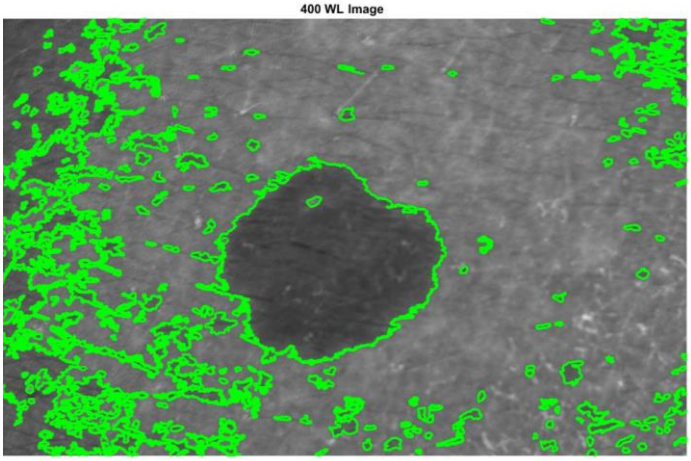
Wavelet analysis is used to divide information present on an image (signals) into two discrete components — approximations and details (sub-signals). Wavelet transform is a widely used tool in signal processing for compression and denoising [48]. Morphology closing was used to enhance the boundaries of the lesion and remove impairments. The closing operation also smooths object contours, joins narrow breaks, and fills long thin gulfs and holes smaller than the structuring element (skin lesion). A morphological filter is applied also to the image, using a morphological structuring element, **strel**. The creators refer to this element as an essential part of morphological dilation and erosion operations. **Strel** function is used to produce a flat structural element. Applying this algorithm, a disk-shaped structuring element is created specified by the radius of 1.

Results of this Segmentation method





400 WL Image



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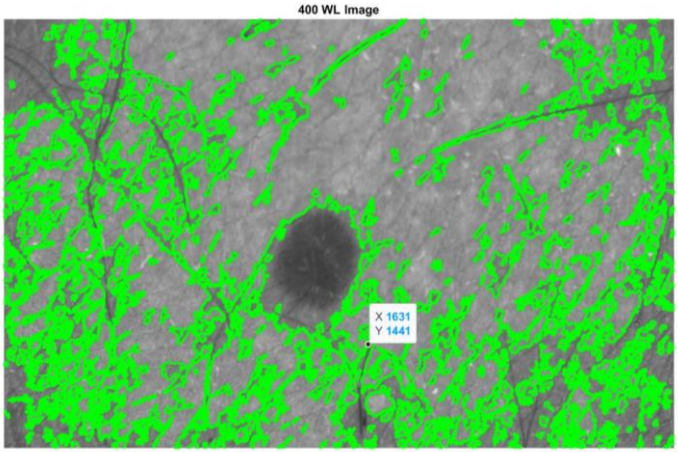
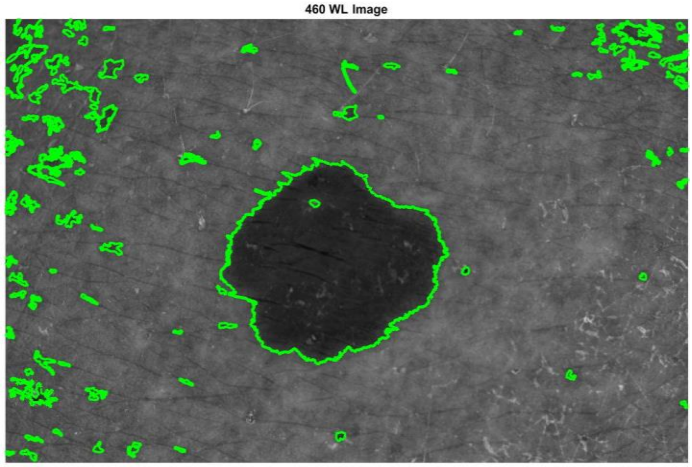
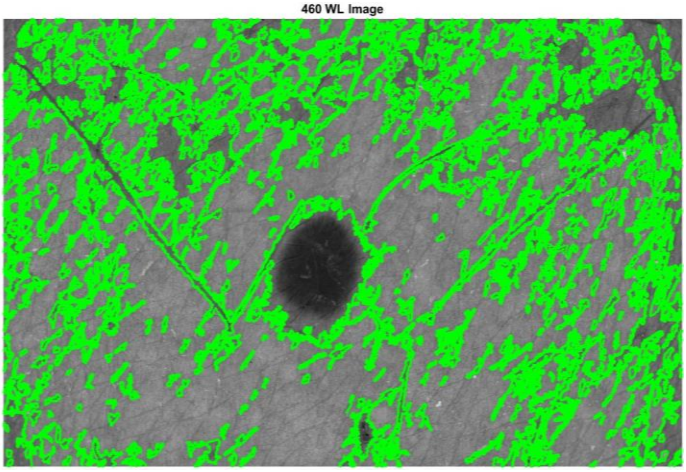


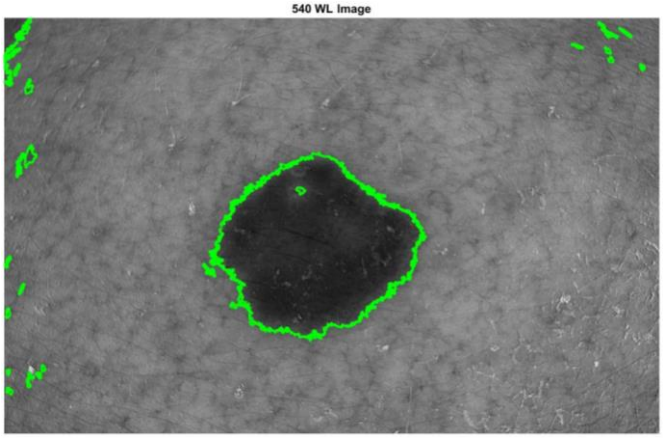
460 WL Image



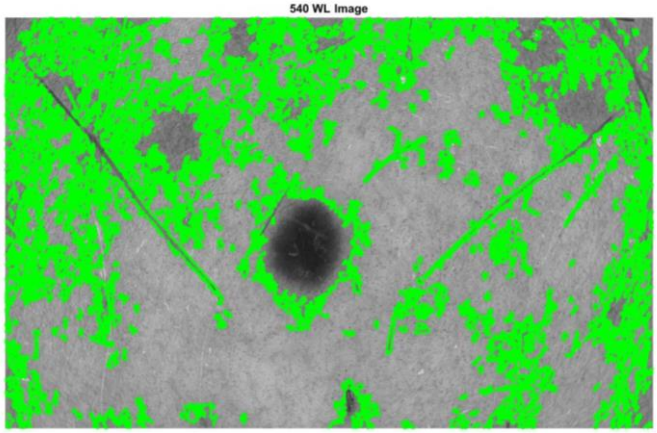
460 WL Image



540 WL Image



540 WL Image



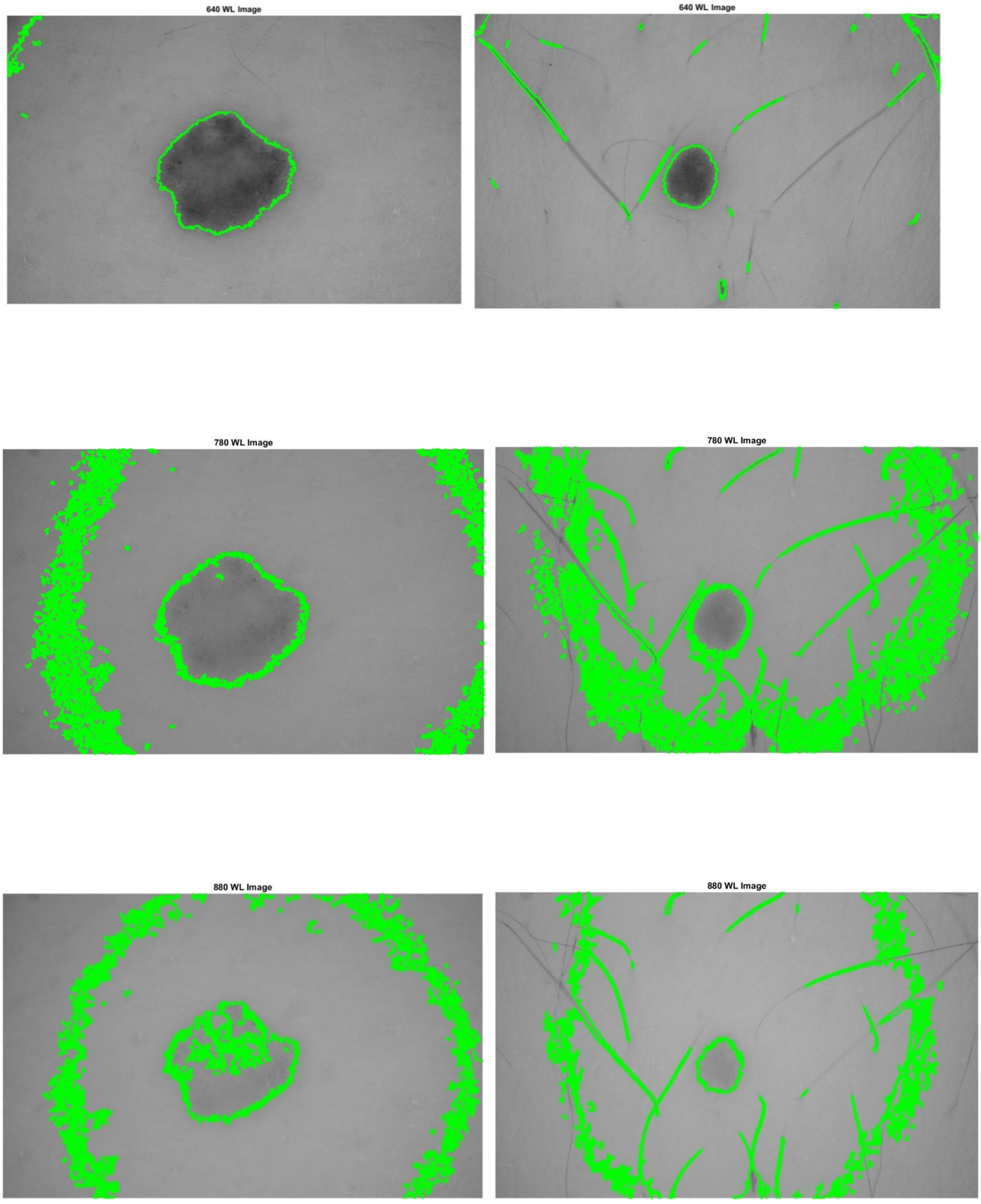


Fig 7. Segmentation output of images using Tyler L. Coye's algorithm

The first row shows the segmentation output of the original images, the other rows show the segmentation output of the lesions that are depicted in different wavebands (400nm, 480nm,540nm, 640nm, 780nm, and 880nm). The main suspicious skin is covered with green line boundary. The area outside green line is normal skin and the part inside green line is the region of our interest.

The advantages of using this approach for skin lesion segmentation is that it has capabilities to separate heterogeneous objects and it is insensitive to noise when the lesion are in the visible light spectrum .The segmentation program described above worked well for images of skin lesions belonging to the first case up to 640nm. On the other hand, the segmentation program fails to detect the border for the original skin lesion images for images of skin lesions belonging to the second case up to 540nm due to existence of thin hairs and dots in the shade of background. In 640nm the result for the second case is much better but they are not still good enough to extract information about the border irregularity, asymmetry and diameter. In 780nm and 880nm the performance of this segmentation algorithm is inadequate, and we observe overlap of the modes of the two regions (skin lesion and background).

5.4 Feature extraction

Feature extraction is the procedure used for extracting meaningful features from dermoscopy images. The aim of this feature extraction through Computer-Aided Diagnosis (CAD) systems is to extract various features from a given dermoscopy images which can discriminate between benign or malignant. The methodology for extracting the feature in many early detection systems for the skin lesion , such as in our project , has been based on ABCD rule. The ABCD rule was introduced by Stolz and used by dermatologists in recognition process of skin lesions to assess the risk of malignity of a pigmented lesion. We chose this methodology for extracting the features because of its effectiveness, efficiency and simplicity of performance and implementation. By observing the early signs using **ABCD** rule, dermatologists can classify whether a skin patch is benign or malignant. If a patch is determined to be malignant, a biopsy will be used to confirm the final result. Although the procedure used above is standard, a dermatologist has subjective bias, and the correct diagnosis depends on a dermatologist's experience.

This method can provide a more objective and reproducible diagnostic of skin cancers in addition to its speed of calculation. It is based on four parameters: A (Asymmetry) concerns the result of evaluation of lesions asymmetry, B (Border) estimates the character of lesions border, C (Color) identifies the number of colors present in the investigated lesion, and D (Diameter) On other hand, (D) also could refers to Differential structures such as pigment network, structureless area, dots, globules, and streaks. [4,16]. Later in 2004, Abbas et al [49] proposed expanding the ABCD criteria to ABCDE rule by combining the evolving (E) lesion during the time. This characteristic refers to characteristics, such as size, shape or color. Most benign moles, melanoma tends to change over time.

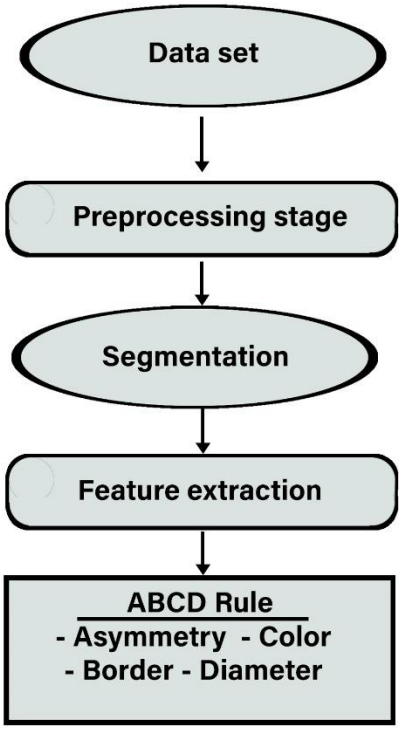
- **Asymmetry** – Melanoma is often asymmetrical, which means the shape isn't uniform. Non-cancerous moles are typically uniform and symmetrical in shape
- **Border** – Melanoma often has borders that aren't well defined or are irregular in shape, whereas non-cancerous moles usually have smooth, well-defined borders.
- **Color** – Most benign pigments have one color or shade. Melanoma has a variety of colors.
- **Diameter** – Melanoma growths are normally larger than 6mm in diameter but it can be smaller.

This section explains some of the features of melanoma recognition.

The main advantage of extracting the ABCD features is the ability to provide an objective second opinion to the investigator which would otherwise be prone to subjectivity, especially that the ABCD features demonstrate fine structures of the skin lesion. ABCD algorithm also is effective and improves early detection with high accuracy for skin lesions leading to a decrease in death rates. The disadvantage however is that many approaches rely on the segmentation performance which could be degraded due to the presence of different artifacts such as hair , bubbles, dots , skin lines . These features affected the extraction process.

However, several factors affect the results when studying diagnostic accuracy of this algorithm. The approaches lack the ability to reflect real-world measures such as in the diameter measurement. Moreover, applying the ABCD rule may not be able to detect melanoma of homogeneous color and regular shape. These limitations are challenges that must be explored, and future work continues to find more effective advantages. [15] The ABCD rule is also used by the American Cancer Society, American Academy of Dermatology and others worldwide to provide simple parameters for evaluation and identification of pigmented lesions that may need further examination. However, it is essential to refer that not all melanomas have all four ABCD features.

