

Department of Electronic & Computer Engineering

Melanoma (Skin Cancer) Long-Term Monitoring

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Course: Electronic and Computer Engineering (LM118)

Academic Year: 2017/2018

Project Number: SMcG/CF 1

Contents

[Contents 2](#_Toc509881509)

[Introduction & Product outline 4](#_Toc509881510)

[Changes to the original plan 5](#_Toc509881511)

[Product List 6](#_Toc509881512)

[Software Used 6](#_Toc509881513)

[Python3.5.2 – Anaconda3.5.0.1 6](#_Toc509881514)

[OpenCV 3.4 6](#_Toc509881515)

[Literature Survey 7](#_Toc509881516)

[Background Theory & Principles of Operation 8](#_Toc509881517)

[Melanoma (Skin Cancer) Background 8](#_Toc509881518)

[Image Processing & Machine Vision Background 10](#_Toc509881519)

[References 13](#_Toc509881520)

Table of figures

[Figure 1 - Process of Otsu thresholding - Courtesy of ‘Scipy lecture notes’ [8] 11](#_Toc509881672)

[Figure 2 - Erosion and dilation of a simple binary image [10] 12](#_Toc509881673)

Abstract

Melanoma is one of the fastest growing skin cancers in Ireland, with over 1,000 people diagnosed each year. It is a particularly dangerous form of skin cancer as it often spreads to other parts of the body beyond the skin where it can become hazardous and difficult to treat. Recently, huge improvements have been made in the diagnosis and treatment of the disease using Image Processing which is possible as the malignant moles associated are visible on the skin.

With the rise in the development of Machine Vision medical applications aimed to diagnosed Melanoma in its early stages, many medical firms have identified the potential that Machine Vision based products has on Melanoma detection and treatment. The overall aim of this project is to demonstrate the capabilities that Machine Vision applications has in a medical context.

Specifically, we will be designing a system to facilitate the monitoring process of Melanoma or other types of skin cancer. The usefulness of such a product could have huge benefits & implications for society and the medical sector at large, particularly for patients in measuring any changes in their malignant moles.

Due to the unpredictable nature of Melanoma, and the importance of monitoring its progress, the aiding of said monitoring process will lead to numerous benefits. These benefits include reducing the cost, skill level and knowledge required to monitor melanoma, and a dramatic improvement in the treatment and outcome of diagnosed patients.

# Introduction & Product outline

The general purpose of this project is to develop a system to facilitate healthcare professionals and patient’s in the monitoring process of Melanoma or other types of skin cancer. This system will involve integrating aspects of hardware and software engineering in its design to build a functional prototype, which can provide a viable method of measuring the progress of a malignant mole on a patient’s arm. This project could prove to be an invaluable tool for healthcare professionals in the treatment of skin cancer and improve the outcome of patients.

To develop the system, it makes sense to build and test the software and hardware components separately before being combined during the final stages of the project. These components include:

* Hardware and Sensor Design & Integration
* Machine Vision Implementation for Image processing & Feature extraction
* Software Implementation for Monitoring Melanoma

The overall aim of this project is to design and develop a working prototype of a product to monitor Melanoma, while at the same time increasing my knowledge of the various concepts used to develop the product. This involves learning how to implement Image Processing techniques by using the Python library OpenCV and designing an adequate environment to apply these techniques effectively.

The hardware and sensor development aspect of the project will require combining a camera module with a Raspberry Pi and using an ultrasonic sensor to measure the distance of the imaged mole from the camera. A condescend light and a white sheet of paper as a backdrop will also be used to deliver uniform lighting and an uncomplicated background which will ensure consistency in the images.

The software aspect of the project will require combining various Image Processing techniques such as Preprocessing, Segmentation and Feature Extraction. Preprocessing and Segmentation of the image will remove the unwanted regions such as the background skin and hairs while highlighting the moles as the focus of the image. Feature Extraction methods will then be used to obtain the useful information from the segmented image. For this project the feature extraction methods used will be based on the ABCDE mnemonic which is a commonly used by dermatologists to classify a malignant mole. Combining these techniques to compare and analyse images of a malignant mole at various stages of its development will provide healthcare professionals and patients a method to monitor any changes in the moles features.

The Melanoma monitoring method will involve creating a Python script on a Raspberry Pi to take an image of a mole with a camera module, applying various Image Processing techniques on the image taken to separate the mole in the image from the skin and background and saving the new image of the mole on the Raspberry Pi. A combination of Image Processing techniques and mathematical manipulation will then be used to extract information about the features of the mole. A second image is taken of the mole in the same environment and processed with the same Image Processing steps. The features of both images are compared forming the basis for the melanoma monitoring method. Any changes in the mole’s appearance will be noticeable and measured.

