Smartphone App Concept for Medical Applications.

Alexander Gustafson
University of Applied Sciences,
Zürich,
Switzerland,
alex_gustafson@yahoo.de

August 28, 2016

Dozent: Reto Knaack (knaa@zhaw.ch)

School of Engineering, Abteilung Zürich
Studiengang Informatik

Abstract

The market for smartphone based medical applications is a relatively new and growing quickly. The majority of medical apps are relatively simple health management and tracking applications that might remind a user to take his or her medicine or monitor blood pressure and heart rate data provided by accompanying devices. However, more sophisticated apps can directly provide diagnostic information by capturing and analysing data directly. Several apps exist that can asses the risk of skin cancer by tracking changes in the growth of skin lesions over time.

Contents

Chapter 1

Introduction

TODO: Medical Apps / future promise and benefits / communication with experts / fast diagnosis

TODO: Fields that can benefit from Medical Apps on smart phones

TODO: What is cancerous melanoma? danger? importance of early detection.

1.1 Project Description

This bachelor project will investigate the following questions:

- What smartphone based medical apps are available that can track and assess the risk of skin lesions?
- What methods and algorithms can be employed by mobile phones to calculate the risk?
- What is necessary to build a mobile app that can provide a risk assessment of skin cancer melanoma from captured images?

1.2 Goals

1. Research the medical app market to gain an overview of areas of development, what apps are available, what trends are discernible. Of special interest are apps that use internal sensors (e.g., camera) and mathematical algorithms to detect skin cancer melanoma.
2. Gain familiarity with machine learning and image recognition algorithms. Describe the basic principles of these algorithms.
3. Research and compare available data and algorithms (e.g. in computer vision / machine learning). Define the relevant attributes that can be used to train the algorithm. This can also include changes in size over time.

4. Based on the research and comparison choose a specific algorithm and data with which to proceed. The algorithm must be able to
   (a) identify the skin lesion correctly,
   (b) compute the relevant attributes,
   (c) use these attributes to classify the skin lesions whether it is possibly cancerous or not
5. Implement the algorithm as a prototype (using Python for example). Using images of a skin lesion as input, the algorithm will provide a risk assessment as output. Implement tests that can calculate the accuracy of the algorithm. Compare the implemented algorithm with at least one other algorithm.
6. Create a concept for a medical mobile app that can utilise the features of modern smartphones to provide a risk assessment of skin cancer melanoma based on captured images. This includes a full requirements analysis, i.e. use cases, functional / non-functional requirements, architecture.
7. Implement as proof of concept specific aspects of the medical mobile app.

1.3 Expected Results

1. Results of the medical app market research including graphical presentation of trends and statistics.
2. Documentation of the available data and algorithms including high level excursion into the theory behind machine learning and image recognition algorithms.
3. Comparison of available data and algorithms. Definition of relevant attributes.
4. Decision, which algorithm to use.
5. Documentation of the implementation of the algorithm, including tests, evaluation and comparison with at least one other algorithm.
6. Documentation of a concept for a medial app, including defined use cases, requirements, architecture and implemented design patterns.
7. Proof of Concept: implementation of specific aspects of the medical mobile app.

Chapter 2

Market Research

2.1 Data Gathering

2.1.1 Gathering Data from the Apple iTunes Store

Searching the Apple iTunes store is typically done manually via the iTunes Application from which text and data cannot be automatically extracted. Therefore, searching for and gathering data about IOS Applications is not easy. However, Apple does provide an rss feed that can be used to list Apps in specific categories and ordered according to how new, or how popular they are and if they are free or not. The rss feed is limited to 100 items per category. The data provided by the rss feed is minimal, not much more than title and a text description of the app. There are no sub-genres or tags than can be used to further differentiate the apps.

Using a python script data was gathered from the following rss feeds:

Top 100 Free Medical Apps Top 100 Grossing Medical Apps Top 100 Paid Medical Apps This combined results included data about 255 IOS apps. The title and description fields were imported into a database. Other information from the data such as price, right, or image link were ignored.

2.1.2 Gathering App Data from the Google Play Store

In order to gather data from the Goole app store a script was programmed that could extract lists of apps from a specific url. The following urls were scanned:

- Top Paid Medical Apps : https://play.google.com/store/apps/category/MEDICAL/collection/topselling_paid
- Top Free Medical Apps : https://play.google.com/store/apps/category/MEDICAL/collection/topselling_free

For each app listed the script would extract the url of the app's detail page. From the detail page more imformation would be gathered and stored in a database. The data set is similar to that of the itunes rss feed. The title and description text were imported, other fields such as pricing and copyright were ignored.

Data on 480 Medical Apps for Android was imported. However a significant percentage of the apps could not be classified because the description text was in a language other than English, German, or French.

2.2 Categorization

The term ”Medical App” is broad and neither the iTunes nor Google app stores offer any kind of sub categorization. In order to get a better overview of what sort of Medical Apps are available it was necessary to manually browse the gathered data and assign categories to the apps.

A database management tool was created using the python based Django Web Framework. Django provides many tools that makes constructing and interacting with databases very easy. The built-in backend administration tool can be configured to browse, edit, and filter data.

In order to quickly browse through and categorize over 700 apps. The Django backend admin was configured so apps could be categorized one after the other with a minimum of clicks or scrolling. The user was presented a list of uncategorized apps. The first one is clicked. The user is then presented with a page displaying the title and summary text of the app and a field from which a category can be selected. Once saved, the app is no longer presented on the list, the user can select the next app at the top of the list.

2.2.1 Description of Categories

- **Community** - provides some soft of social networking service through which the user can share data with her family or with a network of people suffering from similar disorders.
- **Fun / Entertainment** - These apps have to real medical purpose. They are for enjoyment only.
- **Alert / First Response** - Apps that assist first responders or that help users alert first responders that help is needed.
- **Health / Lifestyle** - Relaxation and meditation apps, or ovulation and fertility reminders
- **Resource Finder** - Apps that locate resources in the vicinitly, nearby pharmacies or care providers.
- **Reminder** - Apps with timer or calendar functionality that might remind a user of an appointment or manage medince consumption.
- **Algorithmic / Diagnostic** - These are apps that provide some sort of diagnositc information based on data that as been gathered by sensors or entered by the user. Examples are seizure detection apps, or stroke severity evalutaion apps.

- **Learning / Educational / Reference** - By far the largest category, this includes apps that provide reference information about diseases or education material like anatomy apps for example.
- **Organisational** - Apps in this category might help a user or practitioner organise, share or track data and documents. Examples are apps that help users track the status of their blood pressure or blood sugar levels, create health diaries, or manage clinical data and images.

2.3 Results

2.3.1 IOS Medical Apps

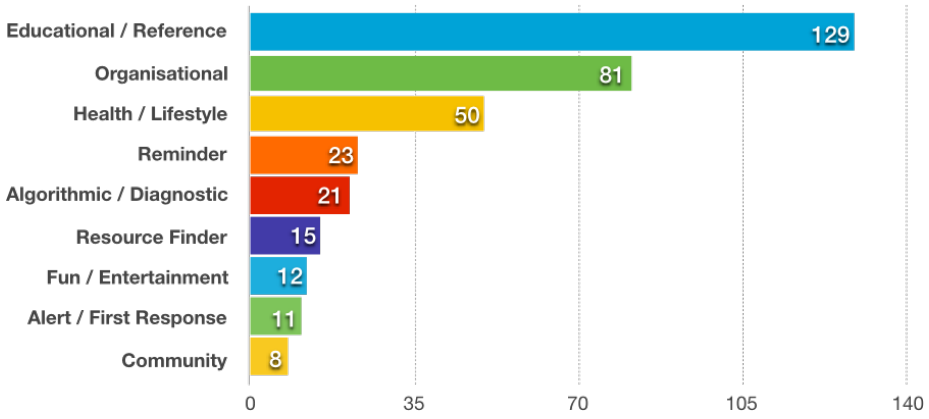

Figure 2.1: Medical Apps on the iTunes Apple Store, Search conducted on 17.05.2016

2.3.2 Android Medical Apps

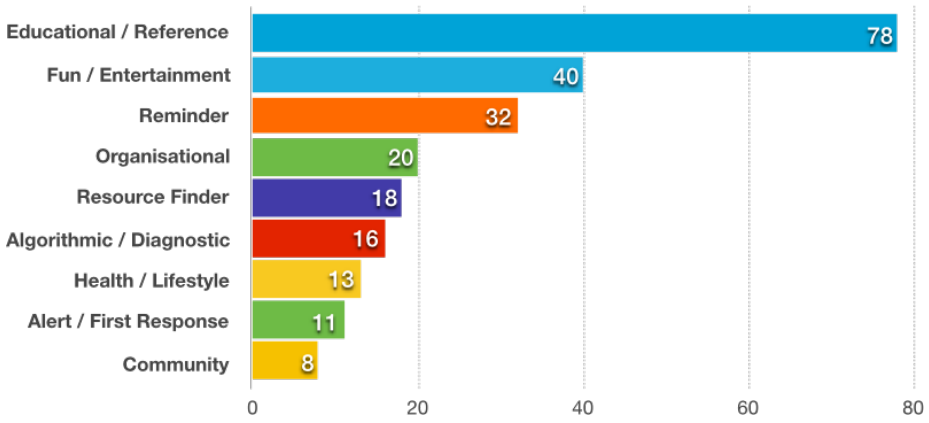

Figure 2.2: Medical Apps on the Goolge Play Store, Search conducted on 17.05.2016

2.3.3 Dermatology Apps 2013 vs 2016

Mobile apps are an especially good fit for dermatology-related care. Most dermatological conditions are by nature visible. The initial diagnosis and follow up monitoring is mostly done visually. A mobile device with a camera can aid patients and practitioners in the diagnosis of a dermatological condition and tracking it's development. The article Mobile Applications in Dermatology [4] in 2013 identified 229 dermatology-related apps across 5 app platforms (Android, Apple, Blackberry, Nokia, and Windows). These were grouped into categories based on their primary functionality. The "Self-surveillance/diagnosis" category was the second largest on the Android and Apple platforms, with 13 and 24 apps respectively.

