PM

Color Measurement Using a Smartphone Applied to Madeira Wines

MASTER PROJECT

José Carlos Vieira da Silva
MASTER IN INFORMATICS ENGINEERING

UNIVERSIDADE da MADEIRA
A Nossa Universidade
www.uma.pt

January | 2015

Color Measurement Using a Smartphone Applied to Madeira Wines

MASTER PROJECT

José Carlos Vieira da Silva
MASTER IN INFORMATICS ENGINEERING

SUPERVISOR
José Carlos Marques

CO-SUPERVISOR
Mon-Chu Chen

Color Measurement Using a Smartphone Applied to Madeira Wines

José Carlos Vieira da Silva

Jury composition:

, Professor Karolina Baras

, Professor José Carlos Marques

, Professor Yoram Chisik

March 2015

Funchal – Portugal

RESUMO

A visão computacional é uma área que usa técnicas para adquirir, processar, analisar e perceber imagens do mundo real de modo a produzir informação numérica ou simbólica na forma de decisões [1].

Este projeto tem como objetivo utilizar a visão computacional para analisar uma amostra de vinho Madeira e caraterizá-la pela sua cor (vinhos doces ou secos, novos ou envelhecidos têm uma cor específica).

Utiliza-se técnicas de comparação de histogramas para analisar as imagens captadas de uma amostra num recipiente especial criado para este propósito.

A análise da cor de uma amostra de vinho através de uma imagem obtida a partir de um *smartphone* pode ser difícil. A imagem captada pode ser influenciada por vários fatores tais como, a iluminação, o que está por trás da amostra (fundo da imagem) devido às várias posições em que a imagem pode ser obtida (diferente captar a imagem contra uma parede ou contra o chão).

Através do uso de novas tecnologias como a impressão 3D, foi possível criar um protótipo que visa controlar o efeito de fatores ambientais externos na imagem captada.

Os resultados alcançados deixam bons indícios para futuros trabalhos. Apesar de ser necessário efetuar mais testes, os primeiros realizados tiveram uma taxa de sucesso na ordem dos 80% a 90% de resultados corretos.

Este relatório documenta o desenvolvimento deste projeto e todas as técnicas e passos necessários para executar os testes.

PALAVRAS-CHAVE

Visão-computacional

Vinho Madeira

Cor

Smartphone

Impressão 3D

Histogramas

ABSTRACT

Computer vision is a field that uses techniques to acquire, process, analyze and understand images from the real world in order to produce numeric or symbolic information in the form of decisions [1].

This project aims to use computer vision to prepare an app to analyze a Madeira Wine and characterize it (identify its variety) by its color. Dry or sweet wines, young or old wines have a specific color.

It uses techniques to compare histograms in order to analyze the images taken from a test sample inside a special container designed for this purpose.

The color analysis from a wine sample using an image captured by a smartphone can be difficult. Many factors affect the captured image such as, light conditions, the background of the sample container due to the many positions the photo can be taken (different to capture facing a white wall or facing the floor for example).

Using new technologies such as 3D printing it was possible to create a prototype that aims to control the effect of those external factors on the captured image.

The results for this experiment are good indicators for future works. Although it's necessary to do more tests, the first tests had a success rate of 80% to 90% of correct results.

This report documents the development of this project and all the techniques and steps required to execute the tests.

KEYWORDS

Computer-vision

Madeira Wine

Color

Smartphone

3D Printing

Histograms

ACKNOWLEDGEMENTS

I want to thank all of those that somehow influenced me or helped me through the development of this project.

Professor José Carlos Marques and Professor Mon-Chu Chen for all the orientation on this project.

To all my colleagues that always helped me when I needed most. Special thanks for all the chemistry colleagues that helped me with the wines and all the tests on the lab.

To Madeira Wine Company for all the samples provided under the IMPACT II project.

To my family, especially my parents that always supported me since the beginning of my studies.

A special thanks to Marisa for always encouraging me to do this project and for being always by my side and for keeping pushing me forward.

INDEX

FIGURE LIST

TABLE LIST

ACRONYMS

3D – Three-Dimensional

CCD - complementary coupled device

CNC – Computer Numerical Control

HSL - Hue, Saturation, Luminance Color Model

HSV – Hue, Saturation, Value Color Model

iOS – iPhone Operating System

JPEG - Joint Photographic Experts Group

LAB (CIElab) – A color space defined by the Commission Internationale de l'Eclairage

LCD – Liquid Crystal Display

OS X - Macintosh Operating System X

RGB – Red, Green, Blue Color Model

SDK – Software Development Kit

1 INTRODUCTION

Smartphones are really popular nowadays. Their extraordinary processing power is increasing continuously making them a powerful tool for many purposes other than just make calls.

Engineers developed some ingenious applications and we can simply grab our smartphones out from our pockets and analyze if a mole is cancerous or not, or we can measure our heart rate. All of this is made using the camera on our smartphones together with some computational algorithms.

Expensive machines can be replaced by these much cheaper devices that we can take everywhere. Although, in some cases smartphones need to evolve more to be more accurate, and it will be difficult to someone to trust a smartphone instead of a machine worth thousands of euros.

Android and iOS are the most used systems in the smartphones world. Both have their pros and cons but iOS is known by is stability and quality.

Currently Madeira Wine is being measured / characterized by its color at the University of Madeira through the project IMPACT II (MADFDR-01-190-FEDR-000010) financed through the Regional Development Institute, under the program '+ Conhecimento (INTERVIR +)'. Dry or sweet wines, young or old have a specific color. This work is being done by Professor José Carlos Marques from the Chemistry Department at the University of Madeira and is the base for this project.

We can notice the sweetness and distinguish the wines using our senses. When we smell or taste, we can tell if a glass of wine compared to another one is sweeter or not because we can feel the sugar contained in the wine. Also, only looking at a glass of wine, by the color we can tell the sweetness as dry wines are lighter than sweet wines.

Using the senses to identify something is tricky because the human beings don't have all the senses developed in the same way, also, it may require some practice and previous knowledge related to Madeira Wine.

Although on the lab we can distinguish the wines, this option is not available to general public, and even to professionals it requires some time to analyze the retrieved data.

There were 102 billion app downloads in 2013 with perspective to grow. It's a high profitable market, with billions in revenues. Specifically related to lab use of smartphones, the number of app downloads to be used on the lab is not known, but it's expectable to be a sizeable portion. It has potential to grow [1].

The choice of a smartphone app to perform advanced experiments may be useful, as almost everyone has a smartphone nowadays.

1.1 Motivation

Being able to reproduce the functions of an expensive laboratory machine in a smartphone is a difficult challenge with lots of limitations but is also a great opportunity to develop something new.

This can bring the opportunity for the wineries to test their wines to see if it fits within the standards expected for that wine.

Madeira Wine is known worldwide. Associate new technologies to this product can open doors to new opportunities, new markets.

Typical Madeira Wine consumers are older adult people, something like this project can cause curiosity in other persons to buy the wine if a more commercial version of the app reaches the regular consumer.

The idea of grabbing the smartphone, take a picture and get the variety of the wine can lead to some changes in the fermentation process and in the quality control procedures.

1.2 Goals

This project intends to:

Prepare an app for a smartphone to identify a Madeira wine by the color.

1.3 Document Organization

This document is divided in seven main chapters.

The first chapter is the introduction were a brief description of the problem and the goal of the project are stated.

The second chapter, the State of Art, describes how the problem is currently solved. Some related works are also stated on this chapter.

On the third chapter, there is a domain research that includes all the relevant data for this project. There are some notions about Madeira Wine, digital cameras, smartphone cameras, color, 3D printing, developing for iOS and the notion of Histogram.

The fourth chapter is the implementation of the project. It describes all the steps and procedures, how the idea was generated and evolved during the execution of the project. It has also all the details about how the software was created and how it works. Contains also the origin of the ideas for the App logo and splash screen.

On the fifth chapter, there is the description of the test procedure, the test results and their analysis.

Chapter 6 is the conclusions for this project and report and an overall overview of the work that was done.

Chapter 7 presents some ideas for future work. They can be implemented if the app is intended to be published.

2 STATE OF THE ART

Although there is no related work (known to date) regarding the use of smartphones to specifically measure wine color, they can be used to measure color from anything in a photo using one of the many apps available built for this purpose.

Specifically related to wine color, there are some works that used other platforms to do that function.

2.1 Color measurement

There are many mobile and desktop applications to measure color. Most of them work the same way, the user clicks on some point of the test image and the software calculates and displays the result using RGB, HSV, LAB, or other color models.

The following example in Figure 2.1, demonstrates the use of Adobe Photoshop to pick the color values using different color representations from a clicked point.

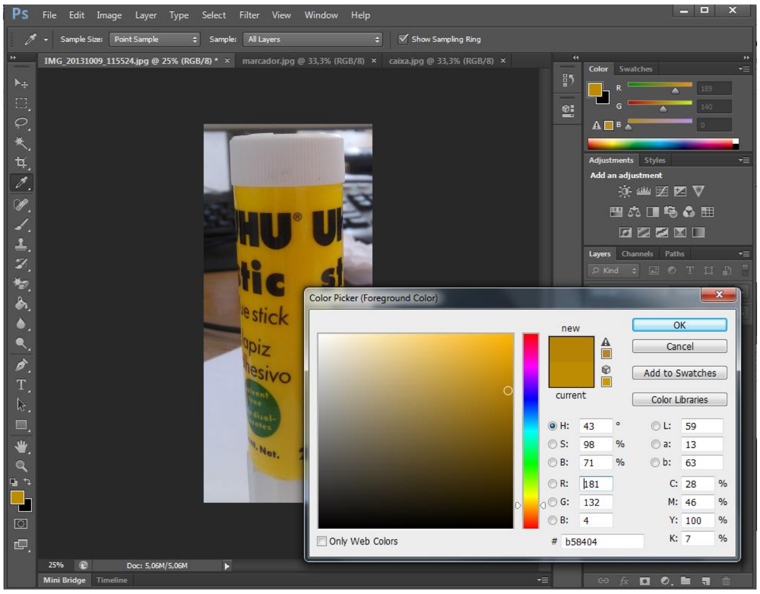


Figure 2.1 - Color picker example

For mobile platforms, there are many more applications to measure color than there is for other devices such as laptops. This market is growing as more and more smartphones are reaching the market. For example, iOS app ColorMeter in Figure 2.2 displays the color of some given point in an image in many color models such as RGB, HSV, Lab*, etc. [3].

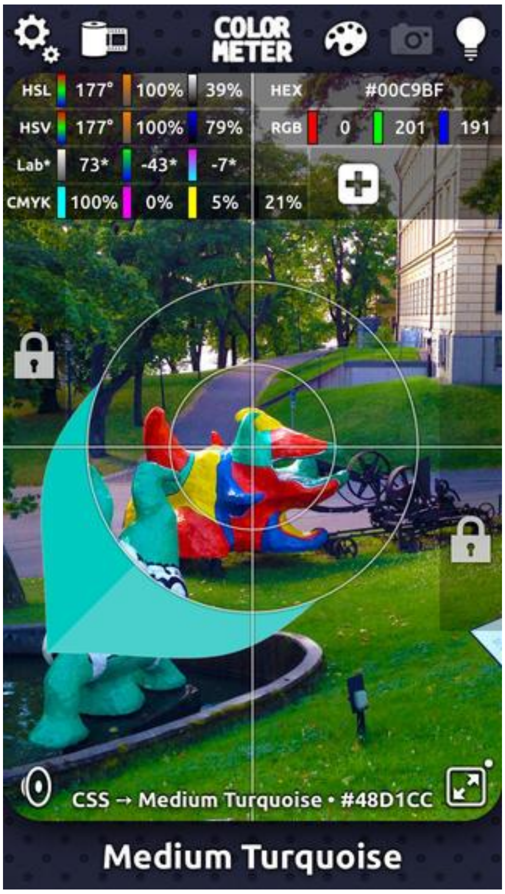


Figure 2.2 - ColorMeter - iOS App [3]

2.2 Wine color measurement

Wine color measurement is a specific area where color measurement techniques are applied.

Some work has been made in this area to predict the color of wine from grapes [4], to ensure quality control [5] and in University of Madeira with the Madeira Wine color characterization for example.

Wine color is very important for the perception of quality and is a useful indicator for issues related to wine development and fermentation.

It’s important to keep color variations controlled. People expect some kind of wine to be from a certain color. If the color variation is big, the consumers will be sceptic about that wine.

Color monitoring is also useful to document the effect of fermentation variables on wine color [5]. For example, when the new fermentation techniques are tested.

2.2.1 RELATED WORK

This work of establishing color standards and improve wine fermentation techniques analyzing the color, applied to Madeira Wines, is being made at University of Madeira.

Two different techniques are used to try to define a color for each wine brand using Ultraviolet–visible spectroscopy using the Glories method (measuring the absorbance at 420 nm, 520 nm and 620 nm) or by the CIElab method (using full Ultraviolet-visible spectrum).

The equipment used in this process, Shimadzu, model spectrophotometer UV-vis 2600 presented in Figure 2.3 is an expensive and complex machine.

This methods require practice and specific formation and competences because the retrieved data is complex, so, only experienced technicians are able to perform those tests.

Figure 2.3 - Shimadzu UV-2600 UV-VIS spectrophotometer [6]

3 DOMAIN RESEARCH

This chapter covers some concepts that are highly important to understand this project. Madeira Wine, digital cameras, smartphone cameras, color, 3D printing, developing for iOS and the notion of Histogram are essential topics.

3.1 Madeira wine

Madeira Wine is a fortified wine produced in Madeira Island, Portugal.

This wine is available in different sweet/dry variations [7]. The grapes varietals define the wine:

- Sercial – A white wine grape that is used to produce a dry style of Madeira.
- Verdelho – A white wine grape used to make a semi-dry variation of Madeira.
- Bual - A white grape that makes a semi-sweet Madeira.
- Malmsey – A white grape that typically registers sweet when made into Madeira.

Another varietal is Tinta Negra, a red grape which is the most common in the island. This one has the particularity of being able to produce sweet, medium-sweet, dry and medium-dry wines according how the producers conduct the fermentation process.

3.1.1 MADEIRA WINE COLOR

The different variations of Madeira have different characteristic colors.

Dry wines have a light yellow color, medium-dry a golden color, medium-sweet a dark gold to brown color and finally sweet wine have a brown color has noticed in Figure 3.1.

Figure 3.1 - Madeira Wine color variations [8]

3.2 Digital cameras

Digital cameras work like a conventional camera. It has a series of lenses that focus light to create an image of a scene. The difference is that instead of focusing the light onto a piece of film, it focuses onto a semiconductor device that records light electronically. The computer then breaks the electronic information to digital data.

3.2.1 COMPONENTS AND TECHNICAL DETAILS

This section covers some of the most important components and technical details about digital cameras.

3.2.1.1 Sensor

The image sensor as the one presented in Figure 3.2 is used by most cameras and is named Complementary Coupled Device (CCD). Its function is to convert light into electrons. Simplifying, these sensors are a 2D array of thousands or millions of tiny cells.

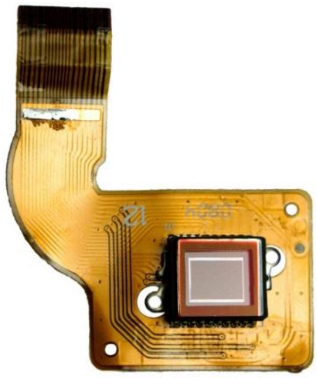


Figure 3.2- CCD sensor [9]

Once the sensor converts the light into electrons, it reads the accumulated charge of each cell in the image.

