

# Initial design and development of a cosmetics colour recommender mobile application

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## **Abstract**

This master thesis report contains the contribution to a beauty advisory mobile application design and development. The system was aimed to converge colour imaging science, new mobile technologies and a potential business within the cosmetics industry in order to provide recommendations on how to select the right cosmetic colour that matches best to one's specific face skin. This project has been planned as a full digital beauty consultancy. However the core and starting point was to provide suggestions on selecting foundations, products of different formats such as liquid-based cream, powder or mousse, manufactured in human skin colour range to cover facial flaws. In this study, following the agile development principles, we mapped the user's face skin colour to a series of foundation codes as the appropriate colour matches. The proposed method leading to these recommendations include performing colorimetric measurements on the foundations, employing a digital imaging system, colour image analysis, and colour difference calculations. User involvement as a key component throughout the design and development phase was fulfilled by surveying the users and integrating their feedbacks into the whole process. We were able to confirm that it is possible to use a foundation transparent bottle as a reference for colour calibration of the application pictures. Our experimental data resulted into promising recommendations while the system was tested under a controlled illumination and using a reasonably high quality camera. Whereas, in a more complex situation, under uncontrolled illumination using a mobile front-facing camera with low quality, having only one foundation bottle as colour reference; the helpfulness of the results dramatically decreased.

### **Keywords**

Image color analysis, Image analysis, Mobile computing, Software design, Software as a service, Software engineering, Measurement techniques, Calibration



Dedicated to my dear parents Alireza and Fakhri, my lovely sister Parisa and my beloved Quentin Lauv, for always believing in me, supporting me unconditionally and making my life so colourful as it is!

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# 1 Introduction

## 1.1 Problem description and motivation

Studies have previously confirmed that many cosmetics consumers, have experienced purchasing products that do not fulfil their expectations in terms of colour. [4]. Only the US colour cosmetic industry alone is a 29 billion dollar market which is subjected to grow exponentially [7]. This remarkably high market value held by colour cosmetic products clearly emphasize on the amount of money women are willing to spend for make-up products, subsequently the importance of their degree of satisfaction with each and every purchase they make. Hence it is essential to pay more attention to providing services to help the cosmetic consumers make better decisions in parallel with producing products of higher quality everyday. More specifically, certain cosmetic products are chosen based on different attributes such as their format and colour, among countless brands available in stores, making it more complicated than others to be selected 2.

One of the most difficult-to-choose cosmetic products is foundation; a liquid-base cream or powder, available in various skin tone colours, that covers the facial flaws as well as uniforming the surface of the skin [8]. Previous studies by Estée Lauder show that " Over 94% of women wear the wrong foundation [4]". The term 'wrong' has been referred to as a description of colour mismatch between one's skin colour and the foundation colour that can be highly frustrating especially when it comes to more sensitively chosen and less frequently changed products such as foundations 2. Since the representation of one's skin color is judged in accordance to the changes of environment's illumination, it happens quite often for many to purchase the wrong foundation under a store's lighting condition, which ends up looking significantly different elsewhere. As a result of these wrong choices being made, a number of cosmetic providers have previously made attempts to create various cosmetic consultancy systems. Some of which to be mentioned have been simply implemented as internet services, asking the users to follow a few steps, choosing in between different skin shades and under tones, desired coverage and other foundation properties, gradually redirecting them to an appropriate product. Another example is an in-store solution by Boots Company which employs a small color measurement device on the skin, leading to a recommendation based on the measured color [5]. A number of disadvantages to the existing services would be dependency on the users' knowledge of their skin attributes, having to book appointments by the makeup consultants, lack of the launch of in-store services worldwide and therefore accessibility at anytime and anywhere etc.

In an attempt to compensate the above mentioned disadvantages one potential solution addressing a large population of customers could be a mobile application as a foundation recommender. This master thesis is intended to contribute to different scopes of designing such mobile application from the customer needs analysis and business opportunities to providing optimum solutions to the technical challenges for further commercial use by L'OREAL, the largest cosmetics and beauty company worldwide [9] that is ultimately seeking for the science behind

beauty [10].

A number of other virtual beauty consultancy applications are currently known as mobile makeover apps on various platforms giving the users the chance to try hundreds of hairstyles and cosmetics products either for fun or shopping [11]. Our proposition is to develop a mobile application, to some extent similar to the makeover apps, by color scientific analysis of L'OREAL True Match foundations, for further commercial use.

Designing this system has to overcome a number of major challenges such as finding solutions for a stable lighting condition as well as performing color calibration on the images taken by the mobile camera. Also, having measured a full color palette of the foundations within a specific brand, ground truth data will be provided to the app for further mapping the user's skin color to a series of foundation codes as the closest color matches within 20 shades of L'OREAL True Match available for this study.

## 1.2 Objectives and research questions

Before getting started with the development phase, following the agile development principles, preliminary considerations were taken into account. Knowing the fact that environment's illumination largely affect the color perception of an object [12] [13]; approaching a mobile application to define one's skin color under any illumination was a major challenge being addressed in this study.

Mobile Media Devices (MMDs) of latest generations have previously been used for color measurement or color picking Based on previous studies evaluating color picking mobile applications; color calibration would compensate the color variations of a certain target while using different mobile cameras to some degree [14].

However, an optimum calibration for human skin color needed a reliable color reference accessible for user's. We proposed to use the L'OREAL True Match foundation containers, through which the color is visible, as the color reference. The container is a highly glossy bottle leading us to question the possibility of using these glossy bottles within our imaging system. As a result, the following research questions were progressively generated to study the above mentioned challenges:

RQ1: Can the foundation package itself-a glass jar through which the color of the foundation is clearly visible-be used as a reference for further calibration of the image under controlled circumstances (A standard illumination and a high quality imaging system)?

RQ2: Having a foundation bottle as calibration reference, Can using a mobile camera, under the same illumination lead us to reasonably consistent results for color calibration of the image?

RQ3:Having a foundation bottle as calibration reference, Can using one mobile camera in other locations with different illuminations provide us with consistent results for color calibration of the image?

## 1.3 Covered Scopes and contribution

This master thesis covers different phases of designing and implementing the proposed cosmetics color recommender mobile application following the Agile development principles, as listed below:



1. Customer needs analysis
2. System requirement studies
3. Feasibility studies
4. Designing and testing solutions to the main challenges (Illumination changes, finding an acceptable reference for calibration) with respect to the previous works for similar applications.
5. Involving users and their feedbacks through L'OREAL Marketing team in UK to adjust the solutions if needed.

#### **1.4 Thesis structure**

The structure of this Master thesis is planned in 7 chapters as follows:

1. Introduction: Providing a brief description about the Master thesis, Background and motivation of the project's Research questions being addresses and the planned contribution.
2. Background: Reviewing the relevant literature, giving preliminary background knowledge in advance to help the reader have a better understanding of some technical discussions covered in the later chapters.
3. Related works: Reviewing the previous works, and researches in the same area targeting similar problems, their methodologies and findings.
4. Choice of methods: This chapter justifies the decisions being made to approach the research questions for this study. A workflow of the whole development process is given as well as a general schema of the mobile app to be system.
5. Experimental setup and results: the practical experiments conducted for this study are explained. First an online survey to study the customers' needs and confirm the need for this project being worked on. Second, a colorimetric measurement performed on the foundations available for this study in order to obtain the ground-truth color data for the products. And third, four rounds of experiments conducted to study the research questions. Moreover the findings of the practical experiments are given for each section in numerical and graphical formats.
6. Discussion: This chapter discusses the findings as well as analyzing the probable reasons behind the given results.
7. Future opportunities: This chapter discusses possible directions to take in the future to improve the results of this Master thesis. Additionally, some ideas for incremental functionalities to the mobile app after the release are given.

## 2 Background

### 2.1 Colour and cosmetics

#### 2.1.1 History of colour and cosmetics

Colour is a highly valuable concept related to three different categories of human activities. First the aesthetic value relating to the visual quality of colour defined by different attributes such as tints (Lightness), shades (darkness), hues and tones. Second the economic value related to all sorts of investments on the production, circulation and application of dyes and pigments as well as producing coloured objects. And third the social, cultural and religious codes determining the value of colour by assigning different meanings and applications to certain colours.

Despite all the significant advances to the production process of colors; from the natural substances such as minerals, animals and plants, to the chemicals being harnessed in mid-19th century and forward, many applications have remained the same. For example, what we refer to as make-up today has been through a long way back in the history. [15]

The use of cosmetics historically goes back to almost 6000 years ago. Archaeological evidences exist from the ancient Greece and Egypt in particular confirming the background. However across the globe from Africa to middle east and the far east, Europe and America people have had been consuming cosmetic products over the years for different purposes. [16]

The Europeans approaching North America for in late 15th century could not help but notice the fashionably decorated bodies of the inhabitants of the New World; body painting was of great socio-cultural importance among them. [17] Same matter applied to the old world, referred to the modern Europe today; whitened faces and reddened cheeks and lips were commonly gained looks.

In North America, the inhabitants prepared colors with several herbs, minerals and the earth [18]. Blood roots were exploited for medicinal purposes worldwide to reduce swellings and aches as well as being mixed with oil for painting faces. Ochre on the other hand was more preferably used to provide a red hue on the skin.

Although the reddish painted bodies were strange to Europeans-the new comers- it was not entirely new to them. Throughout Europe, the period of time between the 16th and the 18th century has had been termed the transatlantic cosmetic encounter, the rise of painted faces by new pigments of a heated polemic, regarding the propriety of the painted faces. [15]

To wear or not to wear face paint was a widespread question to mostly women across Europe for centuries. Italy emerged as the center of face painting renaissance, leading to further adoption of Spain. By the early 17th century, the painted women and professional beauticians were known figures in various societies. Whitened faces later on emerged as a sin of aristocratic culture as well as a hallmark of court which thrived in France and all over Europe afterwards. The way paint was worn in court, as a thick layer of white colour to cover all signs of ageing and disease [15] ; could have had been a possible emerging point for the cosmetic application of paint to cover all

sorts of facial flaws.

In the early 90's, Eugene Schueller founded the French Harmless Hair colouring Co which later on expanded into what we know of L'OREAL today, one of the major leaders of the cosmetics industry. A few years later a German pharmacist, Paul Beiersdorf developed the very first cream binding oil and water which is now selling worldwide in over 150 countries as Nivea. But it was not until Elizabeth Arden followed by a polish immigrant founding the first beauty salons, when the definition of the cosmetics industry emerged into providing services outside home as well as just selling products. What they did was indeed a turning point by pulling out the household affairs to a new era. Slowly the cosmetics industry consisting of skin care, make-up, fragrances concatenated with consultations and services became a multi-billion dollar industry. [7]

"An industry driven by sexual instinct will always thrive [7]"

"The beauty industry" today involves billions of dollars considering the high standard requirements of mankind. This industry has evolved from the basic human needs to a largely potential business to provide more and more fancy products and services alongside the development of new technologies everyday. [7]

Now what can we do today to create another turning point?

"Tactics that help customers accomplish their tasks more effectively and provide personal recognition are the most effective in engendering customer loyalty" [19]

One of the key factors of success in every business is "customer satisfaction". Nowadays creative use of all the countless existing resources to provide personalized services, could be largely in favour of maximizing customers satisfaction and increasing the number of buyers.

'Personalization' refers to the act of employing technology to accommodate the differences between individuals. The concept has gained popularity over the years in different fields such as the world wide web, education, health care, Business to business (B2B), Business to Customer (B2C) services and above all the social network. [20]

Consumption of cosmetic products is no exception; as the exponentially growing market value of Cosmetics industry clearly confirms the urges to personalize one's look. [7]

Technology on the other hand has had been playing a major role in leading all kinds of industries and businesses over the past few decades. Therefore it would be highly beneficial to exploit the possible opportunities these new technologies can offer to address the problems customers might be facing or to provide services with higher quality and more precision than before. In other words, since the ultimate goal of every business is to sell more, why not consider an automated mobile advisory system namely a native mobile application accessible through the app store for everyday and everywhere use? The advantages of such system will further be discussed in later chapters.

### **2.1.2 What is foundation?**

In this section, a description of foundations as make-up products is provided.

In June 2006, Estee Lauder conducted a study engaging over 2500 women through the Oprah magazine [21] to find out the degree of difficulty for most women to choose the right foundation matching their skin colour. The result of the study stated that over 94% of women wear the wrong foundation as well as 70% claiming that they face difficulties finding their exact match [4].

Women spend significant amounts of money on cosmetics products everyday and all over the world; thus wearing the wrong foundation shade, more specifically a foundation that doesn't match their skin color, would be of high frustration. But why is it so hard to find the right match? To address this question, the following questions will be sequentially answered:

1. What is foundation? Why do women wear foundation? How does it differ from other make-up products?
2. How does the environment illumination interact with the colour of an object?
3. How does the human visual system work? How does the visual judgement of colours differ from person to person?

To begin with, why foundation products have been chosen as the core implementation of a make-up consultancy mobile application?

The Europeans approaching the North America for the first time in late 15th century were surprised by the decorated faces of the inhabitants of the newly found land. [15]

However in the modern world what we refer to as "Foundation" has evolved from a white substance to a liquid, creamy or powder substance made in different shades of human skin colour, which is applied on the skin aiming to give an even and uniform look to one's face. There are different characteristics defined for foundations which must be taken into consideration while choosing the right product.

- Colour classification: Many brands classify their foundations into three basic colour shades, warm, neutral and cool.
- Coverage: The degree of transparency, sequentially sheer is the most transparent of all, light, medium and full coverage which is produced to cover as much undesired skin characteristics as possible such as freckles, rashes, moles etc.
- Formulation: There has been various formulations of foundations being produced over the years; having improved step by step in order to match different skin types characteristics. such as oil-based, alcohol-based, powder-based, water-based, silicon-based and mineral products. [8]

Depending on one's specific skin attributes including dryness, oiliness, UV sensitivity, allergic reactions, desired coverage etc.. it makes it somehow easier to narrow down options while choosing the right product. However, there may be unwanted factor affecting the individual judgement of specifically the colour classification, making the process more complicated.

## 2.2 Colour imaging science

One of the core aspects of this project is the interaction of the colour science into the optimal use of colour information for a beauty advisory system. In this section a brief explanation of the basic knowledge needed in this area will be given.

It is hard to imagine life in no colours for those of us benefiting from a well-functioning visual system. But how does everything in this world appear in different colours has scientific explanation in physics and chemistry.

**Colour imaging science:** The study of formation, manipulation, display and evaluation of colour images through various input and output media devices such as Display monitors, scanners, cameras, printers, etc.. 'Formation' refers to the capturing and sensing process of recording an image, 'Display' of an image is achieved through various output media devices such as display monitors, photographic or half-toned prints etc.. The imaging chain completes from capturing to display, through 'manipulation' engaging image processing techniques such as degradation, correction, enhancement and compromise. [12]

Understanding the whole imaging pipeline can be difficult due to the diversity of engineering, optics, physics, chemistry and mathematics fields being involved. Thus in order to use an imaging system for a certain application a general competence over the above mentioned scientific fields would potentially suffice; however more in-depth knowledge will be studied for special cases depending on the project requirements.

**Light:** Since we are studying colour imaging process for the proposed application of this thesis, the first step is to define what exactly light is. Images are formed by the interaction of light and matter; therefore a camera tends to focus the spatial and spectral distribution of light on its sensors to record an image. Light, over the years has been one of the most significantly studied subjects in physics. Quantum Electrodynamics (QED) has a very broad definition of light and its behaviours interaction with matter; however this definition is very abstract and beyond our comprehension. That is why we only use the definition of light in accordance with the observable facts. Light is the visible range of electromagnetic waves, due to its wave nature we can conclude that it has temporal frequencies and can be described as periodic functions. Light also carries out energy, since we can feel the heat from sunlight once being absorbed. Light has a complex nature and QED theory is not often used where its not needed. Instead, for colour imaging that simpler behaviours of light are being under study, we can rely on geometrical and physical optics for more simplicity [12].

**Radiometry:** One very important factor to be studied in colour imaging science is to know how much light is available to our sensors. All imaging devices have limited range of operations to control the amount of light irradiating their sensors; which is vital to the quality of an image. Radiometry involves the study and measurement of the energy flow of light through different stages of forming an image. In this area, some basic concepts that we need to know in prior to our experiments are explained below. [12]

When light illuminates an object or a surface, it is partially reflected; a measure of how much a certain material reflects the incident light is called the reflectance factor of that object/surface which is calculated regardless of the angular distribution. Depending on an object's molecular behaviour and certain characteristics, the incident light can be diffusely or specularly reflected. The diffuse reflection refers to light being reflected from a broad range of angles [13] ; the specular reflection on the other hand refers to the light being reflected from the exact same angle as projected on the surface of an object. The reflectivity of a surface is introduced to define the characterization of a surface, given by the ratio of the reflected power over the incident power. [13]

Another event while interaction of light and matter, is the light being absorbed by the object and further transformed to another form of energy such as heat. Thirdly, the incident light may be partially transmitted through the surface of an object. The three mentioned events (Reflectance, Transmittance and absorption) factors relatively characterize the surface.