## Changes to the original plan

My initial plan for this project was to implement the Image processing and feature extraction components in a custom-built enclosure which was going to provide the environment to capture the images of moles on a patient’s arm. The enclosure was to be fitted with multiple infrared-sensitive cameras to obtain a full representation of all the moles on a patient’s arm by combining the images. A Raspberry Pi connected to the enclosure would provide a method for capturing and storing the images on the system as well as the implementation of the software required for monitoring Melanoma.

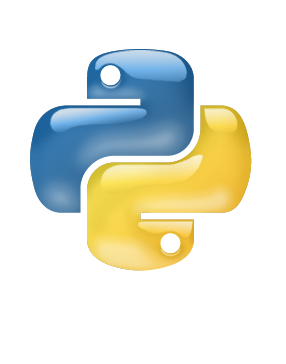
However, I encountered many issues when attempting to build an enclosure with multiple infrared cameras in a feasible way. Mainly, I was having difficulty connecting multiple cameras to a Raspberry Pi and aligning the cameras to minimise the overlap in the images. So, I decided to alter the project to incorporate a normal camera module to capture the images of the moles and to design a suitable environment to capture the images without using an enclosure. This will allow me to focus on a single suspicious mole and monitor its development it progresses.

## Product List

* Raspberry Pi 3 – Model B
* Raspberry Pi Camera Module – V2
* SanDisk 16GB SD Card with NOOBS pre-installed
* Raspberry Pi Power Supply – 13W, 5.1V, 2.5A
* HC-SR04 – Ultrasonic distance sensor
* 3 – 1 kΩ Resisters
* 4 – Male to female jumper wires

## Software Used

### Python3.5.2 – Anaconda3.5.0.1

Python is a high level, object-oriented programming language which is used for a variety of purposes. [1] It has an elegant syntax that is easy to code in. Anaconda is an open-source distribution for the Python language which simplifies package management and deployment. It has a large number of open-source libraries built into the distribution making it easy to expand programs by importing new module. Python also has many volunteers constantly improving the language and open-source libraries.

In this project, we will be using Python for implementing the image processing aspects of the project. There is a large amount of online support for Python in this specific application, and many of the standard Python libraries have built-in functions which will be used. Python also comes as standard with the Raspbian operating system for the Raspberry Pi.

### OpenCV 3.4

OpenCV (Open Source Computer Vision Library) is a library for computational efficiency with a strong focus on real-time image processing applications. The library is cross-platform and was released under the open-source BSD License so it’s free to use for both academic and commercial use. [2] It was initially developed by Intel before becoming maintained as open-source software by Itseez.

Most of the image processing techniques used in this project will be implemented through the OpenCV library.

## Literature Survey

Automatic Detection of Malignant Melanoma using Macroscopic Images [3]In this paper, three Biomedical Engineering students developed a method for detecting malignant melanoma from benign pigmented lesions using macroscopic images. The Image Processing steps necessary to achieve this were Preprocessing, Image Segmentation, Feature Extraction, and Classification. The students acquired images for training their Machine Learning algorithm from the dermatology atlases called Dermnet where they collected 282 RGB images of various sizes (149 benign and 133 malignant). Preprocessing of the images involved using a median filter and morphological operators to remove impact noise, skin lines, hairs, and reflections. The RGB channels (Red, Green and Blue Channels) of each image was also converted to HSV colour space (Hue, Saturation, and Value) to weaken the effect of non-uniform lighting. There were many methods used to segment the lesion from the skin such as K-mean clustering and Otsu Thresholding to remove unwanted parts of the image. The feature extraction method used for this project was based of the ABCD criteria which is like the traditional process of visual inspection. Finally, a Support Vector Machine classifier was used to predict whether a lesion was benign or malignant.

Smartphone Medical Toolkit [4]  In this project, an Electronic and Computer Engineering student developed an Android application that integrates with a Raspberry Pi connected with an infrared camera module to map the veins on a person’s hand to assist with the process of injection. The student created an LED circuit to emit infrared light at a certain wavelength to avail of the light-absorption properties of veins in the body. An optical filter with a narrow band-pass was also placed over the infrared camera to ensure that only light within the band of interest would be observed. A Python script was created on the Raspberry Pi to take an image with the infrared camera and save the image on the system. The script also applied various image processing to the image taken mainly a type of histogram equalisation known as ‘CLACHE’ performed. The student created an Android application within Android Studio, with the graphical UI and layout of the application designed in Sketch and the application communicated with the Raspberry Pi using the ‘ssh’ protocol. By combining the different aspects together, the student proved that a viable product like this could be created to help the injection process using smartphones.