Table 1. Total Applications

Category	Android	Apple	Blackberry	Nokia	Windows	Total, No. (%)
Reference	22	35	3	0	1	61 (26.6)
Self-surveillance/diagnosis	13	24	1	0	3	41 (17.9)
Disease guide	20	10	7	0	2	39 (17.0)
Educational aid	7	11	2	0	0	20 (8.7)
Sunscreen/UV recommendation	7	12	0	0	0	19 (8.3)
Calculator	2	9	1	0	0	12 (5.2)
Teledermatology	1	7[a]	0	0	0	8 (3.5)
Conference	2	3	0	1	0	6 (2.6)
Journal	2	4	0	0	0	6 (2.6)
Photograph storage/sharing	1	4	0	0	0	5 (2.2)
Dermoscopy	0	2	0	0	0	2 (0.9)
Pathology	0	2	0	0	0	2 (0.9)
Other	1	6	0	1	0	8 (3.5)
Total applications, No. (%)	78 (34.1)	129 (56.3)	14 (6.1)	2 (0.1)	6 (2.6)	229 (100.0)

[a] Two additional Apple iOS teledermatology applications were identified in a query of the term *teledermatology* during March 2013: HIV-Derm Algo Study (launched October 20, 2012) and SFGH Teledermatology pilot (launched November 12, 2012).

Figure 2.3: Total Applications, Brewer 2013

Using the same search criteria and categories from the article above indicates that the availability of dermatological apps is growing. Today there are 33 dermatological apps on the Apple platform that can be identified as having ”Self-surveillance/diagnostic” features. With the exception of the ”Reference” category, all other categories show significantly higher numbers of available apps.

Category	Apple 2013	Apple 2016	Android 2013	Android 2016
Reference	35	29	22	31
Self-surveillance/diagnosis	24	33	13	23
Disease guide	10	24	20	46
Educational aid	11	23	7	24
Sunscreen/UV recommendation	12	20	7	19
Calculator	9	4	2	10
Teledermatology	7	19	1	12
Conference	3	11	2	17
Journal	4	19	2	10
Photograph storage/sharing	4	3	1	1
Dermoscopy	2	7	0	3
Pathology	2	0	0	0
Other	6	8	1	4
Total	129	200	78	200

Figure 2.4: Demotological Apps by Category, July 2013(Brewer 2013) vs May 2016

It is important to note that the categories listed above are not defined in the stores. The apps must be manually assigned to a category based on an interpretation of the description text in the store and information obtainable on related websites. It is possible therefore that apps that were originally designated to the “Reference” category

might have been interpreted in this paper as a “Educational aid” app for example. The interpretation of the functionality of an app is fuzzy in many cases, and many apps have some crossover functionality. An app developed for self-surveillance will often contain information pertaining to symptoms and treatment (reference).

2.3.4 Dermatological Apps with Automatic Risk Assesment

Of the 55 apps identified belonging to the ”Self-surveillance/diagnosis” category, only 2 provided risk assesment features based on automatic analysis of captured images.

- SkinVision : https://skinvision.com
- mSkin Doctor https://play.google.com/store/apps/details?id=com.maleemtaufiq.mSkinDoctor

Chapter 3

Image Data Sources

3.1 Dermofit

High quality clinical images with corresponding masks. Great for training and testing.

Image Type	Description	Amount	Comment
Actinic Keratosis	Pre-cancerous patches of flakey or crusty skin, can develop into Squamous Cell Carcinoma	45	Not useful as comparison against melanoma
Basal Cell Carcinoma	Abnormal, uncontrolled growths of the skin's basal cells.	239	Not useful as comparison against melanoma
Dermatofibroma	Common and benign skin tumour.	65	Useful as comparison, some extreme cases might have to be left out of the training set.
Haemangioma	A collection of small blood vessels that form a lump under the skin.	97	Useful as comparison, some extreme cases might have to be left out of the training set
Intraepithelial Carcinoma	A type of squamous cell skin cancer limited to the upper layer of the skin.	97	Not useful
Malignant Melanoma	A type of cancer that develops from the pigment-containing cells known as melanocytes.	76	This is our baseline set, half will be used for training, the other half for testing
Melanocytic Nevus	Typical mole, benign.	331	Very usefull as comparison to Melanoma
Pyogenic Granuloma	Common skin growth, small, round and red in color due to large number of blood vessels.	24	Not usefull
Seborrhoeic Keratosis	Common non-cancerous skin growth.	257	Maybe usefull
Squamous Cell Carcinoma	Abnormal and uncontrolled growth of squamous cells in the epidermis.	88	Not usefull

Table 3.1: Dermofit Image Categories

3.2 DermQuest

Online teaching and learning resource with large image database.

Image were selected based on their usefullness for this project. Usefullness is based on quality and type of image. Dermoscopic images were not selected. Instead images were taken that appeared to be taken with a standard camera. The images only contained the mole to be examined and the surrounding skin area. No other details like eyelids, ears, or dark shadows.

Subgroups of Melanocytic Nevus were chosen. Dysplastic and Intradermal Nevus for the non-cancerous cases, and Malignant Melanoma as the cancerous cases.

Image Type	Description	Amount	Comment
Benign Keratosis		5	
Malignant Melanoma	A type of cancer that develops from the pigment-containing cells known as melanocytes.	39	This is our baseline set, half will be used for training, the other half for testing
Melanocytic Nevus	Typical mole, benign.	51	Very usefull as comparison to Melanoma

Table 3.2: DermQuest Image Categories

3.3 PH2Dataset

Demascopic Images

Many of the mole images extend almost to or even beyond the image border. This makes some of the processing difficult. However the images include an excel spreadsheet which clearly designates what type of mole, including some scoring info such as Asymmetry and Color information. Includes border mask images.

Image Type	Description	Amount	Comment
Common Nevus		79	
Atypical Nevus		79	
Melanoma		39	Baseline set for training

Table 3.3: PH2 Image Categories

Chapter 4

Image Feature Extraction

A digital image is a matrix of pixels that contain color information, typically comprised of the 3 color channels red, green, and blue. A person can look at an image and quickly make statements about it's content. For instance, someone might look at an image of a street scene and be able to easily say "This is an image of a street in a town, there is one automobile, three people and a building in this scene". A person would easily be able to draw outlines around the objects and be able to differentiate between areas in each object.

For a computer to be able to "make statements" about the contents of an image it must use algorithms to group together and differentiate between objects in an image. The grouping together and differentiating of areas in an image is known as *segmentation*. The statements that a computer can make about the content of an image are usually of statistical nature and are refered to as *feature extraction*. Before segmentation an image is goes through a *preprocessing* stage in order to remove or reduce irrelevant information or noise.

There are no universal algorithms for preprocessing, segmentation, or feature extraction. The algorithms employed depend on the context of the images to be analyed and the type of information that one is looking for.

4.1 Preprocessing

4.1.1 Equalization

4.1.2 Median Blur

4.1.3 Gaussian Blur

4.2 Segmentation

4.2.1 Iterative Thresholding

4.2.2 Region Selection

4.3 Image Feature Extraction

Chapter 5

TDS Algorithm

5.1 Description of the Algorithm

Early detection of melanoma greatly increases the chances of successful treatment. A biopsy can be performed in order to gain a definitive diagnosis. However, biopsies are invasive, painful and take time. There are also visual markers Dermatologists look for in order to make a risk assessment. The ABCD Rule, also known as Stokes or TDS Calculation, looks for 4 sets of features. Based on the features the Total Dermoscopy Score (TDS) is calculated.

The 4 sets of features are Asymmetry (A), Border Irregularity (B), Color (C) and Differential Structure or Diameter (D).

Asymmetry can have a value of 0, 1 or 2 depending on the symmetry of the lesion. Where 0 is symmetric and 2 is asymmetric. A value of 1 indicates at least one axis was found across which symmetry exists. The Border score is an integer value from 0 to 8 indicating the presence of border irregularities in 8 regions. Color is an integer value from 1 to 6 indicating the presence of one to six specific colors. Similarly, the value for D indicates the presence of one to five distinct structures or textures. Alternatively, in some literature [10] D is defined as Diameter, where a diameter greater than 6mm results in a value of 5, otherwise 1.

The final TDS Score is the weighted sum of the ABCD Values and is in the range 1.0 to 8.9.

$$TDS = A * 1.3 + B * 0.1 + C * 0.5 + D * 0.5 \tag{5.1}$$

A diagnosis can be made based on the TDS Score according to the following table:

Evaluation	TDS Score
Benign	<4.75
Suspicious	4.75 to 5.45
Malignant	>5.45

Table 5.1: TDS Evaluation [12]

5.1.1 Adaptation for use in a smart phone application

The ABCD Rule, also known as the Total ***Dermoscopy*** Score, is really only applicable to images captured using a dermatoscope. Especially the differential structures are only visible on dermatoscopic images where the subsurface structures are made visible [2].

Since the D component is not applicable to images captured with a smart phone this project will use a modified TDS without the D component. The original TDS formula 5.1 can have values ranging from 1 to 8.9 and D can be 0.5 to 2.5. Without D the TDS can have values between 0.5 and 6.4.

$$TDS_{mod} = A * 1.3 + B * 0.1 + C * 0.5 \tag{5.2}$$

This results in a bening cuttoff score of 3.2 and malignagnt cuttoff of 3.7.