Another practice to be studied is the spectral radiometry. Each device/instrument responds to the input light as a function of wavelength, either spectral or frequency. Therefore, the measurement of light energy flow is quantified within small spectral wavelengths or frequency intervals. The resulting tends to be the same, but the adjective 'spectral' will be added to the measurements of light as a function of wavelengths within the visible spectrum [12].

**Photometry:** In radiometry light flux is measured in terms of power or energy; while in photometry we measure the visible light in terms of how effective it is to produce "brightness", an attribute of the Human Visual System (HVS) in which a source reflects or radiates light, in other words the luminance of a visual target. [22]

In photometric studies as an example we can calculate the reflected luminous flux from human skin under a certain lighting condition. These calculations will be operated with respect to a spectral response function system and a certain light source.

So far we have explained briefly about light and its interaction with matter, clarifying the fact that the colour of an object is proportional to the environment's light source under which an object is being observed or an image is being recorded. Light sources are categorized into two groups.

1. Natural sources: Sunlight/Skylight, Moonlight, starlight
2. Artificial sources: Incandescent lamps, Fluorescent lamps, electric flash lamps, mercury lamps, Light emitting diodes (LEDs) [12]

**Colorimetry:** Despite all the efforts being made in studying all the scientific fields related to colour, from physics, chemistry, optics, physiology and psychophysics to neural science and molecular biology of human colour vision; we are yet far away from an exact explanation of how it all works. The empirical rules experimented and made for the practical use of colour -even though imperfect- from the science of measuring colour is called colorimetry.

The basic measurement of a colour stimulus is its spectral power distribution as a function of wavelength or frequency. Photometry and colorimetry fields of science mainly tend to link objective physics and subjective perception, and moreover quantify the capacity of light stimuli producing colour in our visual or an imaging system.

In this study and this specific application of colour science, we are proposing a colorimetric measurement of different foundation products within a specific brand, in order to obtain ground truth data on the foundation colours. This data will be further used in calibration of the user's skin colour once an image is taken with the mobile application. The chosen measurement instrument and more details regarding the whole process of colorimetric

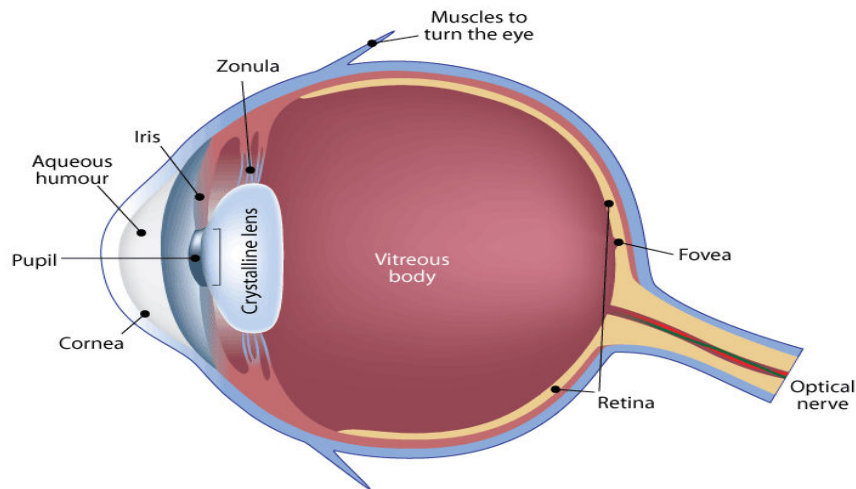


Figure 1: Cross section of human eyeball [1]

measurement will be given in the next chapter.

**The Human Visual System (HVS):** Vision is one of our five senses, helping us to collect and interpret information about our surroundings. The optic nerve plays a major role among our sensory functions by transmitting information from retina to the brain through approximately one million neural fibers. The auditory nerve consists of only 30,000 neural fibers so we clearly see the importance of the visual sense in our life.

So far we have devoted our description of light and colour, mostly to physical stimulus; however colour is not just physics, it is what we see and thus very important to describe how our visual system is functioning to gain a better understanding of the perception and interpretation of light into millions of different colours.

Light enters our visual system through the eyeballs. As illustrated in the cross sectioned figure of the human eye (figure 1), we can see that light enters through the pupil, passing by the crystalline lens hitting retina. Retina is a light sensitive layer at the back of the eye holding the receptor cells. In the middle of the retina there is a small spot called the 'fovea' which is responsible for the sharpness of vision and the location of most of the colour perception [23]. The receptor on retina consists of two types of cells, rods and cones named with respect to their shapes. Rods detect very small amounts of light such as starlight and can form grey images in our vision due to their sensitivity to light. Cone cells on the other hand have lower sensitivity to light and thus are able to send out neural signals to the brain which makes them our photoreceptors. Every morning, the grey world around us starts to look colourful slowly as the sun rises up. That is because our sensation of colour depends

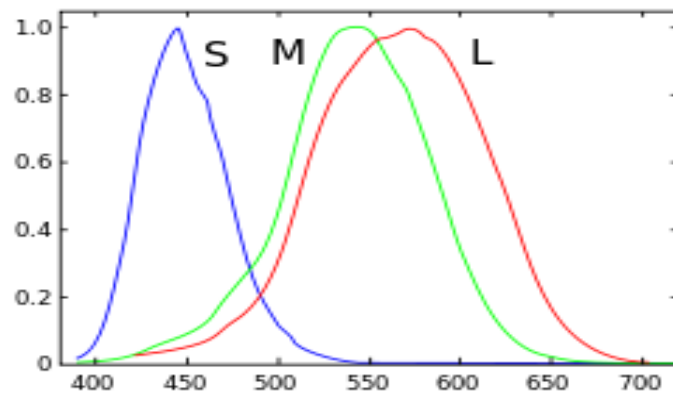


Figure 2: Cones' peak sensitivities [2]

on cone photoreceptors, requiring more amount of light to be able to respond. We have three types of cone cells, each of which having a different response to various wavelengths of light. The figure below illustrates cones and their peak sensitivities; represented with 'L', 'S' and 'M' letters. [13]

The overlap among the three receptors, allow the perceived signals produce about 150 colour hues; otherwise we would have been able to see only three hues in the spectrum.

Although a vision signal is entered into the HVS through the eyes; the main area responsible for interpretation of colours and dedicated to process the input signals (The visual cortex) is located on the back of the brain; hence the brain is mostly responsible for the interpretation of the input signal through the eyeballs and its association with a certain colour [12].

**Device calibration:** In previous decades, the consumers did not have to be involved with colour and light measurement during photography sessions, since everything from image capturing to producing colour prints of the image negatives were handled in conventional photography systems automatically. However, in digital imaging all devices (Scanners, printers, cameras etc...) are manufactured base on different principles. One very important consideration for consistently produce colour on a device or reproduce through various devices, is calibration [12].

By definition, calibration is to ensure that all the above mentioned devices work well together. More specifically, (The other books definition) [13].

By employing device calibration methods, we tend to calculate the true color values obtained from colorimetric measurement of a certain target, to those produced by the image acquisition device. In other words, calibration of a device is the process of adjusting an instrument such that its readings reproduce national or international scale. [13]

**Digital image acquisition:** Image acquisition devices are produced to simulate the process of



perception and interpretation of light within the human visual system. A digital camera pipeline will be described briefly here.

A camera basically consists of an optical system (lens), diaphragm and Aperture to limit the amount of light entering through the lens, light sensors and a series of image processing operations. This whole system is inspired by the human visual system attributes and is produced to simulate it as much as possible. However the camera responses differ from the HVS depending on its sensors, the ultimate goal over the years have been to improve these differences.

The digital camera works as follows:

First of all it has to focus on the target scene, then transmit the scene radiance-the reflected or emitted light from the scene-through the optical lens. A diaphragm is placed before the optical lens in order to limit the amount of irradiance -the amount of light hitting the camera sensors-. A diaphragm's structure is to open and close, having an aperture in the center. The size of aperture determines the amount of light entering through the diaphragm.

Most cameras contain a series of lenses elements within the optical part of the system. Each of these elements are designed and manufactured carefully to direct the entered rays of light through a path to gradually be able to reconstruct the acquired image as close to the real scene as possible. Next, in addition to the diaphragm, before the light sensors and after the optical lenses, a shutter is also placed to open and close by pre-defined time intervals, in order to limit the time period of irradiance. Finally, the directed light hits the camera sensors followed by a series of image processing operations to correct the possible physical errors during the acquisition process. Camera sensors as well as optical lenses, could vary significantly from one brand or model to another. As a result, the sensitivity curves are also different [24].

The raw sensor values representing the filtered colours are called the sensor colorspace. These are initially converted to a reference colorspace, usually CIE XYZ. From here, they are converted to a device colorspace such as sRGB. Somewhere in the pipeline the colors are adjusted based on the light source illuminating the scene. Where this is done as part of the XYZ transform it is called the coordinated color temperature (CCT). Where this is done in the rendered target RGB colorspace it is usually simply called white balance. CCT adjustments are based on the spectral content of a light source. These are defined as tables of chromaticity co-ordinates for standard illuminants. White balance adjustments are typically simple RGB scalars.

Combinations of colour matching algorithms and transforms employing matrix arithmetic determine the image colour values. A colour-matching algorithm will match three or more achromatic (single wavelength) luminescence values to three or more colorimetric values. These are called tristimulus values in CIE colour spaces such as (XYZ). They are usually called triplets in RGB or CMY colour spaces. Matrix transforms are also typically used to adjust colours for white balance or convert colours from one colour space to another [24].

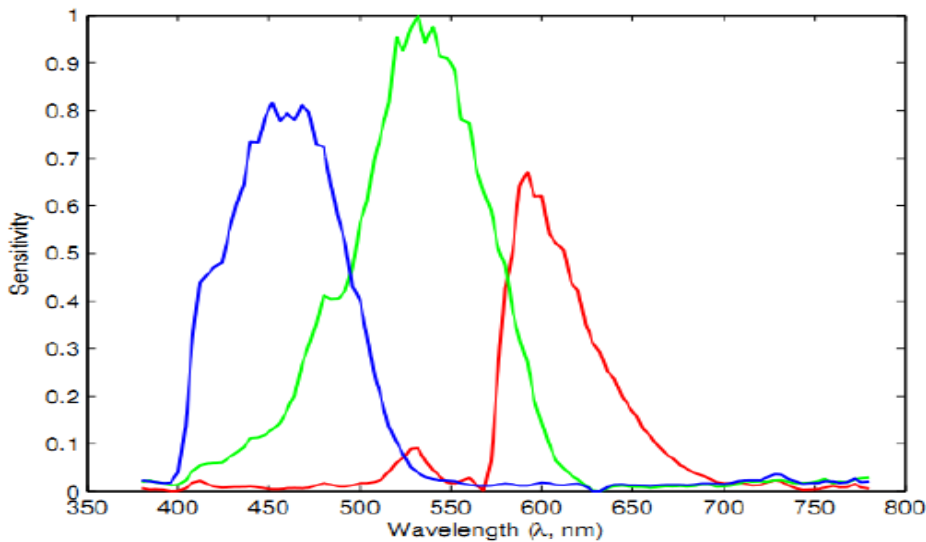


Figure 3: An example of camera sensors responses [3]

As explained before, for personalization purposes, we tend to use various materials and substances daily to give our living environment the desired look. For make-up purposes in particular, foundation products are the coloured substances specifically made to provide the range of colours associated with human skin.

### 2.3 Innovation, Technology, Adoption

Innovation by definition is an idea, practice or an object that is perceived as new. The degree of newness is not necessarily defined by the knowledge involved but a developed attitude toward using the existing knowledge and resources. [25]

Most of the new ideas being analysed today in terms of adoption are technological innovations and as a result the terms "innovation" and "technology" are being commonly used as synonyms [25].

Technology is often thought of as hardware, however it may be entirely referring to information and software. Some innovative products being released in the market are composed of both hardware and software, followed by the software technologies providing new services incrementally in the later phases of diffusion. [25] The process of an innovation being communicated and employed through different channels over time among members of a social system is called diffusion (diffusion of innovation). Diffusion is in other words a special type of communication in which the messages are linked to new ideas [25].

Now where are we standing in the diffusion cycle of the mobile applications diffusion? Who are we willing to target?

Based on Roger's diffusion of innovation theory, those adopting innovations in the early stages are called the innovators. On the contrary power users, are not necessarily the early adopters,

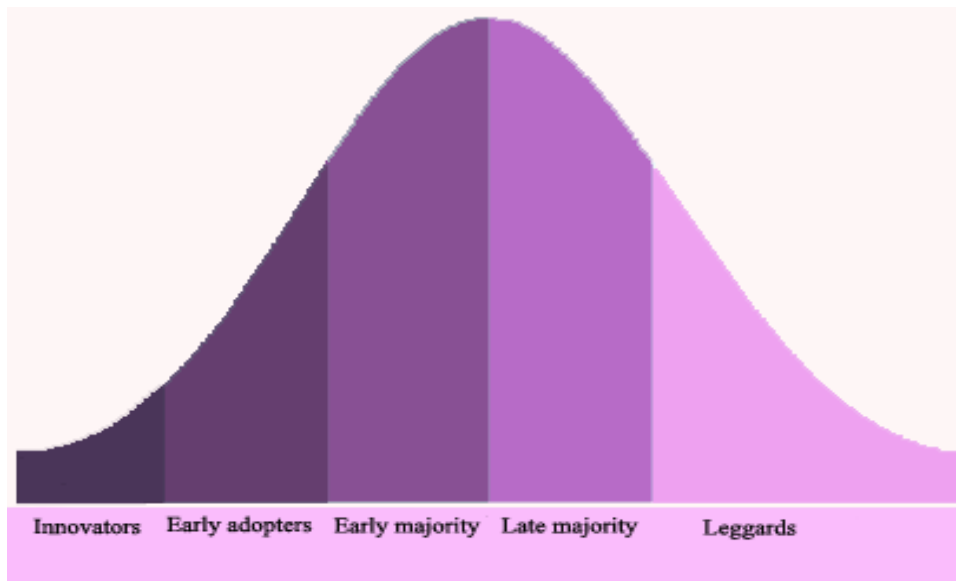


Figure 4: Rogers diffusion of innovation cycle

but those who employ all the existing features of their devices more effectively. A third group of adopters are called the heavy users who spend a considerable amount of time per day using their smartphones and tablets either for entertainment or other purposes.

A previous study on students of a large university in the United states in 2011 shows that among 497 participants, 98.3% use smartphones as well as 27.2% tablets. [26]

One obvious example over the past few years to be mentioned, the latest generation of MMDs (Mobile Media Devices), smartphones and tablets that have innovatively been made of the existing resources and technologies.

Now, as for the problem being addressed by this thesis (described earlier in the previous chapter), it would be favourable to study how MMD users, namely smartphones and tablets might respond to an innovative service developed to help them make a decision while purchasing foundation and possibly other cosmetic products. The idea proposed for this project is to combine what new mobile technologies, colour science and a leading Cosmetics corporation can offer to eventually reach the goal of providing foundation recommendation to the users.

Winston Cherrill argued that "we shape our buildings then they shape us". While the same thing is happening with technology [27]; we need to stand on a more positive point of view letting technology act in favour of our businesses by persuasively communicating with the power and heavy users community that is growing (Actor Network theory) every day.

## 2.4 Software development principles

In this Section the Agile software development with iterations is being described.

The term 'computer' today refers to a much wider range of devices than just a few decades ago. Alongside the smartphones, tablets and their outstanding computational capabilities being

introduced to the market, most businesses have been challenged by the need to develop new tools and applications in order to provide faster, more efficient and easier to use services to their users. However these tools and applications must also be following a series of standard methods in order to be developed.

A good software should deliver the required functionality and performance to the user and should also be maintainable, dependable and reliable [28] In order to develop a software with the explained attributes, it is essential to follow a standard software engineering discipline by means of which we can cover all aspects of software production. Desired software characteristics:

1. Maintainability: Software must be coded in a way that it can further be extended or changed according to new market and customers' needs.
2. Dependability and Reliability: Failure and risk handling in the system.
3. 3- Efficiency: Employing system resources in an efficient way to increase responsiveness and reduce processing time.
4. 4- Acceptability: Acceptable by targeted users that it's being designed for. [28]

Software engineering a systematic approach to production of a software that takes many factors into consideration such as practical costs, scheduling and dependability issues alongside both customers' and producers' needs.