Diagram shows the analysis of the skin lesion using the ABCD rule in proposed system



5.4.1 Asymmetry

Asymmetry (A) is one of the more important parameters used in differentiating malignant tumors from benign lesions. Asymmetry has a weighting factor of 1.3, which is higher than the other weighting factors of all criteria, as displayed in table of TDS below. As we read in different studies benign pigmented skin lesions are usually circular and symmetric , in contrast with melanomas that tend to develop in an uncontrolled fashion and grow at an irregular rate, rendering them to be asymmetric. An asymmetry index based on the principal axes of the lesion was proposed by Stoecker [24] and we follow a method which is based on this the following study. [21] To calculate asymmetry, firstly, the skin lesion is converted into grayscale value. Secondly, skin lesion is translated to the center of the image so that the x and y coordinates of the image coincide with the centroid of the image, as calculated from the moments and area above. Then the image is

rotated -θ˚ to align the x and y coordinates of the image with the centroid principal axes. The orientation angle θ° is defined as the angle between the x-axis and axis around which the object can be rotated with minimum inertia:

$$\theta = \frac{1}{2}\arctan\left(\frac{2m_{1,1}}{m_{2,0}-m_{0,2}}\right)$$

where $m_{1,1}$, $m_{2,0}$ and $m_{0,2}$, are the second order moments or moment of inertia defined as:

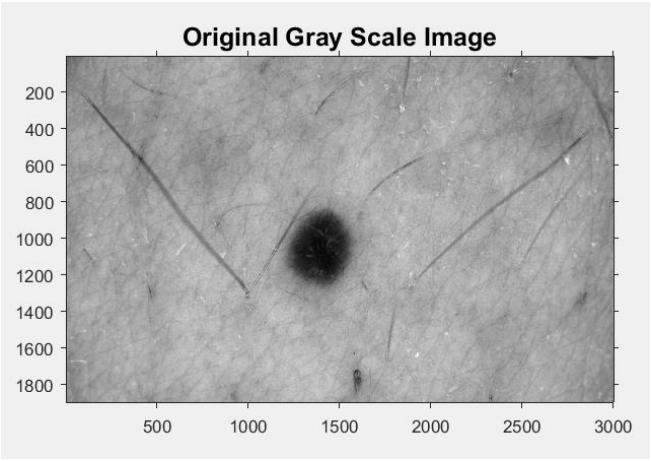
$$m_{p,q} = \sum_i (x_i - x_0)^p (y_i - y_0)^q$$

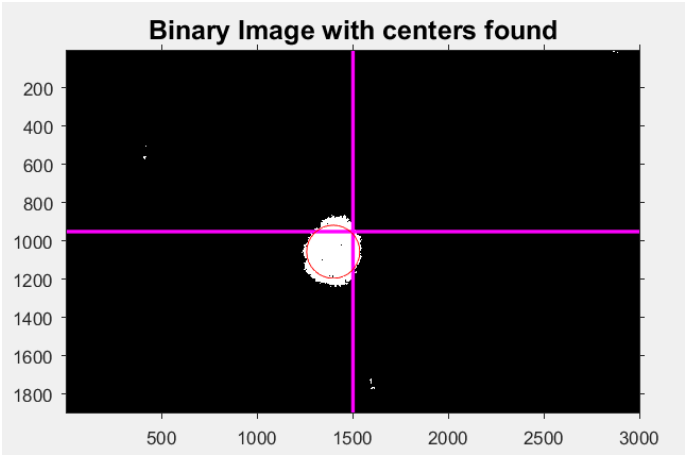
where (x_0, y_0) is the centroid. [25]

In order to compute the asymmetry index, we find the difference between the lesion image and its mirrored image. Both of two images have the same pixel as a center and the same major axis. The degree of symmetry is result of the fraction of the intersection and the union between two areas of the images. An area of an image can be calculated using bw area over the binary image of the segmented region. The more the index approaches 1, the more the lesion will be considered as symmetrical. The symmetry index can be represented by the following mathematic equation:

$$\mathbf{IS} = \frac{\boldsymbol{A \cap B}}{\boldsymbol{A \cup B}} \mathbf{\ x\ 100\%}$$

Each image has an asymmetry measurement in one of three classes: 0 representing fully symmetric because asymmetry is absent with respect to both axes within the lesion, 1 representing symmetric on one of its axes and 2 representing fully asymmetric. In our case if all pixels of two different areas of the images (the intersection and the union one) coincide with each other , then we have 100% symmetry percentage.





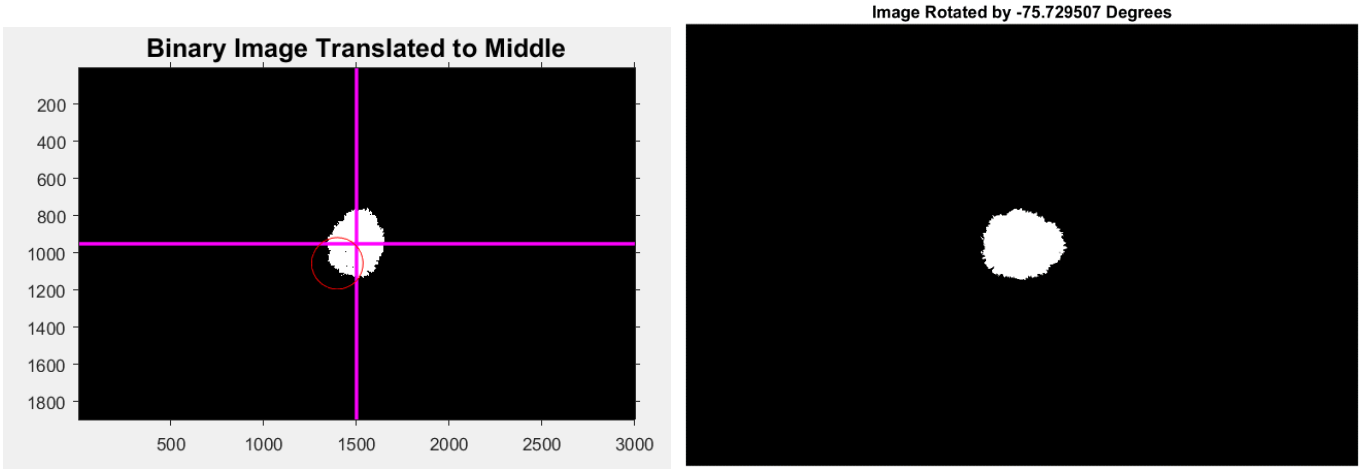


Fig 8. The skin lesion is translated to the middle and then rotated to align with centroidal principal axes .

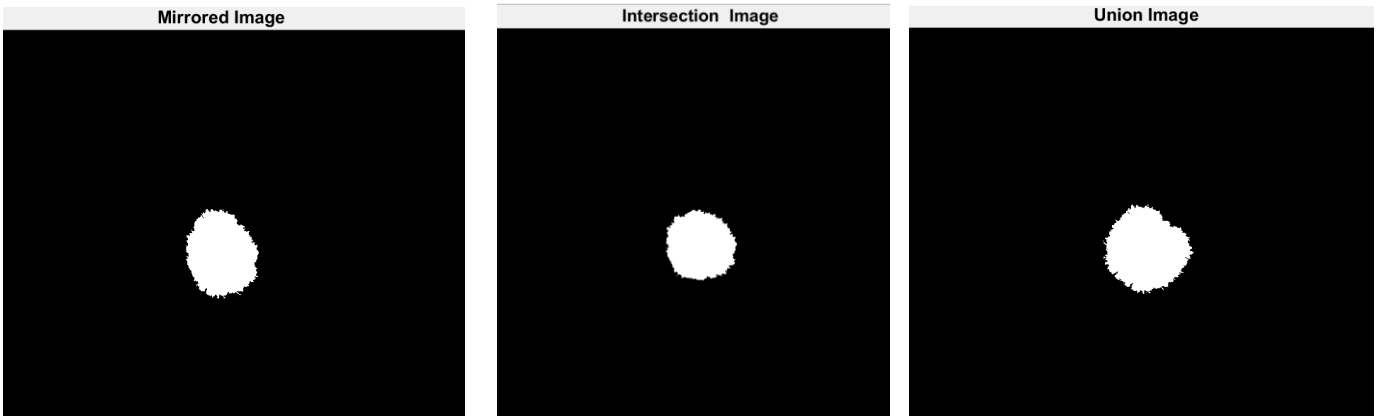
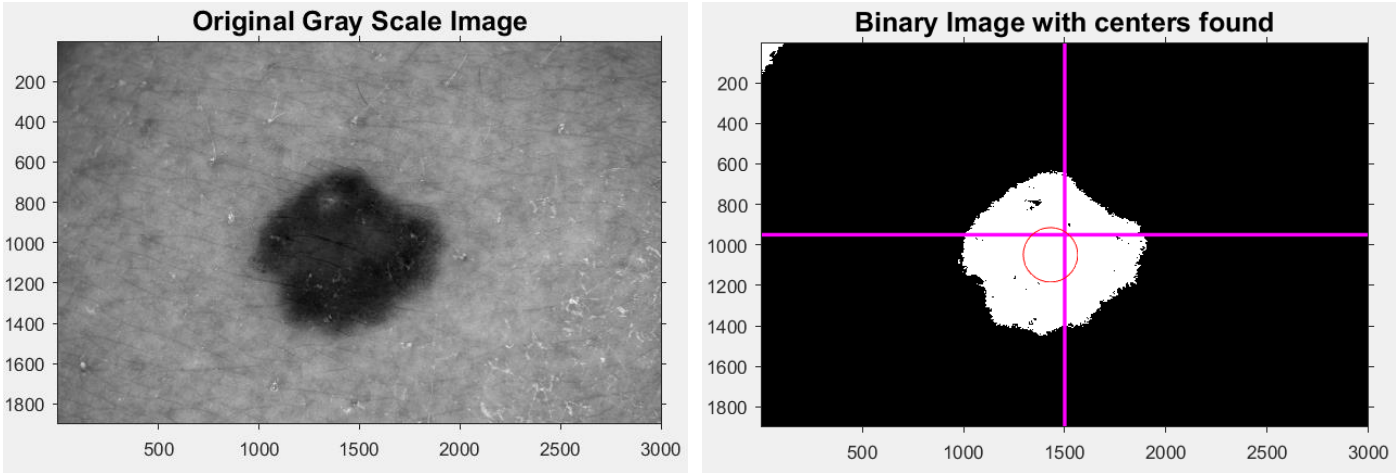


Fig 9. We found the mirrored image of our skin lesion image and then the intersection and the union one.



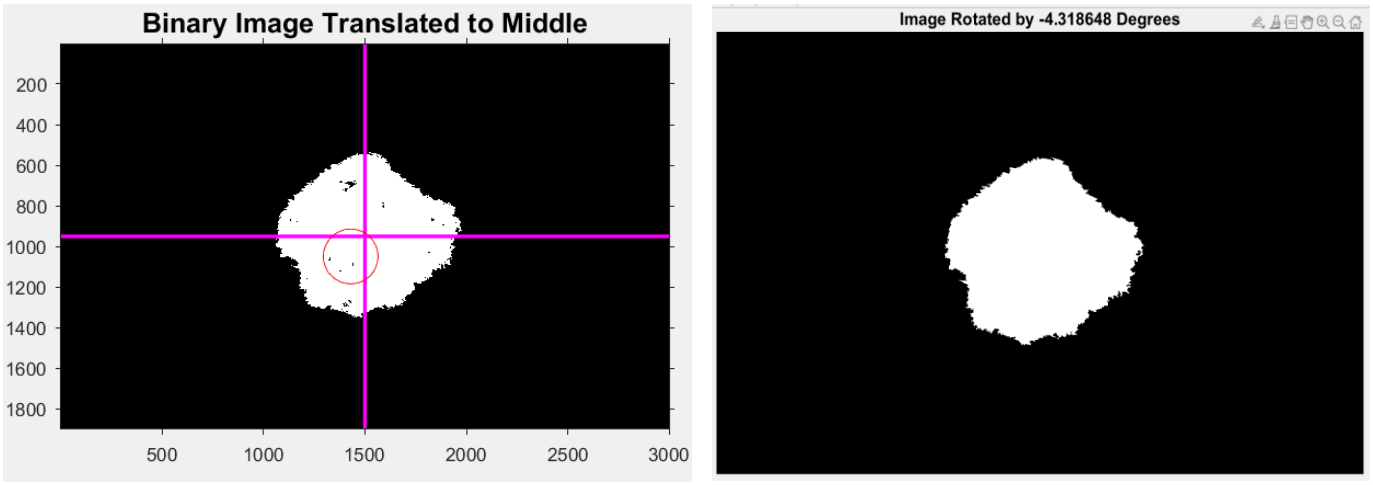


Fig 10. The skin lesion is translated to the middle and then rotated to align with centroidal principal axes

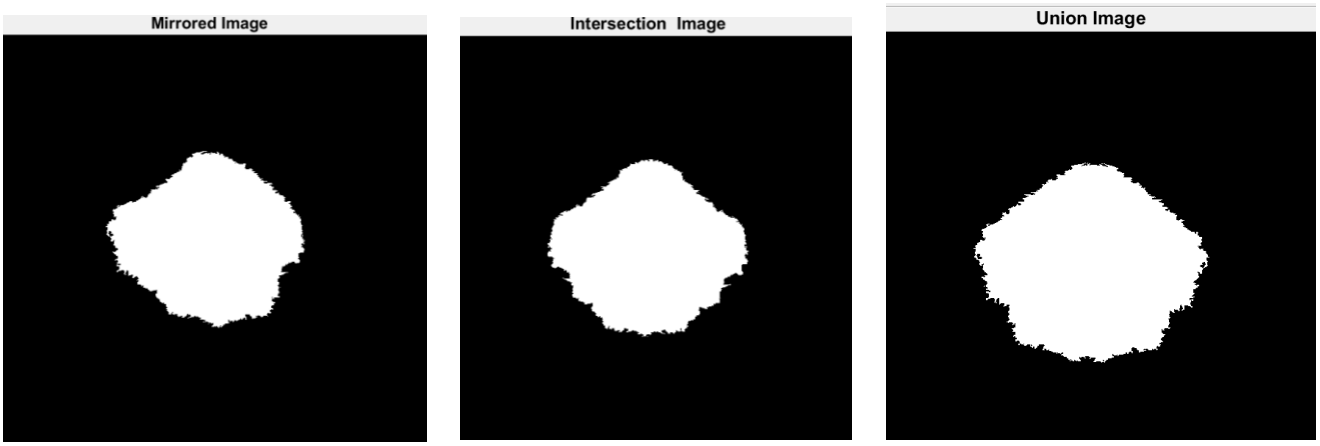


Fig 11. We found the mirrored image of our skin lesion image and then the intersection and the union one.

5.4.2 Border

According to dermatologist, melanomas are characterized by much border irregularity, on the other benign tumors are typical defined by clear border. [22]. Border irregularity is one of the leading parameters in the widely used diagnostic algorithm ABCD rule of dermoscopy which is one of the first proposed diagnostic algorithms and it is one of the most commonly used methods for evaluation of melanocytic lesions. As opposed to benign pigmented lesions which tend to possess regular borders, melanoma lesions have irregular borders due to the uneven growth rate the spread of melanocytes in various directions, and the regression of invasion and/or genetic instability of the lesion. Two of the common ways for this measure are the compactness index and the fractal dimension methods.

Compactness is one of the features s to quantify irregular edges. The compactness is implemented according to equation below. Since the most compact shape is circle, comparison is evaluated on circles of different sizes. The compactness (c) of circle is equal to 1. Irregularity was eventually found using the compactness index :

C defined by: $$\mathbf{C} = \frac{\boldsymbol{Perimeter}^{\mathbf{2}}}{\mathbf{4}*\boldsymbol{\pi}*\mathbf{Area}}$$

where **P and A are the perimeter** (number of points on the detected border) and **area** (number of points on and within the border) of the closed boundary, respectively. Borders with an irregularity index greater than 1.8 were classified as being irregular. [13]

RGB images	Color_mole	Color_wh
Perimeter	10182.114	10140.949
Area	5135920	50550974
Compactness	1,606	1,474

The compactness index is the easiest to calculate, but as many studies reported in many cases, it is inappropriate to describe the shape of the border. Calculating also compact index along boundary is very sensitive to noise.