Although neither of these projects directly monitored Melanoma, I learned a lot from the projects and took inspiration when designing the system for my project.

## Background Theory & Principles of Operation

Throughout this section, the impact Melanoma (Skin Cancer) in Ireland will be outlined. This includes an overview of Melanoma (Skin Cancer), potential risk factors for being diagnosed, preventative measures available in reducing its likelihood and the treatment options for the disease in Ireland.

Also, the principles for which the Image processing and Feature extraction techniques used in this project during the Machine Vision Implementation will be explained. While it may not be possible to explain all the intricacies of each technique used in the project, a brief introduction into these concepts should provide enough of an understanding into how they operate and highlight the importance for each technique in the project. The Image segmentation and feature extraction techniques will be described separately to help with the understanding of each concept and its relevance in the project.

## Melanoma (Skin Cancer) Background

Skin cancer is the most common cancer in Ireland, with 10,304 cases of non-melanoma skin cancer and 1,041 cases of melanoma skin cancer diagnosed in 2014. [5] It is mostly a preventable cancer, and early detection of it will drastically improve the outcome of the patient as the treatment will be relatively easy and cheap. Skin cancer is the abnormal, uncontrollable growth of skin cells which is often developed when the genetic material (DNA) inside the skin cells is damaged which causes the cells to multiply rapidly usually because of overexposure to ultraviolet (UV) radiation from the sunlight or sunbeds. There are two main types of skin cancer: Non-melanoma and Melanoma. Non-melanoma skin cancer is a group of skin cancers that affect the upper layers of skin which mostly comprise of basal cell carcinoma and squamous whereas Melanoma skin cancer is a group of cancers that start in pigment cells (melanocytes) in the skin.

Melanoma is the deadliest form of skin cancer. Although it only accounts for 3-4% of all skin cancers, it is responsible for 75% of all skin cancer deaths and 1 in 8 people who are diagnosed with it result in a fatality. It is particularly dangerous as it can spread to other parts of the body beyond the skin usually through the lymphatic system and when it does, it can become hazardous and difficult to treat.

A person is more at risk for Melanoma if they have pale skin that burns easily, many moles, uses tanning beds regularly or has a family history of melanoma. If you have a higher risk of developing skin cancer, it is best to take extra precautions. The best way to prevent melanoma is to avoid overexposure to the sun, seek shade when the sun is strongest, use SPF 30 sunscreen when necessary, dress sensibly, avoid sunbeds and have regular skin checks.

In Ireland, suspicious moles are first examined by a GP who usually decides if the moles require further testing by a dermatologist who is a doctor that specialises in skin conditions. [6] A dermatologist will use the ABCD method alongside a questionnaire to determine the severity of the mole. The ABCD method for visually inspecting a mole will assess if the mole is asymmetrical, has an unusual border, multiple colours and if the mole is large. Often if the mole looks unlike any other mole on the patient’s body further inspection might be needed. The questionnaire will involve asking the patient if the mole has recently appeared, is changing over time or if the mole has caused any irritability problems such itchiness or bleeding. A dermatologist may decide from this information to do a biopsy if they think it is necessary which is where a suspect mole is removed from your skin so that it can be studied under a microscope to check if the mole is cancerous. If the mole is confirmed to be cancerous, a further operation may be done to remove a wider margin of skin around the mole which may remove the melanoma.

Treatment of melanoma will depend on how far the melanoma has grown into the skin and whether it has spread to other regions of the body. In the early stages if the cancer is detected early enough treatment will involve surgically removing the cancerous with a small area of the skin surrounding it which is known as surgical excision. If the melanoma has been removed, there is little chance of it returning, and no further treatment should be needed. In the case that the melanoma has spread to another part of the body it may not be possible to cure it so measures may be taken to slow the growth of cancer, reduce the symptoms and possibly extend the life expectancy of the patient. Some of these include Radiotherapy and drug treatments such as Chemotherapy to name a few which can have serious side effects on the patient, so it’s better to treat it early to avoid these treatments. It is important that melanoma is detected and treated before it spreads as there are better treatments and higher survival rates.