Evaluation	Score
Benign	$<$3.20
Suspicious	3.20 to 3.7
Malignant	$>$3.7

Table 5.2: Adapted TDS Evaluation

5.2 Automatic Calculation of ABCD Values

The ABCD Rule is used by Dermatologists to differentiate benign from malignant melanocytic tumors. It is a clearly defined rule based on easily recognizable visual features. Clinicians with limited dermoscopy experience achieve better results using the ABCD rule than other methods [12]. The following sections detail methods to automate the calculation of the ABCD scores.

5.2.1 Asymmetry

The ”Center of mass” method of measuring asymmetry is relatively easy to calculate and is more accurate compared to other complex algorithms [8].

This algorithm begins by calculating an array of radii from the lesion's center of mass to border for each of 360 degrees. The coordinates for the center of mass are calculated from the sum of all x and y coordinates of pixels within the lesion's border each divided by the sum of pixels.

For each of the 360 radii r_i a score is calculated by comparing the lengths of pairs of radii that are symmetric across r_i. If the lengths of the pair of symmetric radii have a difference of less than 10% then a point is given. The sum of points is the SFA_i (Score For Axis) for r_i.

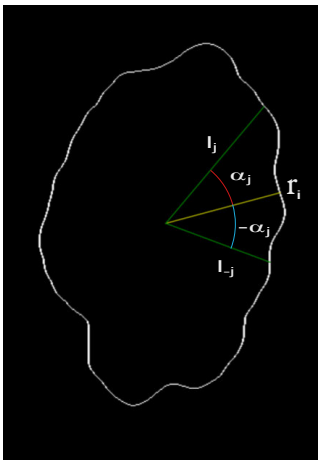

Figure 5.1: Calculate SFA for r_i

The radius with the maximum SFA score is defined as the major axis of symmetry. The SFA of the major axis as well as the perpendicular are stored. The Asymmetry score is evaluated as follows:

SFA Results	Description	Asymmetry Score
major axis $\geq$ 140 minor axis $\geq$ 140	Symmetric across both axis	0
major axis $\geq$ 140 minor axis $<$ 140	Symmetric across one axis	1
major axis $<$140 minor axis $<$140	Asymmetric	2

Table 5.3: TDS Evaluation [12]

5.2.2 Border

An image is generated where only the pixels at the border or the lesion are visible, the rest of the image is black. The pixels are gathered sequentially into an array starting at any arbitrary border pixel and traversing the border continually. It's important that the sequential order of the pixels be maintained since the change in angle and distance to the lesions center will be measured.

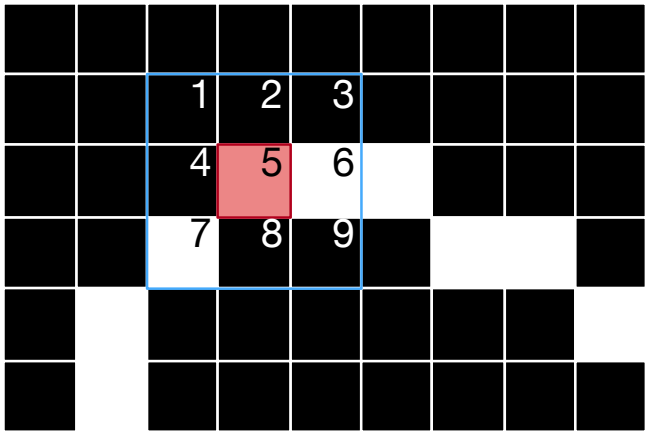

Figure 5.2: Traverse the border sequentially

An algorithm was developed that finds an arbitrary border pixel in an image that is otherwise black by iterating though pixels starting at the top left corner. When it has found a pixel that is not black it tests neighboring pixels, starting with the upper left neighbor and traversing the pixels row by row starting from the left most pixel in a row, as illustrated by the numbered pixels in figure 5.2. The center pixel, pixel number 5, is skipped.

When a non black pixel is detected it is compared to a a list or previously detected pixels. If it has not been previously detected, it is added to the list and becomes the new center. The algorithm is repeated.

If no new non-black pixel is detected the outter range is expanded by one pixel at each edge and the pixels at the edge of a 5 x 5 area are tested. This is repeated until a new pixel is found. This prevents the algorithm from halting if there are discontinuities in the border.

When the algorithm reaches the starting pixels it ends. The list of pixels now contains a sequential list of pixels that are in sequential order.

For each pixel the distance and angle from the lesion's center of mass is calculated. If a lesion's border is irregular the measure of distance and angle from the center will be erratic, whereas is the border is relatively circular and smooth the measure of distance and the difference in angle will not change abruptly between neighboring pixels.

The distance function is averaged around the distance of the start pixel (set to zero) in order to reduce discontinueities. A gaussian lowpass filter is used to reduce noise and aliasing artifacts due to pixelization.

From the smoothed distance function the first derivative is calucalated. From the angle function the difference from neighboring pixels is calculated. The resulting two functions are split into 8 equal segments. Each segment is analysed for strong variations in distance and sign changes in the difference of the angles. A sign change would indicate a very strong change in direction of the border function. For each segment in which strong variations are detected a point in the B score is added.

A lesion with strong variations in one segment, but otherwise smooth border function would have a B score of 1, whereas a lesion with variation is each of the 8 segments would have a B score of 8.

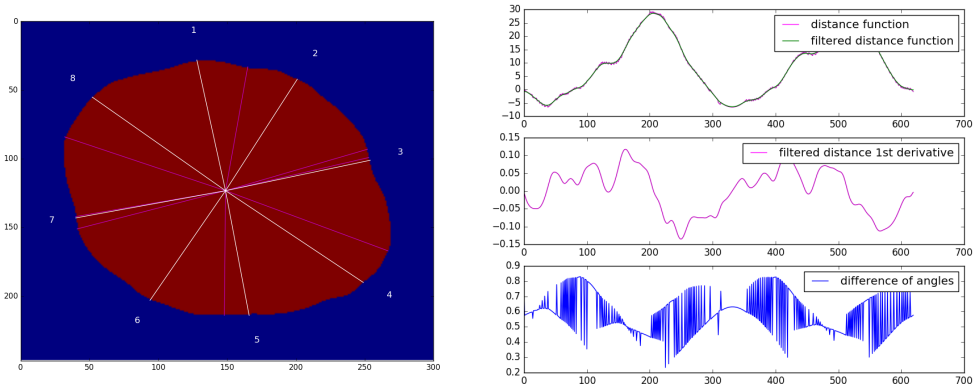

Figure 5.3: Example of border score 0

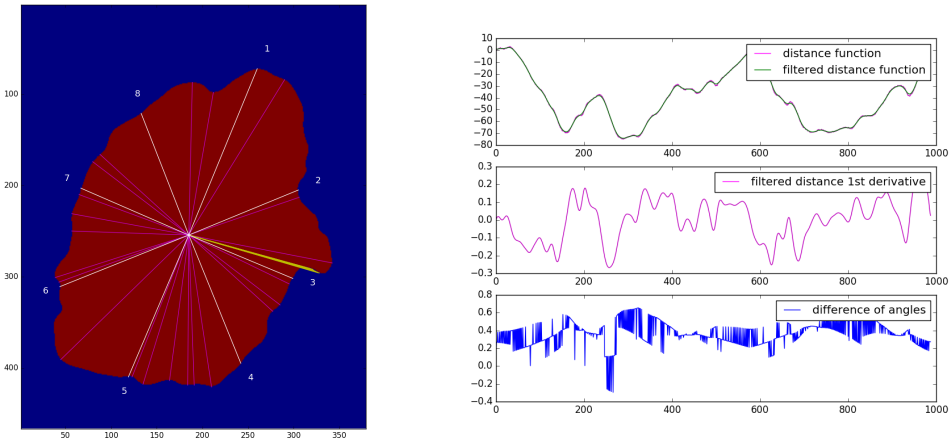

Figure 5.4: Example of border score 4

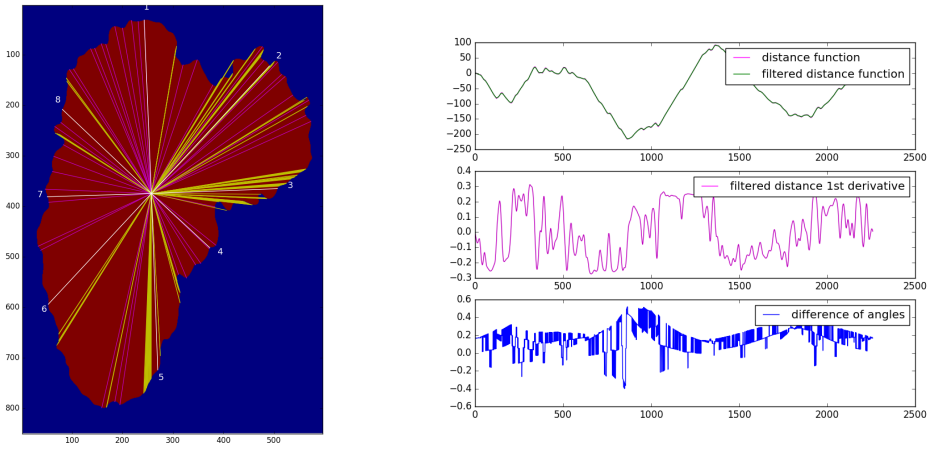

Figure 5.5: Example of border score 8

5.2.3 Color

In order to calculate the color score the *Quantification of Color* [2] algorithm was implemented in which the distance of each pixel to a defined set of colors is evaluated.

The original image is first filtered using a low pass Gaussian filter in order to reduce noise. Then for for each pixel with the lesion area the euclidean distance from 6 RGB values is calculated. The 6 RGB values, as shown in table 5.4, represent the colors that are relevent to the TDS calculation.