The border's irregularity (B feature of the ABCD rule) can be objectively measured also using a **fractal dimension method.** These fractal dimensions are related to the complexity of the shapes and have been used for skin lesion border irregularities characterization. Fractal dimension is an integer value. For line, filed and cube the values is 1, 2 and 3 dimension respectively. However, in case of fractal dimension it may worth fraction. By using Box Counting method, fractal dimension can be calculated and for this Hausdorff dimension method is used. In this method the image is divided into the boxes. More specifically, the lesion (L) is represented by a binary mask. Consequently, the object is designated by 1, and the bottom by 0. The fractal dimension method is used to count the number of boxes (N(r)) contained in the border. The value D is estimated using two terms (r and (N(r)) presented by equation written as follows:

$$\log(N(r)) = D \times \log r + C^{ste}$$

A circle of radius 100 pixels is used to test the fractal dimension (DF). The result obtained by the DF is equal to 99%, which signify that the error is 1% (the theoretical value of the DF is equal to 100%). [21]. We expected

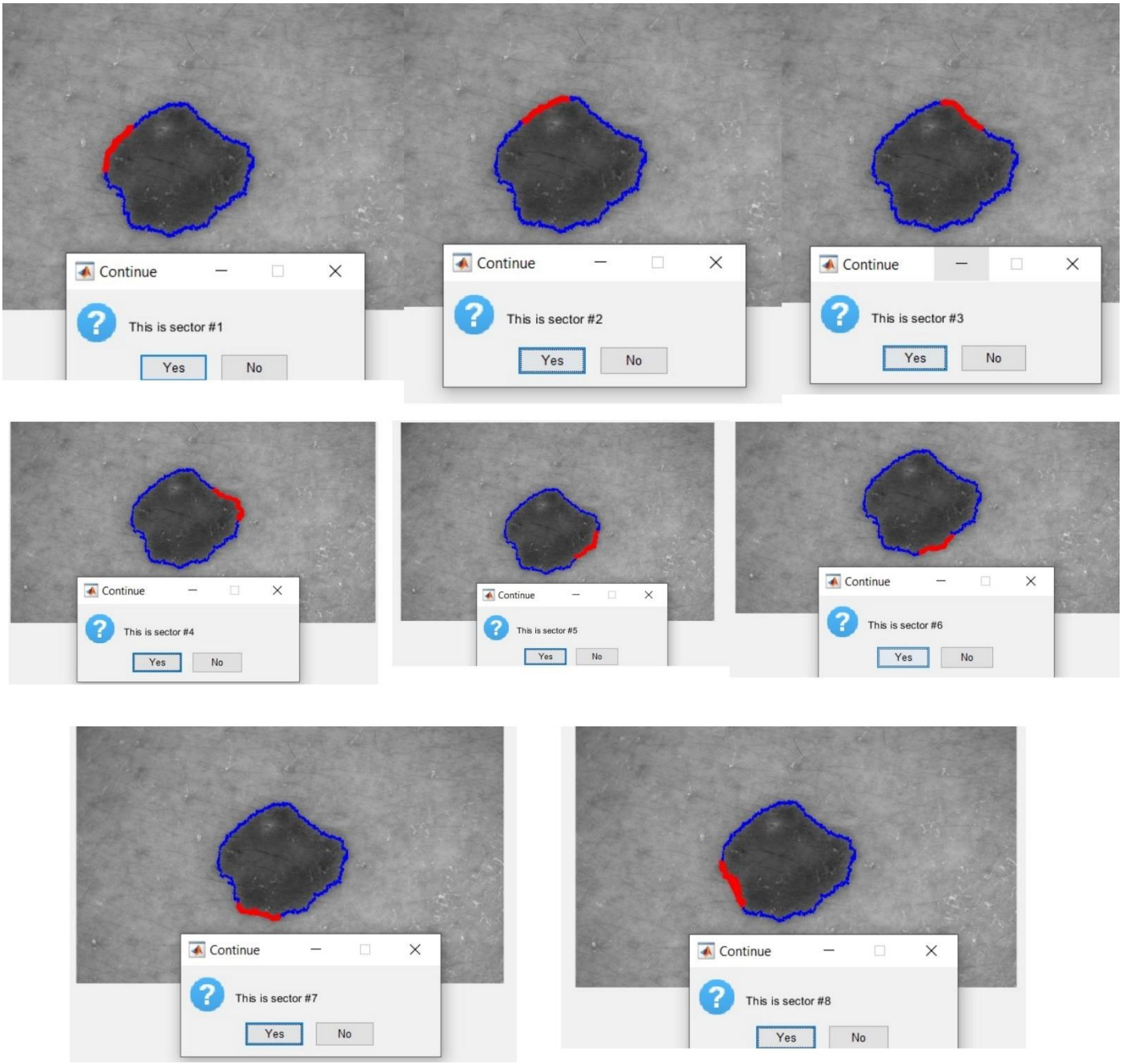
also to obtain higher fractal dimension for melanoma moles, at least in statistical sense, compared to the fractal dimension of non-melanoma moles. Although the fractal dimension does not act well to capture the difference between the uneven nature of the border on a small scale and the significant border irregularities and it is also depends on factors such as pixelization of the images, resolution of the images , the scale at which the object is considered , the noise in the images and the estimator used . All these factors affects the result since medical images typically suffer from at least one of these deficiencies. [18][62].

Border structure can be analyzed also by calculating edge abruptness. Edge abruptness is nothing but irregular boundaries. Lesion with irregular boundaries has large difference in radial distance. The estimation of barrier regularity is done by analyzing the distribution radial distance difference.

Proposed Methodology

Border's irregularity can also be measure by the following way. The borders are represented by the edge pixels of the lesion, obtained as a result of segmentation of the lesion. The lesion area is divided into eight equal parts, and the portions with an abrupt cut are calculated. T**he degree of border ranges from 0 to 8**. . For each sector in which abrupt cutoff of pigment pattern is present, one point is added to the score leading to a minimum border score of zero and maximum border score of eight. The degree of melanoma varies between 3 and 8 . [4] The evaluation of the border related with the existence of a sharp pigment at the periphery of the lesion.

First of all the skin lesion is divided into into **8 equi-angular (45°) areas** using as center the center of mass O of the region. Then the contour points of region are identified and after that I analyzed the sharpness for each portion independently. If the distribution of the radii of the polar coordinates of the contour points exhibit large variation for one of the eight areas the B value is increased by one. This happens for all eighths until the final value of B is estimated that should be between 0 and 8.



The calculation that we describe above is based on the Euclidean distance and the standard derivation in each sector.

$$Di = \sqrt{(x2 - x1)^2 + (y2 - y1)^2}$$

where x2 and y2 are the coordinates of the center of the lesion. x1 and y1 are the coordinates of pixel i in the boundaries over the image.

$$Distance = \sum_{i=1}^{N} Di$$

With N is the number of pixels in the edge belonging to the considered area. Di is the Euclidean distance between the center of the lesion and the pixel i. Then the standard deviation is calculated for each sector with the following equation:

$$s = (\frac{1}{N}\sum_{i=1}^{N}(xi - x)2)^{1/2}$$

where N is the number of elements in the sector. The procedure is the following: each pixel in the border of every sector is compared with its adjoining values. If an element of data is bigger than both of its adjoining, it is a local peak and that segment considered to be irregular. If there are no local peaks, that element is an empty vector and so the segment is recorded to be the smooth border. Within each sector, if the deviation exceeds a certain threshold, the score edge (border irregularity) is 1. This threshold is set empirically to 30. We create an array *stddev* which holds the average standard deviations of the distances from the centroid for each sector in order to see which sectors have high average standard deviations and extract the final borderscore. [16]. The maximum score that can be recorded is eight if local pecks or irregularities are recorded among the eight segments .

The results for two skin lesions are the following:

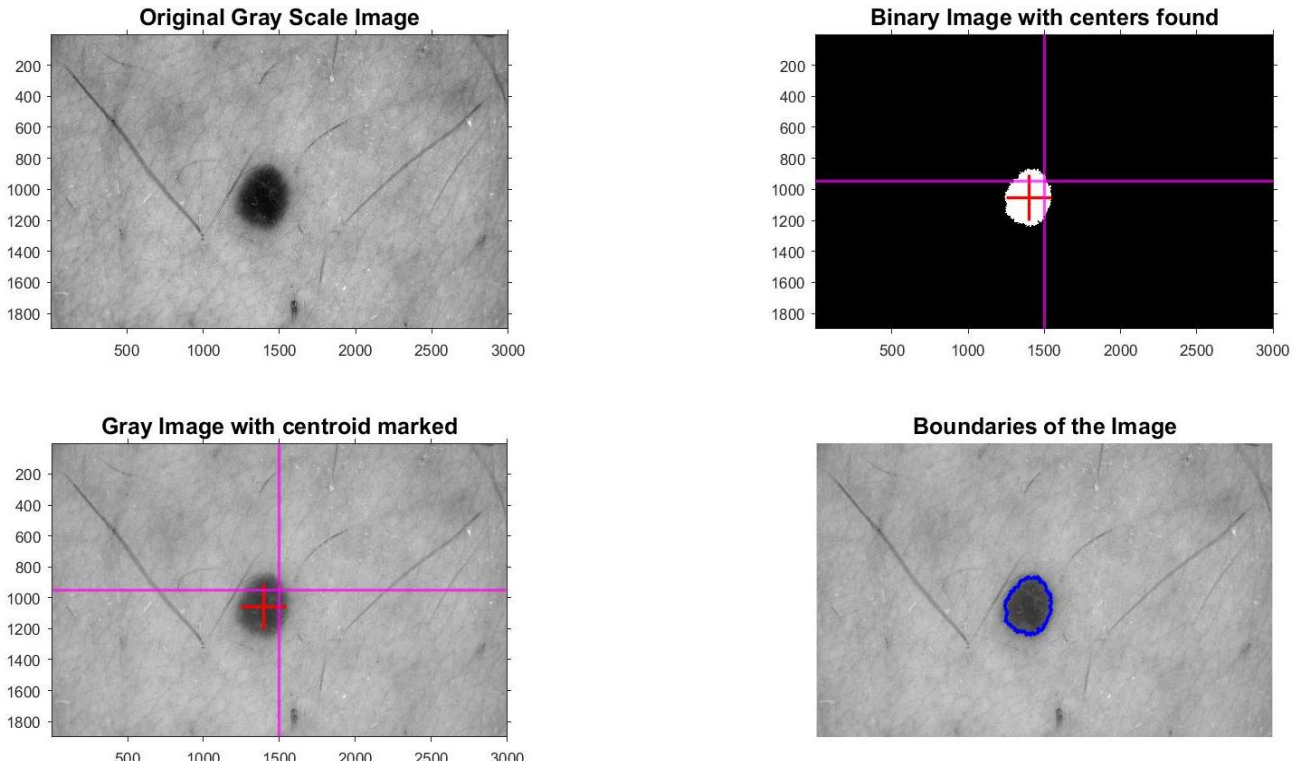


Fig 1. The result of finding the center of the lesion and its boundaries

We take the histograms of distance distribution to observe the probability distribution for distances from the centroid to the perimeter.

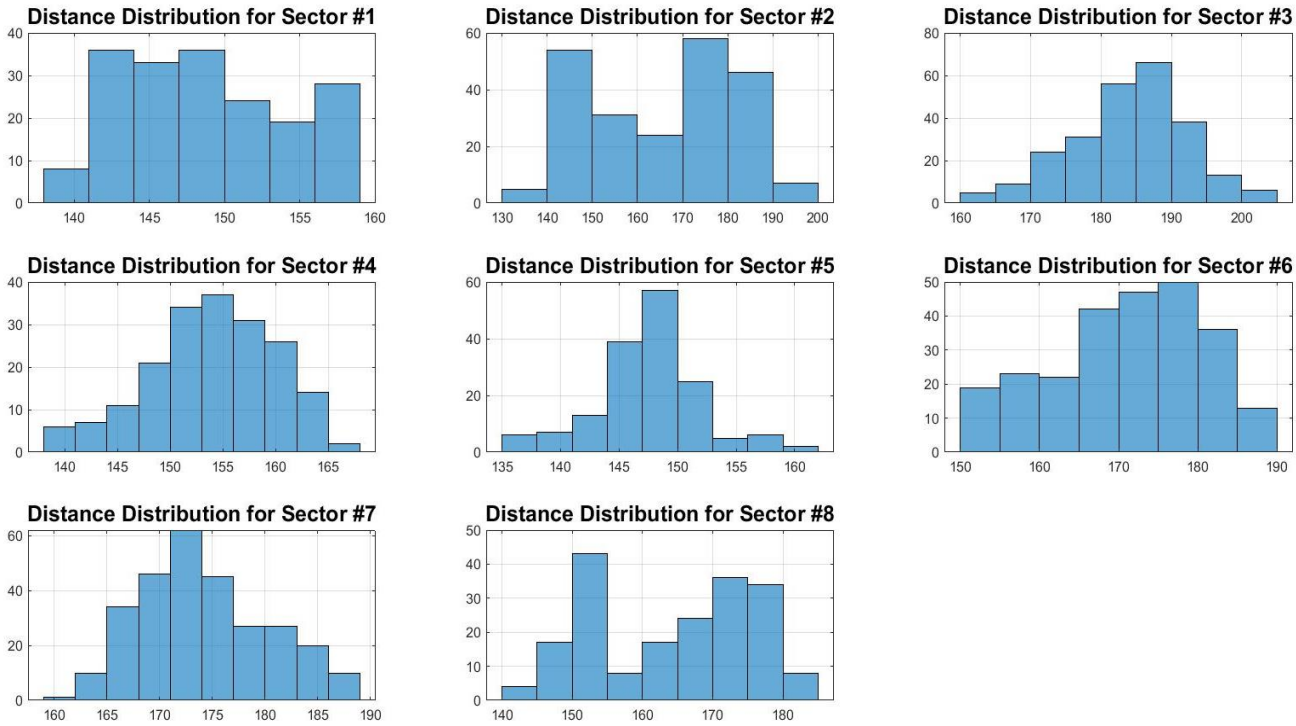


Fig 10. Histograms of distance distribution

stddev

1x8 double

	1	2	3	4	5	6	7	8
1	6.0074	13.5137	8.3879	5.5101	5.6616	10.2856	4.3820	10.1267
2								

Fig 11.The array that holds the average standard deviations of the distance for each sector

```
Command Window
  xCentroid =
           1396.82091848206
  yCentroid =
           1055.68744157427
  numberOfRegions =
       1
  sectorAngleLimits =
    -180  -135   -90   -45     0    45    90   135   180
  distancesWithinEachSector =
    1×8 cell array
      {184×1 double}    {225×1 double}    {248×1 double}    {189×1 double}    {160×1 double}    {252×1 double}    {282×1 double}    {191×1 double}
  borderValue =
       0     0     0     0     0     0     0     0
fx >>
```

Fig 12. Score of Border Irregularity

We repeat the same procedure for the second skin lesion:

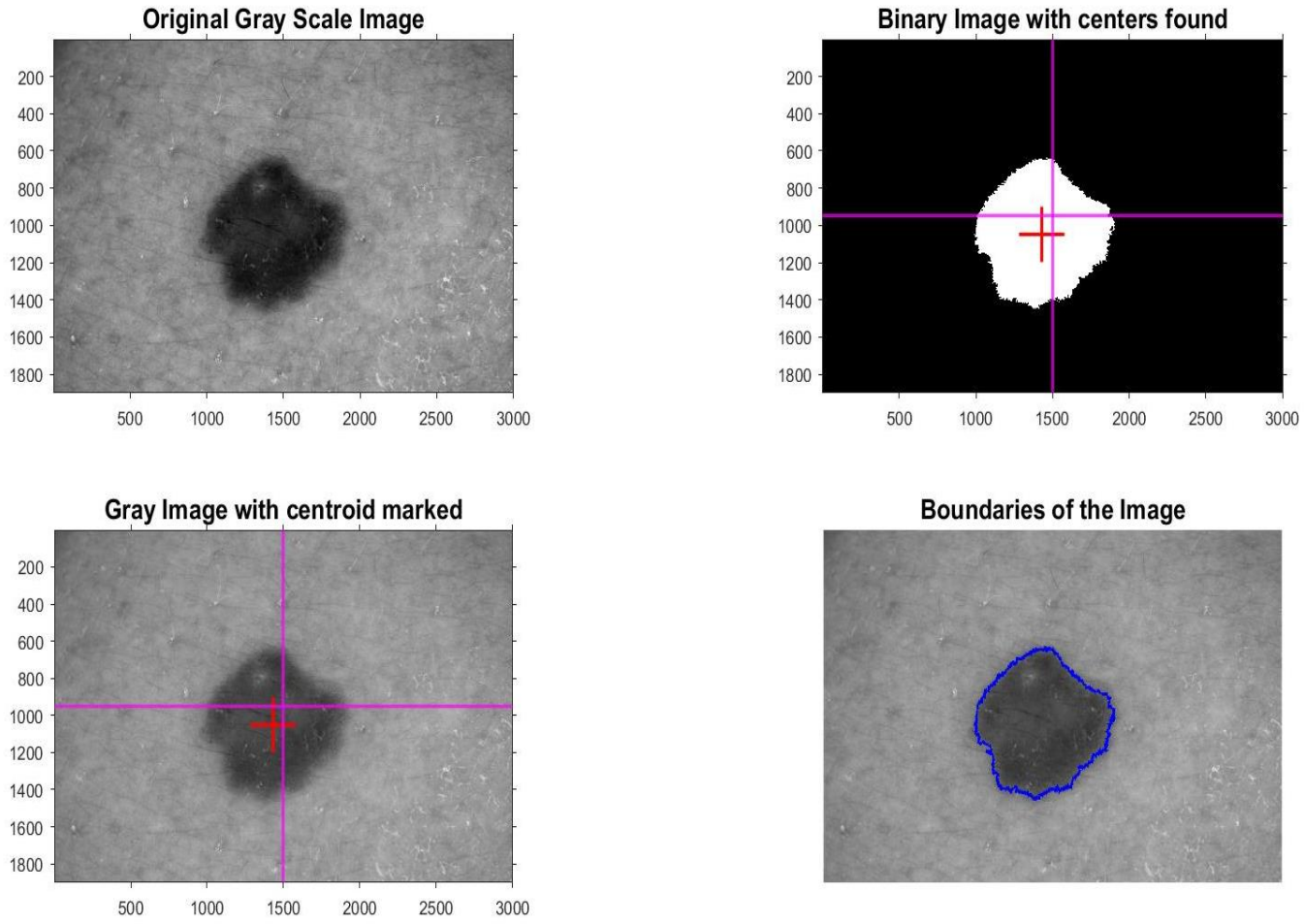


Fig 13. The result of finding the center of the lesion and its boundaries

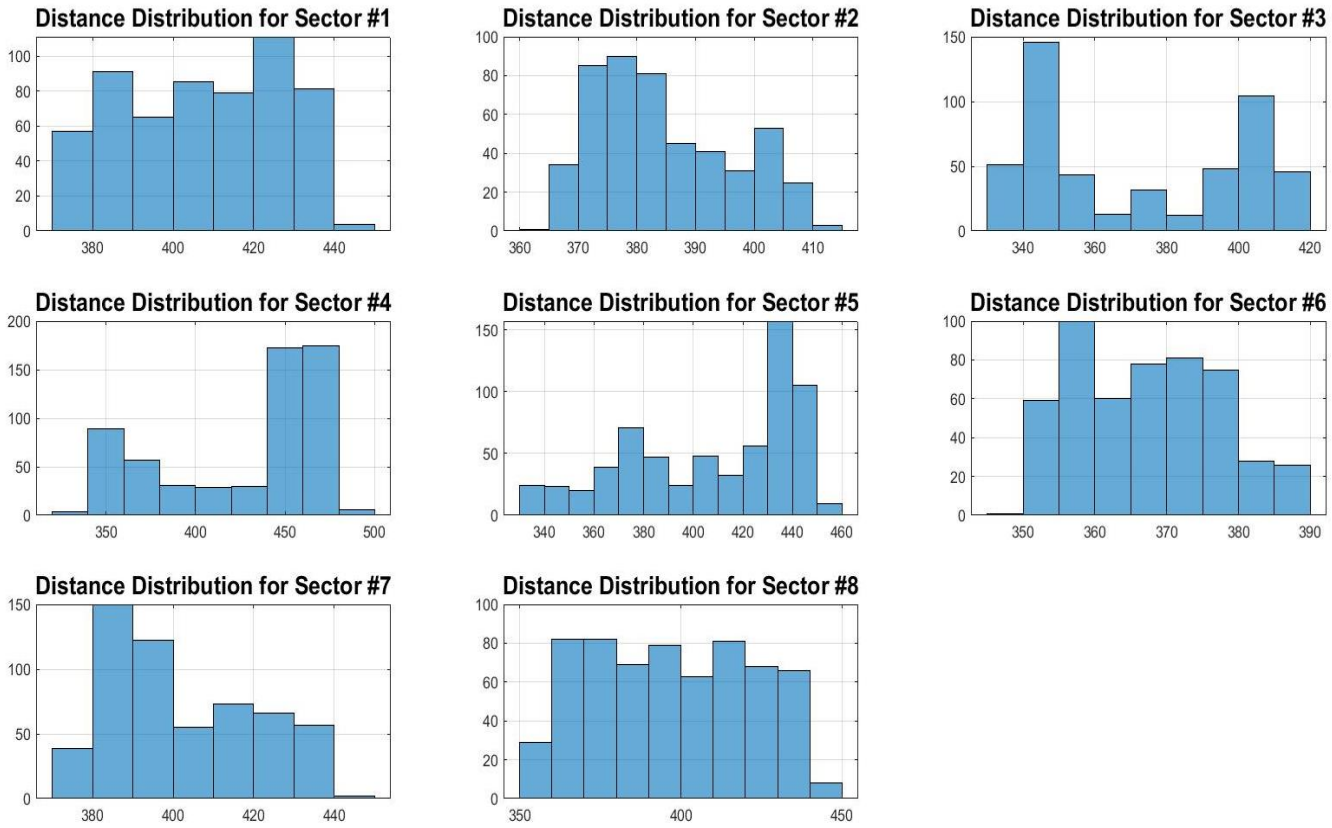


Fig 14. Histograms of distance distribution

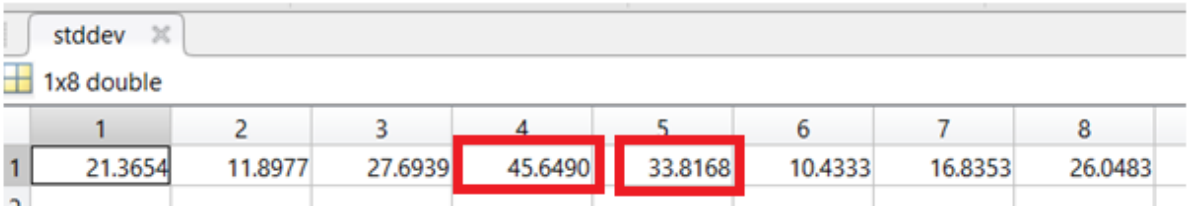


Fig 15. The array that holds the average standard deviations of the distance for each sector

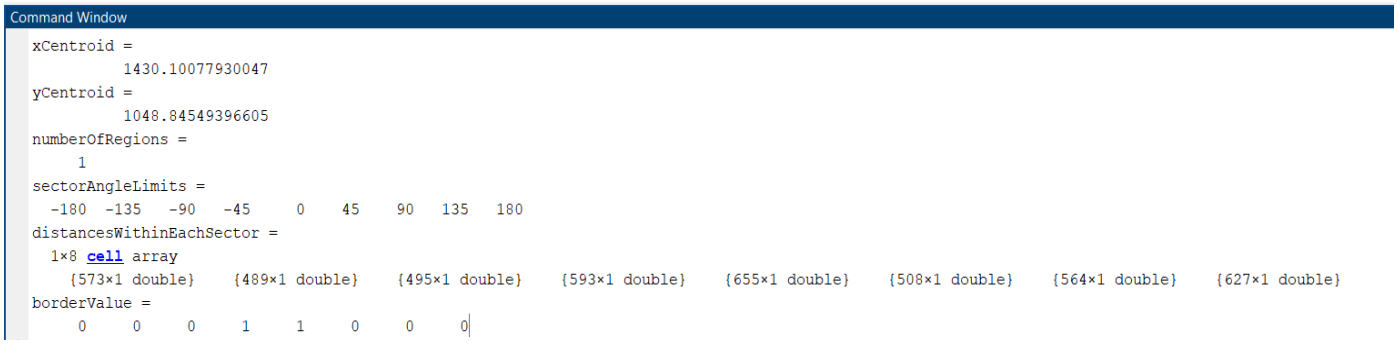


Fig 16. Score of Border Irregularity

5.4.3 Color

Color is considered one of the most important features that are used to diagnose skin diseases . Malignant lesion are represented by several colors. The colors in the lesion area are represented by six colours, the verified colors are: Black, Dark Brown, Light Brown, Red, Blue and White. For the above colors, the color values were originally set based on values reported by Grammatikopoulos [19] in Table 1 , Colors need to be either Unit8 if they are in the range 0-255.

colour	RGB	rgb
white	255,255,255	1.0,1.0,1.0
black	0,0,0	0.0,0.0,0.0
red	255,0,0	1.0,0.0,0.0
light-brown	205,133,63	0.80,0.52,0.25
dark-brown	101,67,33	0.40,0.26,0.13
Blue-gray	0,134,139	0.0,0.52,0.54

Table1. RGB description of ABCD colours.

Melanoma cells are commonly colorful like brown and black that based on the production of melanin pigment at various depths within the skin. A point is assigned to each color if found in the lesion area and then it is summed and multiplied by a weight factor 0.5 as equation: [(white + red + black + light brown + dark brown + blue-gray) $*$ 0.5]. The maximum score is 6 when the lesion contains six colors. Melanoma disease includes at least three colors. Statistical measures are applied to represent the colors in the area of interest. Before attempting to find color variegation (The *C* feature in the ABCD rule) in the skin lesion and verify the existence of each color in the lesion, the image was converted from the RGB color space to the CIE Labcolor space because the distance between two colors in the RGB color space does not closely match the human visual perception, namely does not reflect the "difference" perceived by the naked eye contrary to the CIE Labcolor space. Moreover, CIELab is considered more precise since the distance between colors using this color space corresponds to the perceived color distance. CIELab is device independent, meaning that the color model is based on the perception of the human eye and is designed to describe what colors look like regardless of what device they are displayed on.

This difference can be calculated using the Euclidean distance delta E.

$$\Delta E = \sqrt{(L1 - L2)^2 + (a1 - a2)^2 + (b1 - b2)^2}$$

where L1, a1 and b1 are the components of the CIE Lab colorimetric space of the desired color and L2, a2 and b2 those of each pixel of the image. Specifically in the algorithm used, all the pixels constituting the lesion (i.e. excluding surrounding healthy skin) are scanned and the Euclidian distance in "rgb" coordinates D is calculated between their color and the six reference colors mentioned above. So , we create a Delta E image for each color of six suspicious, to represent the color difference and after that I got the mean Delta E color difference within the mask area only and without compare it with the healthy surrounding skin . We create in this way a classified image , where each image pixel has a value of the six refenrce colors according to the minimum delta E. For example , if a particular pixel has a delta E of 2 for dark brown and a delta E of more than 10 for all the other colors, then that pixel is classified as being dark brown. In this way, we achieve to recognize how many pixels are in each color class. As we study in bibliography a lesion is considered to contain a suspicious color if the pixels belonging to this color represent more than 5% of the skin lesion pixels.

So the last step I had to follow was to scan the RGB segmented image and if the number of pixels of each color is greater than a certain Limit L=5% of the total number of pixels in that lesion, then this color is considered as present in the lesion. I applied the algorithm using L=5% and I got the following results: As I observed also by changing the value of parameter L , the performance of algorithm crucially depends upon the decision parameter L and finally can have an effect on the final color score.

Create Mask Using Color Thresholder App

In this study a MATLAB an app called Color Thresholder has been executed since, with the help of this app image segmentation can be an iterative process. We selected the color space that provides the best color separation.[53]

More specifically we got the following results:

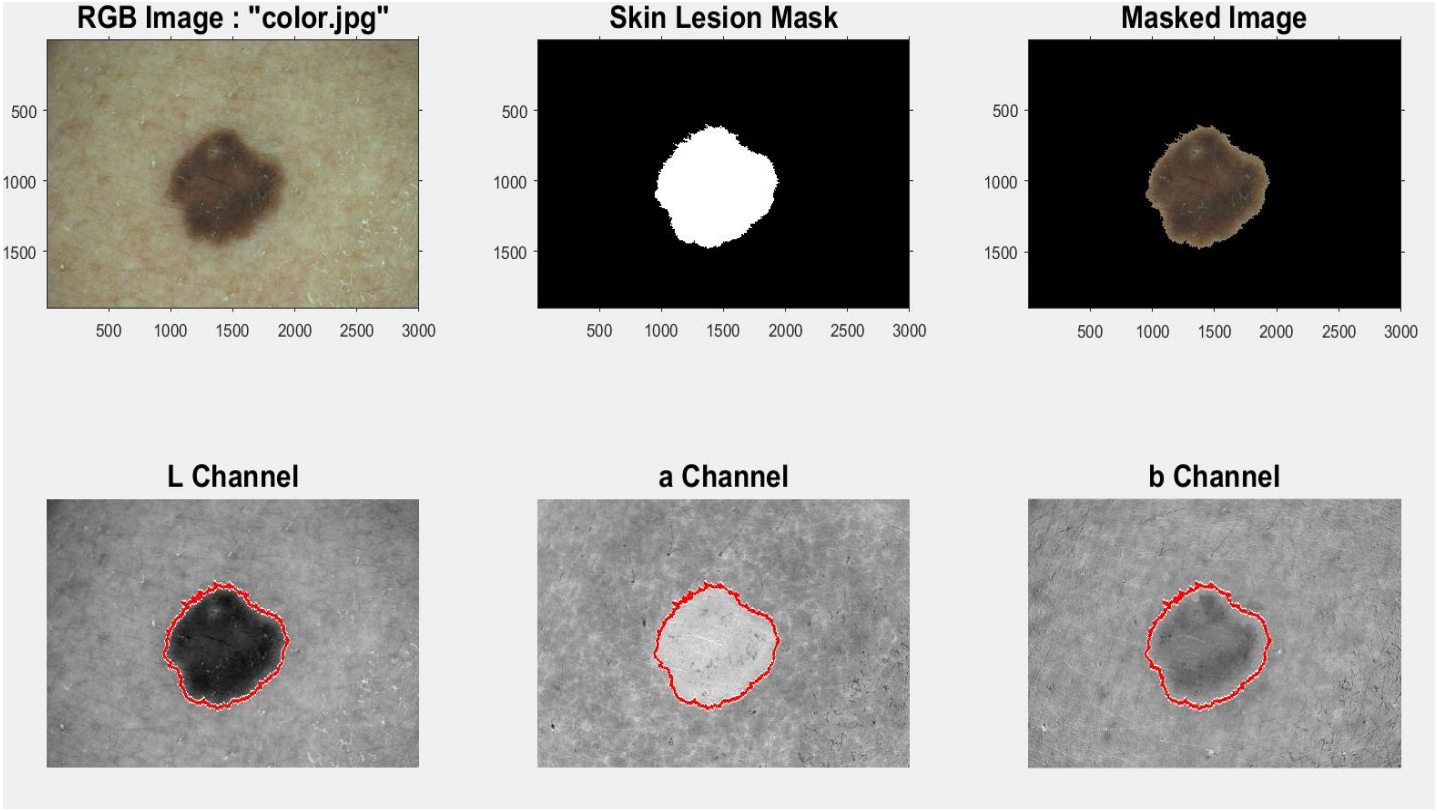


Fig 17. Extraction of the color bands from the original image into 3 separate 2D arrays, one for each color component.

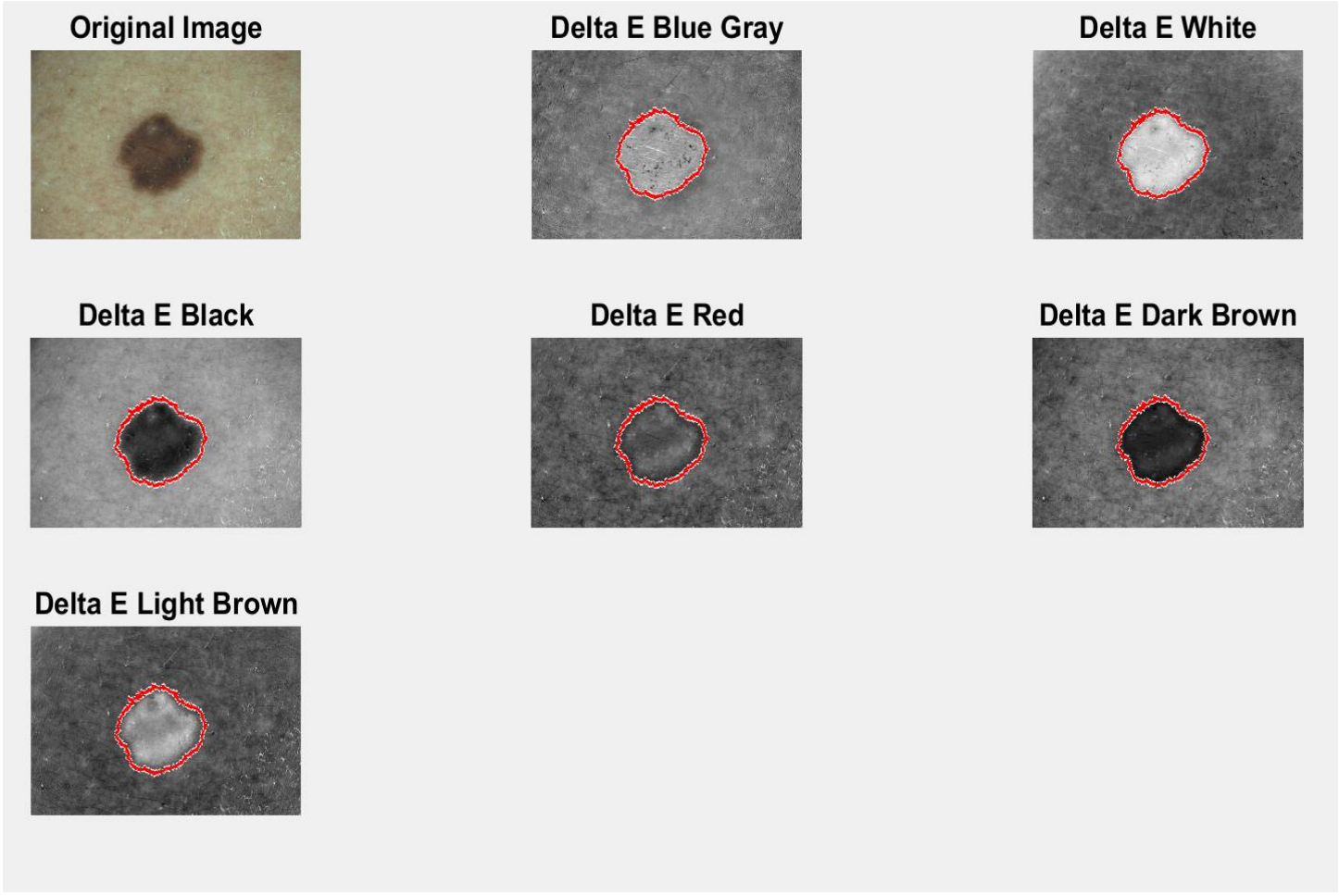


Fig 18. Delta E images for the six reference colors

The classified image is the color class that has the minimum delta E from the image pixel to the 6 reference colors.