The CCD transports the charge across the chip and reads it at one corner of the array. An analog-to-digital converter turns each pixel's value into digital value by measuring the amount of charge at each cell and converting that measurement to binary form.

3.2.1.2 Camera Resolution

The resolution is the amount of detail that the camera can capture and it's measured in pixels. The more pixels it has, the more detail can capture, and, consequently, the larger the pictures can be without becoming blurry.

Resolution can vary from 256x256 to 4064x2704. Professional cameras can capture over 16 million pixels or 20 million pixels for large-format cameras.

Common cameras usually have a minimum resolution of 640x480. It's an ideal size for e-mailing pictures or posting to a website.

3.2.1.3 Capturing Color

The sensor cells are colorblind, only keep track of the total intensity of the light that strikes their surface. Most sensors use filtering to look at light in its three primary colors. Once the three colors are captured, they are combined to create the full spectrum.

Highest quality cameras use three sensors, each with a different filter. The light is directed to the different sensors that respond only to one of the primary colors. The advantage is that the camera records each of the three colors at each pixel location but it's an expensive solution.

A more economical solution to record the primary colors is to place a permanent filter called color filter array over each individual sensor cell.

By breaking up the sensor into a variety of red, green and blue pixels, using interpolation, that means, look at the other pixels in the neighborhood of a sensor and make a guess about the color at that central location it's possible to get the color for all pixels. Figure 3.3 demonstrates the interpolation, which neighbor pixels are used to calculate the color.

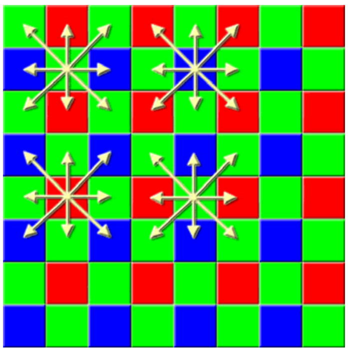


Figure 3.3 - Bayer Sensor interpolation [10]

The most common pattern of filters is Bayer filter pattern. It alternates a row of red and green filters with a row of blue and green filter. As seen in Figure 3.4, there are as many green pixels as there are blue and red combined. This is due to the higher sensitivity the human eye has to green color.

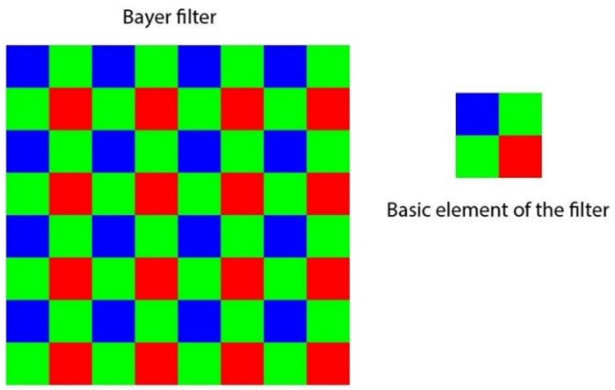


Figure 3.4 - Bayer filter pattern [11]

The advantages of this method are that only requires one sensor and all the color information (red, green and blue) is recorded at the same moment. This means smaller equipment’s and less costs.

Digital cameras use demosaicing algorithms to convert a mosaic into an equally sized mosaic of true colors as the one in Figure 3.5.

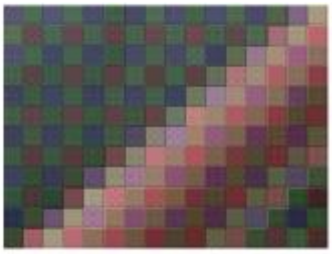


Figure 3.5 - RAW image [12]

Each colored pixel can be used more than once, its true color can be determined by averaging the values from the closest surrounding pixels.

3.2.1.4 Exposure and Focus

All cameras, digital or not, have to control the amount of light that reaches the sensor. The two key elements used for this are the aperture and shutter speed.

- **Aperture:** The size of the opening in the camera. It's an automatic procedure in most digital cameras, but, some allow manual adjustment to give professionals more control over the final image.

- **Shutter speed:** The amount of time that light can pass through the aperture.

These two elements work together to capture the amount of light needed to make a good image. In photographic terms, they set the exposure of the sensor.

3.2.1.5 Lenses

Digital cameras have one of four types of lenses:

- **Fixed-focus, fixed-zoom lenses:** Used on disposable cameras and inexpensive film cameras.
- **Optical-zoom lenses with automatic focus:** Similar to the video camcorder lens. Has automatic focus, but it may not have manual focus. They change the focal length of the lens rather than just magnifying the information that hits the sensor.
- **Digital Zoom:** The camera takes the central pixels from sensor and interpolates them to make a full-sized image.
- **Replaceable lens system:** These are similar to the replaceable lenses on a 35mm camera. Some digital cameras can use 35mm camera lenses.

3.2.1.6 Storing Digital Photos

Most digital cameras have LCD screens that allow to see the picture immediately. Storing images requires a lot of memory. Most cameras use JPEG file format for storing pictures allowing to choose quality settings, for example, medium or high quality.

To make the most of their storage space, most digital cameras use data compression to make the files smaller [13].

3.2.2 SMARTPHONE CAMERAS

Today's smartphone cameras evolved a lot. Some of them are even more powerful than some regular cameras, with better quality, more custom settings, etc.

All of them work with the same basis, a sensor and a lens. This hardware is basically the same found on regular digital cameras, but they have the particularity of being really small as shown in Figure 3.6 [14].

Figure 3.6 - Smartphone camera sensors [14]

The process to capture an image is the same. The light enters the camera via the lens onto the sensor. There, in the sensor, sensible areas record light electronically and then the computers converts this information to digital data [13].

These cameras, similarly to digital cameras, usually capture color using RGB that is a color model that uses the three primary colors (red, green, blue) that is also the color model used in displays [15].

3.3 Color

Color is a rich and complex experience, is the vision system responding differently to different wavelengths of light [1].

3.3.1 HUMAN COLOR PERCEPTION

To describe colors is necessary to know how people respond to them. Human perception of color is a complex context of: illumination, memory, object identity and emotion. All of these aspects can influence the perception of color [1].

When light hits an object, some of it is absorbed and the remaining is reflected. The wavelengths that are absorbed and reflected depend on the object. The reflected ones, determine what color we see [16].

The visible spectrum is a portion of the electromagnetic spectrum that can be detected by the human eye, typically called visible light. A typical human eye responds to wavelengths from about 400-700nm [17]. Table 3.1 relates the color names to their wavelengths.

Table 3.1 - The visible light spectrum

COLOR	WAVELENGTH (NM)
RED	625-740
ORANGE	590-625
YELLOW	565-590
GREEN	520-565
CYAN	500-520
BLUE	435-500
VIOLET	380-435

The following graphic in Figure 3.7 is a good resume for how the human eye works for the reflected wavelengths.

A higher resolution image for better reading can be consulted in Appendix 3 – How the Eye Sees in Color.

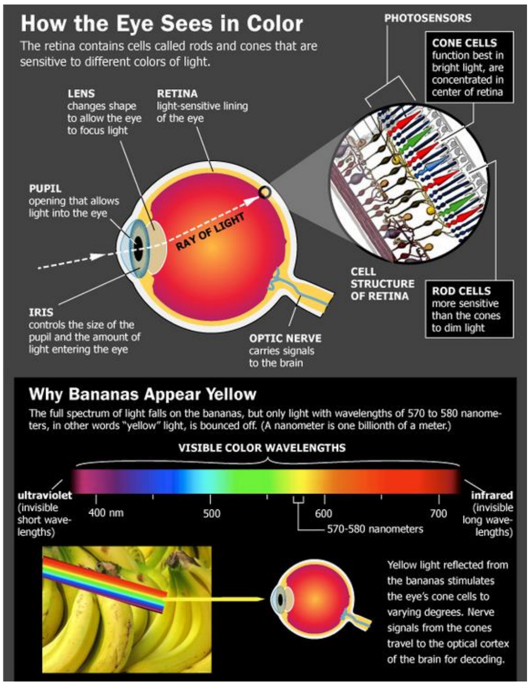


Figure 3.7 - How the human eye sees color [18]

This example can be applied for any object of any color.

Very concisely, the light waves hit the light-sensitive retina at the back of our eye. Then the cones that are one type of photoreceptor, tiny cells in the retina that respond to light, are stimulated. The resulting signal is transmitted through the optic nerve to the visual cortex of the brain, which processes the information returning the perceived color.

Humans have three different cone types, which allows them to discern color better than most mammals, but, plenty of animals have better vision capabilities.

Many fish and birds have four type of cones, enabling them to see ultraviolet light than the human eye cannot perceive.

3.3.2 REPRESENTING COLOR

Color can be represented in many forms. A standard system is required to talk about color. Simple names are insufficient because people can associate a large variety of colors with a given name.

3.3.2.1 Color models/spaces

There is a large variety of color models or spaces, which means, how we can represent a color in some scale. Some examples more relevant to this work are RGB, CIELAB and HSV and are presented in this document.

3.3.2.1.1 RGB

RGB is a color model that uses the three primary colors (Red, Green and Blue) that can be mixed to make all the other color. It is widely used throughout computer graphics and it’s common to find a large amount of existing software routines since it’s been used for many years [19].

This color model can be represented in form of a cube as shown in Figure 3.8.

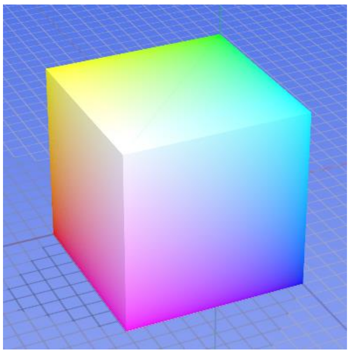


Figure 3.8 - RGB cube representation [20]

3.3.2.1.2 L*a*b*

L*a*b* is one of the color space representations used in the Chemistry lab to represent wine colors. L* represents the difference between light (L*=100) and dark (L*=0). A* represents the difference between green (-a*) and red (+a*), and b* represents the difference between yellow (+b*) and blue (-b*). Figure 3.9 represents the CIELAB coordinate system.

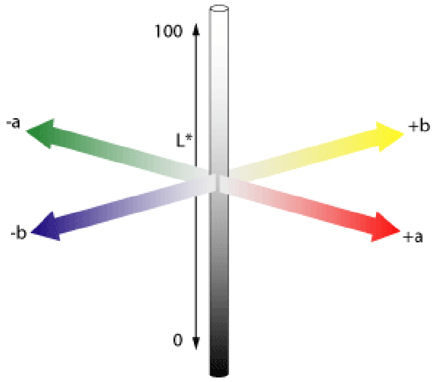


Figure 3.9 - CIELAB coordinate system [21]

This color model can be useful to manipulate images, as the luminance is separate from the color information, however it's not very simple to use because it's not intuitive for most people [21].

3.3.2.1.3 HSV

HSV stands for Hue, Saturation and Value. Hue is expressed in a number from 0 to 360 degrees. Red starts at 0, Yellow at 60, Green at 120, Cyan at 180, Blue at 240 and Magenta starts at 300. Saturation is the amount of Grey (0% to 100%) in the color and Value (or Brightness) works in conjunction with saturation and describes the brightness from 0% to 100% [22].

HSV can be represented as a cylinder as shown in Figure 3.10.

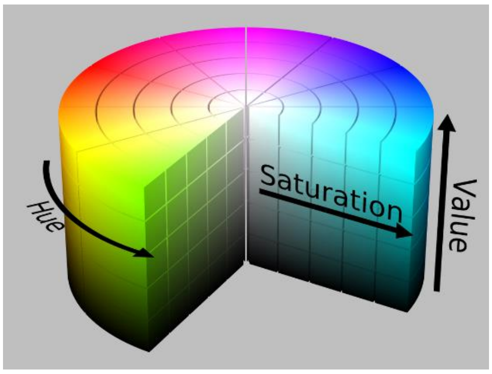


Figure 3.10 - HSV Color model mapped to a cylinder [23]

Different software use different scales, so, for this particular case, the OpenCV library used to calculate and compare histograms on the app has a range of 0 to 179 for Hue and 0 to 255 for Saturation and Value [24].

3.4 3D Printing

3D Printing may sound like something new, something that appeared in the last two or three years. Actually, this notion appeared around 1980 when Chuck Hull created technology to print 3D objects from digital data [25].

The Boom of 3D Printing occurred recently, around two or three years ago as many brands released their domestic 3D printers to the market. With prices around 2000€ for the cheapest printers, it's not a technology available to everyone. Another problem it's the time that is needed to print an object that can go from a few minutes to hours or days depending on the complexity and the resolution of the model.

To create an object to print, it requires a 3D modeling software like Google SketchUp (Figure 3.11) that is a free and quite simple tool to use. Other options are available, but for an unexperienced user SketchUp is the best choice.

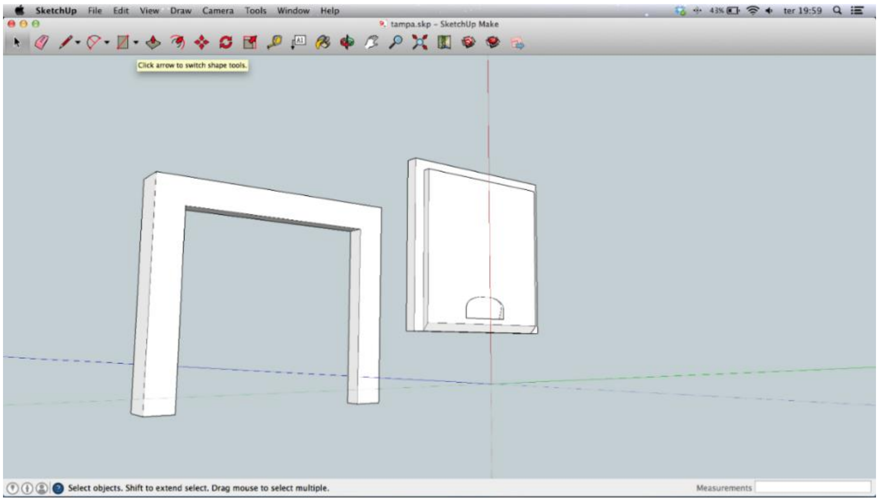


Figure 3.11 - Google SketchUp overview

There are many different brands of 3D printers on the market today, but the most common ones for domestic use work with a filament to feed an extruder that melts it down and deposit it layer by layer to create the object like the printer shown in Figure 3.12.

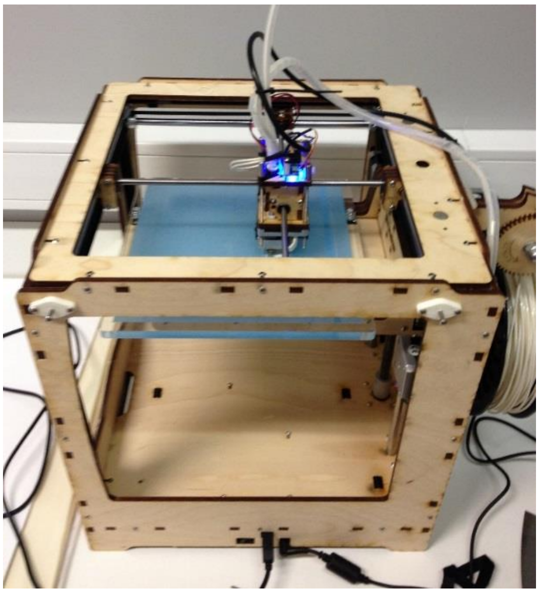


Figure 3.12 - Ultimaker Original 3D Printer

3.4.1 IMPACT OF 3D PRINTING IN INDUSTRY

For many years 3D printing has been an expensive technology, only available to larger enterprises.