Skin cancer is well suited for image processing as the abnormal moles are visible on the skin. There are many advances in the field of Machine Vision which could dramatically change how we detect and treat Melanoma in area of detection and treatment. Computer programs may be developed which could provide non-invasive methods for determining if a mole is benign or malignant.

## Image Processing & Machine Vision Background

Otsu Thresholding

Otsu’s method is a global thresholding technique proposed by Nobuyuki Otsu in 1979, which has become a popular algorithm for converting a grayscale image to a binary image. Otsu’s method assumes that the image contains two classes of pixels (foreground and background) following bi-modal histogram. The aim of this method is to find the optimum threshold value separating the two classes to minimize their combined spread (intra-class variance) hence separating the greyscale image in a binary image. This is best seen graphically below.

For instance, assume an image has L grey levels and the total pixels with grey level I: ni.















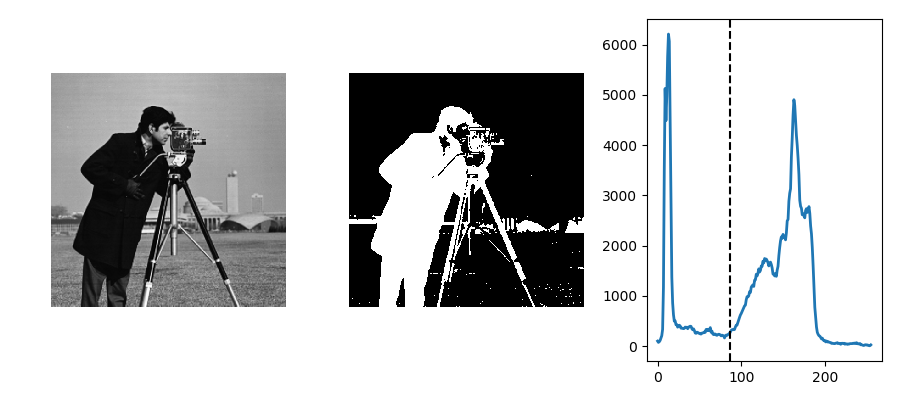


Figure 1 - Process of Otsu thresholding - Courtesy of ‘Scipy lecture notes’ [8]

Morphological Operations

Morphological operations are a useful set of operations that are commonly applied to binary images to process them based on shapes. [9] The main aim of morphological operations is to apply a structuring element (or kernel) which decide the nature of the operation to an input image to generate a unique output image. Various morphological operations are used throughout this project such as Erosion, Dilation and Opening.

Erosion is a basic operation on binary (or grayscale) images that erodes away the boundaries of foreground pixels (i.e. white pixels) based on the structuring element applied. Any holes within the background become larger. Dilation is the opposite to erosion, it increases the size of the foreground pixels (i.e. white pixels). Any holes in the image shrink whereas the boundaries of the image expand. This can be seen in the below diagram.

Opening and Closing operators are derived from erosions and dilation. Opening is erosion followed by dilation using the same structuring element. It is used to remove noise from an image. Closing in contrast is dilation followed by erosion using the same structuring element. It is used to close small black points in an image.

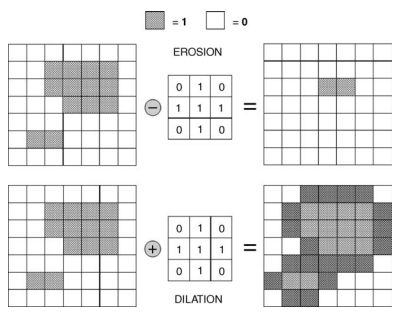


Figure 2 - Erosion and dilation of a simple binary image [10]

Image segmentation using the Watershed Algorithm

Image Segmentation is used to partition an image into meaningful regions to improve its analysis. It is done by separating the objects within the image by finding the boundary regions around the objects and removing the unwanted regions. The main aim for image segmentation in this project is to remove the skin and background from the image to create a new image containing only the mole of interest.

The Watershed algorithm is a specific type of marker-based image segmentation introduced by Serge Beucher and Christian Lantuéj in 1979, which has become a classic method for segmenting an image. It is based on an analogy of rain filling low-lying regions in a landscape.