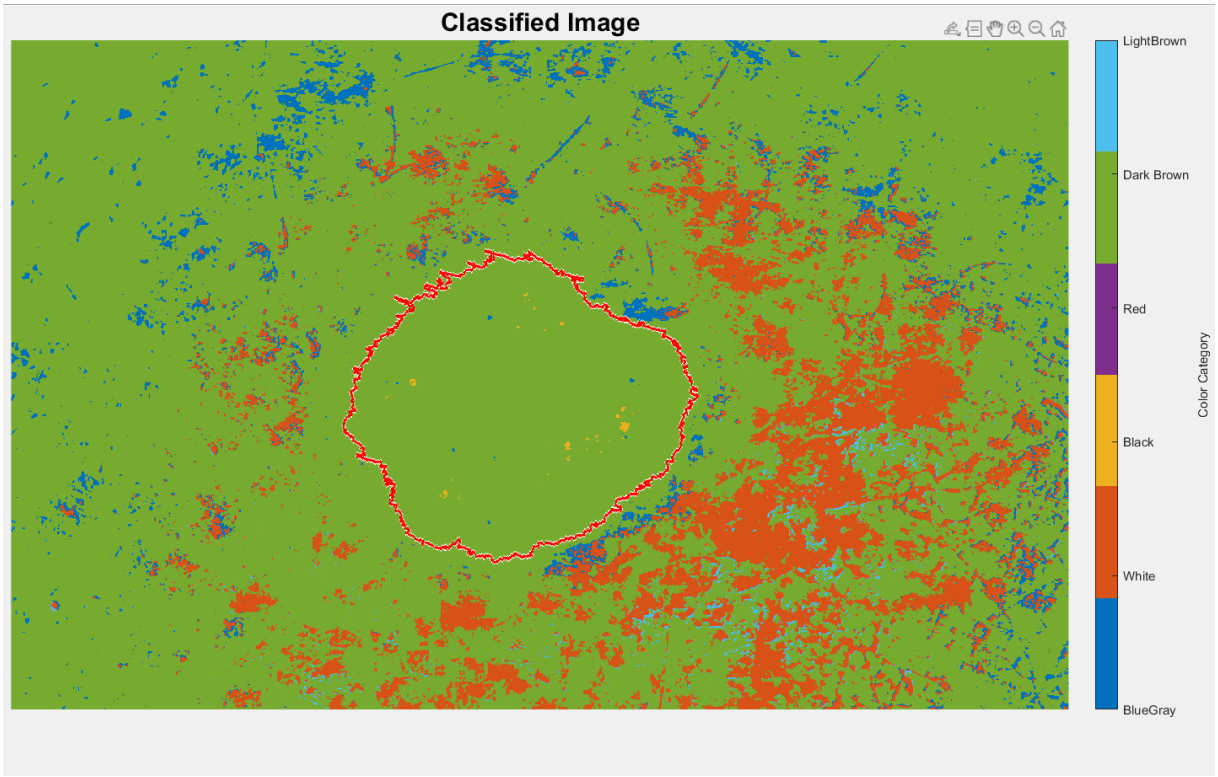


Fig 19. Here is the image showing the classifications. As we can observe most of the skin lesion is classified as being in the dark brown category.

The last step was to check if the number of pixels belonging to each reference color exceeds by 5% of the total number of pixels of the lesion. So we had to get the fraction of each class within the masked lesion area. We decide to take the histogram of the classified image in order to count how many pixels are in each color class. We got in this way how many pixels have value 1, how many pixels have value 2, and so on.

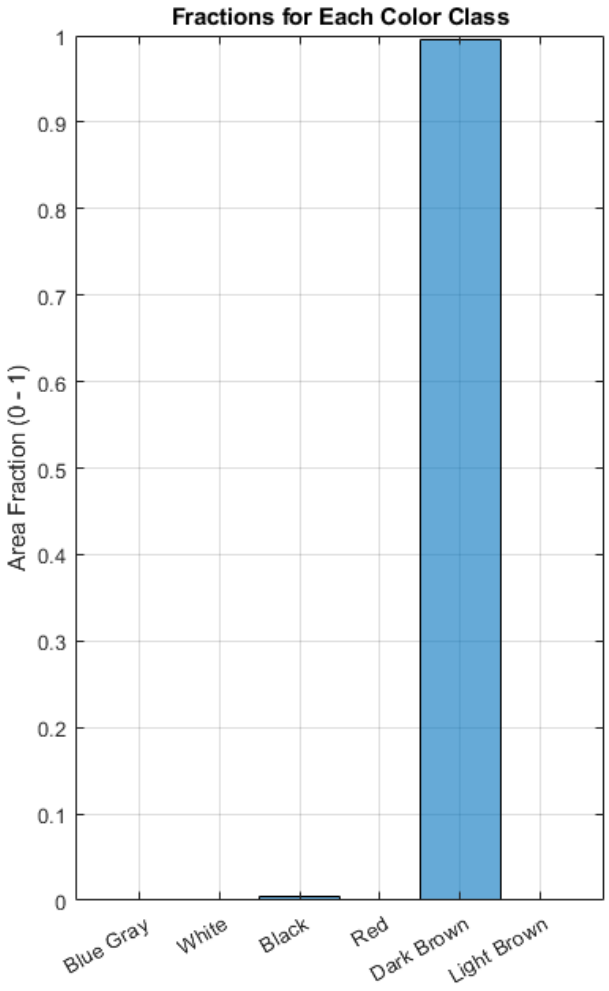


Fig 20. Histogram of color classes within the mask.

We repeat the procedure for the second skin lesion and we got the following results :

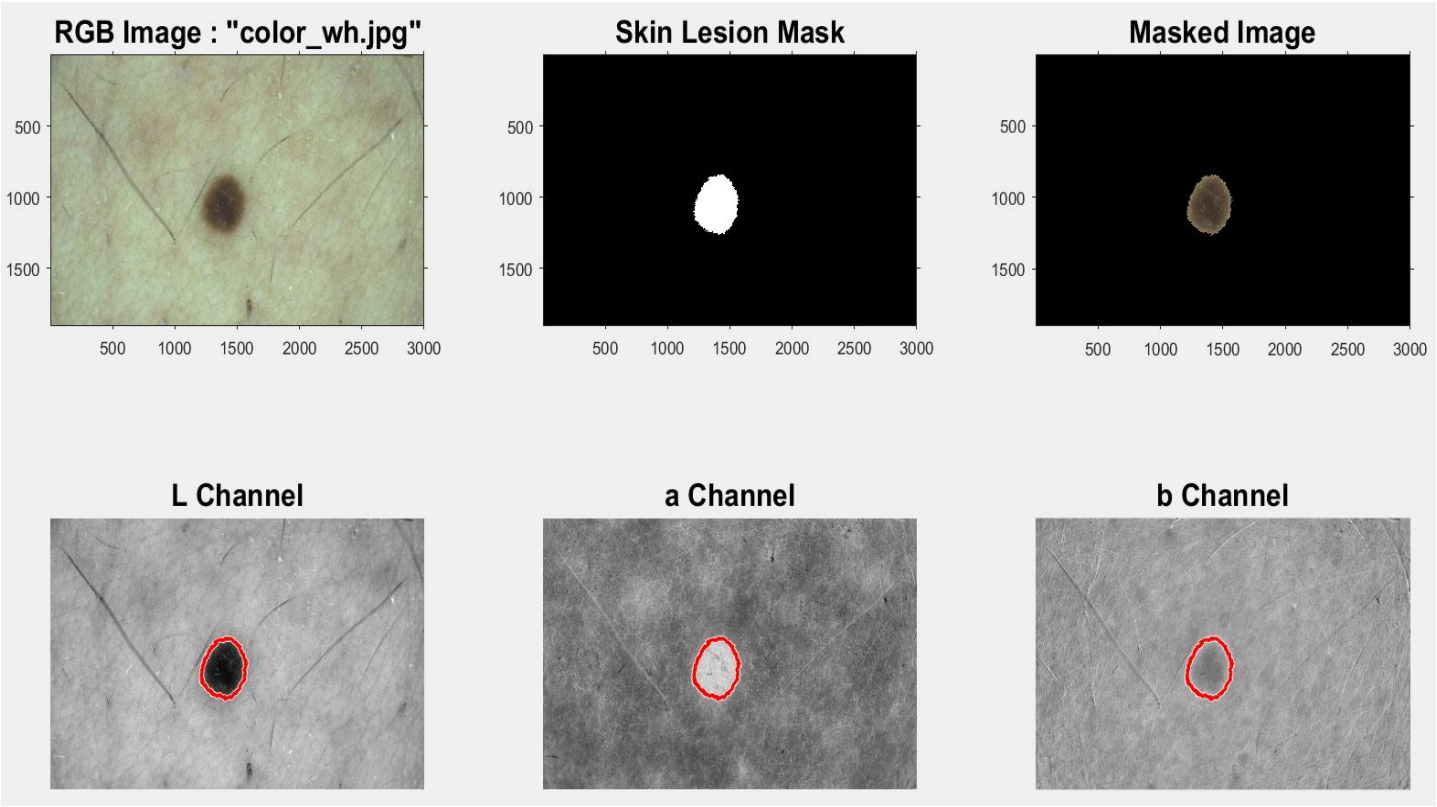


Fig 21. Extraction of the color bands from the original image

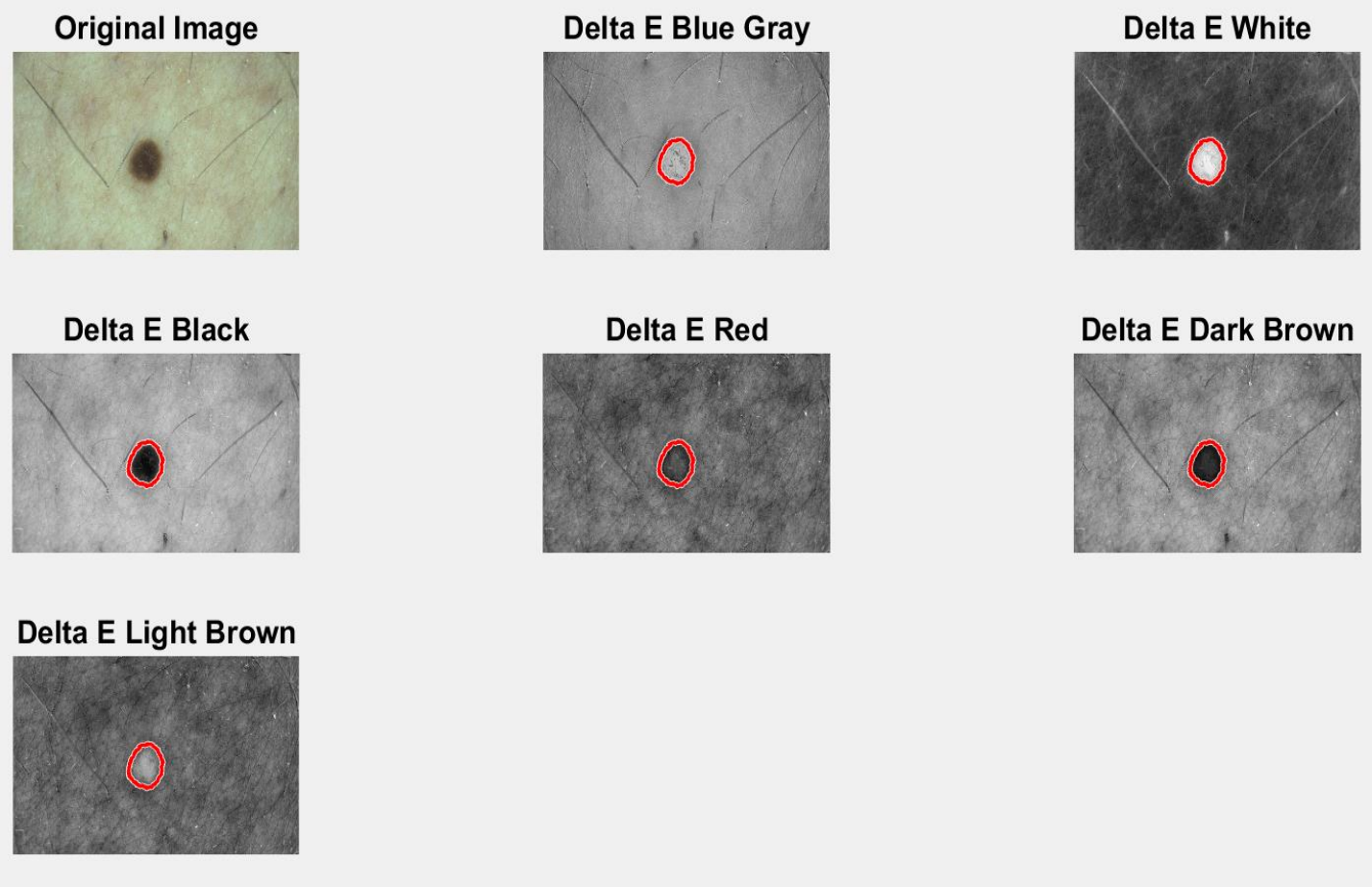


Fig 22. Delta E images for the six reference colors

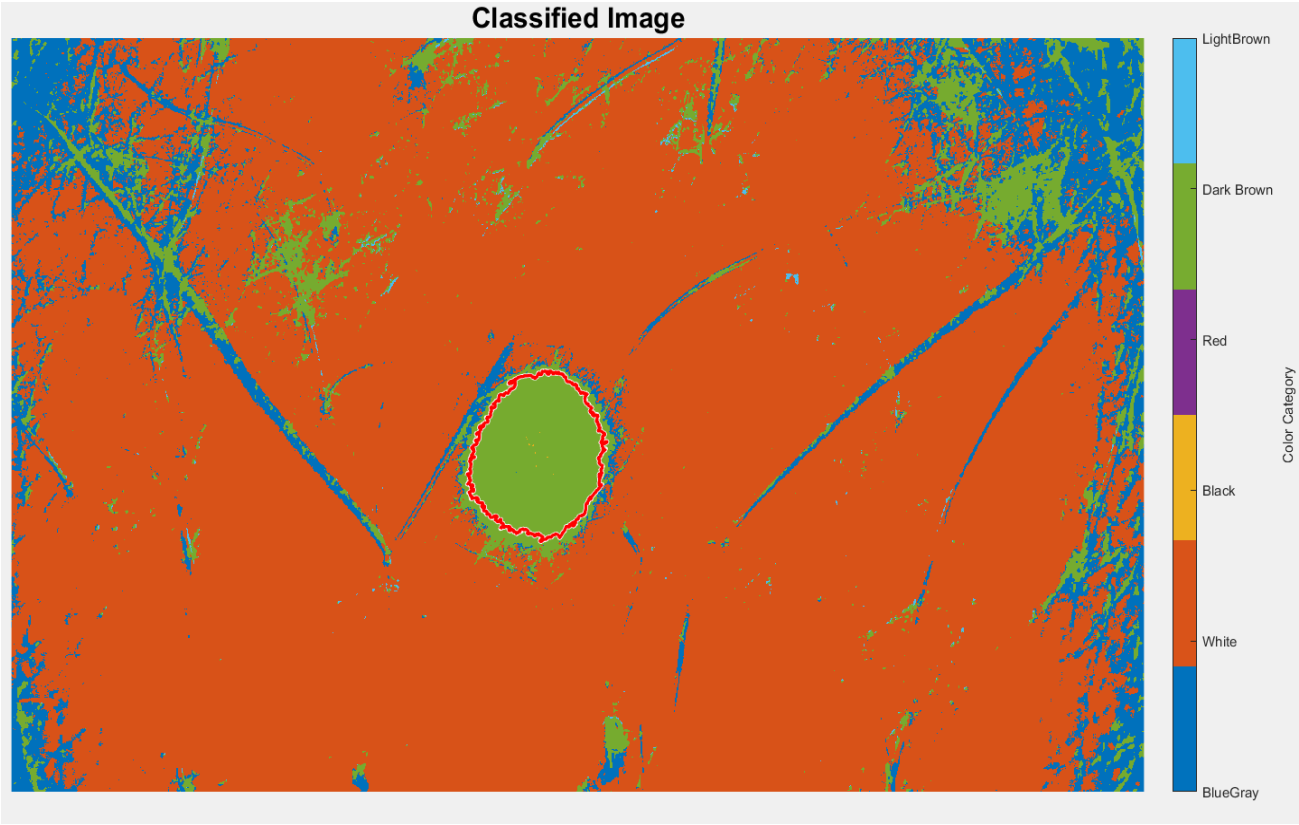


Fig 23. As we can observe most of the skin lesion is classified as being in the dark brown category.