However no universal software engineering method exists that applies to all kinds of systems; therefore depending on the organization developing it and all people involved in such system, the implementation of the existing principles dramatically vary.

The development method proposed in this project is the Agile software development which will be further explained in more details.

Why this method?

Due to a rapid growth of business environments, markets and economic conditions and all in all new opportunities being introduced by release of new products, devices and platforms (Porters five forces ) it is highly essential to develop softwares flexible to changes. In contrast to the older models such as the waterfall model (Explain later), the Agile model is based on iterative and incremental development where adaptive planning is promoted on one hand, and rapid flexible response to changes is encouraged on the other hand. [29]

Rapid software development processes are designed to produce useful software quickly. By using this method, software is not a single-unit product, but a series of increments, each of which including new functionalities.

Consequent to the rapid development, agile development methods were introduced in which small increments are typically developed and released. Meanwhile customers are involved through the whole process in order to get instant feedbacks. Agile methods have been very useful for certain types of systems; as an example, when a software company is developing a small or medium-sized product for sale.

Agile principles:

1. Customer involvement: Customers should be tightly involved to provide an prioritize new requirements, and additionally evaluate systems iterations.

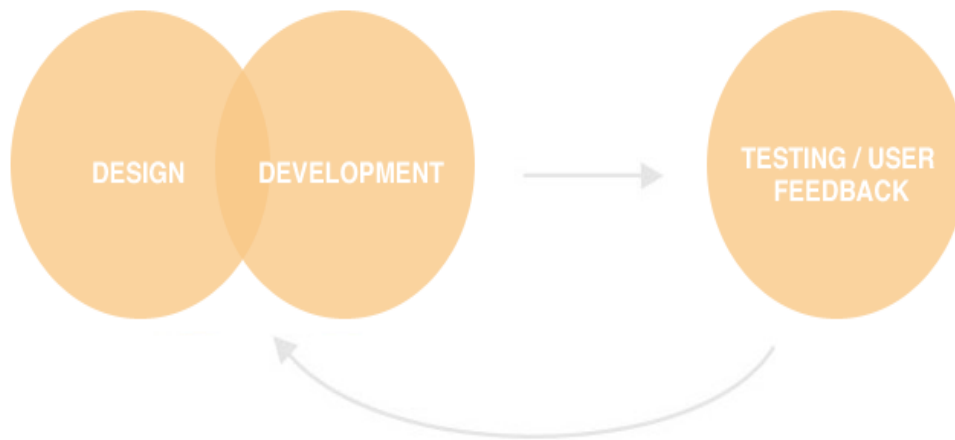


Figure 5: Agile software development with iterations

2. Incremental delivery: Having received the customers' feedback, increments are developed within not-so-long time intervals, based on the new user-defined requirements.
3. People, not processes: Developers should be allowed to use their skills openly to do their tasks their own way and without prescription.
4. Embrace change: System should be designed in a flexible manner to be able to adapt to the changes of all kind
5. Maintain simplicity: Simplicity as well as avoiding all sorts of complexities in the design and development phases would be highly in favour of the changing nature of such system [28].

### 3 Related works



Figure 6: The puzzle is solved/Photo: Alex Beauchesne [21]

A series of online or on-site consultancy services have had been provided conventionally by make-up experts. Some of the cosmetics brands have provided web-based applications to guide their users step by step to choose the right foundation for their skin tone, mainly relying on the user's personal knowledge of their skin characteristics, tones and undertones. Some professional beauty consultants on the other hand have made attempts to publish guidance on how to choose the right foundation. One of which to be mentioned, addressing a large community of women worldwide, has been the 'O' Magazine by Oprah, available both as paper-published version and online version on Oprah.com.

An article published on the 'O' magazine tried to point out the difficulties of finding the right foundation and gradually provides professional tips on how to choose the right shade. "Too much and you look like a clown. Too little and you look unpolished. Very tricky stuff, foundation! Here, answers to all your questions about choosing it, using it —but never abusing it— and looking naturally flawless." [21]

The main focus of this article is to help women get to know their skin characteristics and choose in between various types of foundation such as powder based, oil-based, minerals, etc; depending on the dryness, redness, desired coverage and so on. Same service has had been provided by a large number of beauty salons worldwide; nevertheless only a few scientific studies

have approached this issue, that will be explained in more details in this section.

Also in terms of scientific analysis of images, other attempt for different industries have been made such as recommendations systems for dental selection of a matching colour, which will also be further explained in this section.

### 3.1 An imaging based mobile cosmetics advisory

Studies have shown that women make 85-90% of the consumer buying decisions each year [7], both for traditional packaged goods and durable goods such as consumer electronics [7] [30]. Women are highly Influential on most purchase even if they are not directly responsible for making decisions in some cases [31]. studies on women's purchasing behaviour have also confirmed that women make decisions based on different criteria in terms of observation, discovery and values [30] [32].

There have been studies in 2008 and 2010, making similar efforts, focusing on the above mentioned observations and making attempts to provide mobile make-up consultancy systems for women in order to help them choose what exact foundation product to purchase. The reason that these studies have addressed foundations in particular, lies beneath the fact that foundations are hard to choose, which has been confirmed by surveying on women using make-up [31] [4]. These studies have reported the process of design, perception, adoption and usage of a mobile cosmetic advisory service, on the basis of the fact that women tend to use mobile camera much more often than men and are basically considered as the key mobile camera users [31]. The system has been design such that the user exploits the mobile camera they own, take a picture of themselves and send it via Multimedia Messaging Service (MMS) so a server by means of which the analysis is be performed and gradually the recommendations will be sent back to the user. These Colour Match services basically follow the workflow illustrated in the figure 7.

1. First the user takes a picture using a mobile camera while holding a colour chart specifically made for the picture calibration further.
2. due to intensive imaging technology computations needed for such advisory system, the taken image is send via Multimedia Messaging System (MMS) to an advisory service host at a back-end server, and leaves the tasks to be handled on the server side.
3. The server-side system uses colour science and image processing algorithms to calibrate the received image.
4. Computer vision algorithms have been implemented on the server side; in order to detect the face and the colour chart positions, moreover extract the skin area and the colour.
5. A set of filters are then applied to the extracted skin area, to eliminate the shiny and in shadow areas f the skin, to provide more accuracy of the obtained skin colour value.
6. Next having the true colour values of the chart and their extracted values from the image, a matrix is created from the differences between each colour within the image and the true value accordingly. This matrix is used for colour correction and calibration of the face skin colour, which has been taken under an unknown lighting condition.
7. Using an expert system and previously studied female subjects, the system locates an exem-

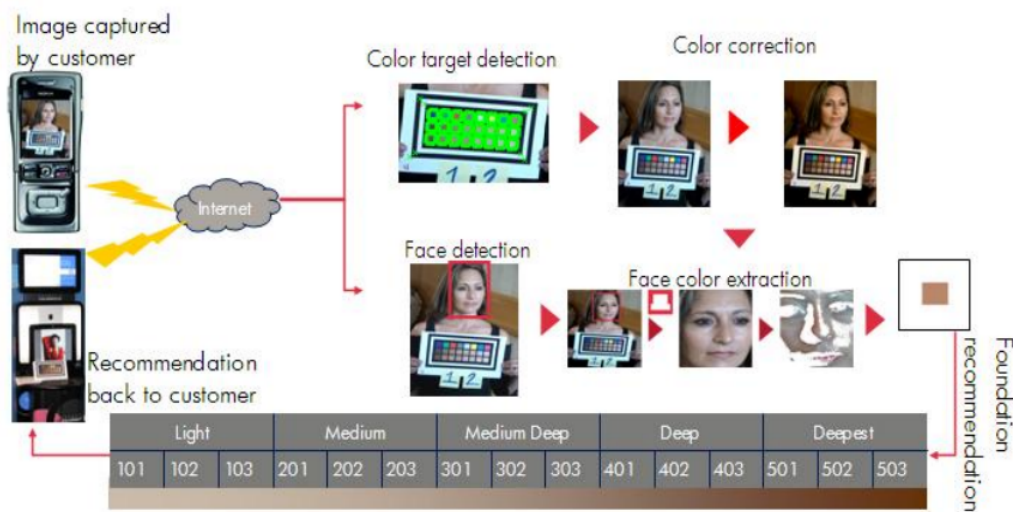


Figure 7: The color match mobile advisory workflow [4]

plar (studied female subjects) whose skin colour matches the test subject (user) acceptably; then employs statistical classifiers within a database of beauty experts' opinions on the exemplars.

The photo analysis described above, works regardless of the image quality, environmental illumination and camera specification, in just a few seconds. In addition, this system have provided comparable results as of those found between two different beauty experts under different lighting conditions, different consumer imaging devices and different cosmetics product lines. Therefore, it can be further modified and extended to contribution of other make-up brands and beauty advisers as the user prefers [33] [34].

In addition to the above mentioned mobile systems, a recently launched system by Boots company have tried to approach the same problem of foundation selection from a different angle. A small measurement device is made available in certain store; once the customers book an appointment from the consultants, the device is employed to measure their skin colour directly, to avoid environment illumination and other factors affecting the perceived colour of one's skin colour [5].





Figure 8: No7 Foundation Match maker device [5]

### 3.2 Artificial tooth colour recommender for dentistry

Other works have also been done following similar workflow to provide recommendations to users based on colour scientific analysis and image processing, however for other problems in dentistry. One example to be given here is an internship by a Master's student in Gjøvik University College attempting to provide suggestions to dentists, which exact artificial tooth colour would match a certain patient's dental colour. However, this project has not been implemented as a mobile service, but a professional imaging system as well as a software being developed for this purpose. A general schema is shown by Figure 9.

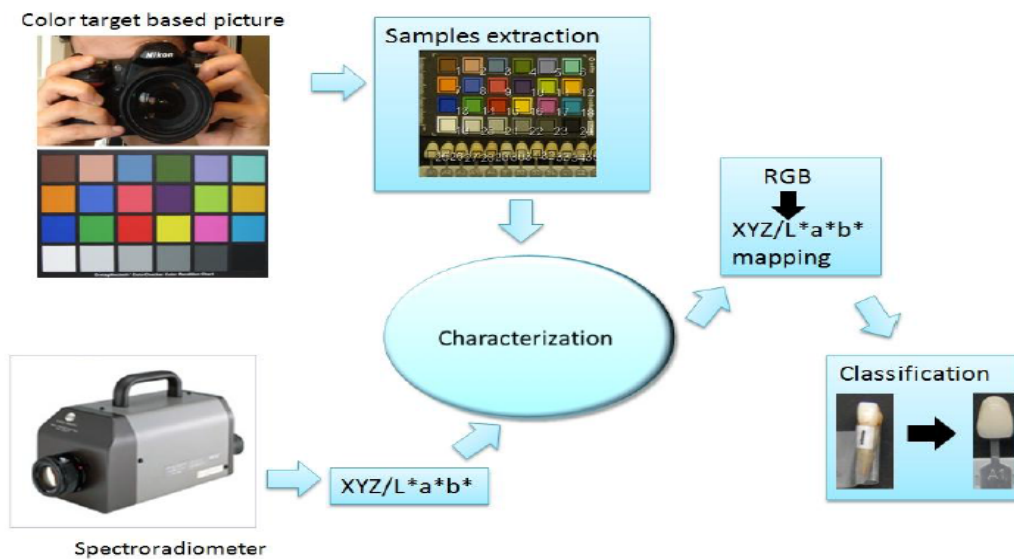


Figure 9: The color match mobile advisory workflow [3]

In dentistry, the process of selecting an artificial tooth colour for patients is most commonly performed visually by the dentist. Although a number of tools are available to assist the dentist, such as a VITA easyshade advance device or a simple fake gingival mask, still there is need for



(a) Dental gingival mask



(b) Vita easyshade advance

an inexpensive aiding application.

The implemented system uses a digital camera as the imaging system, a spectroradiometer a colour measurement instrument and a series of image processing tools to perform the characterization process. The Spectroradiometer is a measurement device that records the spectral radiance of a scene [13]. The recorded values for the artificial tooth samples provided for this study are used as the ground truth data, for further mapping the images taken from a patient's teeth colour to their real colour values.

CIEdeltaE has been used to calculate the total colour difference between samples in this study. Using an improved version of the Matlab code, fairly promising results have been reported.

### 3.3 Colour measurement using mobile phone camera

The world of digital media devices rapidly grow and thus, many real objects must be digitized for further manipulation by means of these devices. The digitization and manipulation of these objects is performed on different properties such as shape, density and colour [14]. One good example here area would be the digital imaging system, when a camera digitizes the input visual signal from a scene to record the colour and shape of the target scene. Later on, these recorded images can be used in various applications and purposes. Knowing that every digital device is able to produce a pre-defined colour gamut due to the design and manufacturing specifications; when various devices interact with each other, colour reproduction could be of a challenge. The colour gamuts producible through digital devices are not universal and we need methods to be able to manage these reproductions in a way that a deep red appearing on a display would not be printed out as brown. Colour management is basically concerned with the mentioned problems of this kind and focuses on the controlled conversion of color representations in between devices [35]. One way of dealing with these color variations on different media devices would be device calibration through colour measurement. The process of measuring and recording the spectral power distribution of the light emitted or reflected from an object, is colour measurement.

The most commonly used measurement devices are spectrophotometer devices, that tend to record the spectral power distribution of reflected light from a target surface/object. These devices, despite of being available worldwide, are quite expensive and not feasible to be used for small projects concerned with color management. Therefore, it would be of high assistance to

come up with innovative ways of creating possibilities through which, an easy to use imaging system such as a smartphone camera would be employed for colour measurement (color picking).

Modern mobile Media Devices (MMDs) including the latest generation of smartphones and tablets have a processing power much higher than computers had in 1961 for landing the first man on the moon [14] [36]. Inspired by these processing capabilities, a previous bachelor thesis have focused on this problem and developed a real-time mobile application using two different colour picking algorithms, thanks to the power of latest generations of smartphone processors, making this kind of applications feasible to be implemented. This application has been developed for Android system, tested and evaluated on different Android mobile phones with various camera resolutions.

	Camera sensors	Camera chip manufacturer
Sony Xperia S	12 mpx	Sony
Motorola Razr XT 910	8 mpx	Omnivision
Samsung Galaxy Tab 2 10.1	8 mpx	Samsung
Samsung Galaxy S 5.0	3.15 mpx	Samsung
HTC Flyer P512	5 mpx	Sony and Omnivision

Table 1: Specifications of the mobile phones being tested for colour measurement mobile application [14]

Due to some policies of most smartphones manufacturers some post image capturing processes are operated automatically such as white balancing and compression. As a result, what we have access to through the mobile device imaging system, is a JPEG file that is compressed and manipulated already. Fortunately, the image files colour data is stored in sRGB colorspace values, which is a standard RGB colorspace for displays, printers and online publishing [37].

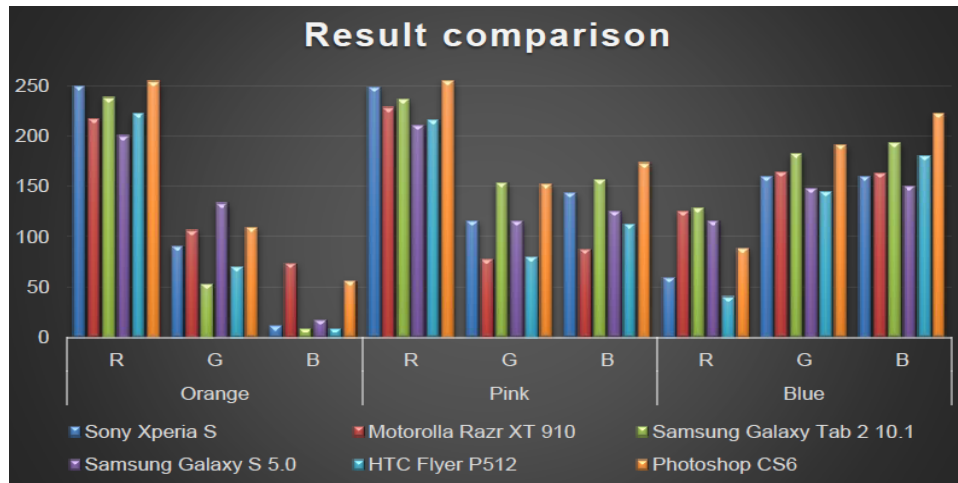


Figure 10: Results comparison among all the Android mobile phones being tested in this study, RGB values for three target colours are illustrated for each mobile phone separately [14]

Spectrophotometers are directly and very closely in contact with the object under colour measurement, while smartphones on the other hand are able to pick the colour of an object from a certain distance which results into a large impact of the environment's illumination on an object's colour representation. Consequently this study has come to the conclusion that colour calibration for different illuminations would be largely in favour of the measurement accuracy [14] .