With the costs for lower end plastics printing machines increasingly cheaper, this technology is becoming one of the most important tools in industry.

For example, the automotive industry has benefit from this technology as exemplified in Figure 3.13. Non-functional prototype can be built to test purposes, but, nowadays, the technology evolved in such a form that it’s being used to make production parts. It allows to produce parts that would be difficult and expensive to build without 3D printing. This reduces the cost of building to a fraction. For example, one car project can cost 100.000€ less using 3D printing [26]. There are also benefits in terms of time. Usually it’s faster to build a 3D prototype and print it than waiting for a factory to build it.

Figure 3.13 - 3D printing in industry [27]

The tendency is to build printers that work with other materials, such as titanium and stainless steel for example. Although their cost is bigger than conventional plastic printers for now, they already exist and their evolution happens every day. Also, pieces made of metal are stronger that the plastic ones, allowing industries to make more effective tests with their prototypes.

Typically, these printers use layers of metal particles that the laser melts down to create the pretended object as the Figure 3.14 demonstrates.

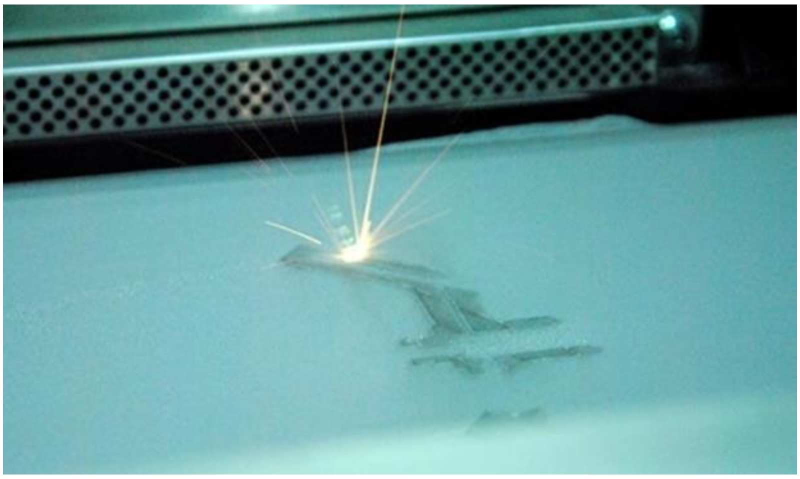


Figure 3.14 - 3D laser printing [30]

These printers are an alternative to CNC machining. They not only allow to create more complex parts, as they also reduce the wasted materials as shown in Figure 3.15.

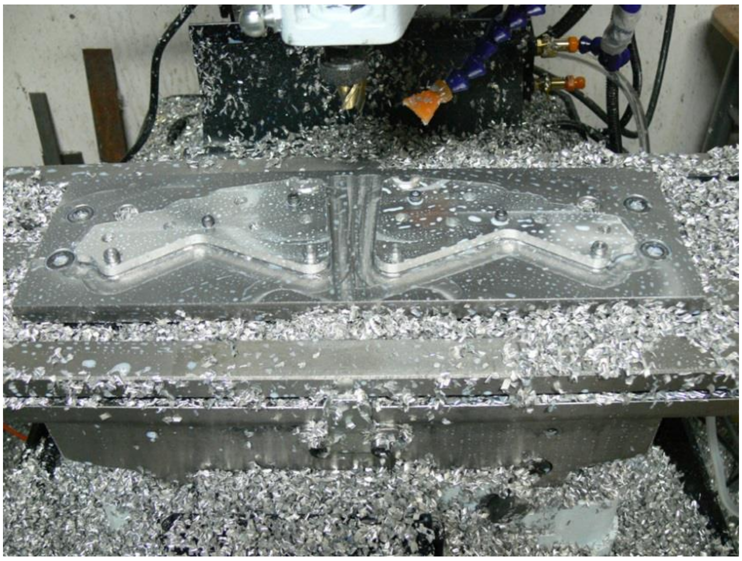


Figure 3.15 - CNC machining waste material [31]

Both CNC and 3D printing have their pros and cons. CNC is more complex but it's a more mature technology but at the moment it's better to build production parts. Sometimes 3D printing may require a few attempts to reach a good print result [30].

3D printing will have an important role in people's life in the next years. It's a path to explore at the moment for many reasons such as, fast prototyping, reduced waste of materials and reduced costs.

3.5 iOS Development

To create iOS apps, the programmer as well as having knowledge of Objective-C must have certain tools required to create and test them [31]:

- Mac computer running OS X 10.8 (Mountain Lion) or Later
- XCode
- iOS SDK (included in XCode)
- iPhone (Optional, XCode provides the tools needed to test the app)

Figure 3.16 represents an overview on the development sequence, from the interface build to coding and testing. The test can be made using the inbuilt simulator or using a physical device.

Figure 3.16- iOS Development overview [32]

Objective-C is not a difficult programming language to learn. Like other languages, there are plenty of examples online that the programmer can follow and adapt to his concept.

The structure of an iOS project may be very complex at the beginning, but the user can easily learn following some tutorials found online.

XCode is Apple's integrated development environment (IDE) that includes a source Editor, graphical user interface editor, and many other features. It can be downloaded for free from App Store.

Figure 3.17 illustrates an example of XCode interface.

The functionalities are easy to find and the organization of the interface is customizable, allowing the user to change it according to its preferences.

To build a user interface the editor simplifies that work, the user can pick and drag any interface elements already built into XCode into the corresponding interface.

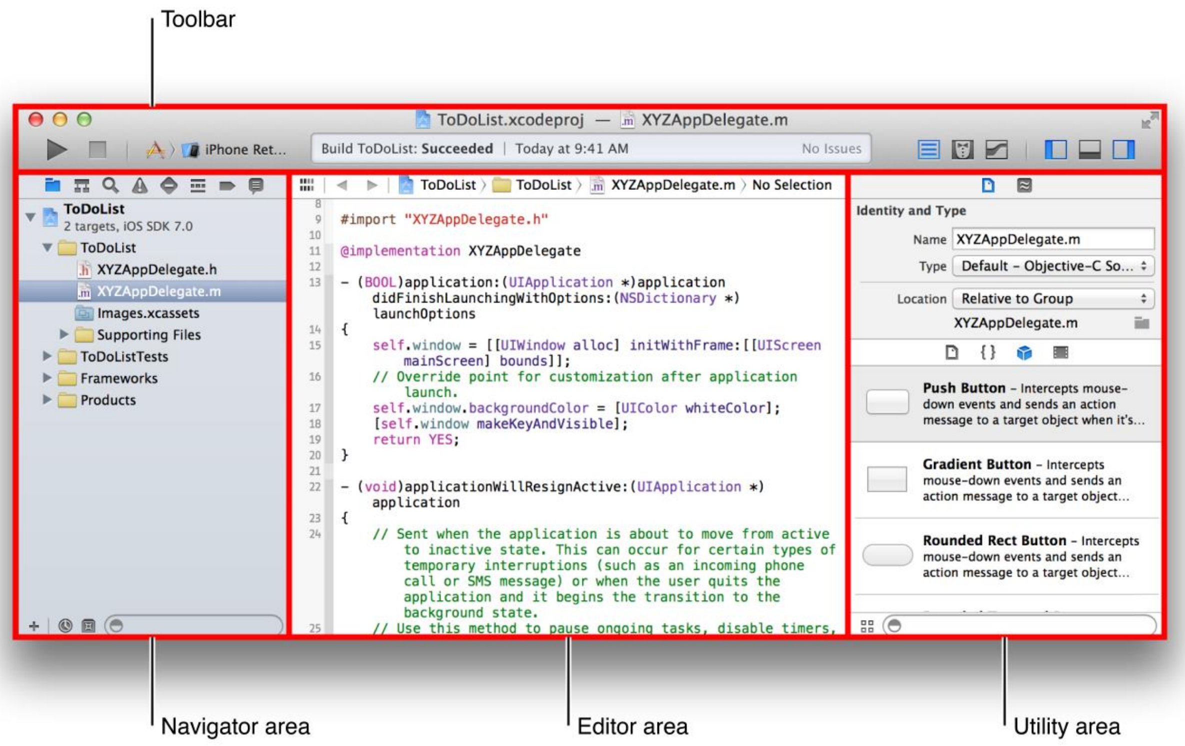


Figure 3.17 - XCode Overview [33]

3.6 Histogram

A histogram (Figure 3.18) is a graphical representation, similar to a bar chart, which organizes a group of data points into specified ranges. Condenses the data series into an easily interpreted visual by taking many data points and grouping them into ranges or bins [34].

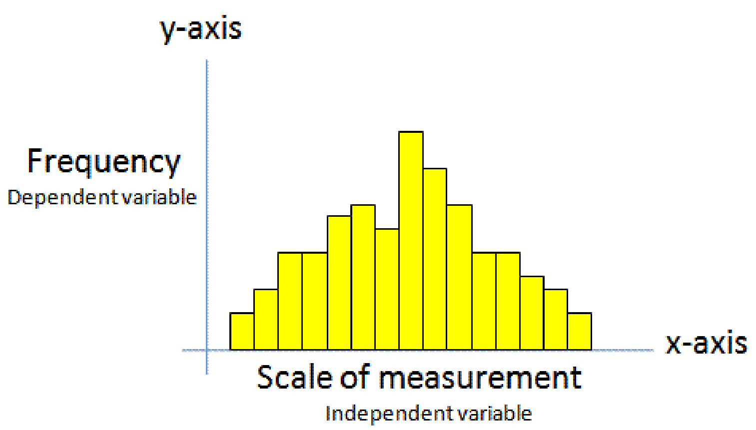


Figure 3.18 - Histogram example [35]

4 IMPLEMENTATION

Although this project has a specific goal, to identify a Madeira Wine by the color, there was not a path to follow at the beginning of it.

The first thing to do was to know more about this wine, its characteristics and why the color is different between varieties of wine. The color of the Madeira Wine is directly related with its sugar content and fermentation process. Sweeter wines are darker than dry wines.

As the idea is to use a smartphone to take a photo and measure the color of a wine sample, the first tests were some photos of random objects standing on a table to simplify the process and understand how the project could start, how color could be measured.

4.1 Initial approach

The first tests were very important for the project development.

Pallets of colors were printed and put side by side with an object to take a photo. Then RGB + HSL values for both the object and paper were taken from random positions using a regular desktop software to identify which pallet line has a color more similar to the object.

It was clear that light was affecting the photos. The same object (a red rule) has different colors. The red in Figure 4.2 is brighter that the red in Figure 4.1. Light variations are one of the constraints of this project. Also, the quality of the smartphone camera wasn't the best, some colors seemed different than in real object and focus was not good.

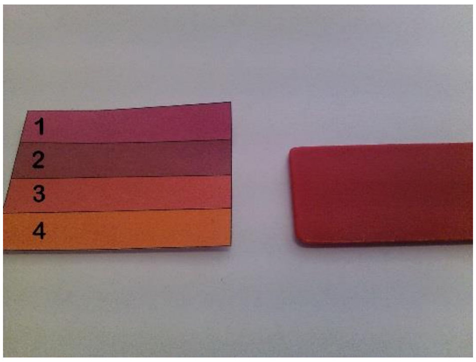


Figure 4.1 - Red rule and pallet

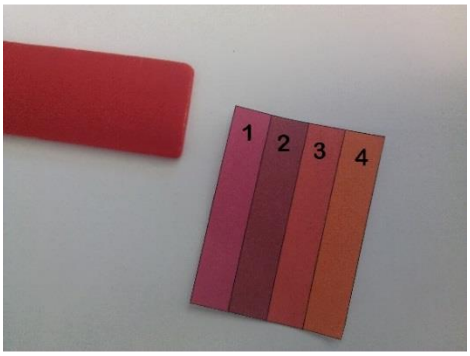


Figure 4.2 - Red rule and pallet, different angle

For the color analysis, the first step was to grab RGB value from a random position for the rule from both Figure 4.1 and Figure 4.2. This value was also converted to HSL Range. The collected data is present in Table 4.1.

Table 4.1 - RGB and HSL values for rule in Figure 4.1 and Figure 4.2

	R	*G*	*B*	*H*	*S*	*L*
Figure 4.1	148	46	46	239	117	103
Figure 4.2	121	32	42	236	140	72

The next step was to grab a RGB value from a random position from each line of the palette presented also in Figure 4.1 and Figure 4.2. These values are also converted to HSL and presented in Table 4.2.

Table 4.2 - RGB and HSL values for color pallet in Figure 4.1 and Figure 4.2

	Palette Line	*R*	*G*	*B*	*H*	*S*	*L*
Figure 4.1	1	137	51	70	231	110	88
	2	115	51	56	237	93	78
	3	150	57	41	6	137	90
	4	168	80	39	13	150	97
Figure 4.2	1	150	66	88	230	93	102
	2	103	50	63	230	83	72
	3	143	58	58	0	101	95
	4	149	65	48	7	123	93

Comparisons were made between the RGB and HSL values for the pallet and the object such as RGB distance, HSL distance and Hue difference in order to understand which of this comparisons was the most accurate. The results are available in Table 4.3.

Table 4.3 - Comparison between object and palette lines in Figure 4.1 and Figure 4.2

	Palette Line	*Distance RGB*	*Distance HSL*	*Difference H*
Figure 4.1	1	37,42993454	34,36568055	-5
	2	24,35159132	47,39198244	1
	3	38,301436	230,7227774	-230
	4	67,24581771	224,6196786	-223
Figure 4.2	1	46,56178691	25,65151068	-9
	2	48,27007354	46,88283268	-9
	3	17,69180601	239,6685211	-239
	4	19,13112647	232,2929185	-232

The formula used to calculate the distance using a tridimensional system is:

$$d3_{ab} = \sqrt{(x_b - x_a)^2 + (y_b - y_a)^2 + (z_b - z_a)^2}$$

The Hue difference is just the subtraction of the two Hue values from the pallet and the object.

The results were not accurate because the RGB values vary a lot. For the Figure 4.1 the pallet corresponding line was color number 2 and for the Figure 4.2 it was number 3. This means two different matching results for two different photos from the same example.

Using only one metric to describe the difference between the images is not enough. The more metrics are calculated, the more accurate will be the comparison. Taking as reference only the RGB distance, HSL distance or Hue difference is not conclusive.

This same results happened for other test photos. The light variations in the images were evident.

4.1.1 LESSONS LEARNED

Using a cheap android smartphone was not getting very accurate data, it was decided that an iPhone would be a more reliable smartphone with a quality camera, and as there is not so many different versions of the iPhone it’s a better device to focus the app development, because different camera hardware’s affect the photos and there is hundreds of Android devices on the market.

To avoid light influence, the environment in which the photo is taken must be controlled. That’s easily done in the lab by the sophisticated machines that are used in the original project to measure wine colors. The wine stands in a quartz recipient inside the machine fully protected from external light sources.

This inspired the creation of a piece of hardware that could be used to take a photo avoiding light influence.

4.2 3D Prototypes

The two prototypes created are the recipient that covers the container with the wine sample and the container cover.

Next there is a full description how to 3D print and build them.

4.2.1 BLACKBOX

Blackbox is the name given to the piece of hardware used to cover the iPhone and the recipient. This device prevents the light influence on the tests as all interior remains full dark being only affected by the controlled flash light and is built to fit an iPhone 4s.