Color	R	G	B
White	255	255	255
Red	204	51	51
Light Brown	153	102	0
Dark Brown	51	0	0
Blue Gray	51	153	255
Black	0	0	0

Table 5.4: RGB values of the six possible TDS-relevent colors [2]

For each color a counter is incremented when a pixel is found that is closest to it. The end results are divided by the total number of pixels within the lesion's boundaries. For each color with a value greater than 0.01 a point is given to the TDS C score.

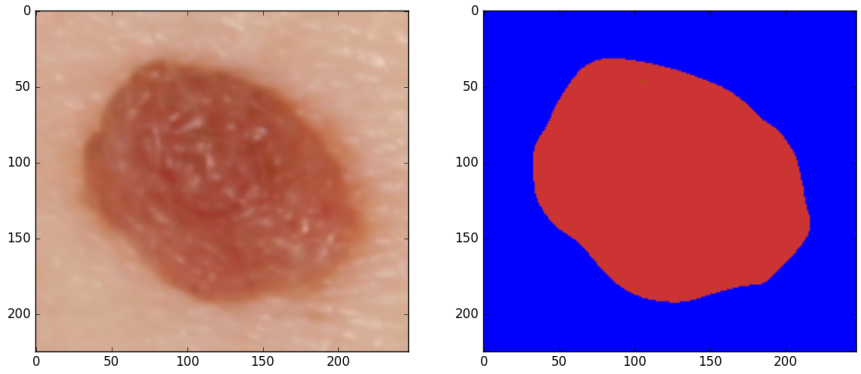

Figure 5.6: Example of color score 1

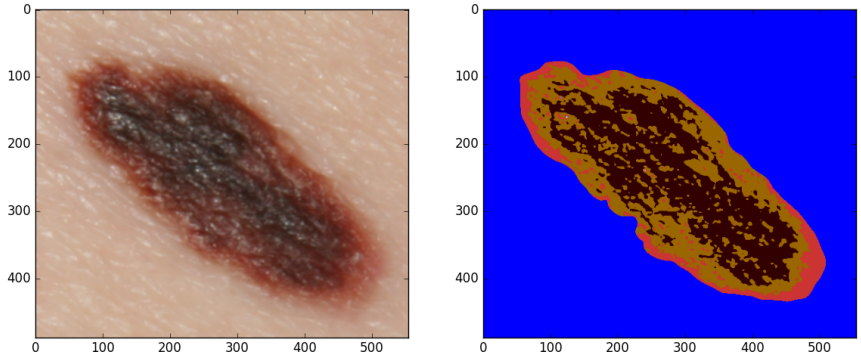

Figure 5.7: Example of color score 3

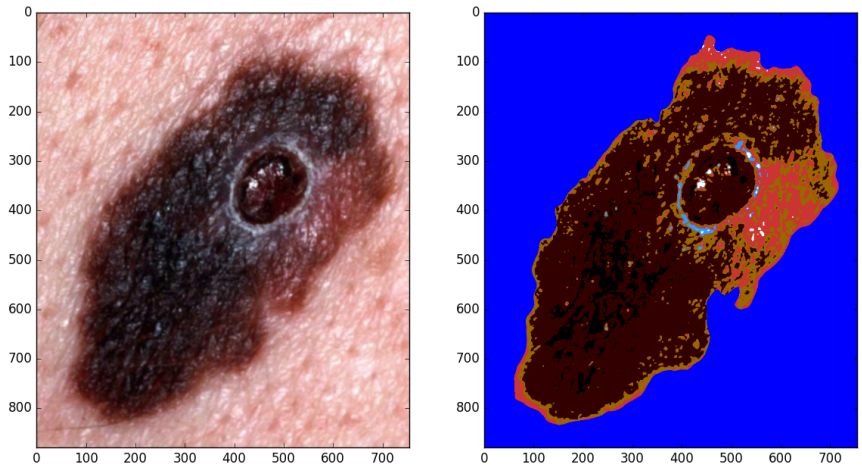

Figure 5.8: Example of color score 4

5.2.4 Differential

5.3 Two Examples

5.3.1 Postitiv Example

5.3.2 False Example

TDS Values were calculated but classification result was false.

5.4 Results of Algorithm

Performance Evaluation
Chapters 11.1, 11.2, maybe 11.3

Chapter 6

Machine Learning

6.1 Section Title

6.2 Results of Algorithm

Performance Evaluation

Chapters from book 11.1, 11.2, 11.3, 11.5, 11.6

Chapter 7

Implementaion of the Algorithm

7.1 Section Title

Chapter 8

Concept of the Application

In section 2.2.1 categories of medical smart phone apps were defined. Apps in the same categories might have a similar feature set and capabilities. An app in the *Alert / First Response* category might have a database that stores important contacts in the user's area and a user interface that allows the user to quickly alert a contact in an emergency situation. An app in the *Learning / Educational / Reference* category might be modelled as a quiz app which presents the user with a question and several possible answers to choose from. Answers from several questions will can be evaluated and a score is presented to the user at the end of a session. The app would be implemented with a database of questions and weighted answers, as well as an interface that presents the questions to the user sequentially.

One of the goals of this project is to define requirements for an app that provides a risk assessment of a lesion being benign or malignant. A high level description of the primary functionality of the app is the following:

> The smart phone app allows the user to capture and analyse an image of a skin lesion and provide a risk assessment to the user of the lesion being a malignant melanoma.

The user might also like to save the image and results in oder to be able to compare it with other assessments in the future, or to review the assessment with a dermatologist. For comparison it might be useful to save associated metadata, such as the date and location on the body of the lesion. For convenience it might be nice to send the assessment and image via email to a specialist for review. Secondary functionality can be described as follows:

> The app allows the user to save or archive the image and corresponding assessment for future comparison and review.
>
> The user can add, edit, and save metadata associated with the image of the lesion.
>
> The user can browse archived images, assessments, and associated metadata.

The user can send a set of images with associated assessment and metadata via email.

From this high level description some basic assumptions about the app's architecture can already be made. The app will require access to a database that can store information about an image, results of the analysis, and metadata. The app will require a user interface that allows a user to browse and edit data associated with an image. The app requires access to the smart phone's camera api in order to capture images.

In order to formally elicit the requirements the hight level description will be broken down into structured use cases. A set of requirements will be extracted from the use cases.

8.1 Use Cases

In order to capture the formal use cases we will use a schema based on the one defined in Requirement Engineering Fundamentals [7].

ID	Unique designation of the use case
Name	Unique name of the use case
Priority	Importance of the use case according to applied prioritization technique
Description	Use case in user story form
Dependencies	dependencies
Trigger event	Name of the event that triggers this use case
Actors	List of all the actors involved in this use case
Preconditions	List of all necessary constraints that must be met before this use case can begin execution
Posconditions	List of all states the system can be in immediately after the execution of the main scenario
Result	Description of the results that are produced during the use case execution
Main scenario	Sequnce of events that occur during the use case.
Alternate scenarios	Alternative sequence of events that might occur.
Comments	Other infos

Table 8.1: Use Case Template

ID	UC-1
Name	Capture Image
Description	As a user I can capture an image of the skin lesion that I would like to have analysed.
Dependencies	None
Trigger	The user activated the application and selected the ”image capture” navigation item.
Preconditions	The system state which must be active before the Use Case can occur
Normal Flow	**1.** Point the camera at the skin lesion. **2.** Rotate and move the camera until the skin lesion is centered and optimally sized. **3.** The user touches the screen to capture the image. **4.** The user is notified (beep) that the image has been captured **5.** The user can repeat from the begining
Alternate Flow	None
Results	The captured images are placed by the system in a processing queue to calculate the lesion’s border.
Comments	It is important that a user can capture the image with just one hand. If a lesion is located on a user’s hand or arm, it’s not possible to use two hands.

Table 8.2: Use Case 1

ID	UC-2
Name	Confirm correct calculation of skin lesion's border
Description	As a user I want to confirm that the skin lesion's borders have been properly calculated.
Dependencies	UC-1
Trigger	The user selected the "confirm border" navigation item.
Preconditions	At least one image has been queued for border calculation.
Normal Flow	**1.** The user is presented with a list of images. **2.** The following step is repeated for each image in the list. **3.** The user confirms that the border of the lesion has been precisely calculated.
Alternate Flow	**A1.** Border calculation for image has not completed. **A1.3** The user can refresh the image preview until the results of the border are visible. **A1.4** The user confirms that the border of the lesion has been precisely calculated. **A2** Border calculation is not precise or has failed. **A2.3** The user confirms that the border of the lesion has not been precisely calculated. **A2.4** The image is deleted.
Results	After positiv confirmation, images are placed by the system in the risk assessment calculation queue. If no images can be positively confirmed, the user can recapture new images (UC-1)
Comments	

Table 8.3: Use Case 2

ID	UC-3
Name	View risk assessment
Description	As a user I want to view the results of the risk assessment calculation.
Dependencies	UC-2
Trigger	The user selected the ”risk assessment results” navigation item.
Preconditions	The system was able to complete the risk assessment calculation
Normal Flow	**1.** The user is presented with a list of images. **2.** The following step is repeated for each image in the list. **3.** The user can select and view and image and corresponding results in detail.
Alternate Flow	**A1.** Risk assessment calculation for image has not completed. **A1.3** The user can refresh the results details until the results of a risk assessment is available.
Results	
Comments	

Table 8.4: Use Case 3

ID	UC-4
Name	Save image and results
Description	As a user I want to save the image and the results of the risk assessment.
Dependencies	UC-3
Trigger	The user selects the ”save” navigation item.
Preconditions	The system was able to complete the risk assessment calculation.
Normal Flow	**1.** The user is presented with a list of images. **2.** The can select one or more images with the corresponding risk assessment results. **3.** The user can add a title and comment. **4.** The user is presented with a confirmation that the package has been saved.
Alternate Flow	
Results	A package of images and corresponding risk assessment data is stored in the archive with some metadata (title and comment).
Comments	