Any grayscale image can be viewed as a topographic surface where high intensity denotes peaks and hills while low intensities denotes valleys. [11] The topographic intensities can be calculated using Distance transform as a measure of depth/altitude. When the image has been converted to a ‘height’ image, the landscape can be filled with water. Every isolated valley (local minima) detected by the algorithm will be labelled with a different coloured water. As the water rises, depending on the peaks (gradients) nearby, the different coloured waters will start to merge. To avoid overlapping, barriers are built in the locations where the water merges. This process of filling water and building barriers will be continued until all the peaks are underwater. The barriers created from this process should give us the boundaries of the regions in the image. The regions of the image are labelled during the watershed, with the background of the image labelled 1, and the other objects that appear labelled with integers starting with 2. This allows us to alter the image using the labels to create a new image containing only the region of interest which is the mole under inspection in our case.

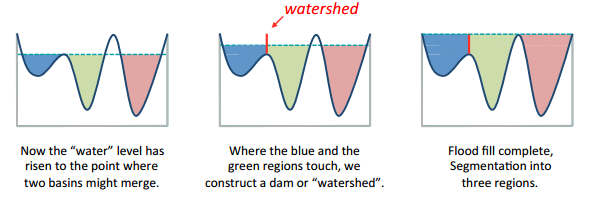


Figure 3 – Illustration of the watershed technique [12]

The Watershed algorithm can be comprised of nine steps, which are executed in the following order:

1. Convert the image to grayscale so that it can be viewed as a topographic image.
2. Threshold the grayscale image using Otsu Thresholding to output a binary image.
3. Use Morphological closing to remove noise and reduce the effects of hairs on the image.
4. Use Morphological dilation to increase the boundary by 1 pixel to increase the regions threshold to find areas that are surely background.
5. Apply the Euclidean Distance Transform to the binary image to output a ‘height’ image to find areas that are surely foreground.
6. Find the unknown region by subtracting the sure foreground from the sure background.
7. Find local maxima of the height image and assign unique labels to each maxima, this is the seed label image.
8. Build the barriers (dams) to stop the regions from merging.
9. Now apply watershed routine to the depth (= -height) image, using the seed labels to start the regions.

It can be difficult to imagine how an image can be separated into different regions using this method so the comparison of rain filling a landscape is useful for explaining the algorithm in a human friendly way.

In this method, tiny imperfections in the binary image could have a huge effect on the watershed technique and cause oversegmentation. Morphological closing is used to prevent this by ‘filling in’ small holes in the foreground of the image, without changing the structure of the rest of the image too much.

The marker-based watershed algorithm used in this project was implemented using OpenCV, with an interactive segmentation as it is possible to specify which valley points are to be merged and which aren’t. OpenCV also handles all the operations needed to achieve a desirable watershed segmentation.

Feature Extraction

Feature Extraction is the process of transforming an input image into features of distinct properties for analysis. Its main purpose for this project is to extract useful information from the segmented image gathered from the watershed algorithm to improve human interpretation of said images. The features gathered from the images of the mole of interest will be compared with images of the same mole under the same conditions at a later stage of the cancers development forming the basis of our method for monitoring Melanoma. By comparing the features of the moles in each image we can identify if the moles are changing or evolving which is important as Melanoma can become difficult to treat when it spreads.

The feature extraction methods used in this project will be based on the ABCD method (Asymmetry, Border Irregularity, Colour Variation and Diameter) which is an approach commonly used by GPs and Dermatologists to assess the severity of a suspicious mole. This method involves inspecting if a mole has an irregular border or is symmetrical, has variation in the colour across the mole and a diameter greater than 6mm to determine the likely the mole is cancerous or identify the risk associated with a malignant mole. There are many useful Image processing techniques available that can be applied to the segmented image of the to obtain information about its features.

To apply the feature extraction methods required to analyse the mole, we must convert the segmented image gathered from the watershed algorithm into a binary image using Otsu Thresholding. The threshold image should show the mole in white pixels and the rest of the image in black pixels. From here, we can use the OpenCV function ‘cv2.findContours’ to search for contours in the image, which just refers to a closed curve. There should only be one contour found in the image which should contain the mole we are interested in analyzing. We can analyse the contour using Image moments to calculates its pixel area, center point, diameter in pixels, eccentricity and orientation. There is also a function in OpenCV capable of finding the four most extreme points in the contour. Using these extreme points and the center point we can evaluate the general shape of the contour by calculating the distance, slope and angle between each of the points.

The main concepts behind the Image processing techniques mentioned will be explained below:

Image Moments

Image moments are the weighted average of the pixels intensities that can be used to describe the features of an image our in this case the contour which should represent the mole we are analysing. The moments of a contour used to represent its mass in pixels (area), center of mass (centroid) and rotational inertia (orientation, major and minor axis).