The first prototype in Figure 4.3 was made of paper, only to understand if the concept would work.

Figure 4.3 - Paper prototype

The first tests were made by simply putting a recipient with wine in the prototype and then take a photo to see if some pattern was found in the photos. All the photos had the same characteristics as presented in Figure 4.4. The upper part was white because of the flash influence and the exact same bottom part of each photo was a clear image of the liquid inside his container.

Figure 4.4 - Captured image without controlling flash light

After achieving this results, from the paper prototype a 3d model (Figure 4.5) was built in the computer and then produced using a 3d printer (Ultimaker Original).

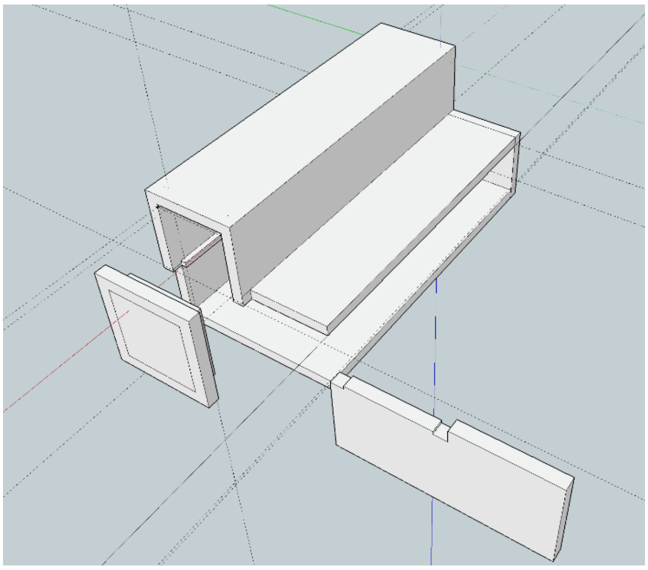


Figure 4.5 - First 3D Blackbox prototype

The prototype in Figure 4.6 is the evolution of the first one presented in Figure 4.5.

For this new version, some size adjustments were made to make the iPhone fit with precision inside it so it won't move. Upgrades, such as the sliding cover that is more practical that the cover from the previous model and the inclusion of a padded interior that provides a better stability to the iPhone inside the 3D model.

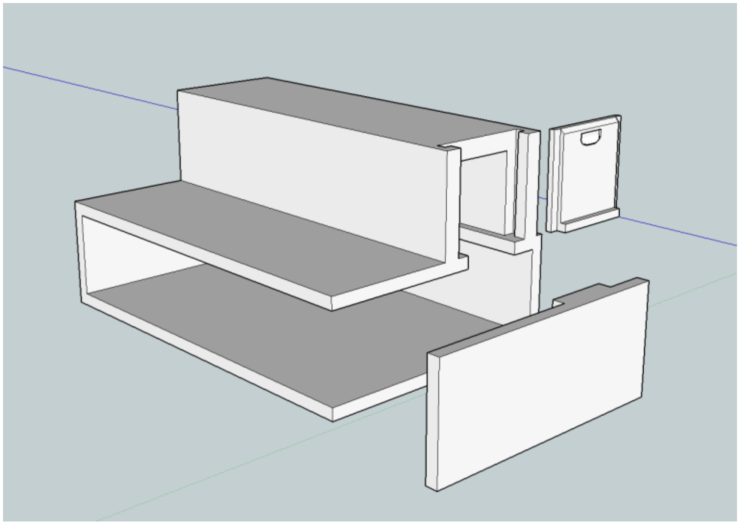


Figure 4.6 - Blackbox 3D model

4.2.1.1 Blackbox assembly

The printed blackbox (Figure 4.6) is composed by 3 pieces, the box, the top cover and the sliding cover for the test cell compartment.

The first step is to print all the pieces that compose the Blackbox and that are all contained in the 3D model presented on Figure 4.6.

Each piece has to be printed individually. On Figure 4.7 the printer is producing the main part of the Blackbox prototype. The top is printed as a separate part because the printer would take more time and more filament to print a suspended part like that one as it would need to print a support structure inside the Blackbox. It would be difficult to clean the excess material inside the prototype and the quality would not be the same. It would be also more difficult to cover the interior with all the padding if it was built in one piece.

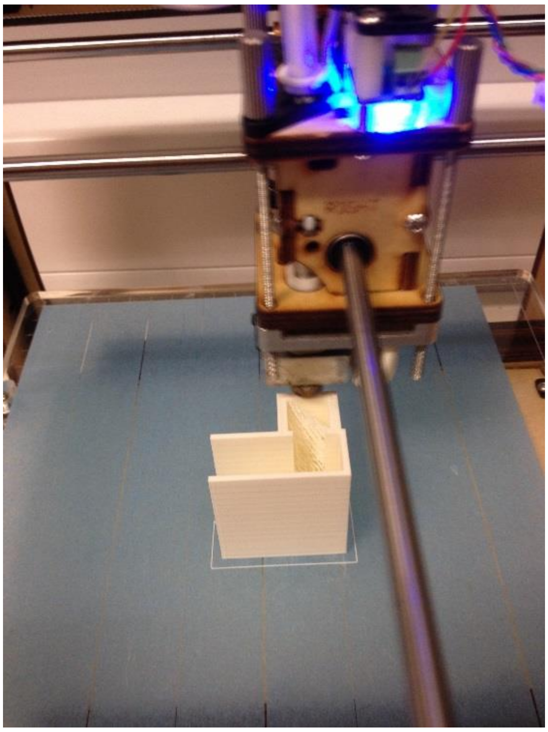


Figure 4.7 - 3D printer producing the Blackbox

After finishing printing the pieces it’s necessary to remove the excess material left by the printer as demonstrated in Figure 4.8. This is easily done using a knife. This only happens with the main component of the Blackbox. It’s the result of accelerating the printing speed to a value that guarantees quality and a small build time. As the printer is a little more accelerated, it will leave some exceeding material in some edges during the movements.

Figure 4.8 - Blackbox pieces as printed

The next step is to cut the pieces for the padded interior as presented in Figure 4.10.

The material used is the furniture self-adhesive vinyl protections used at home to prevent scratches on the floor caused by the move of furniture. This can be bought precut in small pieces or in A4 size that we can cut to fit the size we want, like in this case.

It's easy to draw all the Blackbox faces on the paper as represented in Figure 4.9. Another option is to get the measurements from the 3D model and draw the faces on the paper.

Figure 4.9 - Drawing the Blackbox faces on paper

The interior will be padded in all faces, except the one that has a little space for the iPhone power button. Figure 4.10 represents all the cut parts that are used to cover the interior.

Figure 4.10 - Interior padding

After apply the padding to the prototype, it’s necessary to add some glue to the parts to put them together.

The final step is to put the sliding cover on the prototype, fill the interior with paper and then use a spray can of black ink to paint all the exterior. The prototype interior must be protected so the ink doesn’t blur the inside of it were the wine recipient is placed.

It’s necessary to apply about 4 layers of ink, depending on the ink quality. To know if the prototype is correctly painted, the iPhone must be introduced in the prototype with the flash light on in the same position as if it was to run a test. If there is no light coming from the interior, the prototype is ok, if not, it’s necessary to add another layer of ink and test again.

The choice of the black color comes from the fact that it is the best color to isolate light from something.

The final result is as demonstrated in Figure 4.11.

Figure 4.11 - Blackbox, final build

4.2.2 RECIPIENT COVER

During the evolution of the work, when it was decided the recipient to be used, that is the same actually used to perform the wine lab tests (Figure 4.12), it was noticed that the cover used is not designed to completely seal the liquid inside. This created a problem, because each time we wanted to test another wine, during the process of removing or inserting the recipient inside the hardware prototype the wine spills.

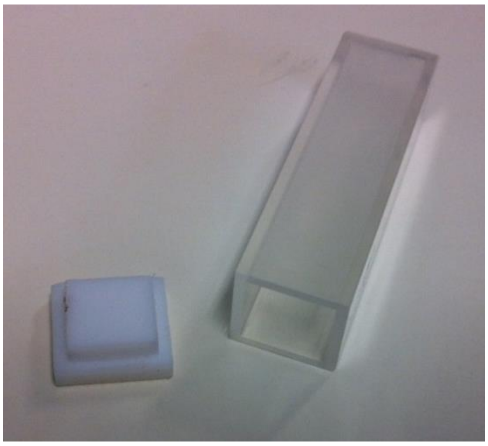


Figure 4.12 - Quartz recipient and original cover

The first piece created to efficiently cover the recipient was made of cork that was cut to fit the size of the recipient (Figure 4.13). This solution works, but it causes a large pressure on the recipient that is made of fragile Quartz glass and there is the risk of breaking it.

Figure 4.13 - Quartz recipient and cork

To avoid the problem of the pressure done by the cover on the walls of the recipient, and making use of a soft filament to use on the 3D printer, it was created a 3D Model (Figure 4.15) of a cover that tries to avoid or disperse the forces done on the recipient using a layer shape, instead of a single face.

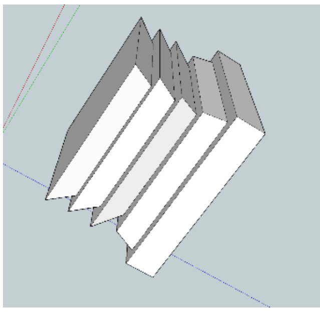


Figure 4.15 - 3D model for soft plastic cover

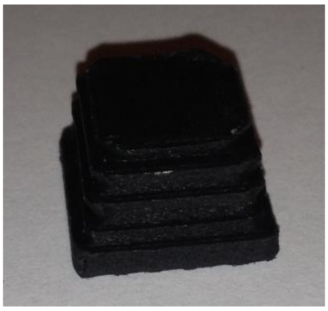


Figure 4.14 - Soft plastic cover

The advantages of a 3D printed cover (Figure 4.14) against the cork one, is that the printed one is faster to build, more durable and all of them will always have the same dimensions. Once the dimensions of the model are adjusted, the printed covers will always fit the recipient (unless a problem occurs during the printing process), while those made of cork are built by hand and will not be consistent. It will be difficult and slower to have two covers with the exact same dimensions using cork.

4.2.3 LESSONS LEARNED

3D printing is valuable for projects like this. It's a fast way of producing pieces of hardware so we can easily test some modifications and even build the final product with some quality.

The most complicated step may be the 3D modeling, dominating the software. In this case it was used the Google SketchUp to build the models that is a simple program to use but that provides all the tools needed to a project like this.

Some techniques were learned during the execution of the work. The blackbox for example, had to be printed in two pieces because the printer doesn't perform well in suspended parts. Although it could print as one piece, this could reduce the precision, and this two piece configuration makes easier the process of padding the interior.

There are some modifications to do on the printer settings to print both the cover for the recipient and the Blackbox. This custom settings will improve the print quality, for example the fill density on the Blackbox faces is increased to build a more solid object. For the recipient cover, the settings are also changed because the soft filament requires specific parameters, it is more difficult to find a correct set of settings to print using this filament because the flexibility of the material requires a higher temperature and a lower printing speed in order to print with quality.

The following settings can be changed on the Cura Printing Software on the Top Menu Expert-> Switch to full settings-> Basic.

Blackbox:	**Recipient Cover:**
Shell thickness: 1,2	Shell thickness: 0.8
Fill density: 40	Fill density: 15
Printing speed: 50	Printing speed: 20
Printing temperature: 200	Printing temperature: 220

The average time to print all the pieces for the blackbox is around 4 hours. It's possible to do it faster, but the quality can be affected if the speed is increased or the fill density is lowered.

For the recipient cover the printer will take around 11 minutes. This piece doesn't allow any change to the printer settings. The soft filament requires the settings above, otherwise it won't print an acceptable object.

All these settings are for the Ultimaker Original 3D printer, the model used in this project. Other printers may require other settings.

4.3 System Architecture

This section describes the architecture behind the system. It contains the system requirements, the interface prototypes, their evolution and the class diagram.

The definition of the system architecture only came up later during the execution of the work. Some of the elements presented on this section were create after the development to explain the project functionalities.

4.3.1 SYSTEM REQUIREMENTS

As this was an investigation project, at the beginning the requirements were too vague, the only known requirement was to build an app to identify a Madeira Wine by its color.

After the initial tests the project started to take some course, although, this was a step by step progress, it continued to evolve.

When the tests reached a moment where the app combined with the hardware piece started to produce some results, an idea of the system started to be defined which lead to a list of requirements that had to be implemented in Madeira Wine Analyzer.

4.3.1.1 Functional requirements

FR1. Identify a Madeira Wine by its color.

FR2. Display the results for the analysis made previously made in chronological order.

FR3. Delete a test result from the system.

FR4. Display the list of all Madeira Wine Varieties saved in the system.

FR5. Add or remove varieties of Madeira Wine.

FR6. Display the list of all the base samples saved on the System.

FR7. Set or remove base (known) samples on the system.

FR8. The base samples and Wine Varieties must be set by the user to calibrate the system.

4.3.1.2 Non-functional requirements

NFR1. The application must run in IOS 7.x.

NFR2. The system must be independent when analyzing the data after capturing the image.

NFR3. The size of the captured sample images must be 600x800px.

NFR4. The results must be displayed in a 0-100% scale which indicates the degree of similarity to that variety.

NFR5. The previous result must appear in reverse chronological order (most recent first).

NFR6. The user must have feedback of the current status of testing process.

NFR7. The test time must be as short as possible.

NFR8. The application must start with a splash screen.

4.3.2 USE CASE DIAGRAM

This use case diagram was created to represent the actions that the user can perform on this system.

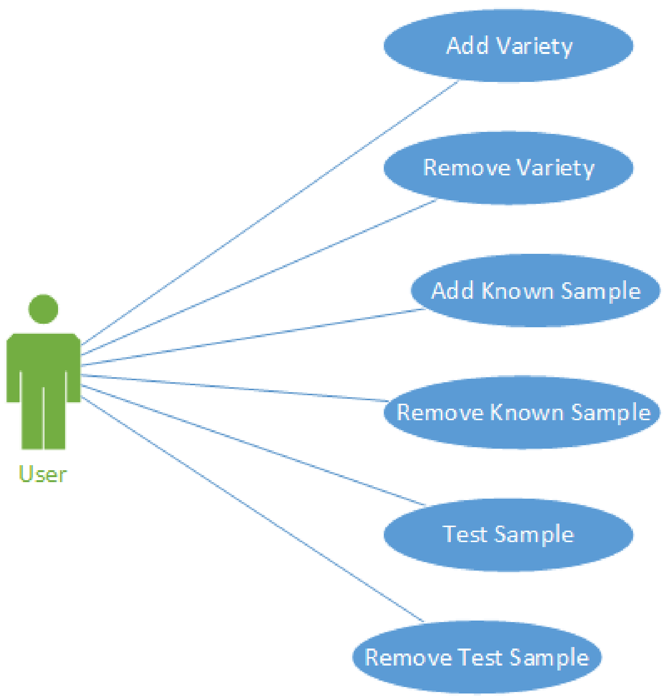


Figure 4.16 - Use Case Diagram

4.3.3 CLASS DIAGRAM

This class diagram in Figure 4.17 represents the core of the app, the structure of the project, the main class, attributes and operations.

This app didn't begin its development with the class diagram as it would be in a normal project. The idea evolved from the beginning and several changes were made. There wasn't an ideas that could be the main focus to develop all the usual structures used in software development.

What is tried here, is to demonstrate the main idea behind the app, as said above.