## 4 Choice of methods

The choices of methods used throughout this study for a cosmetics colour recommender mobile application development is being justified and explained in this chapter.

One of the largest personal female consumers spending is the beauty industry of multi billion dollars. This industry includes, hair products, skin care products, colour make-up products, fragrances, cosmetic surgery, etc [38]. The growth of new technologies in mobile platform on the other hand clearly indicated the brilliance of bringing both areas to convergence and eventually providing beauty advisory services to increase the customer's satisfaction. Noteworthy to list the possible advantages our proposed idea, namely may have, over the previously developed systems for this kind of application.

- Using a printed colour chart for colour calibration, depends largely on the characteristics of the printing system and paper citeCheLee. Although we do not have any reference confirming the users' ranking of these systems, we know that the selected printing system's colour gamut, may potentially cause errors in reproduction of foundation true colours. In our proposed solution we tend to use a foundation package through which the foundation colour is visible, as the calibration colour reference in an attempt to compensate a custom-made foundation colour chart.
- The services implemented in a kiosk inside the store like the Boots foundation match maker, require the customers to book appointments from beauty advisers in-store. In addition, the Boots match maker system has not been launched worldwide, not to mention that even in the UK there is lack of this service in every Boots store according to our survey through L'OREAL Board of Beauty (BOB). On the contrary, a mobile application easily accessible, addressing a very large community of technology adopters.
- For the MMS-based mobile service, since all the data analysis is operated on the server side, data security concerns may be arisen for the customers before sending out their personal pictures.
- A mobile application's business model can be evaluated and confirmed based on the company's strategies, while using an MMS service obliges the customers to pay for MMS fees every time they use the service.

The main goal to this project is creating a recommendation system, providing users of the cosmetics industry with appropriate recommendations. Recommendation or recommender systems are a subclass of information filtering systems, that remove the unwanted or redundant information before presenting to the human user [39]. These systems tend to predict user's preferences or ratings on certain products and services, mainly for online retailers. Recommendation systems

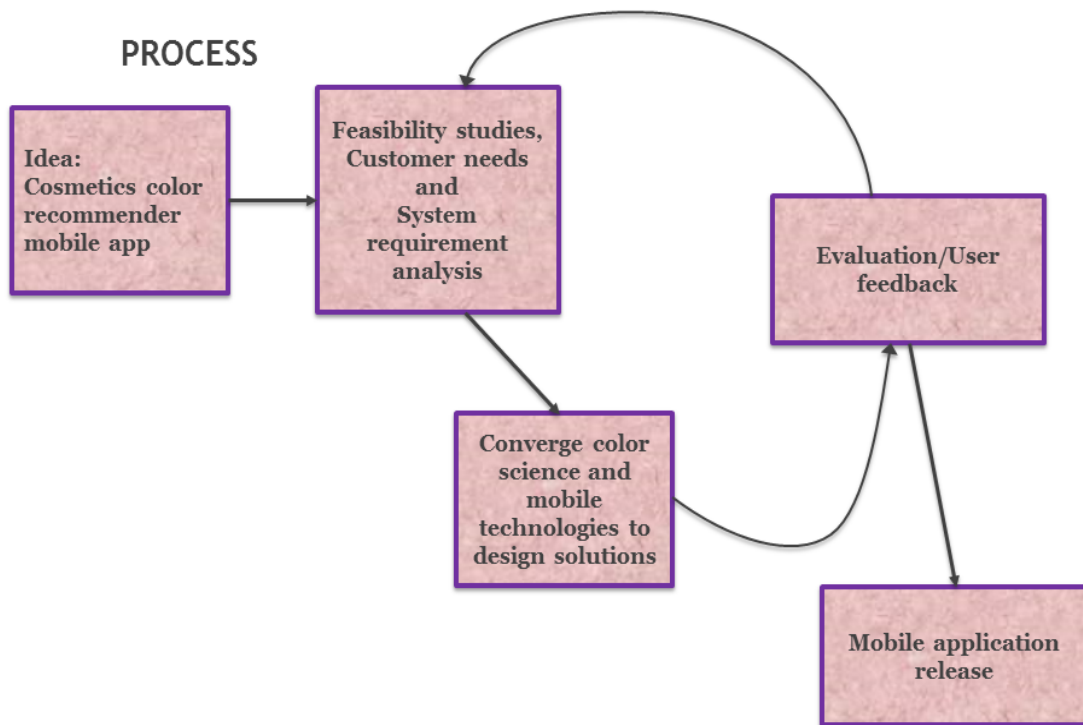


Figure 11: Mobile advisory system development workflow, with iterations

run different algorithms to approach the desired predictions, some of which to be mentioned are 'Collaborative filtering', 'Content-based filtering' and 'hybrid filtering'. These approaches use the similar user's behaviour, items' characteristics or both, to provide desirable recommendations for the customers. As an example, Netflix, one of the most popular media content providers online and the pioneers in employing recommender engines, gives their users suggestions on what movies they may also like, with respect to their own past selections, other users having watched the same content, or the same genre as their selection [40]. However, in our recommendation system, we tend to employ scientific analysis on the user's personal images and skin colour, to be able to provide precise suggestions on what foundation product to purchase. Therefore, a step by step series of ad-hoc experiments were conducted, in order to lead us to design an optimum solution for this application.

Before dealing with the design and implementation phases, we had to decide the development principles to be followed. As explained in Chapter 2 the agile development principles were introduced as a consequence of the need for rapid software development. According to this model, software is not a single unit product, but a series of incremental functionalities being added to the core software, once needed. A mobile application to provide beauty consultations lie within this category of products, and thus this method is hypothesized to work out for this project reasonably. For small to medium-sized software, Agile development has been very useful [28]; while new functionalities can be studied and added incrementally in the future. The main advantages of following the Agile development principles for throughout this project, include customers being tightly involved, incremental deliveries, Embrace changes within the mobile platform developments or customer needs, and finally maintain simplicity. This master thesis contributes to the following phases from the development cycle illustrated in Figure 11.

- Customer needs studies through surveying (user involvement).
- system requirements analysis and preparation.
- Feasibility studies
- Designing solutions
- Evaluation of the proposed solutions (involvement)

#### **4.1 Customer needs analysis**

First an idea was brought up, then the introduced possibilities were brainstormed in form of a project proposal for future business opportunities as the pre-project step. The idea, was to converge 'colour imaging science', 'Mobile Media device technologies' and definitely a potential cosmetics market; to provide professional consultancy based on scientific analysis on the cosmetic products. To do so, one of the largest Cosmetics companies was contacted in prior to the start of this thesis. L'OREAL Paris has been one of the leader companies providing high quality cosmetic products of all kinds worldwide, with an advert of "I trust science, not miracles".

Studies have confirmed the difficulties that most women face during choosing the right foundation colour for their skin tone [4]. To justify the persistence of this problem along with discov-

ering other issues, an online survey was conducted for this thesis. The goal was to collect data on colour cosmetics users' difficulties while choosing their desired colour. We intended to study what factors mainly result in undesirable purchases, what devices they own and their willingness degree of adopting digital assisting services.

We conducted an online survey to study the customer needs besides involving the users and their feedbacks from the initial phases. Over the past 25 years, surveying and questionnaire administration have been remarkably revolutionized by the online services made available for these purposes. About nearly a decade ago, in 2002, 500 million US-dollars were invested on online surveying in the United States; following a rapid growth since. A number of advantages have been introduced by online surveying techniques by simply involving the large community of Internet users all around the world [41]. Due to the shortage of time for this Master thesis, the online surveying has been chosen over one and one interviews and other customer study techniques for the following reasons:

- Global reach
- Flexibility (Time and Place)
- Speed and ease of data collection and analysis
- Technological innovations
- Questionnaire diversity
- Low administration costs
- Control of answer orders
- Convenience [41]

The test survey was sent for evaluation and edit to L'OREAL research department in UK as a part of contribution to this project. The feedbacks resulted into some changes in the survey before being published online. The marketing team with a remarkable background in customer studies for Cosmetics predicts and services in particular was indeed of great assistance in this phase.

## **4.2 System requirements**

After the customer needs studies, the system requirements were considered for this project. Our proposition is to design a mobile application, by means of which the users can take images of their faces under various illuminations, using their own Mobile Media Devices. As explained before in the Background chapter, colour is a sensation perceived by human visual system and interpreted by the brain, as a result of object and light interaction. Thus, the environmental illumination largely affect the perception of a certain object's colour. Same thing applies to the user's face skin, that gains different colours under different lighting conditions. This is why the selection of cosmetics products may end up in failure being chosen under a store's lighting, and gradually looking significantly different elsewhere. In order to overcome this issue, we intended



to collect a series of ground-truth colour data by performing a colorimetric measurement on 20 shades of foundation products, having been sent from the L'OREAL research department in UK, specifically for this study. These images are supposed to be calibrated based on a built-in ground-truth data to map the user's skin colour to a number of L'OREAL True Match foundation codes.

This ground truth data was a key component to the calibration problem. The L'OREAL True Match foundations available for this study were in liquid-based cream format. Due to a lack of colour measurement instrument for liquid materials, we designed an alternative to be able to employ a spectrophotometer for this purpose. More details are explained in the next chapter.

### **4.3 Feasibility studies**

The initial research question generated for this Master thesis has been inspired by the possibility of using the product package as a reference for colour calibration of the images taken by the Mobile application. The idea was to compensate the possible errors caused by the printing systems employed to create colour calibration charts for foundation products.

The first matter to study either or not we can substitute the foundation package itself for a printed colour chart of the foundations. At this stage, although we predicted that environmental illumination and the mobile camera characteristics are two key factors having a critical impact on the system results; we still do not have a clear vision of the starting point. Therefore, we started by creating a controlled situation to start with. The Norwegian colorlab environment with a standard D50 lighting was a reasonably good location as the controlled lighting environment. A camera with a higher quality than the best existing mobile main cameras was chosen as the imaging system to take the first round of experimental images. Also, a number of frequent foundation consumers having a fairly good judgement of foundation selection process were invited to participate to be able to provide a reasonable ranking of the recommendations we provided them with. The results obtained under in controlled situation confirmed the feasibility of using a foundation bottle as the colour reference.

Given the explained conditions and professional cosmetics consumers participation, we studied the first RQ, if using foundation bottles for colour calibration would be feasible at all. The results of the first experiment led us to progressively approach our research questions by changing only one variable at every step.

### **4.4 Designing solutions**

We conducted a series of experiments with respect to our three research questions to simulate the mobile application by stabilizing the variables and changing only one variable at a time for each round of experiments. The first experiment was conducted to determine if we can use the foundation bottles under a controlled lighting and using a high quality camera. Next, we aimed to assess the possibility of extending the same solution for mobile camera and other illuminations.

Consequently, the second and third rounds of practical experiments, with participation of the same expert foundation users took place to collect images under different illuminations, using different cameras. Furthermore, the analysis process on the colour data obtained from the experiments, as well as further calibration and colour difference calculations using the ground truth

data and CIE $\Delta$ E colour difference formula were operated in order to provide the foundation recommendations to the participants based on the minimum calculated colour difference between that certain participant's face skin colour and the 20 foundations true colour data existing.

After each round of experiments, the users were interviewed one by one, to test the recommended foundations and rank the usefulness on a scale of 0 to 10. This way we tended to study their degree of satisfaction with the recommendations, in a similar way that users rank mobile applications.

During the recent years, many studies have focused on skin colour detection in images and videos for various applications. Skin segmentation is commonly used for face detection [42], hand gesture analysis, objectionable image filtering and pedestrian tracking by means of hyperspectral imaging [43], etc. One of the approaches for skin segmentation is classifying the colour of pixels in skin or non-skin regions. The rationale behind this approach is the fact that human skin colour is highly consistent in terms of colour compared to most other objects within digital images and videos. In an attempt to provide skin colour pixel classification, many comparative studies have previously been reported; using different segmentation algorithms such as piecewise linear classification [44] [45], multilayer perceptron [46], Gaussian classification [47] [48], etc. However, regardless of the selected classification method, databases of human skin images as well as ground truth measurement data from the skin colour is needed in prior. Also, various colorspace representing the skin colour value have been assessed in these studies. By using many colorspace, it is confirmed that separating the luminance from the chrominance would be beneficial for skin colour analysis. As a result of this consistency in chromaticity, most of these studies have tried to focus on the changes of skin colour value under different illuminations, using colorspace such as YCbCr or CIElab that separate the luminance and chrominance channels. [49]

Consequently, in this study we also analysed our experimental data in different colorspace such as YCbCr a commonly used colorspace in imaging and video processing, which has a non-linear transformation from the RGB space, CIElab colorspace, with a highly non-linear transformation process from the RGB space and the RGB space itself, giving use the colour values recorded by the imaging system, in three different channels, Red, Green and Blue.

As shown in Figure13 the colour difference calculations are needed as a step of the application an user interaction cycle. Colour difference calculations have great potential in further research and improvement since their outcomes are far from ideal. Therefore we calculated the total colour difference in the CIElab space using the Euclidean distance formula, based on the fairly promising results of the similar attempts in dentistry (Explained in Chapter3).

Finally, after studying our research questions, we conducted a test experiment in the most complex situation possible. Based on our results, we tried to evaluate the proposed method by to simulating an easy-to-use mobile application. We assumed that the mobile that the user has access to only one foundation bottle as the minimum possibility; by holding the foundation close to the face, using two different mobile cameras available for this study, in three different and not distant locations making it convenient to participate.

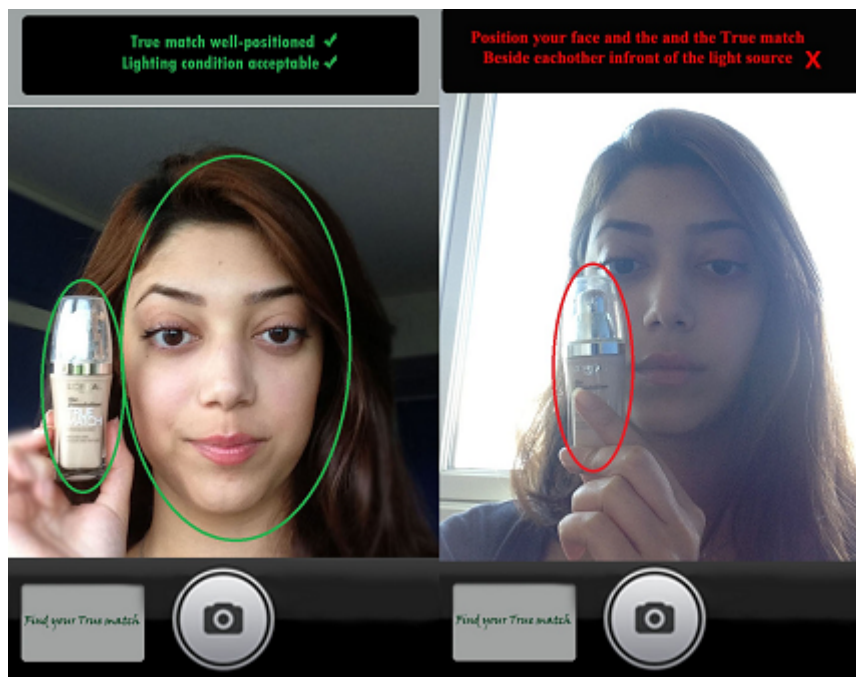


Figure 12: A hypothetical interface of the app giving a preview on how the finally developed app would be used