The raw image moment Mij for the binary image with pixel intensities I(x, y) can be represented as:



The zeroth moment represents the area of the contour (mass). Its calculated by counting all the pixels in the contour.



The first order moments represent the center of mass or centroid of the contour and can be defined as:



where centroid of the contour () is:



M10 and M01 are the sum over x and y respectively and M00 is the area.

The first order and second order moments which are relevant to this project calculated from:



or

The second moments represent the orientation of the contour, which can be derived from the second order central moments as shown below. These second moments also give us the covariance matrix of the contour, which can be used to find its eigenvalues and eigenvectors.







The covariance matrix of the contour in image I(x, y) is:



The eigenvectors of this matrix correspond to the major and minor axis of the contour, so the orientation of the contour found from the angle of the eigenvector with the largest eigenvalue towards the axis closest to this eigenvector. This is found using the formula:



The larger axis is the diameter of the contour in pixels, which is usually the major axis. The eccentricity of the contour, which refers to curvature of the object is some ratio of the eigenvalues.

Assessing the shape of mole using the contour

The shape of a mole is an important feature when assessing the risk associated with Melanoma. As moles that are asymmetrical or shaped irregularly are more likely to be cancerous and the degree of the irregularity could show the severity of the melanoma. It can also show if the melanoma is its early stages. The information from the shape of the mole will be a crucial aspect of our monitoring method as any changes in its shape could indicate that the mole is evolving which would be problematic. To assess the shape of a mole in the image we will need to use the same contour as the previous section.

If we imagine the image as being coordinates in a graph and the contour or mole existing somewhere in those coordinates, by using the center point we calculated previously and specific points on the boundary of the contour we can get an idea of its shape which would translate to the mole we are analysing.

For this project there is an OpenCV function that finds the four most extreme points in the contour. From here we can calculate the distance from each point to the center, draw a line from each point to the center and calculate is slope and finally once we can use the slopes to find the angle between each line. This will give us a general idea of the shape of the moles, any outliers should be noticeable.

Now, when we view an image as coordinates the y-axis will increase in the opposite direction so when we apply formulas to points in the contour the results will be different than expected. Some mathematical manipulation can be applied to solve this issue. This can be easily seen in the diagram below.

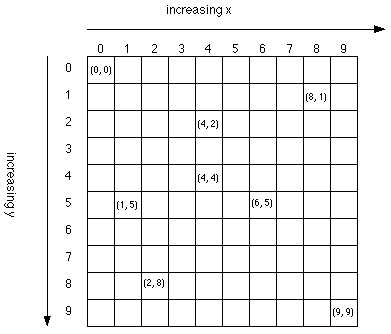


Figure 4 – Basic 9 by 9-pixel grid

The steps for assessing the shape were as following:

Using OpenCV to find the extreme points of the contour. This comprises of the leftmost, bottommost, rightmost and topmost point in the contour. When we have these points, we can draw a line from each extreme point to the center and calculate the distance between each point.

Points:  



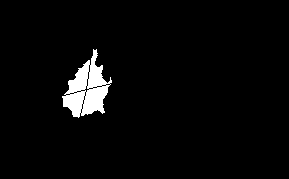


Figure 5 - Test example with the center point and extreme points shown

Next, the slope of each of the lines can be calculated. The order of the points won’t affect our results. The result from each of the slopes will need to be manipulated by multiplying the result by -1 to get the type of result we could expect.

Points:  



Finally, the angle between each of the lines can be calculated by using the slope of each line. The first angle calculated was between the leftmost point to bottommost point, and this process was continued in an anticlockwise direction until all the angles were calculated. The slope values needed to be adjusted for each angle. Multiply the slope to the left of the angle by -1 for each angle calculated except for the last angle between the topmost point to leftmost point where the slope to the right of the angle is multiplied by -1 instead.



Assessing the Colour of the mole

The Colour of the mole is also an important feature to assess as cancerous mole often have a variety of colours. It can be assessed by plotting a histogram graph of the segmented image, which represents the distribution of pixels intensities in a RGB image.

## Design Implementation

## Hardware and Sensor Development

In the below diagram, we see the basic components of the ‘hardware and sensor’ aspect of the melanoma monitoring system and how they interact with each other. The main goal of combining these components is to create a complete system that can take an image of a malignant mole on an arm, process that image on the system and ultimately gather information about the mole at a specific point in its development in order to monitor its progress.

suitable environment for the software implementation

Create a suitable environment for watershed technique

The following system can be explained as follows:

* A Raspberry Pi

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