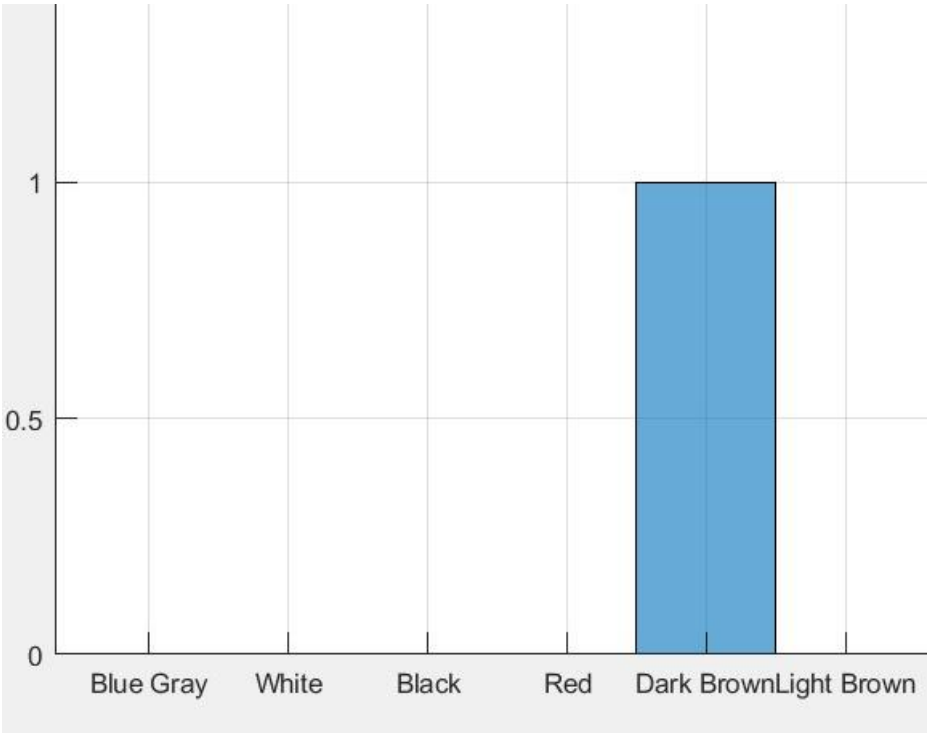


Fig 24. Histogram of color classes within the mask.

5.4.4 Diameter

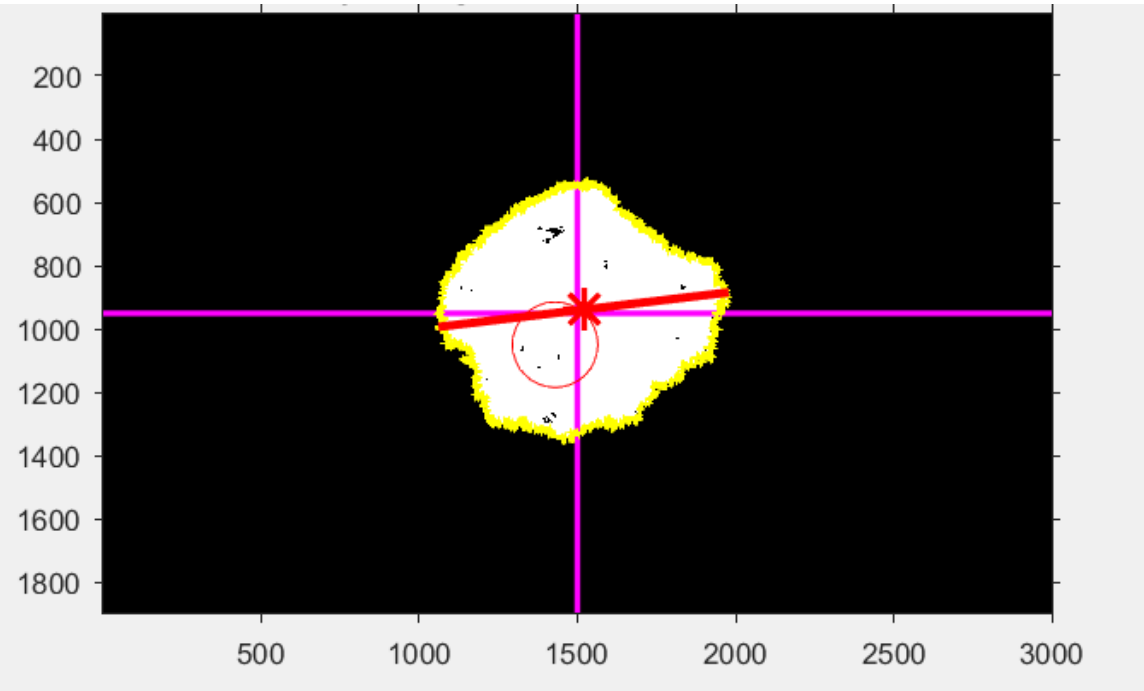
The diameter D is also one of the ABCD criteria. Parameter D was not directly identified as the previously mentioned A, B, and C parameters, where previous literature describes it in two different ways. Some studies describe it as the tumor diameter , while other theories define it as a differential structure [20]. The algorithm that we propose for calculating the diameter is based on finding the long axis of the skin lesion. As many studies describe melanomas usually start with a diameter of more than 6–7 mm. More specifically, when the diameter of the lesion is greater than 6 mm and grows continuously, it is malignant,and when diameter is less than 6 mm skin lesion is a benign lesion. In ABCD rule, the diameter is one of the features that takes the weight 0.5 as (0.5 * diameter). Any lesion with diameter >6 mm will have a D score equal to 5. [4]

The steps that we follow to find the diameter of the skin lesion are presented as follows and are based on the study ***"Segmentation and ABCD rule extraction for skin tumors classification"*** [21]

- Image segmentation
- Determine the coordinates (x, y) of each pixel of the lesion's boundaries
- Calculate the distance between each pair of points to find which two boundary points are farthest from each other.
- The maximum of these distances is the diameter

Additionally, we convert the diameter in mm using the fact *that 136 pixel is equal to 1 mm* according to magnification. Diameter in real world is measured in millimeters (mm) and our diameter results are returned

in pixels , so we represent our diameter results in terms of standard unit (mm). As we already know dermatoscopes are instruments that employ light and magnification to evaluate skin lesions.



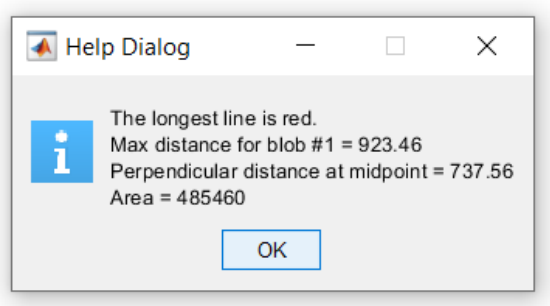
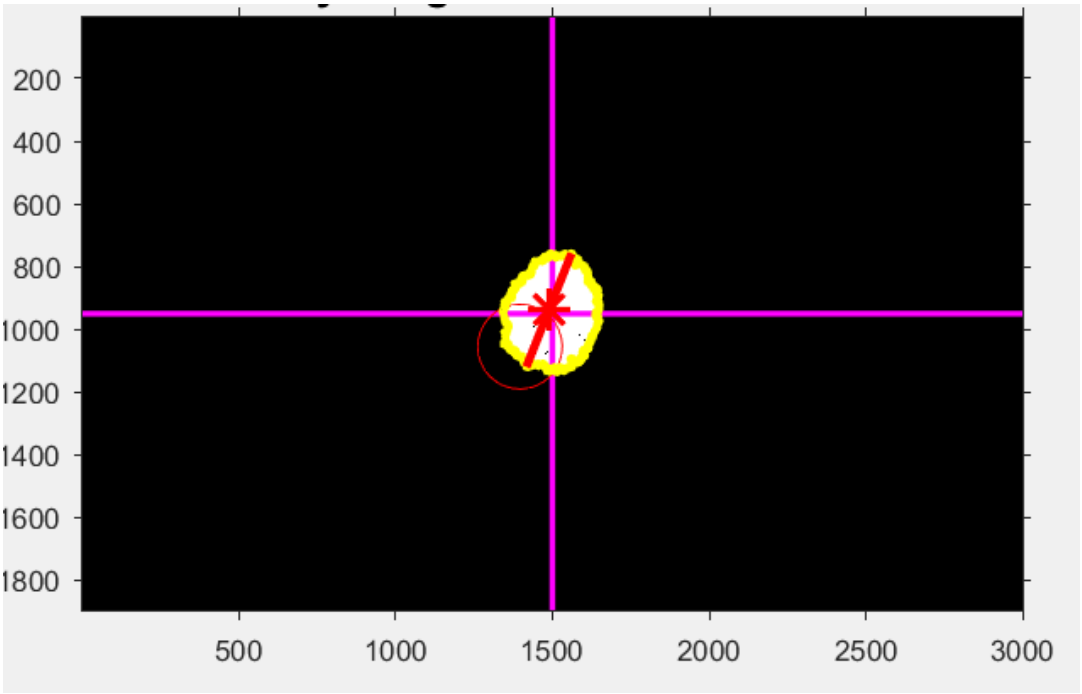
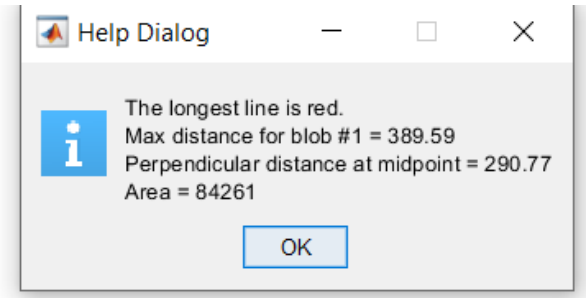


Fig.25-26 The length of the red line is the one which connects the two farthest boundary points.

We repeat the same procedure for the second skin lesion :





Chapter 6

6. Classification

Lesion classification is the final step. There are several existing systems that apply various classification methods. Most lesion classifications are binary in nature, distinguishing between benign and malignant moles. The classification results are typically influenced by the chosen feature descriptors and strength of the classifiers. Due to the astounding advancement of image capturing devices over the years, the data is quite large and image quality has been improved, attracting the interest of image analysts in the classification of dermoscopic images. The extracted features from the skin lesion are used as inputs to a feature classification module to classify each skin lesion.

The two main classification types as reported in the literature in relation to medical imaging are supervised classification and unsupervised classification. Some of the most common classifiers are Artificial Neural Network (ANN) , decision trees (DT)**,** k-nearest neighbors (KNN), support vector machines (SVM) , linear discriminant classifiers and TDS classifiers. These systems use traditional machine learning techniques, therefore the chosen representation for the image and the quality of the extracted features can heavily affect their performance. Hence, a certain level of expertise is required for the feature extraction of the skin lesions.

The literature also records the use of rule-based process for classifying skin lesion images. Frequently used rule-based procedures include Pattern Analysis, ABCD rule, ELM 7-point checklists, Menzies score, 7 Features for melanoma. [52]

6.1 Proposed Method

This stage depends on the summation of the four extracted feature that we analyze above. After taking a score to each one of the presented characteristics (**Ascore, Bscore, Cscore and Dscore**) is multiplied by its corresponding weighting factor, the Total Dermoscopy Score (TDS) is calculated as the equation :

$$TDS = [(A_{score} * 1.3) + (B_{score} * 0.1) + (C_{score} * 0.5) + (D_{score} * 0.5)]$$

where the score ranges of A, B, C, and D are (0 – 2), (0 – 8), (1–6), and (0–5), respectively. This score contributes to identify melanoma or benign lesions as follows:

- if TDS > 5.45 considered to be melanoma.
- if TDS < 4,75 refers to benign lesion.
- if 4.75 < TDS < 5.45 indicates suspicious.

Patients who have TDS between 4.75 and 5.45 are recommended that they should be re-examined at regular intervals against the possibility of developing melanoma, and ones having TDS of higher than 5.45 are recommended that they should be operated for examining of their lesions histopathologically. A suspicious melanocytic lesion without criteria suggestive of melanoma should be monitored in short-term follow-ups within three to four months (6). On the other hand, patients having known risk factors for melanoma but

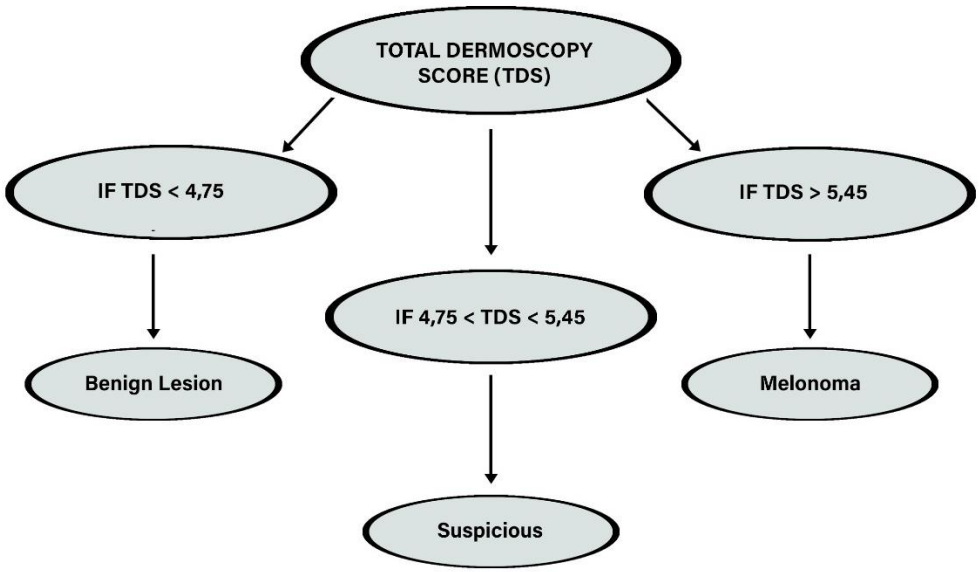
not having any suspicion in their lesions can be monitored using long-term follow-ups within six to 12 months. [2]

Calculation of TDS with the ABCD Algorithm

ABCD Features	Value	Weight Factor	Subscores
Asymmetry		**1,3**	**0 - 2,6**
Symmetric	0		
One-axis asymmetry	1		
Two-axis asymmetry	2		
Border irregularity		**0,1**	**0 - 0,8**
0 to 8 border	0 - 8		
Color (one point for each color)		**0,5**	**0,5 - 3**
White, light brown, dark brown, blue-grey, red, black	1 - 6		
Diameter	1 - 5	**0,5**	**0,5 - 2,5**

6.2 Results

To classify the lesion and by summing up the obtained values from the ABCD algorithm, the Total Dermoscopic Score (TDS) is calculated based on the following formula where each one of the presented characteristics is multiplied by a weighting factor as we described above. Each feature of ABCD rule gets a specific value between a range of values.