Table 8.5: Use Case 4

ID	UC-5
Name	View archived images and data.
Description	As a user I want to view previously saved images and the corresponding risk assessment data.
Dependencies	UC-4
Trigger	The user selects the ”archive” navigation item.
Preconditions	The system was able to complete the risk assessment calculation.
Normal Flow	**1.** The user is presented with a list of archived packages. **2.** The user can select an item in the list **3.** The user is presented with the images, corresponding risk assessment data and metadata for the selected item.
Alternate Flow	
Results	A package of images and corresponding risk assessment data is stored in the archive with some metadata (title and comment).
Comments	

Table 8.6: Use Case 5

ID	UC-6
Name	Send results to dermatologist.
Description	As a user I want to send a previously saved image, feature extraction data and assessment results to a dermatologist.
Dependencies	UC-4
Trigger	The user selects the ”archive” navigation item.
Preconditions	The system was able to complete the risk assessment calculation.
Normal Flow	**1.** The user is presented with a list of archived packages. **2.** The user can select an item in the list **3.** The user can send the item as an email attachment.
Alternate Flow	
Results	
Comments	

Table 8.7: Use Case 6

8.2 User Interface

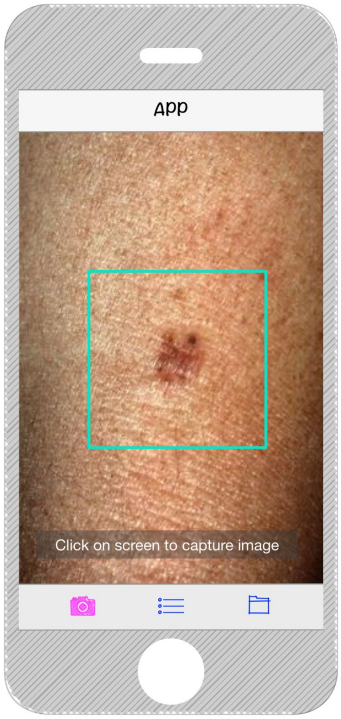

Figure 8.1: Image Capture View

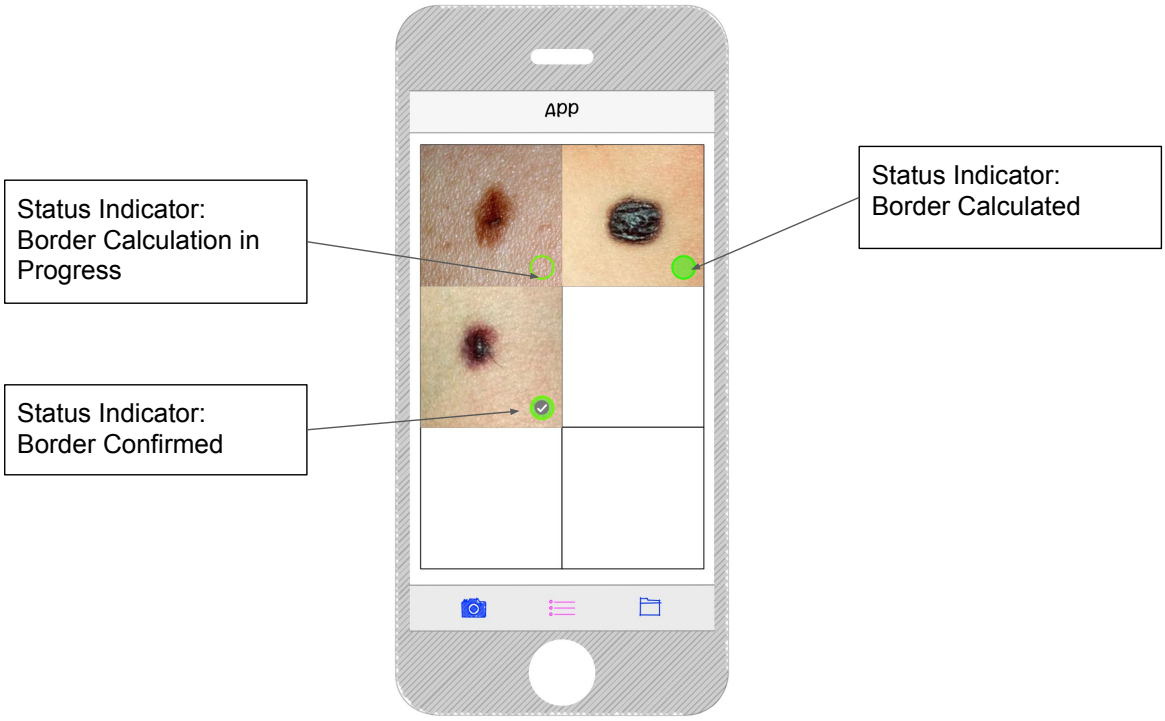

Figure 8.2: Image List View

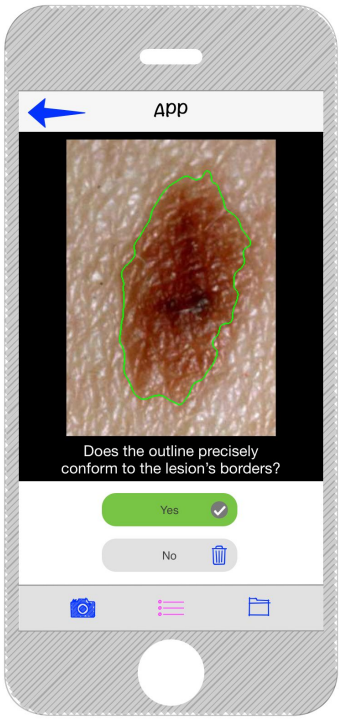

Figure 8.3: Border Confirm View

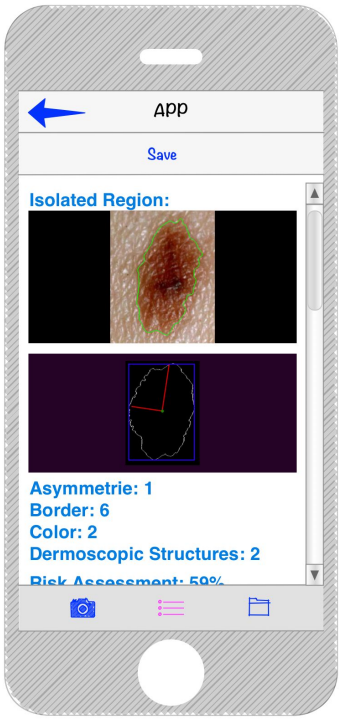

Figure 8.4: Image Detail View

Figure 8.5: Archive View

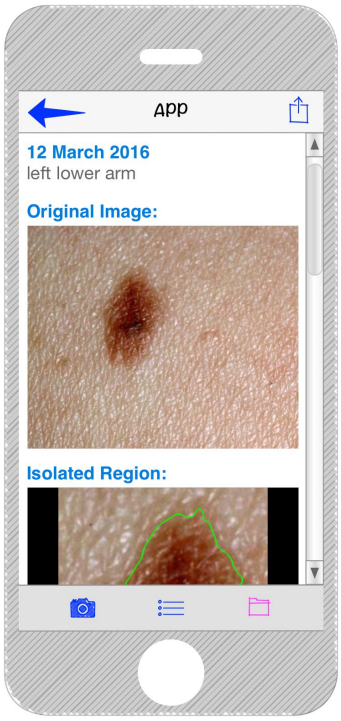

Figure 8.6: Archive Detail View

8.3 Requirements

8.4 Prioritized Requirements

ID	Priority	Name	Implemented
REQ-F-1	-	Preview Camera Input	-
REQ-F-2	-	Capture Camera Input	-
REQ-F-3	-	Border Extraction	-
REQ-F-4	-	Browse Images and Results	-
REQ-F-5	-	Select Image To View in Detail	-
REQ-F-6	-	Border Confirmation	-
REQ-F-7	-	Feature Extraction	-
REQ-F-8	-	Feature Extraction	-

Table 8.8: Prioritzed Requirement List

ID	REQ-F-1
Name	Preview Camera Input
Description	The system will let the user view a preview of the camera's input in realtime
Preconditions	None
Acceptance Tests	
Relations	UC-1
Comments	

Table 8.9: Functional Requirement 1

ID	REQ-F-1
Name	Capture Camera Input
Description	The system will let the user capture an image from the camera's input.
Preconditions	None
Acceptance Tests	
Relations	UC-1
Comments	

Table 8.10: Functional Requirement 1

ID	REQ-F-3
Name	Border Extraction
Description	The system must be able to calculate the border of a lesion in a captured image.
Preconditions	None
Acceptance Tests	
Relations	UC-2
Comments	

Table 8.11: Functional Requirement 3

ID	REQ-F-4
Name	Browse Images and Results
Description	The system will let the user browse through a list of images. The list will display the status of the images.
Preconditions	None
Acceptance Tests	
Relations	
Comments	

Table 8.12: Functional Requirement 4

ID	REQ-F-5
Name	Select Image To View in Detail
Description	The system will let the user select and view an image as well as the results of completed processes.
Preconditions	None
Acceptance Tests	
Relations	
Comments	

Table 8.13: Functional Requirement 5

ID	REQ-F-6
Name	Border Confirmation
Description	The system will let the user confirm that the border of a lesion hat been precisely calculated.
Preconditions	
Acceptance Tests	
Relations	
Comments	

Table 8.14: Functional Requirement 6

ID	REQ-F-7
Name	Feature Extraction
Description	The system must be able to extract relavent features from the isolated lesion image.
Preconditions	
Acceptance Tests	
Relations	
Comments	

Table 8.15: Functional Requirement 7

ID	REQ-F-8
Name	Add To Process Queue
Description	The system must be able to add an image process job to the process queue
Preconditions	
Acceptance Tests	
Relations	
Comments	

Table 8.16: Functional Requirement 8

ID	REQ-F-9
Name	Asign Image to Process
Description	The system must be able to asign an image process to an image process job
Preconditions	
Acceptance Tests	
Relations	
Comments	

Table 8.17: Functional Requirement 9

ID	REQ-F-10
Name	Remove From Queue
Description	When an image process job in complete it will be removed from the process queue.
Preconditions	
Acceptance Tests	
Relations	
Comments	

Table 8.18: Functional Requirement 10

ID	REQ-F-11
Name	Process Queue
Description	The system will process jobs in the process Queue.
Preconditions	
Acceptance Tests	
Relations	
Comments	

Table 8.19: Functional Requirement 11

8.5 Prioritisation

This project will employ a Single-Criterion Ad-hoc prioritisation classification as opposed to an analytical approach such as the Wiegers prioritisation matrix. The rationale behind this choice is that as a single person development project the determination of weights for benefit, detriment, cost, and risk is an ad-hoc exercise. In a larger project with multiple developers and active stakeholders the time and effort required for a prioritisation assessment according to Wiegers would be advisable.