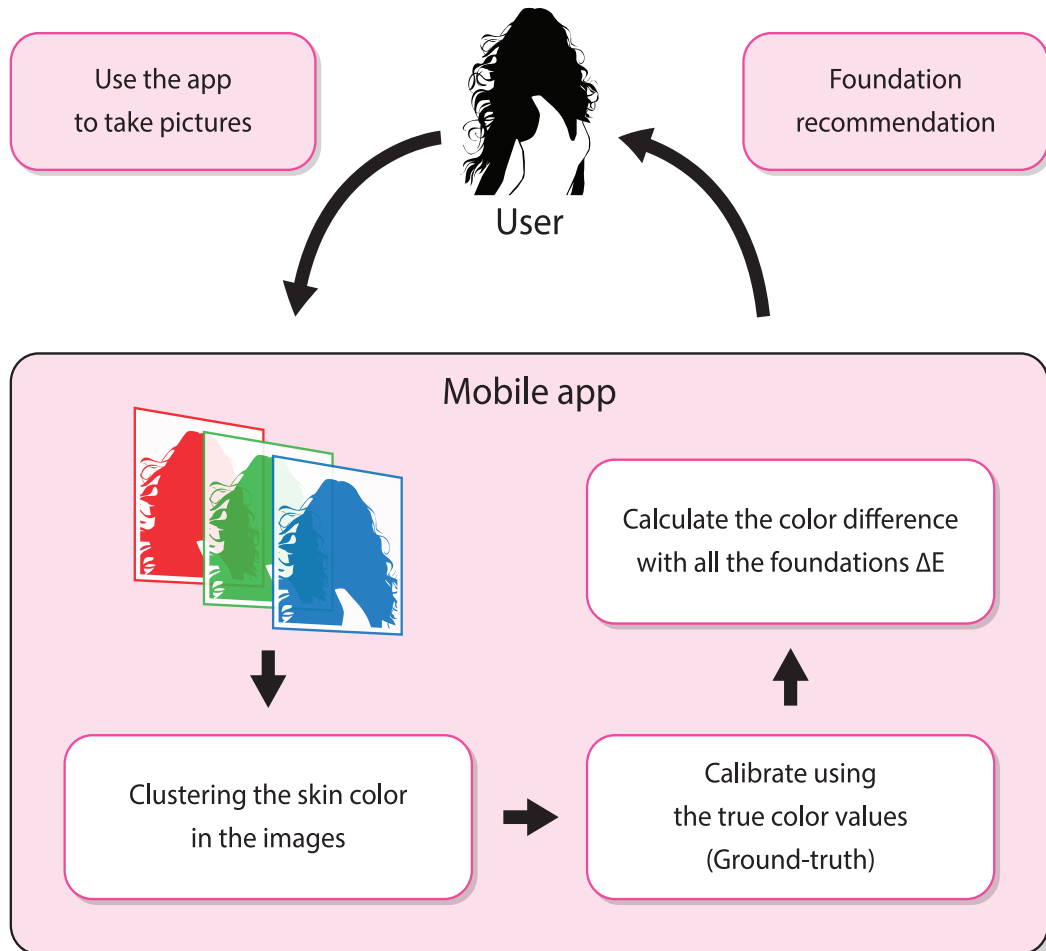


Figure 13: This figure illustrated a general schema of the user experience and a operational processes within the app. First the users take images of themselves, the colour data will be separated in different colour channels (if colorspace other than sRGB are used a colour conversion would be needed here) then by clustering methods the mode of the user's skin color pixels would be taken, next the obtained skin colour value would be calibrated using the ground truth data built-in the app and the colour reference used inside the image beside the face, finally by calculating the colour difference of the users' true skin colour and the foundations, foundation recommendations would be provided to the user.

## 5 Experimental setup and Results

### 5.1 Online survey

As a contribution to this project aimed for L'OREAL, a draft of the questionnaire was sent to their research department in UK, in order to be evaluated before going online. A test survey was made in advance, addressing two different areas. First to determine if color cosmetic users are still dealing with the foundation selection issues, since the last studies by Estée Lauder in 2006 confirming that over 94% of women wear the wrong shade [4]; second, to study the willingness of users to adopt new mobile technologies to receive beauty consultations. The survey was planned to be published on various social networks such as Facebook, Twitter, LinkedIn and Google+ to maintain rapid access through the first connections (friends), secondary friends of friends and so on.

The test survey was evaluated and edited by L'OREAL marketing team in mid-October 2013, due to an overly formal tone of speak, and was corrected into a friendly tone of speak, addressing a test group of about 1000 members of the L'OREAL Board Of Beauty (BOB). In addition, a few more options were added to the multiple choice questions making some of the answers more specific for further data processing. The final version of the questionnaire was conducted based on two areas of interest. First, to evaluate the needs of customers with respect to the difficulties they face while choosing their desired foundation product; and second, to evaluate their degree of willingness to adopt new technologies to assist them through their shopping experience.

As shown in Table 2, eight questions were generated for this purpose, five of which dealing with the participant's personal experience of selecting a foundation, and three others to collect quantitative data on what digital devices they possess.

168 women within the ages of 16 to 65+ participated in this survey during approximately 3 weeks. The results of question number 1 indicates that 86.31% prefer to purchase cosmetics products in-store with or without help from beauty advisor. Questions number 2 and 3 show that about 67.85% of the participants struggle with selecting the right format of the foundation, among all the existing product formats such as cream, liquid-based, powder etc. while 76.19% struggle with finding the right colour for their skin tone. Question number 4 has addressed the foundation tone of interest; 85.71% stated that they prefer to find their exact skin color match, while 13.69% try to look for slightly darker or lighter shades. Question number 5 confirmed the fact that foundation is a quite infrequently changed product, with 81.62% participants stating that they change their foundation less frequent than every 6 months.

The other three questions indicate that 80.36% of the participants have not previously experienced a digital device assisting them throughout their selection of foundation process, 64.88% are willing to receive such assistance, and 77.38% own a smartphone by means of which we are assuming a mobile application can be favourable.

The obtained results, however only among cosmetics consumers in one country (UK), still

1	How do you prefer to purchase foundation?	Percentage
	Online	6,55
	In-store (without help from others)	61,31
	In store (with help from beauty advisors)	25
2	Which of the following statements apply best to you?	
	I never struggle to find the right format of foundation	31,55
	I sometimes struggle to find the right format of foundation	55,95
	I always struggle to find the right format of foundation	11,9
3	Which of the following statements apply best to you?	
	I never struggle to find the right shade of foundation	23,21
	I sometimes struggle to find the right shade of foundation	58,33
	I always struggle to find the right shade of foundation	17,86
4	When selecting the colour of your foundation, what shade are you looking for?	
	Much darker than my natural skin tone	0
	A little darker than my natural skin tone	10,71
	As close as possible to my natural skin tone	85,71
	A little lighter than my natural skin tone	2,98
	Much lighter than my natural skin tone	0
5	How often do you change the foundation you use?	
	At least every month	2,98
	At least every 3 months	14,88
	At least every 6 months	27,38
	At least once a year	17,86
	Less than once a year	22,62
	Never	13,69
6	Have you ever used a digital device to help you find your foundation?	
	Yes	19,05
	No	80,36
7	Would you like to have a digital device to help you find your foundation?	
	Yes	64,88
	No	34,52
8	Which of the following devices do you own?	
	Computer	50,6
	Laptop	83,93
	Android Smartphone	45,83
	iPhone Smartphone	22,62
	Other Smartphone	8,93

Table 2: Mobile application poll results from L'OREAL Board Of Beauty(BOB), (n=168)

emphasize the need for professional consultancy with or without a digital device. The problem of foundation selection still persists since the previous studies in 2006 and 2010 [4], and considering the high percentage of women among all ages own a smartphone or tablet, we decided to approach a mobile beauty consultancy system.

## 5.2 Colorimetric measurement

In this section, the process of obtaining the ground truth colour data is explained by performing an instrumental colorimetric measurement, using the Xrite SP64 Portable Sphere Spectrophotometer available at the Norwegian colour and visual computing laboratory.

The Norwegian Colour and Visual Computing Laboratory at Gjøvik University College was founded in the spring of 2001, under the name The Norwegian Colour Research Laboratory, with the vision to study colour as a light signal, to be captured and reproduced, without isolating it from its traditional context. It was at the time serving the rising needs for colour management solutions in the graphic arts industry [50]. However, various measurement instruments also have been made available over the years which makes it possible to choose the device meeting our needs most.

Before performing the measurement, it is important to consider the basic principles of measuring colour. First define the purpose of measurement, so that we can choose the right type of measurement tool. And second, make sure that the sample to be examined truly represents the material being studied [13].

Twenty shades of liquid-based foundations, packaged in a transparent glass bottle/jar were made available for this study by L'OREAL research department in United Kingdom.

We faced two major obstacles while performing a colorimetric measurement on the L'OREAL True Match foundations. First, a lack of measurement instrument for liquid substances in the Norwegian Colour and Visual Computing Laboratory; therefore, we generated an alternative for this specific time-limited measurement process. In order to compensate this lack of instrument, the steps listed below were followed:

1. First of all a reasonably thick, white and lowly textured cardboard was attached to another cardboard of the same characteristics, but black. We used this custom-made cardboard as a palette to apply the liquid foundations on. The black layer is aimed to prevent as much light transmission through the underlying surface as possible.
2. Second, in order to avoid the whiteness of the palette affecting the colour of the foundation patch being measured further, layers of foundation were applied on the same patch carefully and uniformly. This process was repeated multiple times in order to provide a very thick colour patch representing the true colour of each foundation excluding the underlying cardboards.
3. Next, to level out the final layer and avoid as much texture as possible more care needed to be taken. Therefore, a soft and highly glossy cardboard was employed to create a uniform layer on top, providing a reasonably valid colour patch to be measured.
4. Next, the foundation palette was left for a few hours to be dried out, in an isolated/dust free and dark place by using a plastic cover in the Norwegian Colour Laboratory which is situated



Figure 14: The test foundations colour chart for further colorimetric measurement

in the basement of GUC's IT department, to avoid sunlight incidence for certain applications.

Noteworthy to mention that a few attempts led to failure while applying a liquid foundation on the palette. As an example, fingerprints had to be avoided strictly, therefore a plastic glove was first used and next a knife-like metal tool; both of which were not providing an acceptably uniform colour patch as well as a glossy and nearly ideal texture-free cardboard. The glossy soft cardboard was the best way to smooth out the final layer.

Second obstacle affecting the colorimetric measurement, was the shiny and glittery effect of the foundations once being applied on a surface. During the preparation of the foundations' color palette, we noticed a shiny and glittery effect within the foundation colours. For example the C series (from C1 to C7) had a glittery pink undertone while the N series had a gold undertone. This could cause different colour perceptions through different viewing angles. Therefore, we decided to record all the diffuse and specular reflectance of each colour patch using the SP64 Spectrophotometer, to study how deviated the diffuse and specular reflections would be and furthermore obtain the ground truth colour data representing each foundation.

The SP64 Portable Sphere Spectrophotometer is a versatile instrument designed to provide fast, precise colour measurement information on a wide range of materials, such as paper, paint, plastics, and textiles. The instrument allows you to choose among a number of the viewing conditions such as Illumination, viewing angel and spectral range. In addition, this device allows you to perform the spectral measurement including and excluding the specular reflectance of the target surface. [6] The Xrite Sp64 is able to record the diffuse reflectance of a surface including





Figure 15: The Xrite SP64 Portable Sphere Spectrophotometer [6]

and excluding the specular reflectance.

After getting the colour samples ready for measurement, the measurement device was subjected to calibration as a prior step. It is turned on and left for a sufficient period of time (about a few minutes) to be warmed up. Then measurements of standard white and black patches specifically provided for this purpose by the device producer is operated.

Once the instrument was calibrated, it was carefully placed on a uniform patch of the colour sample. The measurement instrument was then kept in a fixed spatial and angular positioning while the measurement was taking place.

When a sample's colour is determined based on an instrumental measurement, the reported value has uncertainty associated with it. Standard error is intended to be minimized by increasing the number of measurements. The Xrite SP64 performs the measurement of each colour patch for three times.

The Xrite SP64 records color data numerically within the chosen colorspace and viewing angle. For this study the CIE1976 standard observer, 10 degrees viewing angle  $L^*a^*b^*$  colorspace was chosen. The Lab colorspace is a device independent colorspace which tends to mimic the non-linearities of the human visual system perception. The color gamut also includes both RGB and CMYK gamuts [?].

The measurement performed as explained, provided us with diffuse reflectance within the selected colorspace, while the specular reflectance were a function of wavelength from 400-700 nm; therefore in order to obtain the specular tristimulus values a series of simple calculations were followed with respect to the formula below [13]:

$$X = K \sum_{\lambda} S_{\lambda} R_{\lambda} \bar{x}_{\lambda} \quad (5.1)$$

$$Y = K \sum_{\lambda} S_{\lambda} R_{\lambda} \bar{y}_{\lambda} \quad (5.2)$$

$$Z = K \sum_{\lambda} S_{\lambda} R_{\lambda} \bar{z}_{\lambda} \quad (5.3)$$

Where S is the Illuminant power, R the spectral reflectance of the object being measured, x,y,z the CIE matching functions and K the normalizing factor.

In 1920, two experiments were performed in England, on a small number of observers having a normal colour vision. Both experiments were performed within the same viewing conditions, 2 degree viewing angle of the target surrounded by darkness. In 1931 the Colorimetry Committee of CIE standard observer was performed using only the fovea, which covers 2 degrees angle of vision. However there are applications in which the stimuli subtend a much larger viewing angle. Consequently, 10 degrees standard observer was studied which clearly has a firmer statistical foundation being based on many more observers. It is often believed that the 10 degree observer correlates much more with visual evaluations when judging the colour difference [13].

The CIE matching functions of the 10 degree viewing angle, namely CIE 1964 standard observer, is tabulated in Table 3. The D50 standard Illumination(daylight) spectral power as well as one example of the measure specular reflectance are also given in 10 nm intervals, accordingly.

As explained in Chapter 2, light can be defined as the radiant electromagnetic energy that is visible wither to our visual system, the image capturing device or measurement instrument of interest [12]. The electromagnetic spectrum that is visible to us is from 360 to 830 nanometres wavelengths (Ranges vary for different species). Nevertheless, above 700 nm and below 400 nm must carry a high radiant power in order to be visible for us and as a result the spectral reflectance recorded by the SP64 Spectrophotometer available at the Norwegian Colour and Visual Computing Laboratory are being recorded from 400-700 nm range. All the other functions needed for our calculations were within the same range accordingly.

The spectrophotometer operates measurements for several times on the same colour patch in order to avoid as much error as possible. For each measurement, the XYZ tristimulus values are calculated using the 3.1-3.3 formulas. A mean color value is then calculated among the XYZ values for each one foundation colour. Next, a colorspace conversion is needed to take the XYZ colour values to CIElab values in order to be comparable to those of the diffuse reflectance. The Xrite SP64 directly provides us with lab values of the diffuse reflectance of the colour patch being measured.

The XYZ values have been calculated (formulas 3.1-3.3) in Microsoft Excel spreadsheet which is easily transferable to Matlab environment. Despite the fact that this mobile application is intended to be developed for Android systems, the testing of the solutions are programmed in Matlab due to the diversity of image processing functions Matlab provides us with.

Matlab Image Processing Toolbox™ contains a comprehensive set of reference-standard algorithms, functions, and apps for image processing, analysis, visualization, and algorithm development. You can perform image enhancement, image de-blurring, feature detection, noise re-

Table 3: The CIE matching functions for 10 degree observer and D50 light, selected for this colorimetric process

nm	R	D50	x	y	z
400	10,99	49,31	0,0192	0,002	0,086
410	11,1	56,51	0,0847	0,0088	0,3894
420	11,24	60,03	0,2045	0,0214	0,9725
430	11,52	57,82	0,3147	0,0387	1,5535
440	12,07	74,82	0,3837	0,0621	1,9673
450	12,57	87,25	0,3707	0,0895	1,9948
460	12,74	90,61	0,3023	0,1282	1,7454
470	12,77	91,37	0,1956	0,1852	1,3176
480	12,86	95,11	0,0805	0,2536	0,7721
490	13,2	91,96	0,0162	0,3391	0,4153
500	13,79	95,72	0,0038	0,4608	0,2185
510	14,62	96,61	0,0375	0,6067	0,112
520	15,68	97,13	0,1177	0,7618	0,0607
530	16,83	102,1	0,2365	0,8752	0,0305
540	18,38	100,75	0,3768	0,962	0,0137
550	19,95	102,32	0,5298	0,9918	0,004
560	22,46	100	0,7052	0,9973	0,0011
570	25,53	97,74	0,8787	0,9556	0
580	28,72	98,92	1,0142	0,8689	0
590	30,97	93,5	1,1185	0,7774	0
600	32,41	97,69	1,124	0,6583	0
610	32,92	99,27	1,0305	0,528	0
620	33,17	99,04	0,8563	0,3981	0
630	33,31	95,72	0,6475	0,2835	0
640	33,4	98,86	0,4316	0,1798	0
650	33,49	95,67	0,2683	0,1076	0
660	33,71	98,19	0,1526	0,0603	0
670	33,94	103	0,0813	0,0318	0
680	34,32	99,13	0,0409	0,0159	0
690	34,73	87,38	0,0199	0,0077	0
700	34,97	91,6	0,0096	0,0037	0

duction, image segmentation, geometric transformations, and image registration. Many toolbox functions are multi threaded to take advantage of multicore and multiprocessor computers. In addition to supporting a large number of image formats, there are algorithms by means of which you can restore degraded images, detect features, analyze shapes etc [51].