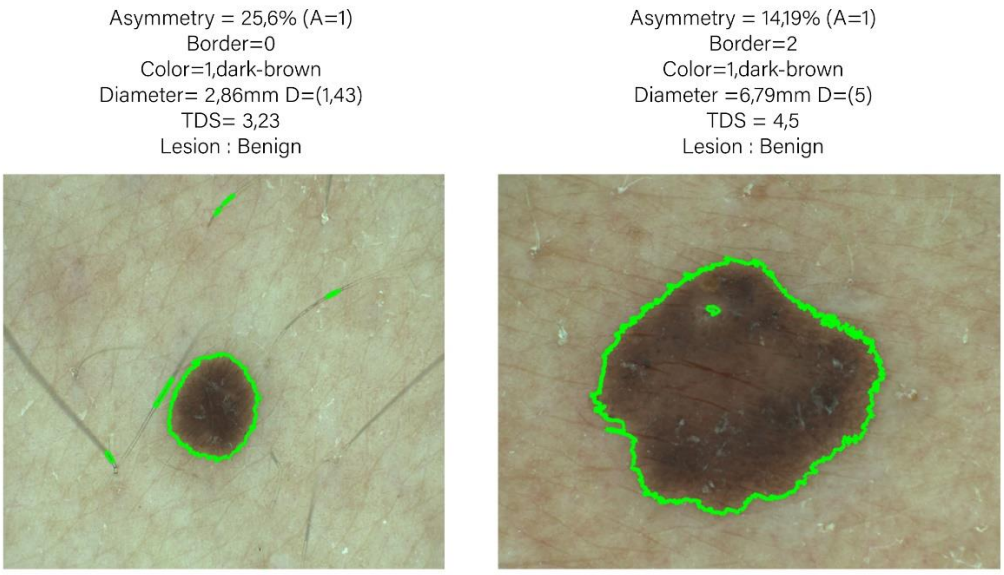


The results are shown below:

Both of skin lesions was benign lesions according to their characteristics.

	color_mole	color_wh
A	14,19%	25,6%
B	2	0
C	1	1
D	6,79mm	2,86mm
	TDS=4,5	TDS=3,23

The proposed method in MATLAB environment which we described above can be helpful and objective for melanoma cancer diagnosis. We managed to distinguish the features associated with shape , size and color properties to detect melanoma on its early stage based on ABCD rule .



6.3 Spectral Features

As we already refer, images in a different wavelength range contain diagnostic information about skin's tissue pathology and can provide more details for differentiating between normal and abnormal skin's tissue compared to RGB color images. Since human vision is limited to visible light, spectral data in the near-infrared region may augment the surgeon's ability to noninvasively identify tumors with increased penetration depth into skin tissue. The overall reflectance information had to be split in two categories because of human's vision feature. The first one is the visible wavelengths until 700nm and the second one is the near-infrared wavelengths, between 700 and 1000nm.

One important benefit of dermoscopy is referred in study [23] where authors clarify that dermoscopy used in conjunction with clinical examination and patient history results in a 50% improvement in diagnostic accuracy. However, it's still in doubt whether dermoscopy can have objective results when it comes to skin moles with diameter smaller than 6mm or featureless melanomas.

On the second part of this study, we try to revisited the ABCD criteria with an analysis of the features of pigmented skin lesions in near-infrared spectral bands. The given images are shown in the wavelength range of 400 nm - 8800 nm. The depth of penetration of light into the skin is directly related to wavelength. Information found at different depths is useful in differentiating benign pigmented skin lesions from malignant lesions. Thus, we can obtain useful information about the skin lesions indiscernible to the human eye. [26,51]

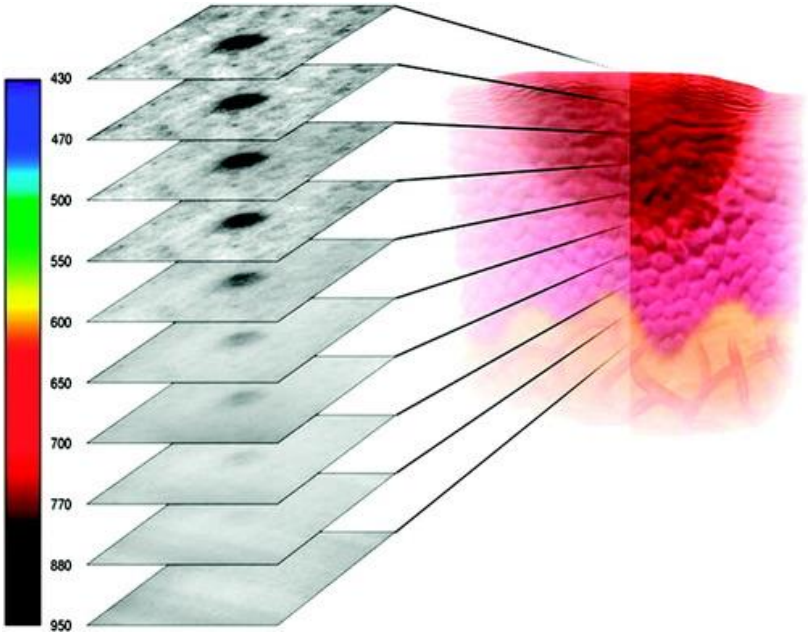
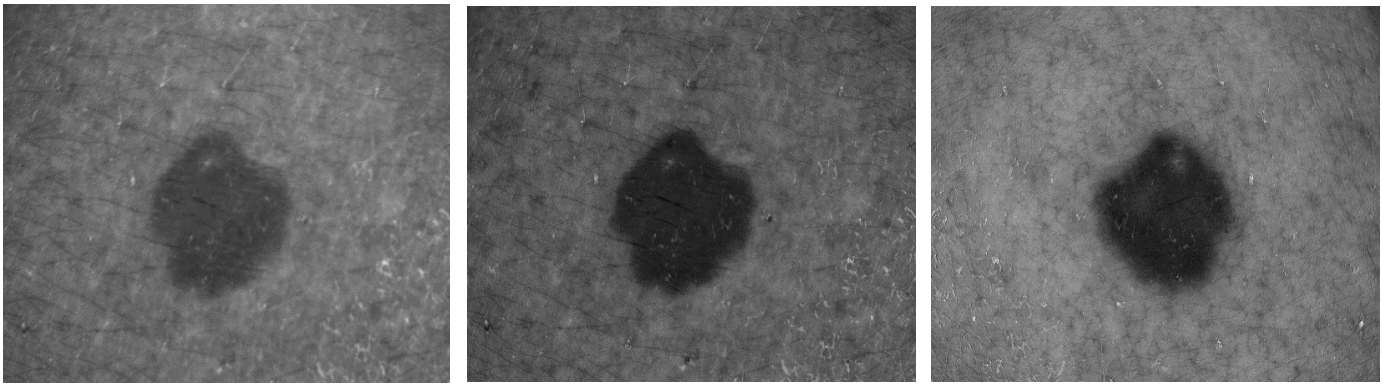


Fig1. The image above can show us how the penetration depth of light into skin varies with wavelength in accordance with the optical properties of skin. [51]

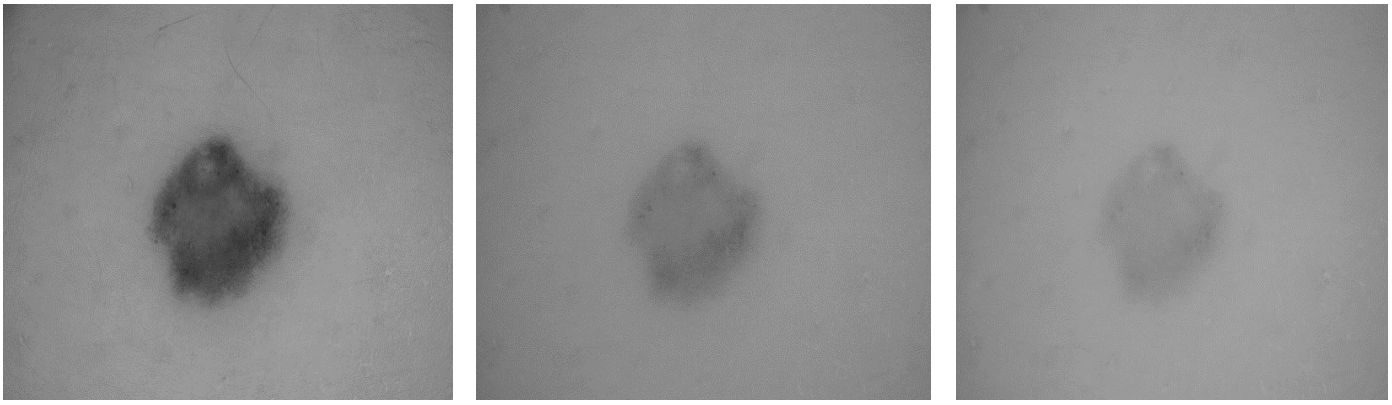
First of we all can extract some conclusions from the given images below:

Skin lesions in different wavebands

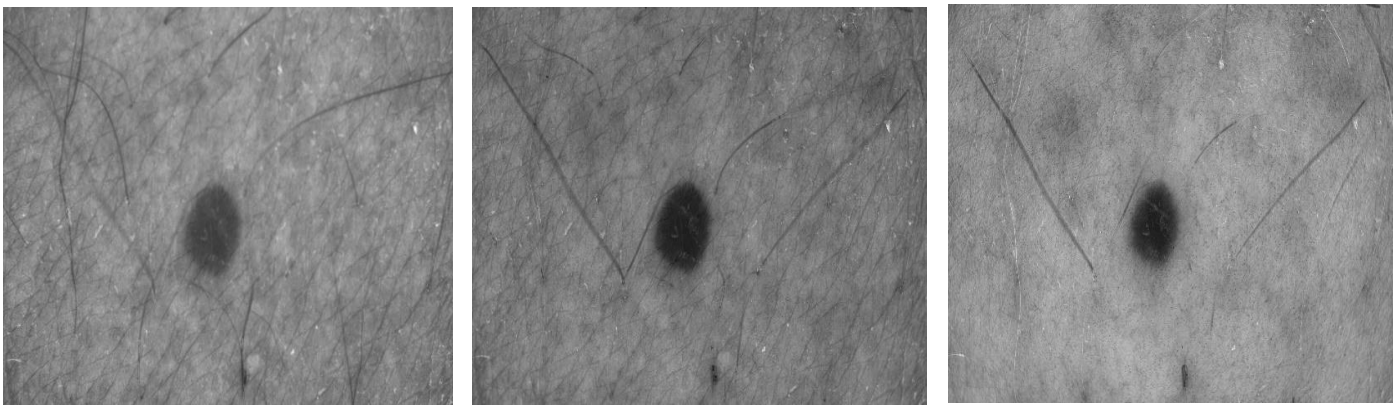
400nm **460nm** **540nm**



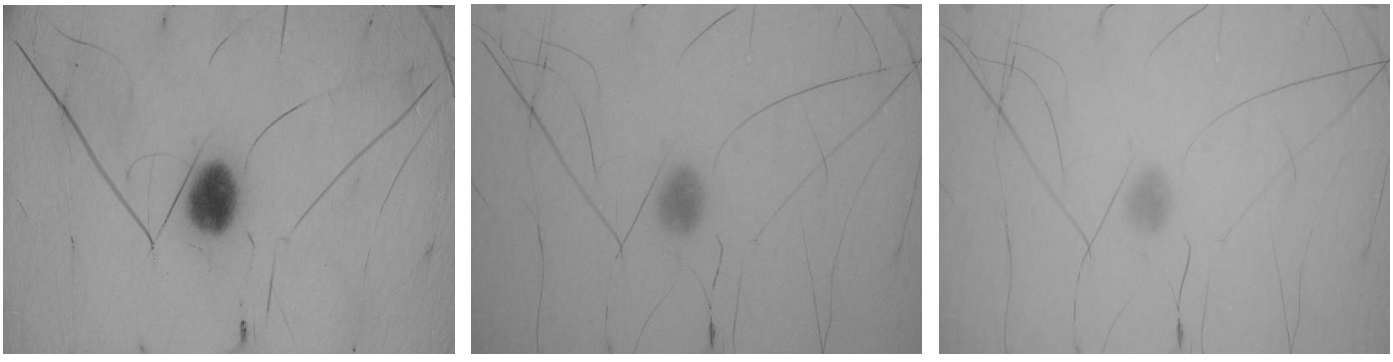
640nm **780nm** **880nm**



400nm **460nm** **540nm**



640nm **780nm** **880nm**



Skin lesions are depicted in six different wavebands (400nm, 480nm, 540nm, 640nm ,780nm, and 880nm) to show the differences in melanin absorption. On the first two rows is the suspicious skin lesion and on the other rows the benign one.

As it can be observed healthy nevi regions get transparent as the measurement proceeds into the NIR. On the other hand, some patches or spots on the nevi remain visible even after 640nm. Especially, in the case

of the first skin lesion, the suspicious region of the nevus remains dark up to 880nm. This is due to the high melanin concentration in this region on the nevi. Melanin is the main skin absorber in the infrared region of the spectrum. As the malignancy of a nevus increases, so does the melanin concentration in the skin. So, dark spots that remain after 640nm can be indicators of a problematic nevus. With reference to the second skin lesion , we can distinguish small melanin concentration in the region of skin lesion but it is essential for pathologists to make the final diagnosis

As we analyzed on **Chapter 4** the quality of interpretation of an image depends heavily on the segmentation process, which plays a major role in image processing and computer vision. We apply Tyler L. Coye's script for the segmentation of skin lesion, and we try to delineate the regions of given images in different wavelengths as we show above. Experimental results on the given images have shown that this method of segmentation is quite capable of providing accurate segmentation results for the first case of skin lesion, but it failed to detect correctly the border for the original skin lesion images belonging to the second case due to the artifacts (skin lines, thick hairs etc.).

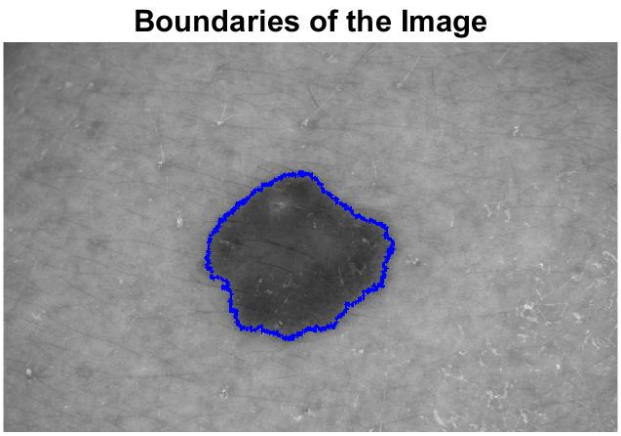
In an attempt to evaluate objectively the involved clinical characteristics and apply ABCD Rule in six different wavebands of the skin lesions we observe that the given images did not provide a satisfactory evaluation of color variegation and thus this parameter was not considered in the current study. Color variegation is one of the most important feature in distinguish skin pathologies such as melanoma from other pigmented lesions and it is a challenge to achieve utilize this feature to obtain valuable spectral information about different pigmented lesion.

6.3.1 Border in the wavelength range of 400 nm - 880 nm

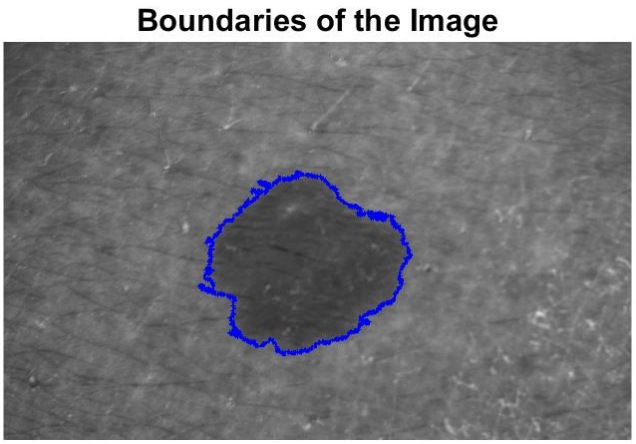
Border irregularity detection was based on the proposed method in the MATLAB environment which we described above. The lesion area is divided into eight equal parts, and the portions with an abrupt cut are calculated. However, it was challenging to obtain an accurate border of the lesion region in the different wavebands, so we try a different intensity threshold for each skin lesion. The threshold of image intensity (relative image lightness) is set manually at a specific value to yield the best possible segmentation. Pixels below that set threshold value are converted to black (bit value of zero), and pixels above the threshold value are converted to white (a bit value of one). In this way we achieve to define the boundaries of each lesion to as satisfactory degree as possible and in order to be close to the boundaries that we detect in the color image. As it comes to threshold if a pixel (x,y) < T (threshold) , then the pixel belongs to background regions , otherwise it is classified into the region of skin lesion. The problem that occurs is that while thresholding process in different wavelengths we can easily include the extraneous pixels that aren't part of the desired region and can easily miss the pixels that are part of desired region. Also ,since the original image has a range of uint8, meaning 0-255, then we used the gray level threshold corresponding to that.