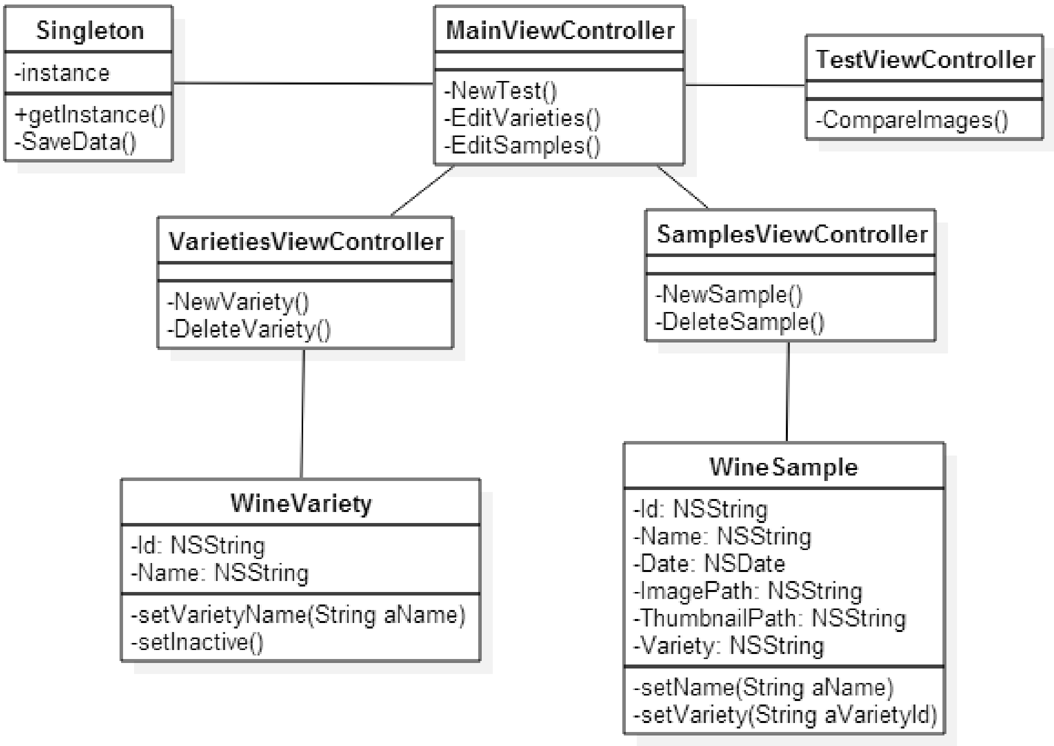


Figure 4.17 - Class Diagram

4.3.4 INTERFACE PROTOTYPES

The interface prototypes came up when the software functionalities were defined and a better interface was necessary, because the interface used to develop the app until this step was a draft, a set of buttons, labels and texts to test if the created concept was working. During the development, the interface was not a priority, because, when a new functionality was tested, it was added a button or another interface element to test if the concept was working.

With several modifications happening to the software structure, it was not necessary to spend too much time in interface design. As expected, with all the modifications that were made to the interface during the development, the final version only came up on the final stages of the app development.

Following, there is the detailed description of all the interfaces and their functionalities.

This prototypes were created using FluidUI, a browser-based prototyping tool used to design mobile touch interfaces.

This software also allows to navigate between the interface prototypes building links between them using the buttons as it was in a real use. This allows to test the navigation and see if everything happens in a logical order.

4.3.4.1 Main Screen

On the main screen presented in Figure 4.18 and Figure 4.19, the user has access to the previous tests he made, to the system settings and a direct connection to a new test.

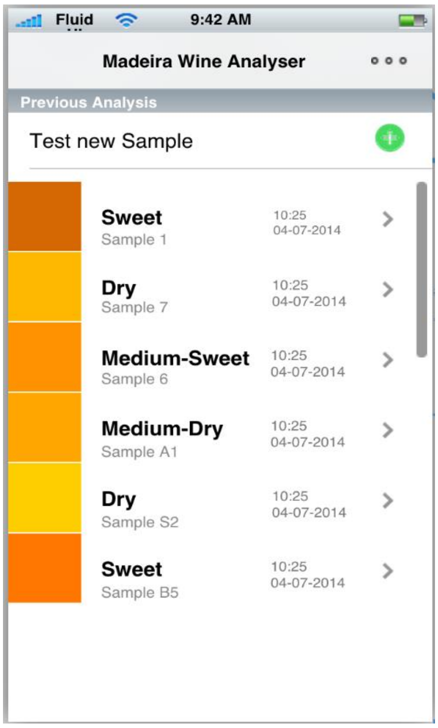


Figure 4.18 - Main screen

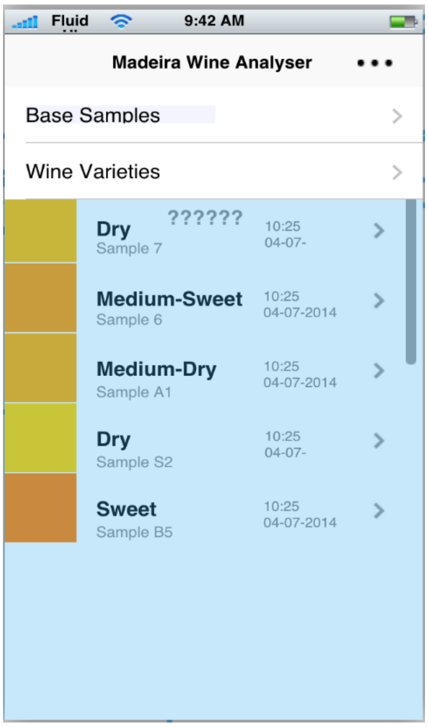


Figure 4.19 - Main screen, settings menu prototype

Each entry on the table is composed by the result from the test, a name given to that sample for identification purposes, and the date and time that the test was made, that can be relevant for some studies.

4.3.4.2 Varieties Screen

On the varieties screen (Figure 4.20 and Figure 4.21), the user has access to all the varieties he added to the system, has the possibility to add a new one or remove an existing variety sliding a variety to the left (usual gesture to delete an entry from a list on iOS).

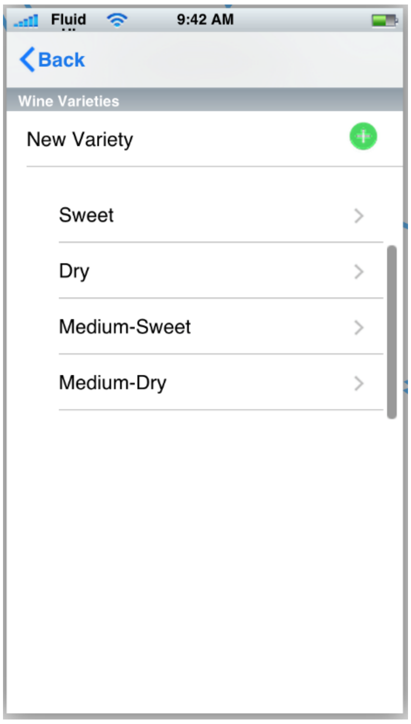


Figure 4.20 - Varieties screen

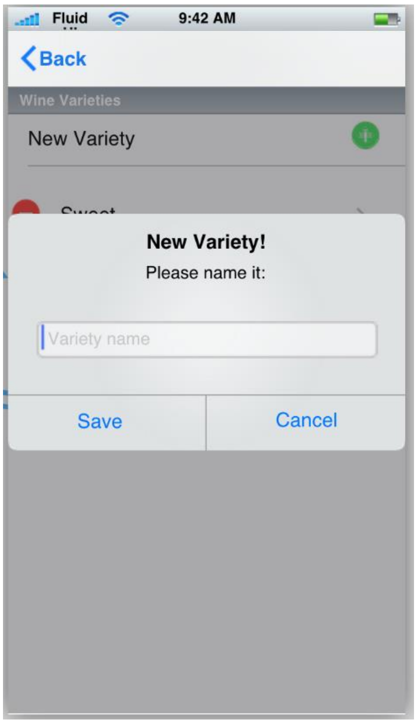


Figure 4.21 - New variety screen prototype

4.3.4.3 Base Samples Screen

This screen (Figure 4.22 and Figure 4.23) presents to the user all the known samples he added to the system, indicating the variety that they belong to. Its functionalities are similar to the ones presented on Home Screen. The user can delete a line from the list by sliding a sample to the left, or can add a new one using the New Base Sample functionality.

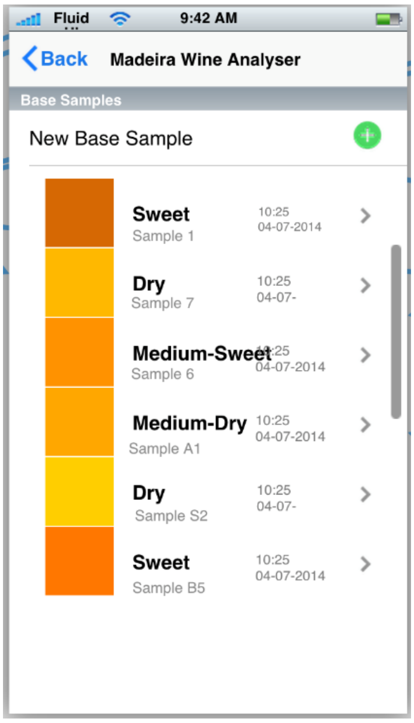


Figure 4.22 - Base samples screen prototype

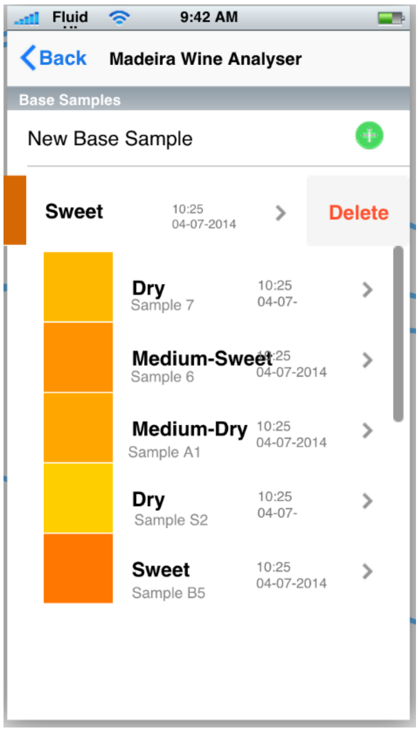


Figure 4.23 - Base samples screen prototype, delete sample

4.3.4.4 New Base Sample Screens

This interface allows the user to create a new base sample. It starts by taking a photo of a wine sample (Figure 4.24), then the user accepts the image if valid (Figure 4.25).

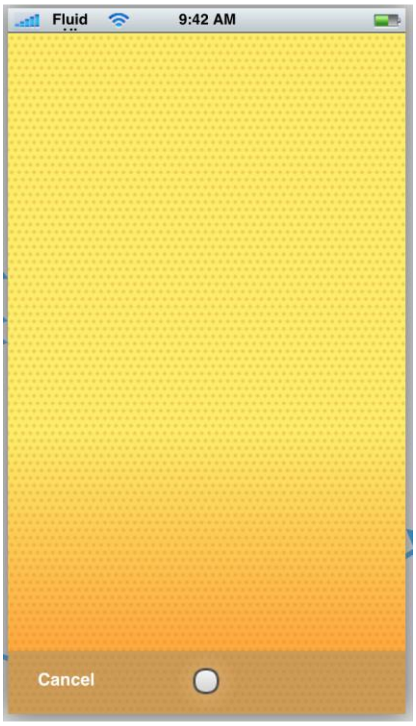


Figure 4.24 - New base sample, screen prototype

Figure 4.25 - New base sample, use photo screen prototype

After capturing an image, the user names the sample (Figure 4.27) and then selects from a list of varieties the one that matches that sample (Figure 4.26).

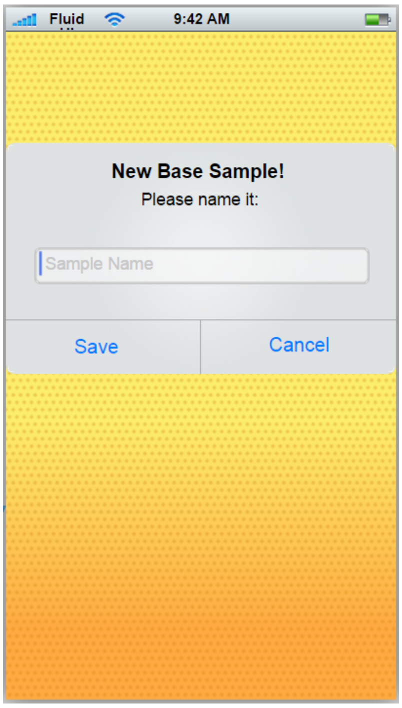


Figure 4.27 - Name new base sample, screen prototype

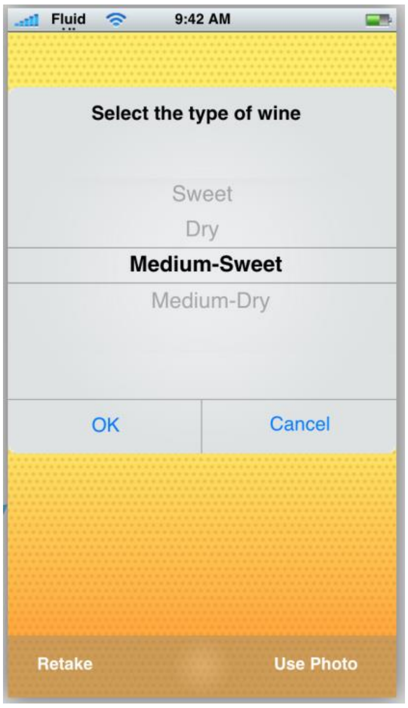


Figure 4.26 - New base sample, select variety screen prototype

4.3.4.5 New Test Screen

To create a new test, the interface is the same as the one to add a new Base Sample.

The user also enters the interface that has the inbuilt camera as shown in Figure 4.24, accepts the captured image if valid as Figure 4.25 demonstrates and adds a name again as he does for a new Base Sample in Figure 4.27.

After all these steps, the app calculates the matching variety and then presents the result in the next interface.

4.3.4.6 Results Screen

In this screen presented in Figure 4.28, the results are presented as percentage. This demonstrates how likely a sample is of a variety.

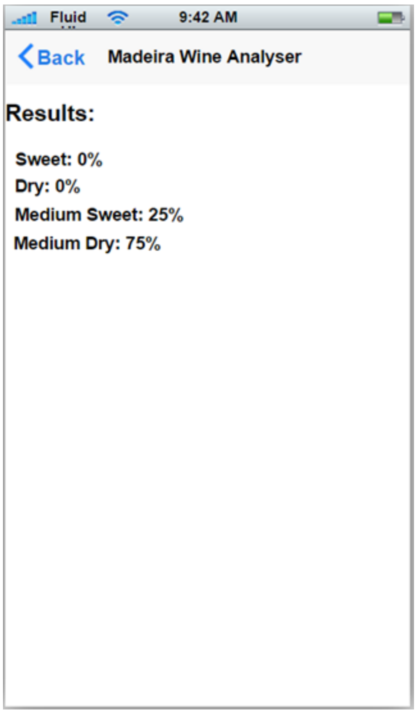


Figure 4.28 - Results screen prototype

4.3.5 FINAL INTERFACE AND EVOLUTION

After building the app with the new interface configuration, it was clear that it has some usability problems. The location of some icons and links makes difficult to use the app when operating with the 3D Prototype.