Using Matlab colorspace conversion functions, we took our XYZ values to the CIElab colorspace. The shiny and glittery effect of the foundations once being applied on a surface, however slight, brought up concerns regarding the reliability of performing measurements using a spectrophotometer, due to possible changes of colour perception within different viewing angles. Hence we calculated the total Colour Difference of the Mean between the recorded colour values from the diffuse reflectance of the foundations, and the specular reflectance. Some other researches in the norwegian colour Laboratory by PhD fellows have also focused on colour measurement of glittery product packages. Therefore we were advised for our application, to approach the measurement using the Xrite SP64 spectrophotometer, recording the colour values including and excluding the specular reflectance. This way we studied the degree of glossiness and shininess of the samples being measured. Luckily, the calculated colour difference turned out to be a reasonably small value, the Mean colour difference of the Mean (MCDM) was a possible representation the foundation colour, as the ground truth.

Table4 shows the measured ground truth colour data for each of the foundations. All the 20 shades available for this study are listed with the relevant codes on the left column while the 'true colour' values are shown in three differer colour spaces. The obtained results led us to the conclusion that the Luminance and chrominance values for the foundations, vary in the same manner as human skin. More specifically, studies have shown that human skin colour varies within the Luminance channel more significantly than the chrominance channels. Subsequently, for each colour channel, the standard deviation(SD) was calculated among all the 20 shades. The higher the SD, the more variations of skin colour within that channel. Table5 shows the SD values per channel, confirming that the L and Y channels have a higher Standard deviation. Thus, it would be beneficial to analyse all the further experiments in Luminance/Chrominance colorspace.

### 5.3 Experiment1

We explained in the second chapter, that an object's colour is dependent on the environment's illumination [12]. Human skin colour unexceptionally, is largely affected by the lighting conditions, thus the true colour can be only obtained by calibration. Also a previously developed and tested mobile colour picker (measurement) application has confirmed that more precise results are obtainable through colour calibration [14]. If we have the true colour of one foundation, we can calculate the vector taking the true colour value to the recorded value of that certain foundation by the camera. Using this vector, we can calibrate the user's skin colour and obtain the true skin colour which will further be used in colour difference calculations that leads us to a series of foundation recommendations, based on the assumption that the lower the colour difference between a skin colour and a foundation colour is, the more appropriate that foundation would look being applied on the face.

The motivation behind our research questions was to examine the feasibility of developing a

Table 4: Foundations true colour values, represented in three colorspace, RGB, CIElab and YCbCr, to give an insight into the variations of chromaticity and Luminance channels

	L	a	b	R	G	B	Y	Cb	Cr
C7	55,3659	20,92994	16,70891	111	46	36	55,2808	-13,5247	29,76525
C5	58,77351	16,02362	20,55475	116	57	37	62,20807	-17,0275	27,84424
R3C3	61,69765	14,18899	18,61835	123	66	45	69,326	-17,1703	27,03723
R2C2	63,72174	14,53658	20,53317	134	71	47	74,86713	-19,3773	29,88681
R1C1	69,87249	14,15828	17,91202	159	91	66	93,22964	-20,5576	32,15431
N8	42,19488	14,4888	20,45733	59	26	14	29,6913	-9,66	15,85321
N7	58,48778	13,54488	19,22026	109	58	38	61,01259	-15,8418	24,33051
N6.5	54,49594	18,23535	26,99064	107	46	23	52,98087	-18,6416	28,93695
N6	57,1818	16,09367	22,79984	111	53	31	58,32018	-17,7577	27,54787
N5	59,8124	14,92449	19,93181	118	61	40	65,03189	-17,1703	27,03723
N4	57,30634	16,68318	24,8045	114	53	29	58,89473	-19,0809	29,00838
N3	64,15401	14,91756	22,42613	138	72	45	76,2026	-21,1396	31,41874
N1	73,19216	14,38964	22,58368	181	101	66	103,9203	-26,7285	38,13918
D8W8	51,40754	14,77075	21,15682	87	42	24	45,9265	-14,074	21,55236
D7W7	54,36112	16,32077	22,33159	101	47	27	52,3359	-16,2864	25,64816
D5W5	58,90892	15,72036	19,74109	116	58	38	62,81011	-16,8793	27,40502
D4W4	60,24789	15,41647	25,66164	124	61	33	65,88727	-21,1342	30,17252
D3W3	62,59872	13,96665	22,73477	129	68	41	71,48337	-20,3985	29,22266
D2W2	69,47339	13,45966	27,9077	164	89	48	91,74302	-28,6226	36,37166
D1W1	71,08087	15,42007	26,52408	176	93	54	97,42843	-28,93	39,74253

	L	a	b	Y	Cb	Cr
SD	7,321663	1,744256	3,111373	18,30311	4,813172	5,364913

Table 5: Standard deviations per channel, for CIElab and YCbCr colorspace within 20 shades of foundations; confirming that the L channel as Lightness, and Y channel as Luminance have higher deviations from the mean value. This means that the foundations' darkness/lightness vary more than the chromaticity. Therefore, we decided to convert all our further experimental image data into one of these colorspace, for a better understanding of foundation and skin colour variations under different illuminations and using different cameras.

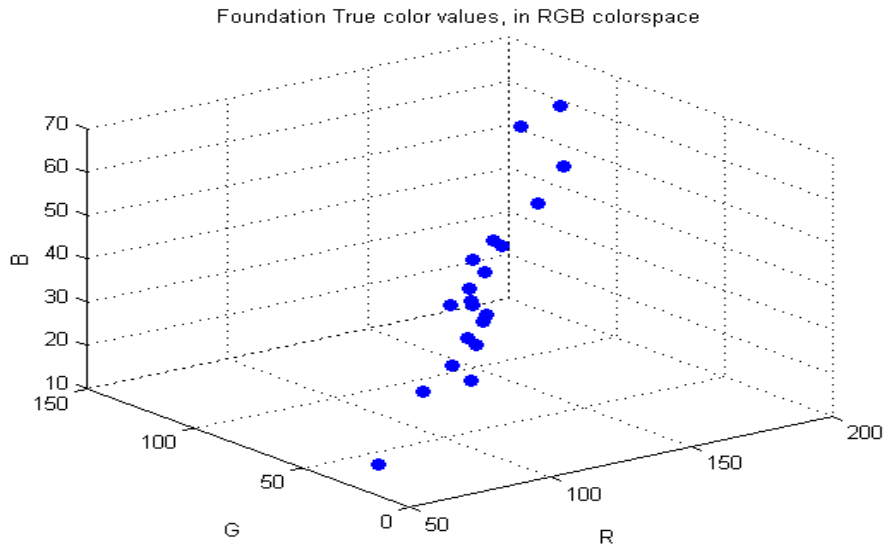


Figure 16: 3D illustration of all the 20 shades of Foundations in RGB space; the color ranges within R (50-200) and G (0-150) channels are more than the B (10-70) channel, however still not dramatically different.

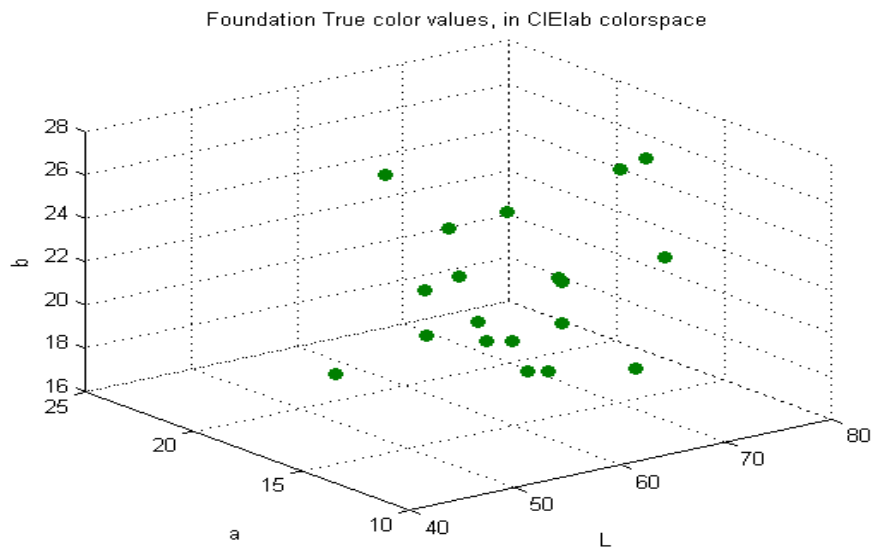


Figure 17: 3D illustration of all the 20 shades of Foundations in CIElab colorspace; the color ranges within L (40-80) channel is more than the a (10-25) and b (25-28) channel, showing that the lightness and darkness of these color values are more critical for further analysis.

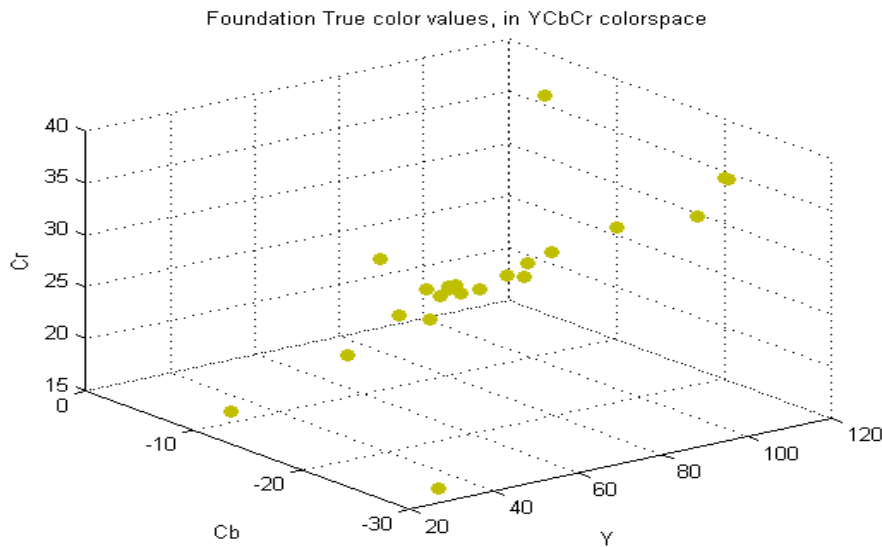


Figure 18: 3D illustration of all the 20 shades of Foundations in YCbCr colorspace; the colour ranges within Y (20-120) channel is more than the Cb (-30-0) and Cr (0-40) channel.

mobile application that uses the device's imaging system as measurement tool. In addition, by taking images in any location using any type of camera, and using a foundation bottle itself as calibration reference; provides us with promising cosmetics colour recommendations. The most complex scenario would be using a low quality front-facing mobile application, under an uncontrolled lighting condition, holding only one foundation bottle as colour reference. However, we took the most obvious factors influencing the final results into account before conducting the experiments.

The experiments were conducted progressively to cope with our research questions. First of all, we needed to confirm the possibility of using the foundation bottles through which the colour is visible, as the colour reference, in substitution for the previously proposed colour charts. To do so, we built up a controlled experimental environment inside the colorlab, under standard D50 illumination (An approximation of daylight). Other considerations were also taken into account, such as the camera quality and number of foundations available in the experimental images.

A number of frequent foundation consumers were invited to take part in this experiment after being given an information sheet providing them with a brief description of the study, security of the taken images etc.

1. Each participant was asked to visually assess the 20 foundation shades available, or test on the skin if needed, in order to make a few choices as if they were about to purchase.
2. A series of images were taken from nude face skins (women with no make-up product applied to their faces) besides the foundation bottle being used as colour reference for further calibration.

3. The face skin sample was selected representing the user's skin colour value.
4. The vector taking the ground truth foundation colour to its color appearance was calculated, within the experimental images.
5. The skin colour was calibrated, using the above explained vector.
6. The colour difference values were calculated between each foundation true colour value and the calibrated skin colour.

We calculated the difference vector between the true colour of the foundation and the recorded value by the camera formula (5.4-5.6). Furthermore, using this one vector, we first calibrated the user's skin colour, then calculated the colour difference values for each foundation available for this study and the user's skin colour 13.

$$\Delta L = L_2 - L_1 \quad (5.4)$$

$$\Delta a = a_2 - a_1 \quad (5.5)$$

$$\Delta b = b_2 - b_1 \quad (5.6)$$

The total colour difference between two colours as a metric of interest in colour science can be given from the Euclidean distance in CIElab [13]:

$$\Delta E_{ab} = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \quad (5.7)$$

While a colour difference of approximately 2.3 is considered as a Just Noticeable Difference (JND) [13]; the higher this value goes, the more different the two colours being assessed are. The minimum colour difference values were considered as the appropriate recommendations.

Three series of foundations (Figure 19) were sent by the L'OREAL research department in prior to the start of this thesis, the DW series, C series, and N series. Each of these foundation series go from the light to dark shades as the code number increases. Each series were placed in an ascending order from right to left on a small table in the Norwegian colorlab having a reasonably good approximation of daylight (Standard D50). The participants were then asked to place their faces above the foundations while sitting on a chair, adjusted according to the height of the table. A canon IXUS 130 camera with 14 Megapixel resolution, which is higher than most existing smartphone cameras, was available to take the first round of pictures. The camera was placed on a tripod with respect to the same viewing geometry as the colorimetric measurements, 10 degrees viewing angle.

Next step was to use these images to give a number of recommendations to each participant, later on they were asked to rank these recommendations for us to evaluate the efficiency of our algorithm. Various face and skin detection algorithms have previously been proposed to automate the process of extracting the skin data we need to use for our calculations. However, for this particular application we decided to involve the user's judgement by deciding which areas are nor in shadow neither illuminated and represent their own true skin colour. There are some





Figure 19: 5 shades of the C series True Match L'OREAL, 7 shades of the DW series and 8 shades of the N series foundations were made available for this study



(a) Experiment1, C series foundations



(b) Experiment1, DW series foundations



(c) Experiment1, N series foundations

Figure 20: First Experiment, in the Norwegian colour and Visual computing Laboratory, under standard D50 light (An approximation of the daylight), using a Cannon 14 Mpixel camera

mobile applications, known as the Makeover apps, which tend to detect all the features in a face, and apply various cosmetics products to those detected areas accordingly. One good example is an application called Modiface [11], that automatically detects the face features(eyes, eye-brows, cheek bones, lips, etc) while gives the user a chance to modify these detections if not accurate enough for any reason. Consequently, we decided to manually crop the acceptable skin areas within each experimental image as if the decision making step, as to find the representable area was left to the user. We also tried to consider that the skin sample and the reference foundation bottles were illuminated as closely as possible.

Once we had all the skin samples of participants besides the ground truth colour data for all the 20 foundations, Matlab scripts were written to provide three foundation recommendations for each participant.

First, all the cropped samples were read from a certain folder including the experimental images. Next, colorspace conversion took place using Matlab image processing toolbox functions. The images are recorded as the camera RGB values. Next, the image data was divided into three different planes, each containing one colour channel data. We intended to access the colour data from each channel. As explained earlier, we calculated the colour difference in the CIElab space and therefore, using colorspace conversion functions we obtained the CIElab values.

Next, we needed a clustering of the skin sample cropped image, to be able to ignore the noisy or damaged pixels; thus the mod of all the pixels was extracted.

Now, assuming that the foundation bottles placed under the participant's face is a calibration reference; we calculated the vector taking each foundation's true colour value(obtained from the colorimetric measurement) to the recorded colour value by the camera. Each vector represents the changes caused by the illumination, positioning of the object in an image that depends on the camera sensors responses etc. Therefore, by averaging all the vectors calculated from each foundation reference, we got one vector to calibrate the sampled skin colour.

Next, we calculated the colour difference value between each participant's sampled skin image(calibrated as explained above) and each of the foundations true colour value(obtained from the colorimetric measurement). Eventually, the three minimum colour differences are reported to the participants as foundation recommendation.

The online survey by the L'OREAL marketing team reported, 10,71% of participants prefer to find a foundation that is slightly darker than their own skin colour, 85,71% look for a foundation as close to their skin tone as possible and 2,98% are likely to wear a slightly lighter shade of foundation than their own skin colour. Noteworthy to mention that the total colour difference formula directs us to the closest match based on three colour channels; nevertheless we do not know if the recommended foundation is darker or lighter. As a result, we decided to provide three recommendations in an attempt to cover all colour expectations.