Results

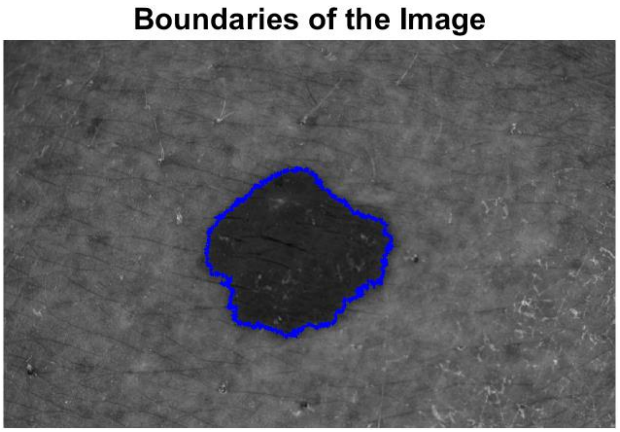
Original Image



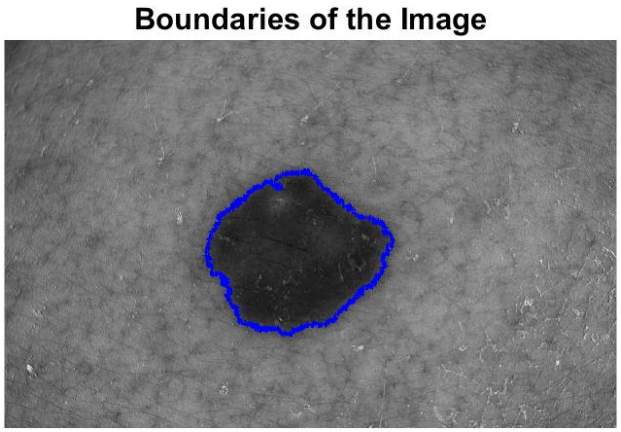
400WL



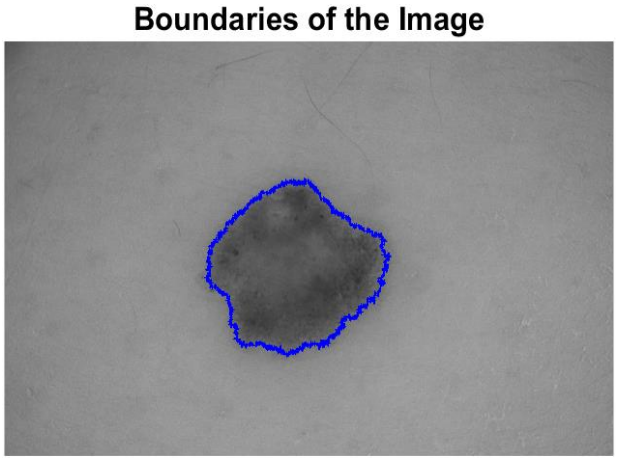
46OWL



540WL



64OWL

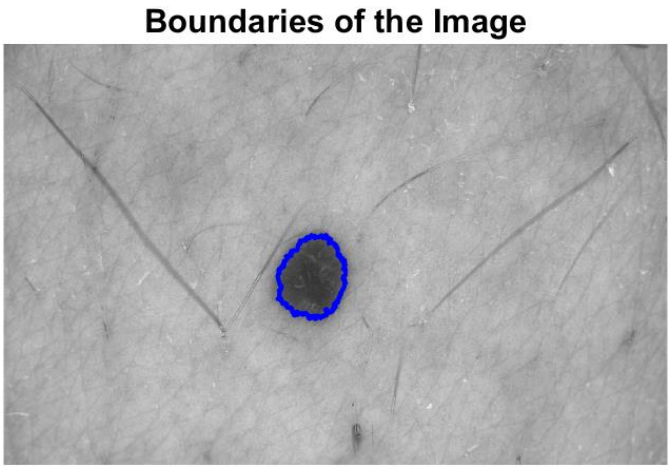


By calculating the intensity thresholding, we obtain segmented binary images as shown below. We tried to decrease the discrepancy between borders of original image and the other ones. In the case of the skin lesion in 400nm the result was not desirable. Boundaries showed a conspicuous difference with the original one and the total border score of this image in this wavelength was 3. As we can observe, in this wavelength there is low contrast between the lesion and the surrounding skin. Because of this, border detection is a very challenging task. In 780nm and 880nm the performance of this method for detection border irregularity is

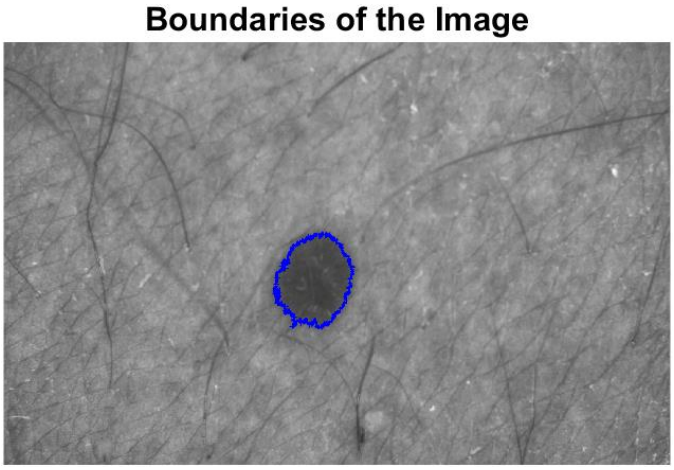
inadequate since it is impossible to define the boundaries of the lesions and the pixels that are part of the desired region.

We repeat the same procedure for the second skin lesion after the DullRazor technique

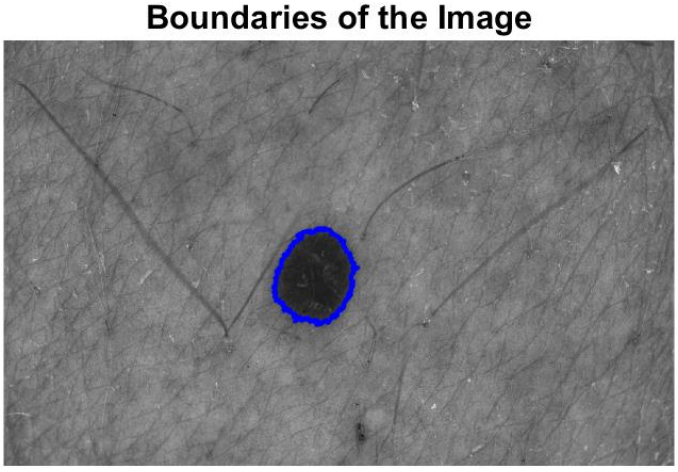
Original Image



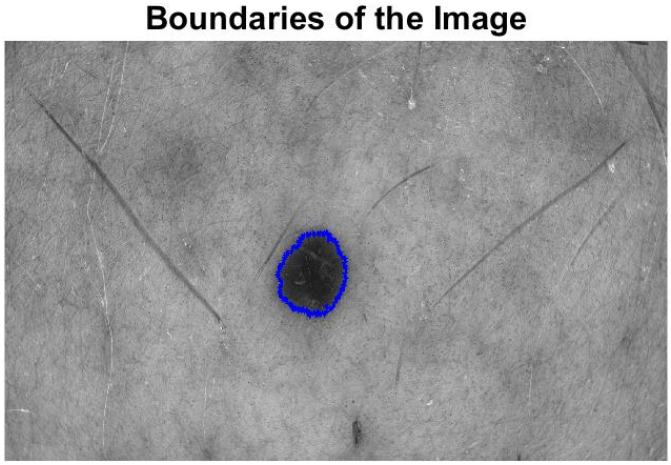
400WL



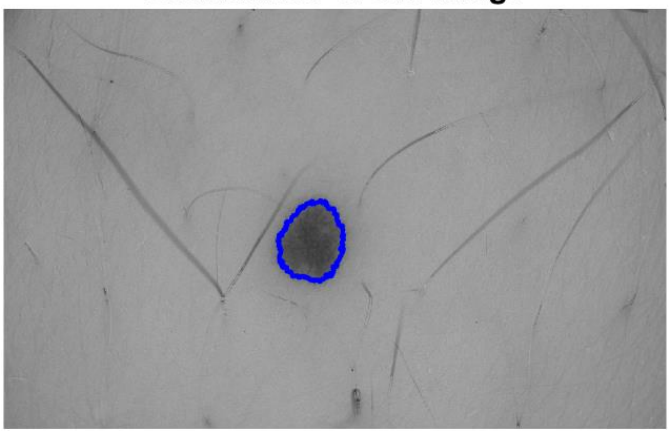
46OW



540WL



64OWL



Despite the artifacts and intrinsic cutaneous features such as black frames and skin lines we managed to detect the lesion border in wavelength bands ranging from 400 nm to 640 nm and obtain the same border score as in the original image. The only exception that we must point out was the case of the first skin lesion in the wavelength of 400nm where we couldn't find the value of threshold to have the same border score as the RGB Image. In the case of the second skin lesion, we didn't find any sector with an abrupt cut, thus the border score is 0. Threshold values according to each wavelength band are in the tables below.

Color_mole Border	400mm Intersection depth	460mm Intersection depth	540mm Intersection depth	640mm Intersection depth	780mm Intersection depth	880mm Intersection depth
Threshold	95	50	70	110	-	-
BorderScore	3	2	2	2	-	-

Color_wh Border	400mm Intersection depth	460mm Intersection depth	540mm Intersection depth	640mm Intersection depth	780mm Intersection depth	880mm Intersection depth
Threshold	90	70	80	105	-	-
BorderScore	0	0	0	0	-	-

6.3.2 Asymmetry in the wavelength range of 400 nm - 880 nm

Asymmetry is one of the clinical features suggestive of malignancy where a set of methods and techniques are used for detection. The methodology of calculating asymmetry in skin lesions is described in detail in the previous chapter. We applied these techniques in images of skin lesions at wavelengths from 400 to 880nm and we got the results as shown in the table below. As we can observe on the Table there are minor deviations in asymmetry with the RGB images of two cases and the lesions in four different wavebands.

Color_mole Asymmetry	400mm Intersection depth	460mm Intersection depth	540mm Intersection depth	640mm Intersection depth	780mm Intersection depth	880mm Intersection depth
Threshold	100	70	100	100	-	-
Asymmetry	0,152	0,146	0,135	0,145	-	-

Color_wh Asymmetry	400mm Intersection depth	460mm Intersection depth	540mm Intersection depth	640mm Intersection depth	780mm Intersection depth	880mm Intersection depth
Threshold	110	90	100	110	-	-
Asymmetry	0,27	0,243	0,235	0,25	-	-

6.3.3 Diameter in the wavelength range of 400 nm - 880 nm

As we already refer above diameter of skin lesion plays an essential role in melanoma diagnosis. The proposed method that we apply define that the maximum diameter as the longest distance between 2 points located on the lesion border. We had images obtained at wavelengths of 400, 460,540,640,780 and 880 nm. We had to face the problem to define which pixels are in the skin lesion and which are not in different wavelength bands. In order to overcome this situation, we try a different intensity threshold for each skin lesion and we came up with minor deviations when it comes to the final results of diameter in given skin lesions. Results of diameter are given in the table below .

Color_mole Diameter	400mm Intersection depth	460mm Intersection depth	540mm Intersection depth	640mm Intersection depth	780mm Intersection depth	880mm Intersection depth
Threshold	85	50	70	110	-	-
Diameter	6,994	6,77	6,835	6,705	-	-

Color_wh Diameter	400mm Intersection depth	460mm Intersection depth	540mm Intersection depth	640mm Intersection depth	780mm Intersection depth	880mm Intersection depth
Threshold	80	50	80	110	-	-
Diameter	2,992	2,940	2,869	2,83	-	-

Images at 780-880 nm

The variables related to lesion shape features such as border irregularity, diameter and asymmetry were determined for wavelengths until 640nm, where the contrast between skin and lesion border allowed to us to recognize the lesion contour for all cases. For near-infrared wavelengths it was impossible to calculate all these features. Our proposed methods failed to detect identify tumors with increased penetration depth into tissue in the in the infrared spectral region (between 780 and 880nm).

Chapter 7

7.1 Conclusions

Skin cancer has been rising increasingly during the last years and it have been proved to be very fatal disease. Investigations have shown also that is paramount importance to achieve early, fast and effective detection of skin cancer, since the survival rates in patients depend on the stage of the cancer. This study relies on extraction and quantification of specific information for morphological and spectral features that can be used to distinguish malignant, suspicious, and benign lesions. To achieve this goal, techniques in MATLAB were used for implementation ABCD Rule. **Pre-processing** stage plays a major role for the segmentation of the lesion area and for the extracted features which lead to high accuracy in diagnosis of skin lesion. In this stage we observed that the proposed methods worked successfully in segmenting the majority of challenging cases such as thick hair and skin lines, low contrast and noise. The study presented segmentation methods as the second stage of the procedure we had to follow , which ensured a good result and avoided overlap between the lesion area and healthy skin , when it comes to the skin lesions belonging in the first case. On the other hand, the **segmentation methods** detect the border for the original skin lesion images belonging to the second case with lower precision. There were some challenging samples which were not properly segmented by the proposed methods. The reason for this failure was the presence of noise elements such as hairlines and dark spots that cause impediments in extracting an accurate region of interest. We partially segmented these images but was not as accurate as of the images which did not contain any artifacts. Thus, in the future, the design of any pre-processing technique will be taken into consideration for removing all noisy elements, primarily hairlines, from skin lesions.The result of the segmentation was then used in the next step by the **ABCD rule** in order to classify pigmented skin lesion as benign or malignant ones. The qualitive determination of each skin lesion based on some specific features. Specifically, we proposed methods which measure the color information contained in the lesion, border irregularity, asymmetry and diameter.Finally, the extracted features from the skin lesion used as inputs to a **feature classification** module for each skin lesion and **Total Dermoscopic Score** (TDS) was calculated. It is important also to refer that the above estimated parameters of ABCD rule are not enough for the detection of melanoma because different types of melanoma are spreading widely which do not have all these features. If a skin lesion is determined to be malignant, a biopsy will be used to confirm the result.

The second part of our study presented the important role of **dermoscopy** and its high potential in the objective diagnosis and assessment of the skin pathologies and more specifically, the detection of melanoma. In an attempt to examine the images in the wavelength range of 400 nm - 880 nm we try to revisited the ABCD criteria. Spectral features of each skin lesion helped us to conclude that melanoma shows important differences in contrast to benign lesions. Definitive factor regarding to this is that melanoma cells have based on the production of melanin pigment at various depths within the skin, in other words we examine high melanin concentration in this region on the nevi. Because of this characteristic, melanomas remain rather detectable above 700 nm , while benign lesions became transparent. In our study , both of the skin lesions, remained detectable above 640 nm , especially the first one. Thus, Information found at different depths is useful in differentiating benign skin lesions from malignant ones. Due to our try to apply ABCD Rule on different wavelengths we faced the challenge to obtain an accurate border of the lesion region in the different wavebands and we decided to try a different intensity threshold for each skin lesion. Thus, we established boundaries between the skin lesion and the healthy skin and obtain good segmentation results. The results of applying ABCD Rule in the wavelength range of 400 nm - 640 nm was an efficient procedure which can help us to obtain useful information for skin lesions. Although, it was impossible to apply ABCD Rule on skin lesions in the wavelength range of 780 nm - 880 nm. Our methods failed to work in the in the infrared spectral region.

Summarizing, the results of this study are significant and quite promising for the future and can be a great help in early detection of malignant melanomas for faster and efficient treatment .

7.2 Future work

There are a few options for expanding the work presented in this study. Some potential research topics for the future are below:

- In planning for future work, we could use a different dataset of skin lesions (more complicated images with bigger variability and difficulties regarding to borer irregularities and shape) to determine whether our methods are effective. Moreover, we could try different classifiers like KNN or SVM which could be tested and adopt the one with the higher accuracy.

- In the present study we didn't examine in detail the utility of the Evolving (E) in skin lesions. The evolving of lesion can be defined as the change of size, shape, symptoms such as itching and tenderness, surface, or shades of color, which are indicator to be malignant melanoma.We can't underestimate the importance of diagnosing melanoma early in its evolution, since if melanoma can be detected in an earlier and more easily treatable phase , more lives can be saved.

  -We used DullRazor method for detecting and removing thick hairs from the region of interest of skin in order to distinguish the lesion from the healthy skin. We should improve the method to detect and remove artifacts such as thick hair, dark spots or skin lines since they cause a significant degradation to the segmentation and finally complicate the border detection procedure.

- As we already refer accurate color information is especially important for melanoma diagnosis in dermoscopy images. In the present study, it would be optimal to develop color calibration method for images used in dermatology and investigate the influence of color calibration on the final diagnostic performance. This method can help us to compensate for various imaging conditions such as magnification factors and light conditions.
- We can develop algorithms to detect and classify skin lesions in a **real time application** during dermatological diagnosis.

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