On the main screen, the location of the new test button/link is covered by the Blackbox as demonstrated in Figure 4.29 when the iPhone is inserted on it, so this functionality went down to the bottom bar as well the settings button.

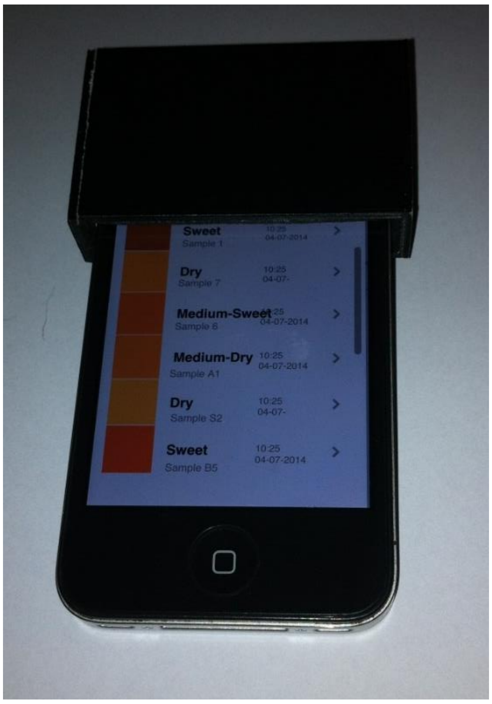


Figure 4.29 - Blackbox covering top buttons

In order to keep some consistency in the app and facilitate the access to all functions, the setting button also moved to the bottom bar as shown in Figure 4.30 and Figure 4.31.

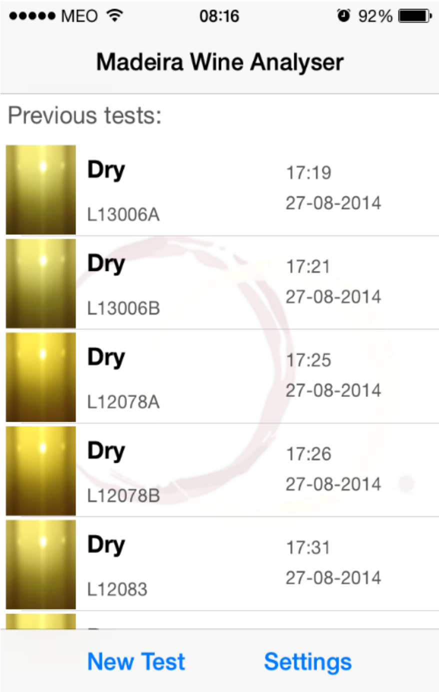


Figure 4.30 - Home Screen, final version

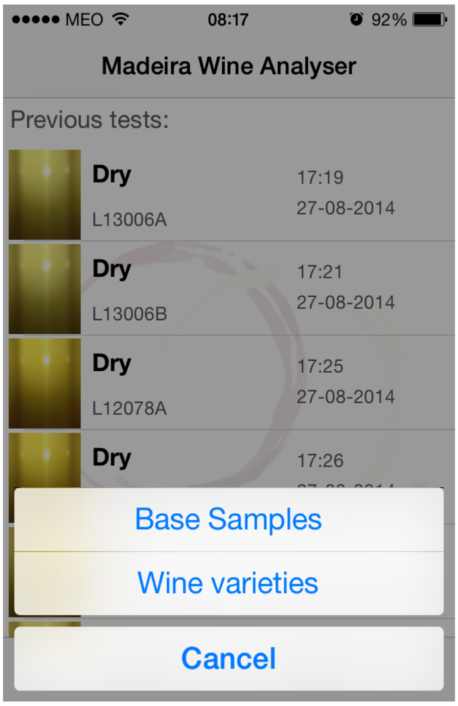


Figure 4.31 - Home screen, Settings final version

This solution is much “cleaner” than the previous one, it has better appearance and makes the entire navigation easier.

On the Base Samples screen, Figure 4.33, the changes had the same basis, access the functionality when the device is inserted on the prototype, so the new base sample button went down to the bottom bar.

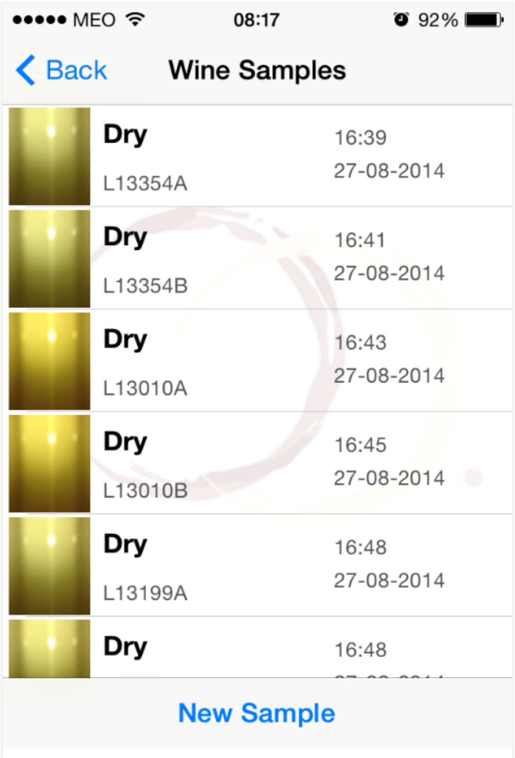


Figure 4.33 - Base samples Screen, final version

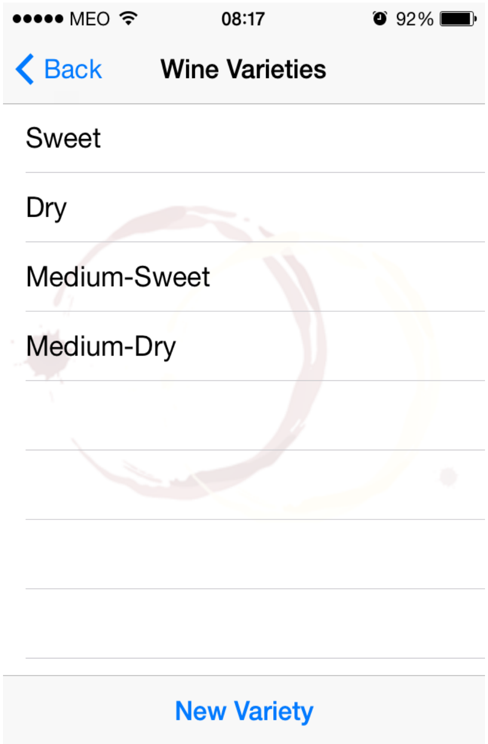


Figure 4.32 - Varieties Screen, Final version

The Varieties Screen, Figure 4.32, although it doesn't require to use the prototype, it was decided to use the same configuration as the other screens to keep consistency between them, so the new variety button went down to the bottom bar.

4.3.6 LESSONS LEARNED

The process of building the architecture for this project was not the usual one in software engineering.

The project didn't had a specific path to follow at the beginning. It was not possible to build use cases, class diagrams, or even write the full list of requirements before start developing the app.

The architecture was defined during the execution of the project and it was not defined until the end of it. The development was based on programming a functionality, testing, modifying if necessary and add new ones as new ideas were occurring during the implementation.

The interface prototypes were also built as the project evolved and new functionalities were added.

Has a consequence of the continuous development, the class diagram that is another important element in software engineering, wasn't also built before starting the development. In this document is presented a version of the class diagram containing the main classes to demonstrate the structure behind the app.

4.4 Software

The smartphone application is built to run on iPhone using iOS 7.x and was also evolving continuously during the project as new features where created.

4.4.1 VERSION 1

The first version of the software created has its origin in the first tests made with all the objects and color palettes.

The functionalities where very simple. It only allowed to take a photo and then click in some point of the image so the software could print out the RGB values for that point and also the average RGB value for the whole image. This test was made with wine and the paper prototype created. The photos were taken inside home with artificial light, in full dark, and outside with sun light.

One of the first steps to do before test for RGB values was to control the flash light intensity. Using full flash, the upper half becomes white, and the lower half had the wine color.

After controlling the flash light intensity, the colour of the wine in the image became more clear as demonstrated in Figure 4.34 in comparison with the image without controlling it presented in Figure 4.4 that has a predominance of the white color induced by the flash light.

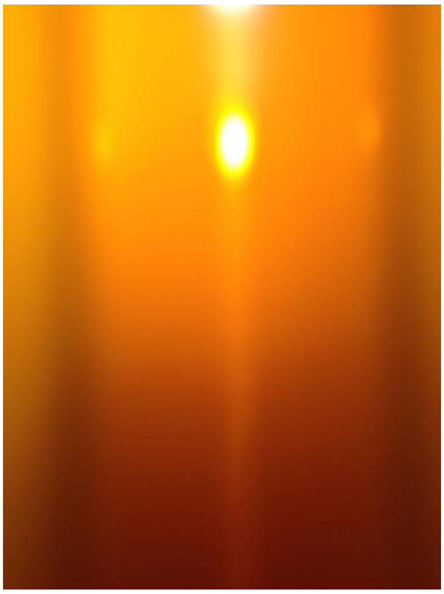


Figure 4.34 - Captured image with controlled flash light

In Figure 4.35, having the two situations side-by-side, on the left without controlling the flash light, and on the right with the controlled flash light, it's clear the improvement on the image quality.

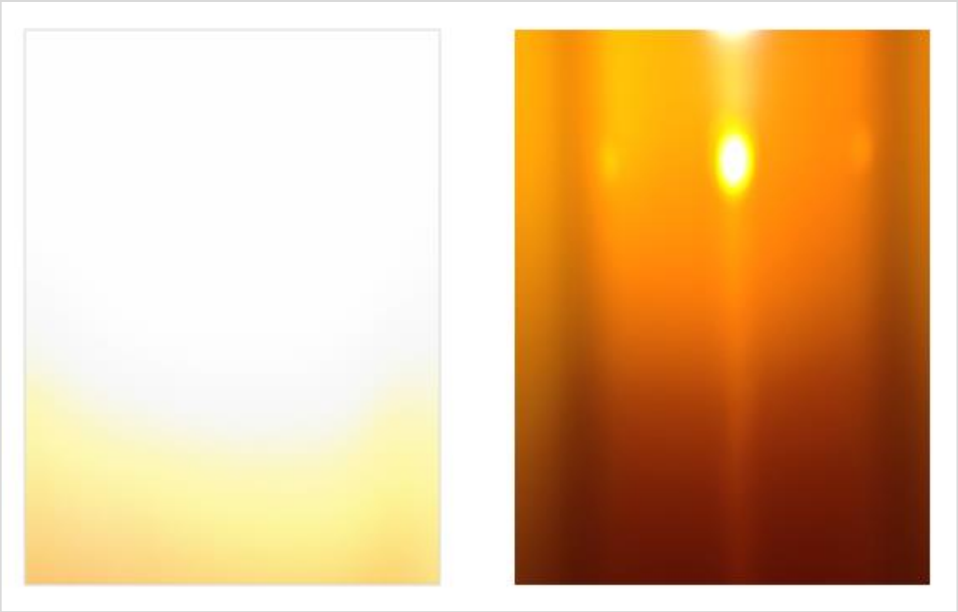


Figure 4.35 - Image comparison, with flash (left image) and without flash light (right image)

Clicking in some point and retrieve its color information for comparison purposes is not enough, the images have many color variations because of the flash light and the shadow of the container. The average RGB values for all the image are more precise, and, with this test, we can notice from Table 4.4, Table 4.5 and Table 4.6 that the values don't change significantly in all the different spaces, proving that the Blackbox prototype was working.

Some differences for the average RGB values between tests for the same sample at this stage could be errors introduced from the paper prototype. This prototype was not very stable, the recipient and the smartphone were moving inside it and affecting the results. This problem was corrected when the 3D printed one was adjusted to perfectly fit both the iPhone 4S and the recipient.

Table 4.4 - Test inside home, normal light conditions

	R	G	B
TEST 1	181	131	14
TEST 2	182	132	14
TEST 3	180	130	14
TEST 4	181	131	14
TEST 5	182	131	14

Table 4.5 - Test inside home, artificial light conditions

	R	G	B
TEST 1	181	131	14
TEST 2	181	132	14
TEST 3	181	131	14
TEST 4	181	131	14
TEST 5	181	131	14

Table 4.6 - Test inside home, dark environment

	R	G	B
TEST 1	181	131	14
TEST 2	181	130	14
TEST 3	181	131	14
TEST 4	180	130	14
TEST 5	182	132	14

4.4.2 VERSION 2

The second version is an improvement of how the color is measured and introduces the image comparison methods.

After being able to measure the average RGB values on version 1, on this second version it was recommended to find a more complete method to analyze the images. Following Professor Mon-Chu recommendations to explore histograms, the next step was to do some research on how they could be used to compare images.

The research quickly revealed a solution. There is a library that can be used to compare images using Histograms that is called OpenCV [36].

OpenCV uses a series of comparison methods to measure the degree of similarity ($d(H_1$ and $H_2)$) between two Hue-Saturation histograms (H_1 and H_2) generated from two images. These four metrics are:

- Correlation:

$$d\,(H_1, H_2) = \frac{\sum_I (H_1(I) - \overline{H_1})(H_2(I) - \overline{H_2})}{\sqrt{\sum_I (H_1(I) - \overline{H_1})^2 \sum_I (H_2(I) - \overline{H_2})^2}}$$

Were

$$\overline{H}_k = \frac{1}{N} \sum_J H_k(J)$$

and N is the total number of histogram bins.

- Chi-Square:

$$d\,(H_1, H_2) = \sum_I \frac{(H_1(I) \; - \; H_2(I))^2}{H_1(I)}$$

- Intersection:

$$d\,(H_1, H_2) = \sum_I \min(H_1(I), H_2(I))$$

- Bhattacharyya distance:

$$d\,(H_1, H_2) = \sqrt{1 - \frac{1}{\sqrt{\overline{H_1 H_2} N^2}} \sum_I \sqrt{H_1(I) \cdot H_2(I)}}$$

For correlation and intersection, the higher the metric, the more accurate the match. For Chi-Square and Bhattacharyya distance, the less the result, the better the match.

Starting from the base code from this library, this version was able to compare an image from a photo captured at the moment with some previous selected and saved images, giving as result the image that is most similar considering all the four methods.

This method is more accurate, because it uses four different metrics to analyze the images instead of just comparing the Hue average value or only the RGB average values.

4.4.3 VERSION 3

The next step was to apply the histogram comparison techniques and adapt the software to wine comparison.

Some features were added to the app:

- Add and remove wine varieties: When this step was reached, it was clear that the user should be able to manually introduce the wine varieties that he wants to study, because they can change in the future, or accordingly to what the user wants to test.
- Add and remove base samples: The user as the possibility to add or remove some known samples to the system in order to calibrate it. These samples are images the user identifies as being from a given variety (already introduced in the system), and they will be used in the future to compare against an unknown sample that the system has to guess its variety.

To identify to which variety an unknown sample matches to, the system proceeds this way:

1. Given a captured image from an unknown sample, and after labeling it with a name, the system creates a counter for each variety in its list. This counter will be used later to identify the variety with more matches.
2. Converts the image from RGB to HSV, that is the color space used by OpenCV and calculates the Hue-Saturation histogram for the unknown sample.
3. Apply sequentially the four comparison methods between the Hue-Saturation histogram of the captured image and the other Hue-Saturation histograms from the known samples inserted into the system.
4. For each comparison method, for the image that matched the unknown one, the system gets its variety and then, on the counter, it increments the value for that variety.
5. Once finished all histogram comparisons, the system presents the result for each counter that represents how much the given unknown sample matches each variety, in a scale from 0% to 100%. The system can consider that a sample has 25% probability of being Medium-Sweet and 75% probability of being Medium-Dry.