All the participants were finally invited for an evaluation of the recommendations provided by the algorithm in one-by-one interviews. Three recommendations were given to each of them, followed the question of "How useful do you find these recommendations we provided you with?". An average ranking of 8.2 was given by the participants. Good to mention that all these participants were frequent foundation buyers and we believe that they provided highly reliable feedbacks on the results.



Figure 21: The Red circles indicate the areas in shadows or illuminated, the green square shows a potentially good area that can be selected for further processing. We carefully selected the appropriate areas based on the illumination trying to find the areas that have gained similar amount of light to the bottom of the foundation bottles that were least curved and thus glossy.

Participant/Foundation	Personal choices	Cannon_Colourlab	Ranking
1_C 1_DW 1_N	D5E5,C5,D4W4	C5,N5,R3C3 D5W5,C5,N5 N5,R3C3,D5W5	8
2_C 2_DW 2_N	R2C2,R3C3,N3,D1W1,D3W3	C5,R3C3,N5 R3C3,C5,R2C2 C5,N5,R3C3	9
3_C 3_DW 3_N	N3,R3C3,R2C2	N3,R2C2,D3W3, R3C3,R2C2,D3W3 N3,R3C3,N7	9
4_C 4_DW 4_N	D1W1,D2W2	R3C3,R2C2,N3 R3C3,D3W3,N3 R3C2,N3,R2C2	7
5_C 5_DW 5_N	C5,D5W5,N7	C5,R3C3,N5 N7,D5W5,C5 C5,N7,D5W5	8

Table 6: Recommendations provided by the proposed method and the images obtained from the first experiment, using the Cannon 14 Mpxl camera inside the Colourlab; while having each series of L'OREAL True Match foundation bottles lined up under the faces of participants. As we observe from the results, a maximum number of 4 foundation codes were generated for each participant, all of which were confirmed to be helpful throughout the selection process by interviewing the participants.

## 5.4 Experiment 2

The second round of experiment was conducted with respect to our second research question. We wanted to evaluate our proposed method to provide recommendations, by changing one variable. As we discussed briefly about the digital imaging pipeline, that is designed to simulate the Human visual system as much as possible, some characteristics may significantly vary from camera to camera. Namely, the camera sensors' responses can be different even within the same brands from model to model. In addition, mobile cameras to some degree differ from professional photography cameras. These cameras are designed to be small and integrated inside a small device. Many image processing operations are automated for ease of use, hence we cannot have access to the camera raw data before being compressed as a JPEG file. JPEG compression is a lossy method that compresses mainly the chromaticity of the pixels rather than the luminance. Based on JPEG compression principles, the luminance and chrominance channels are separated, while only the chromaticity data is subjected to lossy compression and stored. Lossy compression techniques are irreversible once being decompressed. Other post-capturing operations such as white balancing have also been automated for mobile cameras. All the mentioned automations, phone camera sensors etc, make quite an impact on the imaging outcome.

As a result of this variety within the imaging systems, while having to develop a mobile application, we decided to integrate the mobile camera into the cycle. Thus we replaced the Cannon camera used for the previous experiment with 2 mobile cameras available for this study. The latest generations of Mobile Media Devices' cameras have a fairly good quality, making it seem more reasonable to consider them for colour scientific analysis.



(a) Samsung Galaxy Note 2



(b) Iphone5

Figure 22: Two mobile devices were selected for the experiment based on the existing resources for this study, Galaxy Note 2 Camera: Main (Rear) : 8 Megapixel Auto Focus Camera with LED Flash, Back-illuminated sensor (BSI) Sub (Front) : 1.9 Megapixel VT Camera [52]; Iphone5 Camera: Main (Rear) : 8 Megapixel Back-illuminated sensor (BSI), Auto focus, Touch to focus, Digital image stabilization, Face detection, Geo tagging, High Dynamic Range mode (HDR), Panorama Sub (Front) : 1.2 Megapixels [53]



(a) Experiment2, iphone5



(b) Experiment2, Galaxy Note2

Figure 23: Second Experiment, in the Norwegian colour and Visual computing Laboratory, under standard D50 light (An approximation of the daylight), using iphone 5 and Galaxy Note 2 main cameras

Participant	Colorlab/iphone5	Colorlab/Galaxy Note2	Ranking
1	C5,D5W5,R3C3	N3,R3C3,C5	8
2	N5,R2C2,R3C3	R2C2,R3C3,C5	7
3	R3C3,N3,C5	R2C2,R3C3,N3	9
4	R2C2,N3,R1C1	R2C2,N3,R3C3	7
5	C7,D5W5,C5	C7,D5W5,N7	8

Table 7: Experiment2 recommendations

The exact same steps as the first experiment was being followed at this stage too. The participants were again asked to place their heads upon the foundation bottles, in the exact same situation inside the Norwegian Colourlab, under D50 light, but this time using a mobile camera instead, as if the mobile application is being used.

### 5.5 Experiment 3

The first and second experimental results and the participant's rankings made us realize that it may be possible to achieve acceptable results to some degree by the proposed system. We examined our proposed method again, by changing yet another variable to determine if the utmost concern of illumination impact on the skin colour would break the positive results.

The third round of our experiment was repeated in the same order as the previous experiments, while we replaced the colourlab illumination with an uncontrolled lighting environment (GUC's canteen). The canteen illumination is a mixture of indoor lighting (lamps) and daylight through the windows making it a more complex lighting condition. Since we insisted on having the same participants taking part in each round, to be able to study the variations of recommendations for each and every one of them throughout the changes of variables, the experiment was largely dependant on the participants' schedules. Therefore, the image capturing process took place in different days, causing a variation on the daylight due to the sunny or cloudy weather besides the positioning of the sun during the day.

Participant	Canteen/iphone5	Canteen/Galaxy Note2	Ranking
1	C5,D7W7,R3C3	N3,R3C3,N5	6
2	N5,R1C1,R3C3	R2C2,N1,C5	6
3	R3C3,C7,D4W4	R2C2,R3C3,D4W4	6
4	R2C2,N1,R1C1	R2C2,N3,D4W4	5
5	C7,D5W5,D8W8	C7,D5W5,D7W7	6

Table 8: Experiment 3 recommendations



(a) Experiment3, iphone5



(b) Experiment3, Galaxy Note2

Figure 24: Third Experiment, in G -building/Gjøvik University College Canteen, using iphone5 and Galaxy Note 2 main cameras

## 5.6 Experiment 4

So far, we confirmed that under controlled lighting, using a high quality camera (14 Mpxl higher than most smartphone and tablet cameras) while having minimum 5 foundation bottles lined up under the face (Since the 5 True Match C series were used as reference); it is possible to provide promising recommendations. Next we confirmed that by exchanging one component of the experiment, the high quality camera to the mobile main camera, we are still able to provide reasonably fulfilling recommendations. And third, we confirmed that by changing the controlled lighting environment to an uncontrolled environment the recommendations could be less fulfilling according to user rankings. Finally, we decided to move on to the most complex situation and test the proposed method on a hypothetical mobile application. We conducted another round of experiment to study if this application would work while the user is holding up one foundation bottle close to the face, using different mobile phones and being under different illuminations.

Participants were asked to hold one foundation bottle as close to their face as possible, using two different front-facing mobile cameras in three not very distant locations, the Norwegian Colorlab environment, Gjøvik University College Cafeteria and outside in daylight, convenient enough for participants. We tried to simulate the process of using a mobile app easily anywhere and by means of the minimum resources available.

The recommendations provided to the participants following the proposed cycle of the application 13, were not consistent nor by using different mobile cameras, neither under various illuminations. We confirmed this inconsistency by interviewing the participants one by one to get

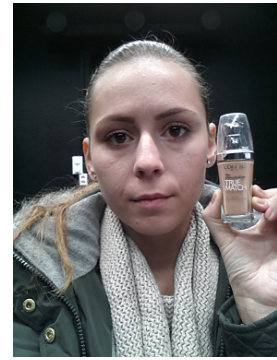




(a) Outdoor lighting



(b) Indoor lighting



(c) Colorlab/D50

Figure 25: Pictures of one participant in 3 different locations using a Samsung Galaxy Note2



(a) Outdoor lighting



(b) Indoor lighting



(c) Colorlab/D50

Figure 26: Pictures of one participant in 3 different locations using an Iphone5



Table 9: Colour difference Values calculated from the preliminary experiment's images of one participant, using a Galaxy Note 2 and Iphone5, in three different locations. The values are all above 2.3 (JND) and 6 foundation codes were generated as colour recommendations in different situations that are highlighted in the table; some of which were far from a desirable colour for the participants.

F-code	Colorlab Note2	Colorlab Iphone5	Outdoor Note2	Outdoor Iphone5	Indoor Note2	Indoor Iphone5
C7	8,04512	13,01077	14,97136	13,84346	6,262444	11,1195
C5	5,838336	9,13935	11,22696	10,08729	3,739947	9,275719
R3C3	3,735064	5,47713	8,256991	7,97043	3,421127	6,195571
R2C2	5,451203	5,297157	6,820099	5,763902	5,512557	7,402491
R1C1	8,459783	3,823104	2,245419	3,769603	10,22203	7,292006
N8	20,51229	24,73654	27,61498	27,00943	18,2784	23,42227
N7	5,815054	8,680656	11,57611	10,98642	4,140263	8,681254
N6.5	13,64434	16,73837	17,88602	17,45399	11,41938	17,19205
N6	8,578125	11,67379	13,46638	13,09679	6,396574	12,02598
N5	5,014603	7,788044	9,983022	10,16291	3,375088	8,169354
N4	10,22007	12,94265	13,98004	14,25496	8,163137	13,64525
N3	7,184959	6,833581	8,46793	7,423056	6,984799	9,216527
N1	13,24498	9,32702	7,758603	6,462436	14,4615	12,84989
D8W8	10,12333	13,8481	16,15604	15,95634	7,714761	13,60713
D7W7	10,12333	13,8481	15,00938	15,95634	7,714761	13,60713
D5W5	5,146275	8,591755	11,55637	10,92093	3,04221	8,548126
D4W4	10,13504	11,5391	13,7580372	12,38746	8,663389	13,11834
D3W3	7,466521	7,762925	9,889028	9,010241	6,791872	9,805423
D2W2	14,57314	12,24284	11,2147	10,71944	14,72876	15,64701
D1W1	14,09917	11,47229	9,789064	9,105782	14,5893	14,85105

	Note-colorlab	Note-indoor	Note-outdoor
1	R1C1,N1,D1W1	R1C1,R2C2,N1	R3C3,R2C2,D5W5
2	R3C3,N5,D5W5	D5W5,N5,R3C3	D4W4,N5,R1C1
3	R1C1,R2C2,R3C3	R1C1,N1,R2C2	R1C1,N1,R2C2
4	R3C3,C7,R1C1	N5,R3C3,D5W5	R1C1,R2C2,R3C3
5	N7,D5W5,C5	D7W7,C5,N6	R2C2,N4,N7

Table 10: Recommendations provided by the proposed method and the experimental images.

their feedbacks on providing them with 6 or 7 foundations as to start with their selection. All participants agreed that it would not be much helpful for them to be given more than 4 recommendations among 20 shades. As we discussed earlier, human skin colour ranges shortly in terms of chromaticity, and when we calculated the colour differences from one foundation shade to the next, we observed that the foundations' colour change very slightly. Therefore in order to be able to map the calibrated skin colour of the user to the exact right foundations with the minimal colour difference, we need to improve our system and provide higher consistency of results.

	Iphone-colorlab	Iphone-indoor	Iphone-outdoor
1	N1,R1C1,D1W1	D4W4,D3W3,N3	R3C3,N7,N5
2	R1C1,R2C2,R3C3	R3C3,R1C1,R2C2	R1C1,R2C2,C5
3	R1C1,R2C2,R3C3	R1C1,N1,R2C2	R1C1,N1,D1W1
4	R3C3,C7,R2C2	R3C3,N5,D5W5	R1C1,R2C2,N3
5	N5,D5W5,C5	D5W5,N4,C5	R3C3,C5,N7

Table 11: Recommendations provided by the proposed method and the experimental images

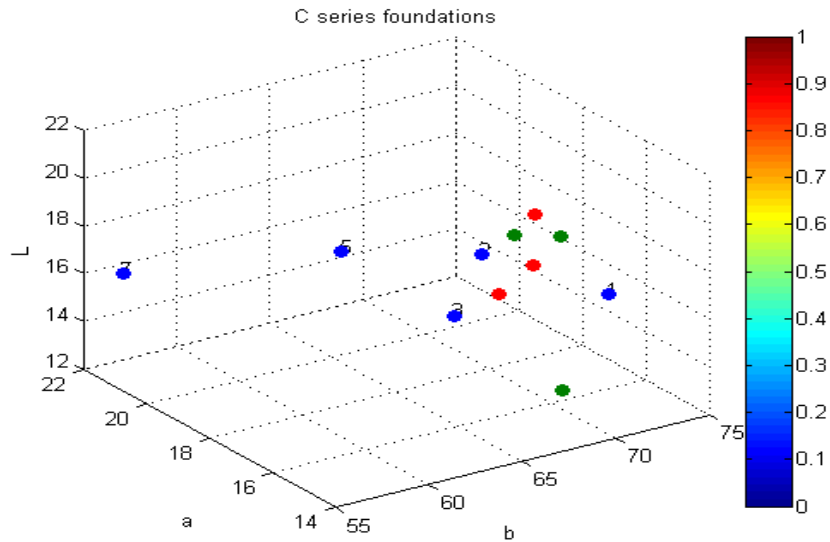


Figure 27: 3D illustration of the C series foundations and participants calibrated skin colour values in three different locations, The blue dots represent the foundation while the rest, each colour represents one participant. As we observe in this figure, the calibrated skin colours are not close enough to be mapped to a real colour match. Each of the calibrated skin colour values can result into a different colour recommendation.

This last experiment gave us a preview of using a mobile application to receive foundation recommendations having access to the minimum number of foundations possible. The results however as shown in Table9 were highly noisy and inconsistent. The users' rankings also indicate that the usefulness of the recommendations have dropped significantly.

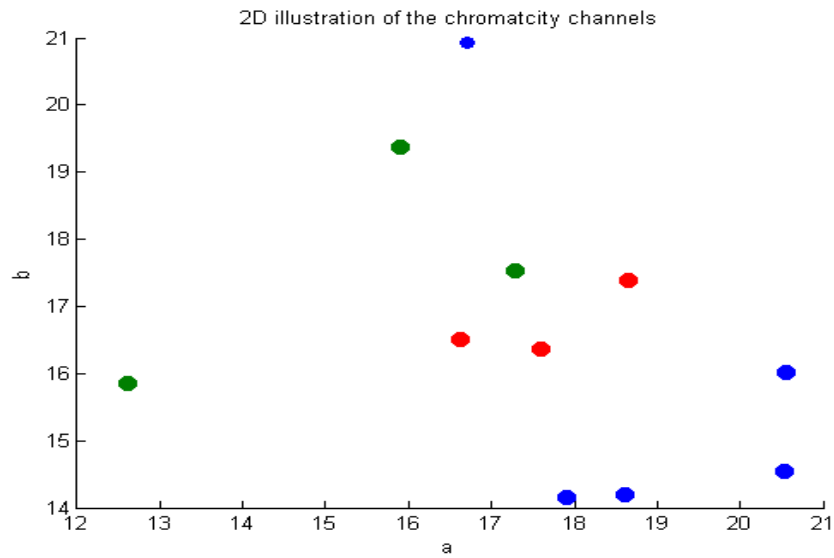


Figure 28: 2D illustration of the previous figure, mapped on only the chromaticity channels ( $a^*$ ,  $b^*$ ). The red and green point represent 2 participants skin calibrated in three different locations.