The following are the prioritisation classes as defined in [7]:

> **Mandatory**: A mandatory requirement is a requirement that must be implemented at all costs or else the success of the system is threatened.

Optional: An optional requirement is a requirement that does not necessarily need to be implemented. Neglecting a few requirements of this class does not threaten the success of the system.

Nice-to-have: Nice-to-have requirements are requirements that do not influence the system's success if they are not implemented.

8.6 Software Architecture

8.6.1 MVC

Since the 1970s the Model View Controller (MVC) pattern is the standard architectural design pattern for applications that present the user with a graphical user interface. It was developed out of a need for modularity, to encapsulate responsibility of specific concepts to separate program modules, or Separation of Concerns. MVC identifies three main components that program code should be grouped into, namely [11]:

Model: The representation of some object of knowledge, encapsulates code managing the associated data and behaviour (business-logic).

View: The visual representation of the model. The view can feature or hide aspects of the model and thus act as a presentation filter. The view observe the model for changes and update the presentation accordingly.

Controller: The controller allows the user to interact with the model. It allows the user to trigger behaviours implemented in the Model.

In the classic MVC pattern the model does not "know" about the view or the controller. And the controller does not effect the view. Instead, both the view and controller monitor the model using an observer mechanism and synchronise themselves when updates to the model occur.

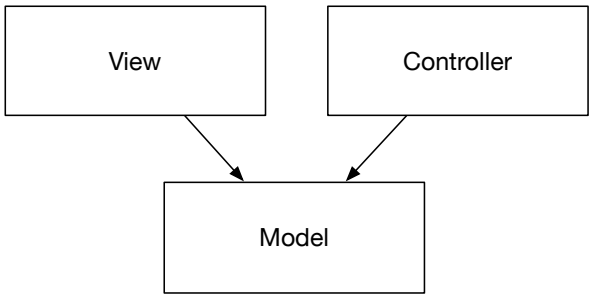

Figure 8.7: Classic MVC

8.6.2 Modern MVC

Modern MVC has evolved from being a software design pattern which handles components of an application to an architectural design pattern that defines the structure of an application itself. It has many similarities to the Layer Architecture. The responsibilities of each layer are slightly different to the typical presentation, business, and persistence layer definitions.

Most modern web frameworks such as Ruby on Rails, Symfony or the IOS environment refer to themselves as MVC based frameworks. The modern MVC concept has changed slightly. The component definitions are the same, but some responsibilities have shifted. Modern MVC strictly separates the model from the view. All modern frameworks state that the view should have as little logic as possible. Any logic implemented in the view should only be relevant to presentation. The view components should not directly reference the model components [3] [1].

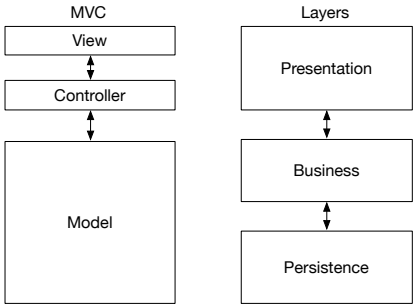

Figure 8.8: Modern MVC vs 3-Tier Layered Architecture

This division of responsibility has the added benefit of increased testability. GUIs are difficult to test, by removing as much logic as possible from the user interface there is less necessity to test it. The controller and model components can more easily be tested independently of one another using normal unit tests [5].

8.6.3 MVC Derivatives

Many MVC derivatives exist. The main differences are where the division of responsibility is made and how it is labeled. MVVM defines a view model instead of a controller. The view model acts as a facade around the model and introduces a data binder element that is responsible for keeping the view and view model synchronised. The MVT, calls the view a template and the controller a view. The slight difference is that the template is basically a static file, with no logic, and placeholders for the data. The Django web framework uses this model, but there is little difference to the other MVC derivatives such as MVP (model view presenter). The AngularJS web framework takes ends the discussion of which design to follow by labelling itself a MVW (model view whatever) framework [6].

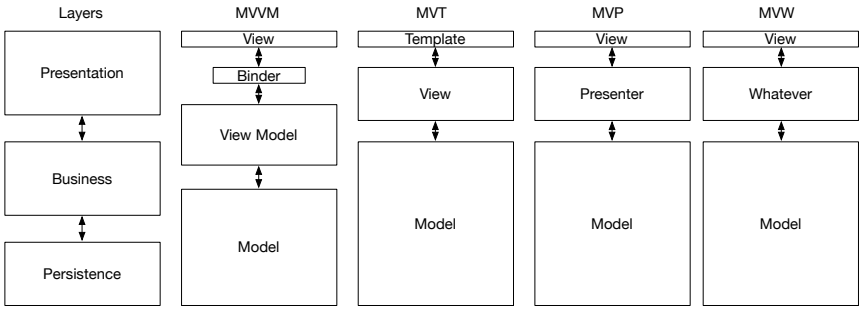

Figure 8.9: MVC Derivatives Overview

8.6.4 MVC and Smart Phone Applications

Although most frameworks and environments targeted toward mobile application development use concepts from MVC, it can be difficult to define strict devision of responsibility, especially in conjunction with services provided from an online server. Often the responsibilities of the controller are reimplemented server side, some model management might occur in the app. Server and application code are developed using different languages and often most likely different developers. One solution is is to develop the app as a thin client, where it basically becomes the view component of MVC and the controllers and model are implemented on the server. Taken to the extreme, the app runs in a standard web browser and server provides the view components that emulate a native mobile user interface. This is referred to as a web app. Any logic in the view is implemented using javascript. Hardware support is limited to what the mobile browser provides access to. In order to extend hardware support a hybrid approach can be used in which the app implements a custom browser view which is extended with native capabilities. Here is division or responsibilities as defined by MVC become fuzzy. A fully native app working in conjunction with a web server will not conform well to the definitions of MVC.

8.6.5 VIPER

VIPER is a new software architecture pattern which extends MVC with some addition concepts that make it more adaptable to mobile applications, especially when they are extended with online server based services. The classic controller is split into a presenter and a controller, the model component is split into a central data manager communicating with many services and entities [9].

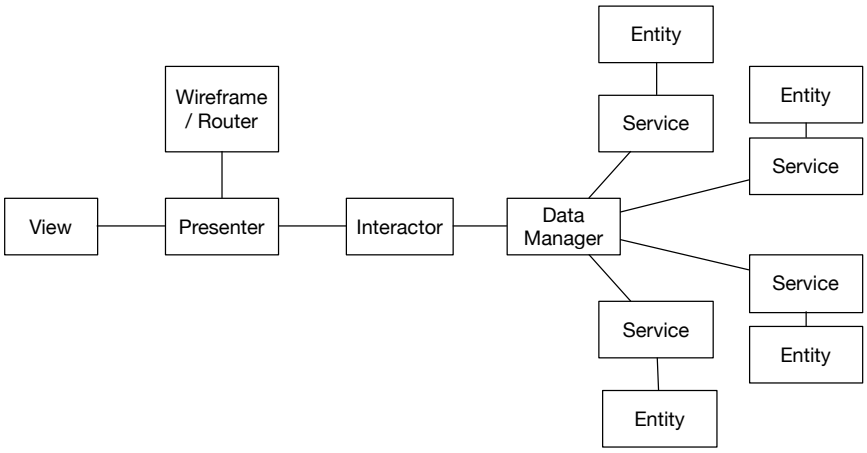

Figure 8.10: VIPER Overview

View: The view corresponds to the view as defined in modern MVC definitions, it is a slim component with as little logic as possible. It presents the current state of the models and provides "widgets" with which the user can interact.

Presenter: The presenter passes data to the view and handles events from the view. The presenter might perform some basic validation, in the case of a user sign-up scenario, for example, the presenter might validate that a user's email is indeed formatted as a correct email, it will not validate if the email has already been used by someone else.

Interactor: Business logic is handled by the interactor. Most a what the model component in MVC was responsible for is handled here. The interactor however does not know anything about data storage, databases, or persistence. It does not know if data is local or accessible via a network.

Data Manager:

Service:

Entity:

Wireframe / Router:

Bibliography

[1] Symfony Book: Chapter 2 - Exploring Symfony's Code, The MVC Pattern, 2015. [Online; accessed 2016-8-27], link.

[2] Jose Fernandez Alcon, Calina Ciuhu, Warner ten Kate, Adrienne Heinrich, Natallia Uzunbajakava, Gertruud Krekels, Denny Siem, and Gerard de Haan. Automatic Imaging System With Decision Support for Inspection of Pigmented Skin Lesions and Melanoma Diagnosis. *IEEE*, 3(1):14–25, feb 2009.

[3] Apple. Model-View-Controller, 2015. [Online; accessed 2016-8-27], link.