In Appendix 2, the scheme describes this process described above.

This new functionalities added more complexity to the system. Consequently, the interface response started to slow down.

The main thread should be used only to update the user interface. All other functionalities such as data loading, data processing, all that requires huge processing power should be done in a separate thread.

The use of NSOperation and NSOperationQueue simplifies the process of multithreading, the solution for this responsiveness problem. All the tasks or operations are an instance of NSOperation class, and, NSOperationQueue class is responsible to start the operations, ensure they run in the appropriate order, and take into account any priorities that have been set [37].

The process for using NSOperatioQueue is the following:

1. Instantiate a new NSOperationQueue object

```
NSOperationQueue *queue = [NSOperationQueue new];
```

2. Create an instance of some NSOperation

```
NSInvocationOperation *operation = [[NSInvocationOperation alloc]
initWithTarget:selfselector:@selector(methodToCall)object:nil];
```

3. Add the operation to the queue

```
[queue addOperation:operation];
```

4. Release the operation

```
[operation release];
```

For this app, the process of analyzing the images and identify the variety is made in a separate thread using this technique explained above.

Before multithreading use, when the user performed a test, the interface was locked in the screen that requests the user for a name for that sample, from the beginning of the test until the end.

This solution allowed to use the main thread to prepare the user interface to load the results into, and also allowed to create a progress view, where the user gets feedback from the system and verifies that the app is working as demonstrated in Figure 4.36. This user interface updates were not possible before, because the main thread was locked in the image processing.

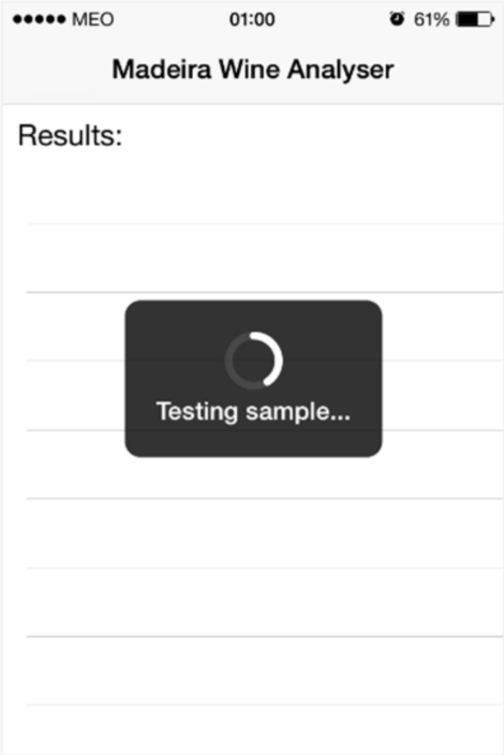


Figure 4.36 - Processing feedback

4.4.4 VERSION 4

One of the main updates was the image sizes used in the app.

The test was initially done using a full size image, as captured from camera. This was creating serious memory problems. The app reached some moments in which simply closed.

It was necessary to do some tests to know to which point the image size can be reduced without affecting the final result. Also, it is recommended by Apple to avoid manipulate image objects greater than 1024x1024px in size due to memory constraints [38].

In Appendix 1 – Image size tests, all the results in green indicate that the result is the same for those image sizes. The result in red, for the sample L12084 Test B, indicates that for the size 500x667px, the result is different.

One wrong result in a universe of 180 tests is not very problematic, but considering the Table 4.7, the average size for an image with dimensions 500x667px and 600x800px is very similar, and also the test time for these two sizes is also very similar, so, it was decided to use the size 600x800px that proved to keep the same results as the original size and allows to save lots of memory.

Table 4.7 - Image Size vs Test Time

Size (px)	Average Size (Megabytes)	Average Test time (for each image)
500X667	0,5 MB	0,040s
600x800	0,7 MB	0,050s
750x1000	1 MB	0,070s
2448x3264	9 MB	1,378s

4.4.5 FINAL IMPROVEMENTS

After finishing the coding, and with a working version, it was decided to do some improvements on the software.

Review the code and do some “cleaning” was part of the job, but it was also necessary to create a more efficient way to load and save the data contained in the app. Previous to this improvement, the data was loaded once the user opened the app but it was only available for the class that loaded the data, not a very practical approach since the loaded data is used in almost all class.

The singleton pattern [26], it’s simple to implement and can be used in this situation, where it’s only necessary to have an instance with a global point of access.

So, using this pattern, an instance of it is created when the app is loading, containing all the app data loaded from memory. If some class needs that data, it has only to call the instance of the class implementing the singleton pattern. As the data as already been loaded, it doesn’t have to be loaded again, saving time and memory.

Making use of the functions already present at the base code contained on the project, it can be detected when the app is closing. This is useful to save data, so, when the app closes, automatically saves the data to memory.

4.5 Logo

For the logo creation it was intended to use some aspect related to wine, and something specific to Madeira Wine.

The logo in Figure 4.37 includes the marks left on a table by a glass of wine [40] and the name of the app using a similar font to the one originally used to stamp original Madeira Wine bottles. The colors are also associated to Madeira Wine color variations.

Figure 4.37 - App logo

4.6 Splash screen

The splash screen (Figure 4.38) that appears when the app is loading includes the logo and associations with University of Madeira and Madeira Interactive Technologies Institute.

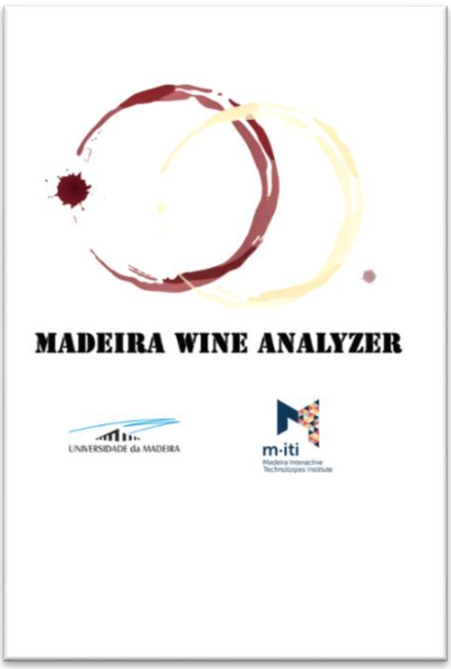


Figure 4.38 - App splash screen

5 TESTS AND RESULTS

This chapter covers the tests, explains all the procedure together with demonstrative photos, describes the wine samples used and also contains the results analysis.

5.1 Procedure

This section describes all the steps and material required to test a sample.

It's necessary some laboratory equipment to simplify the process:

- Pipette
- Quartz test cell
- Cotton swab
- Distilled water
- Paper towels
- Blackbox prototype
- Test cell lid
- IPhone 4S with Madeira Wine Analyzer App
- Wine samples

The use of this equipment doesn't require specific formation, but it's necessary to be careful when handling it because some of this equipment is fragile.

The app must be set-up before the first test. The varieties to study must be inserted in the system as well as the known samples. The process to capture an image for a known sample is the same as the one to capture an image of a sample to test.

Following, there is an ordered sequence of steps with an associated image to illustrate each procedure.

5.1.1 STEP 1

Place the wine in the quartz test cell without completely fill it, leaving enough space to put the lid.

It's easier to do this process using a pipette as demonstrated in Figure 5.1.

Figure 5.1 - Preparing a sample to test

5.1.2 STEP 2

After the recipient is properly capped, it’s necessary to clean its faces from any wine residues or any fingerprints using a paper towel. To avoid the fingerprints, it’s recommended to hold the recipient using the opaque faces.

Once the recipient is fully clean, it can be placed inside the Blackbox prototype with one of the clear faces facing the open space where the camera will be as demonstrated in Figure 5.2.

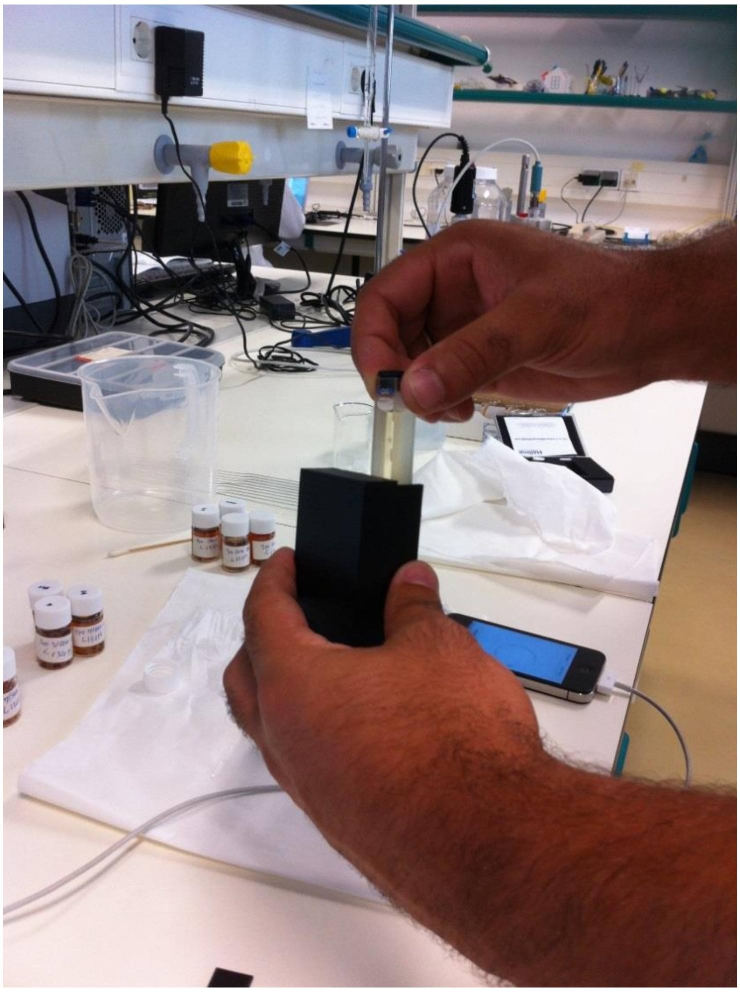


Figure 5.2 - Inserting the test cell in the Blackbox prototype

5.1.3 STEP 3

The next step is to slide the Blackbox lid that covers the place where the test sample was inserted and insert the IPhone to capture an image of that sample.

Once the iPhone is inserted it won't move inside the Blackbox and the image can be captured pressing the button New Test in Home screen (Figure 4.30) that will open a look alike camera app. Once the image of the wine appears on screen, the system will automatically focus the image for about two seconds. During the focus, a rectangle will appear in the center of the screen. Once this is done, the image can be captured as demonstrated in Figure 5.3.

Figure 5.3 - Testing a sample

After taking the photo, the app will calculate which variety the test sample matches.

The results are expressed in a 0 to 100% scale that represents how much the sample is likely to be from that variety as represented in Figure 5.4.

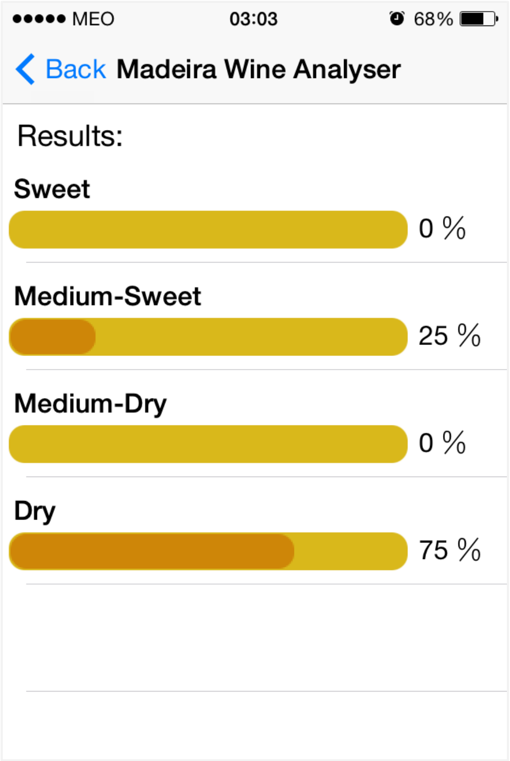


Figure 5.4- Test results (Example)

5.2 Results Analysis

The tests were made with a total of 21 samples, the maximum number of different 3 year old wines available at the moment. From those, 6 are Dry, 2 Medium Dry, 6 Medium Sweet and 7 are Sweet.

From the 21 samples, 11 were set as known samples in the app, that is, we take a photo and identify the type of wine for calibration purposes. The choosing process was completely random. The samples were on the table and 3 Dry samples, 1 Medium Dry, 3 Medium Sweet and 4 Sweet were separated as known samples. The other 10 were the test samples, which the system didn't knew anything about and had to test and guess the result.

Table 5.1 - Test results

Sample	Test	Expected Result	Test Result
L13006	A	Dry	Dry
	B		Dry
L12078	A	Dry	Dry
	B		Dry
L12083	A	Dry	Dry
	B		Dry
L12282	A	Medium Dry	Medium Dry
	B		Medium Dry
L12079	A	Medium Sweet	Medium Sweet
	B		Medium Sweet
L12108	A	Medium Sweet	Medium Dry
	B		Medium Dry
L12076	A	Medium Sweet	Medium Dry
	B		Medium Dry
L13363	A	Sweet	Sweet
	B		Sweet
L12074	A	Sweet	Sweet
	B		Sweet
L12075	A	Sweet	Sweet
	B		Sweet

Analyzing the results on Table 5.1, the test results for the samples L12108 and L12076 were expected to be Medium Sweet and the system identified them as Medium Dry.

It's expected that the system fails in some cases, because, there are so many wine color variations, and some are very similar. This is a problem that can be diminished using more known samples in the app.

As the problem is with the Medium Sweet samples, and the sample L12079 was already correctly identified by the system, L12079 was added as known sample to test if any of the incorrect results can now be correct.

The two incorrect test results are still incorrect. Again, one of the two samples that show incorrect results was randomly chosen to set as known sample, in this case the sample L12108.

A new test was made for the sample L12076, which resulted in a Medium Sweet wine, a correct result.

This demonstrates how important calibration is. Adding another known sample increased the fidelity of the system for this samples. This is a continuous process. On the next production year, more 3 years old samples can be added to the system, and so on, to try to reach a more perfect result. It doesn't mean that the app will be 100% correct.

There is future work to do that is test more samples because 21 samples are not enough, but that was the number available to test at the time.

The results were expectable and demonstrate potential in a future development of this app.

6 CONCLUSIONS

The development of this project was a challenge from the beginning. It joined a difficult scientific area like Chemistry with Software Engineering. It required some attention at the beginning to understand the work that has been done at the lab and some totally unknown concepts.

As this was not a standard project, that we know from the beginning which are the requirements and we have a detailed plan and know what to expect, sometimes it was hard to progress without losing some time thinking how some problem could be solved. This project was a bit of trial, testing, correction, always discovering new solutions and improvements. The fact that this was the first experience on the Apple environment, whether in the MAC OS, iOS or even the programming language Objective-C highlighted even more this situation. Sometimes, after finishing a section of code, that entire section was completely rebuilt because a new and more efficient method was created. It's expectable, because, starting from zero the level of knowledge increased during the execution, and, as the efficiency and responsiveness of the system are very important it worth it to update the coding.