[4] Ann Chang Brewer, Dawnielle C. Endly, Jill Henley, Mahsa Amir, Blake P. Sampson, Jacqueline F. Moreau, and Robert P. Dellavalle. Mobile Applications in Dermatology. *JAMA Dermatol*, 149(11):1300, nov 2013.

[5] Martin Fowler. GUI Architectures, Humble View, 2006. [Online; accessed 2016-8-28], link.

[6] Igor Minar. MVC vs MVVM vs MVP, 2012. [Online; accessed 2016-8-28], link.

[7] Klaus Pohl and Chris Rupp. *Requirements Engineering Fundamentals: A Study Guide for the Certified Professional for Requirements Engineering Exam - Foundation Level - IREB compliant*. Rocky Nook, 2015.

[8] J. Premaladha and K.S. Ravichandr. Asymmetry Analysis of Malignant Melanoma Using Image Processing: A Survey. *J. of Artificial Intelligence*, 7(2):45–53, feb 2014.

[9] Ryan Quan. Brigade's Experience Using an MVC Alternative, 2014. [Online; accessed 2016-8-28], link.

[10] Sophia.M Mallikarjun Mundas Vidya.R Siddiq Iqbal, Divyashree.J.A. Implementation of Stolz's Algorithm for Melanoma Detection. *International Advanced Research Journal in Science, Engineering and Technology IARJSET*, 2(6), jun 2015.

[11] Stephen Walther. The Evolution of MVC, 2016. [Online; accessed 2016-8-27], link.

[12] Ulrike Weigert, Walter H.C. Burgdorf, and Wilhelm Stolz. ABCD Rule. In *Atlas of Dermoscopy*, page 116. Informa Healthcare, aug 2012.

Chapter 9

Appendix

9.1 Optimizations

9.1.1 Border Extraction

9.1.2 SFA Threshold

9.1.3 TDS Evaluation

Name	Source	Category	Asymmetry	Border	Color	TDS
B1052.png	Dermofit	Malignant Melanoma	2	4	3.0	4.50
B287.png	Dermofit	Malignant Melanoma	2	5	2.0	4.10
B302.png	Dermofit	Malignant Melanoma	0	3	2.0	1.30
B314.png	Dermofit	Malignant Melanoma	2	6	2.0	4.20
B65.png	Dermofit	Malignant Melanoma	2	4	3.0	4.50
C158.png	Dermofit	Malignant Melanoma	0	2	3.0	1.70
C201.png	Dermofit	Malignant Melanoma	2	4	3.0	4.50
C263a.png	Dermofit	Malignant Melanoma	2	4	3.0	4.50
C311b.png	Dermofit	Malignant Melanoma	2	8	3.0	4.90
C359.png	Dermofit	Malignant Melanoma	1	3	3.0	3.10
D143.png	Dermofit	Malignant Melanoma	0	1	3.0	1.60
D39.png	Dermofit	Malignant Melanoma	2	3	3.0	4.40
D630.png	Dermofit	Malignant Melanoma	0	2	1.0	0.70
D678.png	Dermofit	Malignant Melanoma	0	0	3.0	1.50
T233a.png	Dermofit	Malignant Melanoma	1	8	2.0	3.10
T86b.png	Dermofit	Malignant Melanoma	1	3	3.0	3.10
A121a.png	Dermofit	Melanocytic Nevus	0	3	3.0	1.80
A21b.png	Dermofit	Melanocytic Nevus	0	2	2.0	1.20
A2b.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
A8c.png	Dermofit	Melanocytic Nevus	2	4	2.0	4.00
A8d.png	Dermofit	Melanocytic Nevus	1	2	1.0	2.00
A8e.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10

B125c.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
B157.png	Dermofit	Melanocytic Nevus	1	2	3.0	3.00
B17a.png	Dermofit	Melanocytic Nevus	1	2	3.0	3.00
B17b.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
B17c.png	Dermofit	Melanocytic Nevus	1	2	1.0	2.00
B17f.png	Dermofit	Melanocytic Nevus	1	3	2.0	2.60
B197d.png	Dermofit	Melanocytic Nevus	1	0	1.0	1.80
B202b.png	Dermofit	Melanocytic Nevus	1	0	3.0	2.80
B293b.png	Dermofit	Melanocytic Nevus	0	1	1.0	0.60
B293d.png	Dermofit	Melanocytic Nevus	0	1	1.0	0.60
B293e.png	Dermofit	Melanocytic Nevus	0	2	2.0	1.20
B311c.png	Dermofit	Melanocytic Nevus	1	4	1.0	2.20
B350a.png	Dermofit	Melanocytic Nevus	0	0	1.0	0.50
B355b.png	Dermofit	Melanocytic Nevus	2	0	1.0	3.10
B356.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
B361a.png	Dermofit	Melanocytic Nevus	0	1	1.0	0.60
B379a.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
B379b.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
B447a.png	Dermofit	Melanocytic Nevus	2	8	2.0	4.40
B447b.png	Dermofit	Melanocytic Nevus	1	3	2.0	2.60
B472b.png	Dermofit	Melanocytic Nevus	0	2	1.0	0.70
B508.png	Dermofit	Melanocytic Nevus	2	5	2.0	4.10
B522b.png	Dermofit	Melanocytic Nevus	0	0	1.0	0.50
B52a.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
B52c.png	Dermofit	Melanocytic Nevus	0	4	2.0	1.40
B543.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
B549c.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
B574.png	Dermofit	Melanocytic Nevus	1	0	2.0	2.30
B598a.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
B612b.png	Dermofit	Melanocytic Nevus	1	2	1.0	2.00
B654c.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
B66c.png	Dermofit	Melanocytic Nevus	0	3	2.0	1.30
B676a.png	Dermofit	Melanocytic Nevus	0	3	2.0	1.30
B676b.png	Dermofit	Melanocytic Nevus	1	4	3.0	3.20
B69a.png	Dermofit	Melanocytic Nevus	1	2	3.0	3.00
B69b.png	Dermofit	Melanocytic Nevus	2	2	2.0	3.80
B89e.png	Dermofit	Melanocytic Nevus	2	1	1.0	3.20
B91a.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
B91b.png	Dermofit	Melanocytic Nevus	1	6	3.0	3.40
B91c.png	Dermofit	Melanocytic Nevus	2	0	2.0	3.60
D144.png	Dermofit	Melanocytic Nevus	2	3	3.0	4.40
D176b.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
D239a.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
D239b.png	Dermofit	Melanocytic Nevus	0	0	1.0	0.50
D271a.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
D291b.png	Dermofit	Melanocytic Nevus	0	2	2.0	1.20

D339.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
D374.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
D384.png	Dermofit	Melanocytic Nevus	0	7	2.0	1.70
D395.png	Dermofit	Melanocytic Nevus	0	0	3.0	1.50
D404.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
D426.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
D427b.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
D492.png	Dermofit	Melanocytic Nevus	2	1	2.0	3.70
D526b.png	Dermofit	Melanocytic Nevus	0	2	2.0	1.20
D567b.png	Dermofit	Melanocytic Nevus	2	2	1.0	3.30
D626.png	Dermofit	Melanocytic Nevus	0	2	3.0	1.70
D715.png	Dermofit	Melanocytic Nevus	0	0	1.0	0.50
D722.png	Dermofit	Melanocytic Nevus	2	6	2.0	4.20
D723a.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
D726d.png	Dermofit	Melanocytic Nevus	0	7	2.0	1.70
D726e.png	Dermofit	Melanocytic Nevus	1	3	2.0	2.60
P103a.png	Dermofit	Melanocytic Nevus	0	3	2.0	1.30
P126b.png	Dermofit	Melanocytic Nevus	2	1	1.0	3.20
P144.png	Dermofit	Melanocytic Nevus	0	1	1.0	0.60
P18.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
P196.png	Dermofit	Melanocytic Nevus	2	3	2.0	3.90
P199.png	Dermofit	Melanocytic Nevus	1	2	1.0	2.00
P2.png	Dermofit	Melanocytic Nevus	0	3	1.0	0.80
P237b.png	Dermofit	Melanocytic Nevus	1	6	2.0	2.90
P256a.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
P271f.png	Dermofit	Melanocytic Nevus	2	2	2.0	3.80
P277b.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
P291.png	Dermofit	Melanocytic Nevus	0	0	3.0	1.50
P304a.png	Dermofit	Melanocytic Nevus	1	0	2.0	2.30
P306a.png	Dermofit	Melanocytic Nevus	1	0	3.0	2.80
P306c.png	Dermofit	Melanocytic Nevus	0	0	3.0	1.50
P337a.png	Dermofit	Melanocytic Nevus	0	0	3.0	1.50
P337b.png	Dermofit	Melanocytic Nevus	0	1	3.0	1.60
P337d.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
P337e.png	Dermofit	Melanocytic Nevus	1	1	1.0	1.90
P354a.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
P359b.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
P365d.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
P365e.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
P376b.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
P376d.png	Dermofit	Melanocytic Nevus	2	5	1.0	3.60
P382a.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
P384b.png	Dermofit	Melanocytic Nevus	1	2	2.0	2.50
P384c.png	Dermofit	Melanocytic Nevus	1	7	2.0	3.00
P392.png	Dermofit	Melanocytic Nevus	0	1	3.0	1.60
P399.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40

P404a.png	Dermofit	Melanocytic Nevus	1	0	2.0	2.30
P404c.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00
P407b.png	Dermofit	Melanocytic Nevus	0	2	2.0	1.20
P407c.png	Dermofit	Melanocytic Nevus	0	1	2.0	1.10
P432.png	Dermofit	Melanocytic Nevus	2	4	2.0	4.00
P435b.png	Dermofit	Melanocytic Nevus	0	3	3.0	1.80
P454a.png	Dermofit	Melanocytic Nevus	1	1	3.0	2.90
P454b.png	Dermofit	Melanocytic Nevus	0	0	1.0	0.50
P45a.png	Dermofit	Melanocytic Nevus	2	1	3.0	4.20
P45b.png	Dermofit	Melanocytic Nevus	1	5	2.0	2.80
P49.png	Dermofit	Melanocytic Nevus	0	0	3.0	1.50
P505c.png	Dermofit	Melanocytic Nevus	2	1	2.0	3.70
P505e.png	Dermofit	Melanocytic Nevus	1	7	2.0	3.00
P509c.png	Dermofit	Melanocytic Nevus	1	1	2.0	2.40
P53b.png	Dermofit	Melanocytic Nevus	0	6	1.0	1.10
P56b.png	Dermofit	Melanocytic Nevus	0	2	3.0	1.70
P58.png	Dermofit	Melanocytic Nevus	0	3	2.0	1.30
P63.png	Dermofit	Melanocytic Nevus	1	6	1.0	2.40
P88b.png	Dermofit	Melanocytic Nevus	0	0	2.0	1.00

Table 9.1: Results of TDS calculation for Dermfit

Name	Source	Category	Asymmetry	Border	Color	TDS
012383HB.jpeg	DermQuest	Benign Keratosis	2	5	3.0	4.60
012824HB.JPG	DermQuest	Benign Keratosis	0	2	3.0	1.70
019462HB.JPG	DermQuest	Malignant Melanoma	2	4	3.0	4.50
019475HB.JPG	DermQuest	Malignant Melanoma	1	2	3.0	3.00
019523HB.JPG	DermQuest	Malignant Melanoma	2	2	6.0	5.80
019563HB.JPG	DermQuest	Malignant Melanoma	2	1	4.0	4.70
019578HB.JPG	DermQuest	Malignant Melanoma	2	2	2.0	3.80
019681HB.JPG	DermQuest	Malignant Melanoma	1	4	3.0	3.20
019682HB.JPG	DermQuest	Malignant Melanoma	1	5	3.0	3.30
019725HB.JPG	DermQuest	Malignant Melanoma	0	2	4.0	2.20
019736HB.JPG	DermQuest	Malignant Melanoma	1	1	3.0	2.90
020192HB.JPG	DermQuest	Malignant Melanoma	1	5	4.0	3.80
020250HB.JPG	DermQuest	Malignant Melanoma	2	3	3.0	4.40
020266HB.JPG	DermQuest	Malignant Melanoma	1	0	3.0	2.80
020268HB.JPG	DermQuest	Malignant Melanoma	1	1	4.0	3.40
020302HB.JPG	DermQuest	Malignant Melanoma	2	8	4.0	5.40
020319HB.JPG	DermQuest	Malignant Melanoma	1	2	5.0	4.00
044936HB.JPG	DermQuest	Malignant Melanoma	2	3	4.0	4.90
005613HB.jpeg	DermQuest	Melanocytic Nevus	0	3	3.0	1.80
005728HB.jpeg	DermQuest	Melanocytic Nevus	2	3	4.0	4.90
005859HB.jpeg	DermQuest	Melanocytic Nevus	0	0	3.0	1.50
005900HB.jpeg	DermQuest	Melanocytic Nevus	0	3	5.0	2.80

006027HB.jpeg	DermQuest	Melanocytic Nevus	2	8	3.0	4.90
006074HB.jpeg	DermQuest	Melanocytic Nevus	1	6	3.0	3.40
006095HB.jpeg	DermQuest	Melanocytic Nevus	0	1	4.0	2.10
010769HB.jpeg	DermQuest	Melanocytic Nevus	2	6	3.0	4.70
010992VB.jpeg	DermQuest	Melanocytic Nevus	0	0	3.0	1.50
011031HB.jpeg	DermQuest	Melanocytic Nevus	0	0	4.0	2.00
011040VB.jpeg	DermQuest	Melanocytic Nevus	0	0	3.0	1.50
011201HB.jpeg	DermQuest	Melanocytic Nevus	1	0	3.0	2.80
011548HB.jpeg	DermQuest	Melanocytic Nevus	2	1	3.0	4.20
011697HB.jpeg	DermQuest	Melanocytic Nevus	1	4	4.0	3.70
011697HB.JPG	DermQuest	Melanocytic Nevus	1	4	4.0	3.70
011936HB.jpeg	DermQuest	Melanocytic Nevus	1	6	3.0	3.40
011936HB.JPG	DermQuest	Melanocytic Nevus	1	6	3.0	3.40
021733HB.jpeg	DermQuest	Melanocytic Nevus	1	3	1.0	2.10
021835HB.jpeg	DermQuest	Melanocytic Nevus	2	2	4.0	4.80
021837HB.jpeg	DermQuest	Melanocytic Nevus	1	0	4.0	3.30
021848HB.jpeg	DermQuest	Melanocytic Nevus	2	7	3.0	4.80
021852HB.jpeg	DermQuest	Melanocytic Nevus	0	0	3.0	1.50
021869HB.jpeg	DermQuest	Melanocytic Nevus	1	0	4.0	3.30
021878HB.jpeg	DermQuest	Melanocytic Nevus	2	1	3.0	4.20
021902HB.jpeg	DermQuest	Melanocytic Nevus	0	4	3.0	1.90
045720HB.jpeg	DermQuest	Melanocytic Nevus	0	1	3.0	1.60
046342HB.jpeg	DermQuest	Melanocytic Nevus	2	1	3.0	4.20
046343HB.JPG	DermQuest	Melanocytic Nevus	1	6	4.0	3.90

Table 9.2: Results of TDS calculation for DermQuest

Name	Source	Category	Asymmetry	Border	Color	TDS
IMD015.bmp	PH2Dataset	Melanocytic Nevus	1	5	2.0	2.80
IMD016.bmp	PH2Dataset	Melanocytic Nevus	1	2	2.0	2.50
IMD018.bmp	PH2Dataset	Melanocytic Nevus	1	1	2.0	2.40
IMD020.bmp	PH2Dataset	Melanocytic Nevus	0	1	2.0	1.10
IMD027.bmp	PH2Dataset	Melanocytic Nevus	2	7	2.0	4.30
IMD038.bmp	PH2Dataset	Melanocytic Nevus	1	2	3.0	3.00
IMD039.bmp	PH2Dataset	Melanocytic Nevus	1	3	2.0	2.60
IMD043.bmp	PH2Dataset	Melanocytic Nevus	2	7	3.0	4.80
IMD045.bmp	PH2Dataset	Melanocytic Nevus	1	1	2.0	2.40
IMD050.bmp	PH2Dataset	Melanocytic Nevus	1	6	2.0	2.90
IMD078.bmp	PH2Dataset	Melanocytic Nevus	2	8	3.0	4.90
IMD103.bmp	PH2Dataset	Melanocytic Nevus	1	5	2.0	2.80
IMD105.bmp	PH2Dataset	Melanocytic Nevus	1	4	2.0	2.70
IMD107.bmp	PH2Dataset	Melanocytic Nevus	2	3	2.0	3.90
IMD132.bmp	PH2Dataset	Melanocytic Nevus	2	5	3.0	4.60
IMD133.bmp	PH2Dataset	Melanocytic Nevus	1	2	2.0	2.50
IMD134.bmp	PH2Dataset	Melanocytic Nevus	2	4	2.0	4.00

IMD137.bmp	PH2Dataset	Melanocytic Nevus	0	5	2.0	1.50
IMD139.bmp	PH2Dataset	Melanocytic Nevus	1	3	2.0	2.60
IMD140.bmp	PH2Dataset	Melanocytic Nevus	1	5	3.0	3.30
IMD142.bmp	PH2Dataset	Melanocytic Nevus	1	5	3.0	3.30
IMD143.bmp	PH2Dataset	Melanocytic Nevus	1	2	3.0	3.00
IMD144.bmp	PH2Dataset	Melanocytic Nevus	1	2	3.0	3.00
IMD156.bmp	PH2Dataset	Melanocytic Nevus	1	3	2.0	2.60
IMD171.bmp	PH2Dataset	Melanocytic Nevus	1	4	2.0	2.70
IMD173.bmp	PH2Dataset	Melanocytic Nevus	0	7	2.0	1.70
IMD204.bmp	PH2Dataset	Melanocytic Nevus	0	1	2.0	1.10
IMD243.bmp	PH2Dataset	Melanocytic Nevus	1	8	3.0	3.60
IMD256.bmp	PH2Dataset	Melanocytic Nevus	2	7	2.0	4.30
IMD280.bmp	PH2Dataset	Melanocytic Nevus	1	2	2.0	2.50
IMD328.bmp	PH2Dataset	Melanocytic Nevus	2	1	3.0	4.20
IMD331.bmp	PH2Dataset	Melanocytic Nevus	1	5	3.0	3.30
IMD356.bmp	PH2Dataset	Melanocytic Nevus	2	2	3.0	4.30
IMD360.bmp	PH2Dataset	Melanocytic Nevus	1	1	3.0	2.90
IMD369.bmp	PH2Dataset	Melanocytic Nevus	2	5	3.0	4.60
IMD380.bmp	PH2Dataset	Melanocytic Nevus	1	3	2.0	2.60
IMD382.bmp	PH2Dataset	Melanocytic Nevus	2	4	4.0	5.00
IMD383.bmp	PH2Dataset	Melanocytic Nevus	0	3	2.0	1.30
IMD384.bmp	PH2Dataset	Melanocytic Nevus	2	5	2.0	4.10
IMD392.bmp	PH2Dataset	Melanocytic Nevus	1	6	2.0	2.90
IMD430.bmp	PH2Dataset	Melanocytic Nevus	1	2	3.0	3.00
IMD433.bmp	PH2Dataset	Melanocytic Nevus	2	4	3.0	4.50

Table 9.3: Results of TDS calculation for PH2Dataset