Capturing a photo that has the same characteristics such as light conditions and patterns affecting the image equally in all situations was the most important aspect to achieve. A steady color reading is required to perform a comparison between images. They all need to be captured under the same environment.

The device memory was another big concern since the beginning. Dealing with lots of data may lead to problems when data volume increases. From the beginning that some memory warnings where happening when testing the images for the histogram comparisons. It was later noticed that the images where too large in pixels and Megabytes because they were being used as captured, so it was necessary to re-dimension all the images when they were captured.

The image resizing implementation took some time to do. On the first tries, the resized image was losing quality, so it was necessary to find another way to do it that was achieved after some research. After the resizing implementation it was clear that the tests were faster.

With the smaller image, a test that usually took about 1 minute is now done in a couple of seconds. After solving the memory problem the concern was if resizing the image was affecting the result, which proved not to be a problem for the size chosen that was 600x800px.

The application as room to grow in terms of reliability. The more known samples the system has, more precise it will be because it has more references to compare to.

One limitation is the fact that the app only analyses the visible colors, and for that color range, some wines appear to have the same color. For example, a medium-dry wine may be similar to a medium-sweet as happened on the tests. The variety of colors that Madeira Wine has as result of different ways of harvesting, fermentation and maturing process makes it more difficult to test.

The idea was to use only a smartphone as far as possible, but, due to the environment constraints presented on the work, such as light conditions, the creation of the 3D prototype was inevitable. Although it’s an extra hardware to be used, the results indicate that the prototype controlled the environment influence in the image.

The app only works when used together with the Blackbox device. It limits its use as it requires an external device and not only the iPhone. The user has to carry the Blackbox with him to perform a test, but, if the app is prepared to be used in the future in a winery for quality control for example, that’s not a significant problem as the person who performs the tests will be prepared with all the necessary equipment to test the samples.

The results for this experiment are good indicators for future works as the software is able to analyze the color of a Madeira Wine sample, fulfilling the initial goal of preparing an app for a smartphone to identify a Madeira wine by the color with a success rate of 80% to 90% on the performed tests as explained on the results analysis.

7 FUTURE WORK

Technology evolves every day. For example, the newer iPhone 5S has a more powerful camera than the iPhone 4S used on this project and a different flash technology with two LED called True Tone that allows to capture photos that look more natural adjusting variably the color and intensity for 1000 combinations [41]. Now, by the ending of this project, the iPhone 6 has been released with even more processing capabilities. It never stops improving. Using one of this new iPhones can improve the quality of the project.

The Blackbox used to put the recipient containing the wine inside, keeping it out from light influence can be evolved to a most practical device. Maybe it's is possible to find a solution that allows to simplify the hardware, making it smaller or even discarding it completely, although discarding it is a bit ambitious because of all the influences that the external environment has on the test as demonstrated on this project.

If this application is prepared in the future to be launched for more users, it could benefit from using cloud storage. This feature would provide a way for data sharing. For example, the known samples can be shared by all the users, and, when a user adds one known sample to the device, the other users can also receive that information to calibrate their system. It would provide a collaborative way of testing samples. Also, users could have the possibility to save their data so it won't be lost if for some reason they lose the device or loose the data in device software updates.

Some other features can be added to the app such as a detailed information about the wine, curiosities, where to buy, etc. This could be for a commercial variation of this app directed to general public. This can bring more interest around the wine.

As the iOS version as evolved on the final stage of this project from version 7 to 8, the app has to be submitted to new tests to confirm if everything works. Apparently, there is no problem with that, but only future testing can verify this.

8 REFERENCES

[1]. D. Forsyth and J. Ponce, *Computer Vision: A Modern Approach.* USA: Prentice Hall, 2003.

[2]. B. Tulsi (2014, May 01). *"Good chemistry*", labmanager.com [Online]. Available: http://goo.gl/f4bdQX [Accessed: 13-08-2014

[3]. W. Marten. *"ColorMeter",* itunes.apple.com [Online]. Available: http://goo.gl/72ftvC [Accessed: 01-10-2014]

[4]. Bioenos. *"Colourimetric procedure to determine the color of wine from the grapes"*, bioenos.com [Online]. Available: http://goo.gl/G1RGZ8 [Accessed: 01-10-2014]

[5]. ETS Laboratories, *ETS Wine Color Analysis*. (2013). Available: http://goo.gl/vqrZb1 [Accessed: 01-10-2014]

[6]. Shimadzu UV-2600 UV-VIS spectrophotometer. [Online image]. Available: http://goo.gl/8NiVDx [Accessed: 29-10-2014]

[7]. S. Slinkard. *"Madeira Wine"*, wine.about.com [Online]. Available: http://goo.gl/w0NyRs [Accessed: 20-05-2014]

[8]. Madeira Wine Color [Online image]. Available: http://goo.gl/kf8n7J [Accessed: 21-05-2014]

[9]. CCD Sensor [Online image]. Available: http://goo.gl/j2RfVm [Accessed: 05-11-2014]

[10]. Interpolation, Bayer filter pattern [Online image]. Available: http://goo.gl/bVVdiQ [Accessed: 05-11-2014]

[11]. Bayer filter pattern [Online image]. Available: http://goo.gl/p31j7p [Accessed: 05-11-2014]

[12]. Raw image vs processed image [Online image]. Available: http://goo.gl/MQ04C0 [Accessed: 05-11-2014]

[13]. K. Nice, T. V. Wilson and G. Gurevich. *"How Digital Cameras Work"*, electronics.howstuffworks.com [Online]. Available: http://goo.gl/8CkgkI [Accessed: 29-05-2014]

[14]. D. N. Mendonza (2013, August 1). *"A Tour of the Hardware Found in Modern Smartphone Cameras"*, PetaPixel [Online]. Available: http://goo.gl/XIr3Pz [Accessed: 29-05-2014]

[15]. R. Anderson and P. Krogh (2012, February 27). *"Color space and color profiles"*, dpbestflow.org [Online]. Available: http://goo.gl/p7YO7z [Accessed: 29-05-2014]

[16]. S. Pappas (2010, April 29). *"How do we see color?"*, livescience.com [Online]. Available: http://goo.gl/JIWPFL [Accessed: 30-10-2014]

[17]. A. Z. Jones. *"The Visible Light Spectrum",* physics.about.com [Online]. Available: http://goo.gl/dQZcP4 [Accessed: 30-10-2014]

[18]. K. Tate. "How the eye sees in color", National Library of Medicine [Online image]. Available: http://goo.gl/XL3hhA [Accessed: 30-10-2014]

[19]. *"Color spaces"*, [Online]. Available: http://goo.gl/N46ui5 [Accessed: 29-05-2014]

[20]. RGB cube, [Online image]. Available: http://goo.gl/t5M6fM [Accessed: 29-05-2014]

[21]. SpecialChem. *"CIELab",* coatings.specialchem.com [Online]. Available: http://goo.gl/CFyVV4 [Accessed: 22-08-2014]

[22]. J. Howard. *"HSV"*, About Tech [Online]. Available: http://goo.gl/mjBiAx [Accessed: 30-05-2014]

[23]. HSV Cylinder. [Online image]. Available: http://goo.gl/XkkmfM [Accessed: 30-05-2014]

[24]. OpenCV. *"OpenCV - changing color spaces"*, opencv.org [Online]. Available: http://goo.gl/cX7DfJ [Accessed: 22-04-2014]

[25]. *"3D printing basics"*, blogspot.pt [Online]. Available: http://goo.gl/1xpU4r [Accessed: 21-05-2014]

[26]. K. Hall. *"How 3D printing impacts manufacturing"*, ComputerWeekly [Online]. Available: http://goo.gl/PkJon4 [Accessed: 28-10-2014]

[27]. Industry – 3D printed part [Online image]. Available: http://goo.gl/BqaKL2 [Accessed: 28-10-2014]

[28]. Laser printing [Online image]. Available: http://goo.gl/5EC9nl [Accessed: 28-10-2014]

[29]. CNC [Online image]. Available: http://goo.gl/iytZGI [Accessed: 28-10-2014]

[30]. T. Owad, (2014, March 17). *"CNC Machining VS 3D Printing"*, makezine.com [Online]. Available: http://goo.gl/dRGzZJ [Accessed: 28-10-2014]

[31]. Apple (2013). *"Start Developing iOS Apps Today"*, iOS Developer Library [Online]. Available: http://goo.gl/4eA5yK [Accessed: 30-09-2014]

[32]. Apple. *"iOS development overview image"*, iOS Developer Library [Online image]. Available: http://goo.gl/WubaxW [Accessed: 30-09-2014]

[33]. Apple. *"XCode overview",* iOS Developer Library [Online image]. Available: http://goo.gl/9FCx29 [Accessed: 30-09-2014]

[34]. Investopedia. *"Histogram"*, Investopedia.com [Online image]. Available: http://goo.gl/1WdUtj [Accessed: 01-10-2014]

[35]. Histogram example. [Online image]. Available: http://goo.gl/w2mfzK [Accessed: 05-10-2014]

[36]. OpenCV, "OpenCV – Histogram Comparison", docs.opencv.org [Online]. Available: http://goo.gl/MJtq9O [Accessed: 23-05-2014]

[37]. Brandontreb (2010, March 4). *"iPhone Coding – Turbo Charging Your Apps With NSOperation"*, iCode [Online]. Available: http://goo.gl/peozbs [Accessed: 28-10-2014]

[38]. Apple. *"UIImage"*, iOS Developer Library [Online]. Available: http://goo.gl/5gLDpg [Accessed: 10-08-2014]

[39]. Microsoft. "Singleton", msdn.microsoft.com [Online]. Available: http://goo.gl/dGhdhM [Accessed: 05-10-2014]

[40]. Wine glass marks. [Online image]. Available: http://goo.gl/dOkO83 [Accessed: 15-06-2014]

[41]. Apple. *"iPhone 5s"*, apple.com [Online]. Available: http://goo.gl/UpFAa5 [Accessed: 19-08-2014]

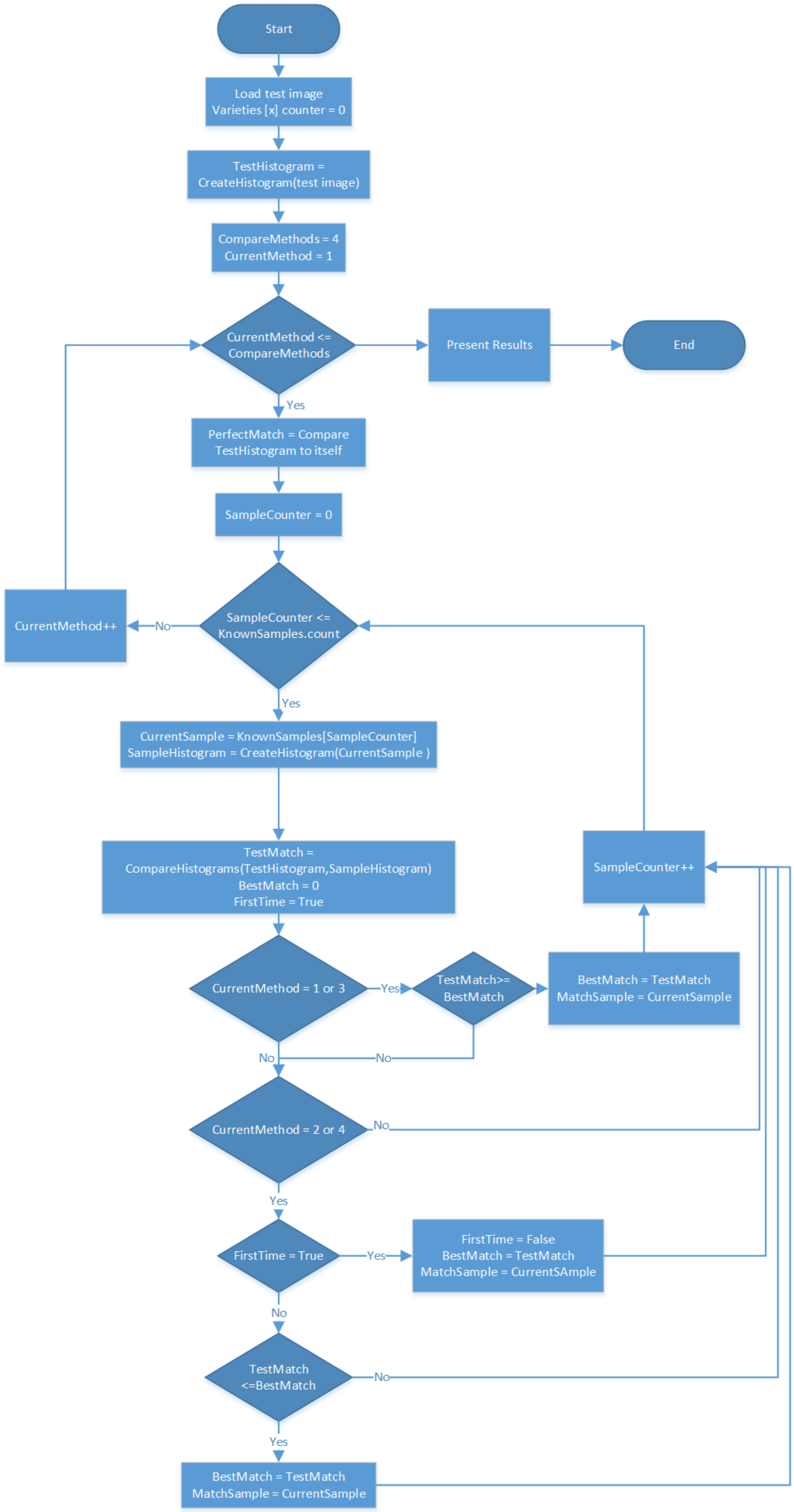
9 APPENDIX

9.1 Appendix 1 – Image size tests

Sample	Variety	Image Size	Correlation	Chi-Square	Intersection	Bhattacharyya	Final Result
L13199	Dry	Full Size	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
		750x1000	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
		600x800	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
		500X667	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
L13006	Dry	Full Size	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
		750x1000	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
		600x800	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
		500X667	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)	Dry (L13354)
L12084 Test A	Medium Dry	Full Size	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
		750x1000	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
		600x800	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
		500X667	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
L12084 Test B	Medium Dry	Full Size	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13114)	Med. Sweet (L13209)	Med. Sweet (L13209)
		750x1000	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13114)	Med. Sweet (L13209)	Med. Sweet (L13209)
		600x800	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13114)	Med. Sweet (L13209)	Med. Sweet (L13209)
		500X667	Med. Sweet (L13114)	Med. Sweet (L13209)	Med. Sweet (L13114)	Med. Sweet (L13209)	Med. Sweet (/)
L12123	Medium Sweet	Full Size	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
		750x1000	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
		600x800	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)
		500X667	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)	Med. Sweet (L13209)

L13363	Sweet	Full Size	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
		750x1000	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
		600x800	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
		500X667	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
L13117	Sweet	Full Size	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)
		750x1000	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)
		600x800	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)
		500X667	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)	Med. Sweet (L13114)
L13198 test A	Sweet	Full Size	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)
		750x1000	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)
		600x800	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)
		500X667	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)	Sweet (L13236)
L13198 test B	Sweet	Full Size	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
		750x1000	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
		600x800	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)
		500X667	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)	Sweet (L13320)

9.2 Appendix 2 – Image comparison flowchart



9.3 Appendix 3 – How the Eye Sees in Color [18]