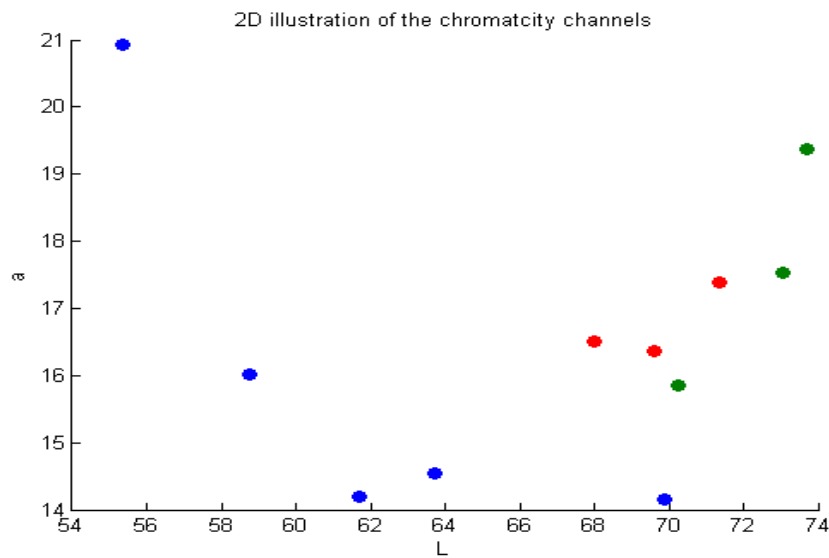


Figure 29: 2D illustration of Figure 27, mapped on only the chromaticity channels ( $L^*$ ,  $a^*$ ). The red and green point represent 2 participants skin calibrated in three different locations.

participant	Experiment1	Experiment2	Experiment3	Test Experiment
1	8	8	6	2
2	9	7	6	4
3	9	9	6	3
4	7	7	5	3
5	8	8	6	3
Average	8.2	7.8	5.8	3

Table 12: We ran a T-test on between two samples, here in this case the two subsequent experiments to determine the statistical p-value with a significance level of 0.05. We had normal distribution within test subjects; our participants remained the same from experiment 1 to the last test experiment.

Hypothesis	P-Value	Confirmation
Ex1 > Ex2	0.3926	False
Ex2 > Ex3	0-0005	True
Ex3 > Ex4	0.0003	True

Table 13: T-Test result between each two subsequent experiments. Under the condition of p-value being greater than the significance interval ( P-Value > 0.05 ), the hypothesis on the first column on the left is confirmed.

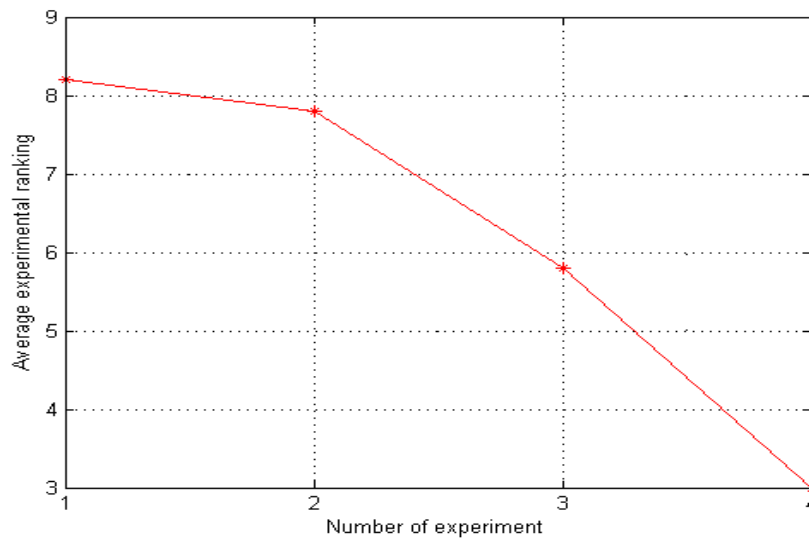


Figure 30: The x axis represents the number of experiment while the y axis represents the average rankings

## 6 Discussion and conclusion

User involvement was a key component in this project. The online survey by the L'OREAL research department collected both quantitative and qualitative data from a test group of women in the UK. As a result of this survey, we confirmed the persistence of the foundation selection problem since the previous studies in 2006 and 2010 [4]. Qualitative data were also collected to search for possible reasons behind the given answers. Some inferences were made in conclusion of the quantitative results given in Table 2 and the qualitative data given by users in their own words and from their own point of view.

80.36% stated that they have never used a digital service to assist in choosing their foundation match before; due to one of the following reasons:

- They have never heard of such a service.
- Unavailability of the service, where they live or work.
- Negative feedbacks from those having used this kind of services.

Nearly all the 19.05% of the rest stated the Boots match maker service as their experience of digital assistance in this process. For some, it has been helpful while a few others stated that the recommendations were completely different from what they would personally choose.

The above mentioned reasons, unavailability of this service in every Boots store, the mixed positive and negative feedbacks from those having experienced it and not having a clue about the existence of such a service; clearly emphasizes the fact that the digital professional beauty advisory systems are at early stages of being developed and tested. In addition, we discovered that 77.38% of the study group used smartphone technologies, hence a mobile application to answer these issues would be favourable to women having to deal with the foundation selection process.

The L'OREAL Board of Beauty consists of women from all over the UK participating in such surveys and tests. The boots No7 Match maker service has also been launched in the UK, as a result, this high percentage of 80.36% never having used this service alongside the 76.19% of participants struggling with finding the right foundation 'color' in particular; confirmed that there is potential for research and development in this area.

Having studied the customer needs for designing this system, we collected the system requirements to begin with. In Chapter 3, we reviewed Mobile Media Devices having been previously used for colour picking and measurement. A number of smartphones were also tested and evaluated in terms of their camera resolution [14]. Advised by the evaluation results 1 10, we calibrated the images taken by our proposed app using a colour reference as close to the foundation colours as possible.

In Chapter 5, we learnt that the L'OREAL True Match foundations available for this study had a shiny effect after having been applied on a surface. The measurement of both specular and diffuse reflectance of each foundation colour patches, resulted into very low variations of only about maximum 0.2 per channel. These variations did not cause a colour difference total higher than 2.3 (Just Noticeable Difference). Therefore we used an average value of both reflections as the ground truth for each foundation for the calibration process.

Using the ground truth the experimental foundation recommendations were provided to the participants. Their rankings led us to the following inferences:

1. We examined our first research question through an experiment conducted in a controlled illumination, using a camera with a higher quality than most mobile main cameras of the recent generation, having a minimum of 5 foundation bottles positioned below the participant's face. The results were a set of fulfilling recommendations as an average of 8.2 from the scale of 0 to 10 was given to the recommendations by the participants through one by interviews. The feasibility of using a foundation glossy bottle through which the colour of the foundation is clearly visible was then confirmed.
2. In the second experiment, we examined the second research question, by exchanging the high quality imaging system to a mobile main camera. The recommendations we provided to the participants resulted into an average ranking of 7.8. Having a significance level of 0.05 and normal distribution within the test subjects; the p-value between the first and second experiment was 0.3925, meaning that the two sets of results were not significantly different. Although the average ranking decreased we believe that based on a limited number of participants the hypothesis of experiment 1 and 2 being equal is true according to the statistical calculations [13].
3. The third experiment focused on the third research question, exchanged the controlled illumination factor with Gjøvik University College canteen. A decreased average ranking of 5.8 resulted into the third experiment recommendations being significantly worse than experiment 2, with a p-value of 0.0005. The hypothesis of experiment 2 being better than experiment 3 was supported according to the p-values [13].
4. Finally a test experiment was conducted to simulate the most complex situation of using the mobile application and evaluated the proposed method. The participants held only one foundation bottle close to their faces, took a picture themselves by using the front-facing camera that is of much lower quality in an uncontrolled lighting condition. In most cases, the recommendations were dramatically far from the desired colour for each participant. Therefore an average of 3 was obtained from the ranking. The p-value between the second and test experiment was below 0.0001 thus the two sets of results were significantly different. The hypothesis of experiment 3 being better than experiment 4 (the final test experiment) was then confirmed [13].

The following may be potential causes of the last two experiments' failure:

- The environment's illumination consisting of mixed light sources inside the GUC canteen, as

well as inequality of light projection throughout the test subjects may have caused significantly different results moving on from the first and second to the last two experiments.

- Mobile front-facing cameras are fairly smaller than the main camera. Therefore the sizes of aperture, optical lenses and the sensor being manufactured to fit on the front side of the phone are smaller. Smaller aperture allows fewer photons into the system causing considerable amount of noise. Also the smaller size of optical lenses cause more aberration as well as sensor limitations, all of which having an impact on the stored colour data [24].
- The majority of mobile phones, apart from a few exceptions in camera phones, do not allow access to the camera raw data. The captured images are store as a JPEG file, automatically white balanced and colour corrected. Based on JPEG compression principles, the luminance and chrominance channels are separated and the chromaticity is subjected to lossy compression. Lossy compression methods are irreversible once being decompressed that can eventually cause numerical changes within the colour values [54].
- Various color difference calculation methods have been developed and improved over the years, none of which have been perfectly efficient for different applications [13]. We obtained the total color differences between the test subjects and reference colour values in the CIElab space relying on previous attempt for dentistry results. However since there is potential improvement in the colour difference formula more significant results may be obtained using other methods.

As a result of this master thesis examination and discussion meetings with the L'OREAL research and marketing team, we were able to confirm that the colour cosmetic recommender can be implemented as a substitute of the Boots foundation match maker device. The application can be used in a controlled lighting condition, using a smartphone main camera (8Mpxl and above) having a minimum of 5 True Match foundations as reference within the images. An alpha product for further evaluation and testing by L'OREAL consumers may be released. The application can be easily accessible to users as we also confirmed through the survey, 77.38% of the participants among the ages of 16 to 65+ all over the UK own a smartphone. By the end of 2013, there will be 2 billion active smartphone and tablets in the world [55]. We believe that the Mobile Media Device diffusion is at a rapid adoption stage by majority of people worldwide; thus our proposed mobile application would be potentially easy to access.

## 7 Future opportunities

This master thesis contributed to a Mobile beauty advisory project, starting with providing recommendations on what foundation color would fit most to one's skin color, based on scientific analysis on images.

The core of this project was the foundation selection assistance while incremental functionalities can be added in the future. Based on our findings the uncontrolled illumination, specifically indoor lighting is still a challenge, as well as using different mobile front cameras. Although We were able to support the idea of using the foundation containers as the colour reference for calibration, the system should still be improved for more precise recommendations under different illuminations. One potential research area would be improving the colour difference calculations for this specific application.

Similar to recommendation algorithms using customer's of online retailers past behaviours, this system can also be improved to employ the user's previous recommendations and beauty advices to be able to analyse other products that match them in terms of colour. As an example, once a series of foundation shades have been recommended, concealers of similar colour tones could also be suggested. Concealers are liquid-based, creamy or powder products available in skin tone colours, specifically made to conceal the darkness below the eyes and above the cheek bone area.

One possibility of adding incremental functionalities would be studying the seasonal changes and variations of skin colour for one user, to be able to provide recommendations of darker shades during summer while the user may be tanned, in contrast to winter that they might be more pale.

The amount of foundation coverage (Low, medium or full coverage) can also be studied further based on the high frequencies within each user's face skin area. If there are dramatic changes of colour values throughout the face, it would be better for the user to wear a full coverage foundation for example.

Other incremental functionalities can be gradually added, such as hair colour recommendations, Sun Protecting Factor (SPF) amount needed for sunny days etc.



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# Appendices

## A Test Online survey

Dear participant,

This study is addressing females only, to collect statistics based on their personal experience of choosing cosmetic products. By filling in the survey kindly, you help us improve solutions to some problems most of us face while shopping. If you have safety concerns, it is beneficial to inform you that no personal information is required and all your answers are sent anonymously to us. Please take a few minutes to answer the following questions.

We thank you in advance and your cooperation is highly appreciated.

1. Please specify your age group:

15-30  
30-40  
40-50  
Above 50

\*\*\* We would like to ask you a few questions regarding your experience of choosing make-up products

2. How do you prefer to purchase make-up products?

Online  
In store  
Through make-up consultants

3. Have you ever experienced problems while choosing the right color for a product?

Yes  
No

4. Which one of the following do you find the most challenging while choosing the right color for you?

Foundation  
Blusher  
Eye shadow

- Lipstick
  - Hair color
  - Other
5. How often do you apply foundation on your face skin?
- Never
  - Occasionally
  - Weekly
  - Daily
6. How often do you change your foundation?
- Never, I use a fixed color
  - Over a year
  - About twice a year
  - Very often
7. Due to what reasons you tend to change your foundation?
- Better quality/brand
  - Variety
  - Color
8. What kind of the following shades do you wear on your face skin?
- Exact same as your own skin
  - Slightly lighter
  - Slightly darker
  - Much lighter/darker
9. How helpful would it be for you to use a consultancy system providing you with foundation recommendation based on your specific skin tone?
- Highly helpful
  - Quite helpful
  - Not much difference
  - Not at all
10. Which of the following devices do you own?

Laptop  
Smartphone  
Tablet  
None

<http://www.stud.hig.no/~110880/>



## B Corrected Online survey

Hi ladies,

As you may be aware, we're about to embark on a really exciting journey of exploring everything FOUNDATION with you! With this in mind, we'd love to hear some of your thoughts on the topic through the following questions. . .

Whether you're foundation obsessed or just use it now and then, we'd love to hear from you! If you never use foundation then do not worry about participating in this activity – we've got lots of other things coming up for you to get involved in

1. Q1: How do you prefer to purchase foundation? [single select]

- Online
- In-store (without help from others)
- In store (with help from beauty advisors)
- Other – if so, please let us know how in the comment box below

And why? [open comment box]

2. Q2: Which of the following statements apply best to you? By format we mean the type of foundation e.g. liquid, mousse, powder etc [single select]

- I never struggle to find the right format of foundation for me
- I sometimes struggle to find the right format of foundation for me
- I always struggle to find the right format of foundation for me

3. Q3: Which of the following statements apply best to you? [single select]

- I never struggle to find the right shade of foundation for me
- I sometimes struggle to find the right shade of foundation for me
- I always struggle to find the right shade of foundation for me

4. Q4: When you are selecting the colour of your foundation, what shade are you looking for? [single select]

- Much darker than my natural skin tone
- A little darker than my natural skin tone
- As close as possible to my natural skin tone

- A little lighter than my natural skin tone
- Much lighter than my natural skin tone

And why? [open comment box]

5. Q5: How often do you change the foundation you use? We'd like to know how often you switch your foundation for a different foundation, be that a different format, brand or shade etc [single select]

- At least every month
- At least every 3 months
- At least every 6 months
- At least once a year
- Less than once a year
- Never

And why? [open comment box]

6. Q6: Have you ever used a digital device to help you find the right shade of foundation? [single select]

- Yes
- No

If yes, what have you used? [open comment box]

7. Q7: Would you like to have a digital device to help you find the right shade of foundation? [single select]

- Yes
- No

And why? [open comment box]

8. Q8: Which of the following devices do you own? Please select all which apply to you. [multiple select]

- Computer
- Laptop
- Android Smartphone
- iPhone Smartphone
- Other Smartphone

If other, please tell us what device this is J [open comment box]

## C Ground truth from colorimetric measurement

Table 14: L'orela True Match DW series

D1W1	L	a	b	D4W4	L	a	b
Specular	71,11119	15,57649	26,80306	Specular	60,29681	15,56165	25,90788
	71,07415	15,5909	26,77947		60,24429	15,57548	25,87255
	71,05991	15,63306	26,74197		60,19621	15,5917	25,84939
Diffuse	71,11	15,22	26,3	Diffuse	60,3	15,24	25,48
	71,07	15,23	26,28		60,25	15,26	25,44
	71,06	15,27	26,24		60,2	15,27	25,42
Mean	71,08087	15,42007	26,52408	Mean	60,24789	15,41647	25,66164
D2W2	L	a	b	D5W5	L	a	b
Specular	69,50558	13,61379	28,18054	Specular	58,93666	15,86852	19,99094
	69,47015	13,62935	28,14192		58,9094	15,87767	19,95919
	69,44463	13,66484	28,12376		58,87746	15,88595	19,94645
Diffuse	69,51	13,26	27,7	Diffuse	58,94	15,56	19,54
	69,47	13,28	27,66		58,91	15,56	19,51
	69,44	13,31	27,64		58,88	15,57	19,5
Mean	69,47339	13,45966	27,9077	Mean	58,90892	15,72036	19,74109
D3W3	L	a	b	D7W7	L	a	b
Specular	62,66699	14,11838	22,99743	Specular	58,93666	15,86852	19,99094
	62,57592	14,12948	22,95641		58,9094	15,87767	19,95919
	62,5494	14,14205	22,93477		58,87746	15,88595	19,94645
Diffuse	62,67	13,79	22,54	Diffuse	58,94	15,56	19,54
	62,58	13,8	22,5		58,91	15,56	19,51
	62,55	13,82	22,48		58,88	15,57	19,5
Mean	62,59872	13,96665	22,73477	Mean	58,90892	15,72036	19,74109
				D8W8	L	a	b
				Specular	58,93666	15,86852	19,99094
					58,9094	15,87767	19,95919
					58,87746	15,88595	19,94645
				Diffuse	58,94	15,56	19,54
					58,91	15,56	19,51
					58,88	15,57	19,5
				Mean	58,90892	15,72036	19,74109

Table 15: L'orela True Match N series

N1	L	a	b	N6	L	a	b
specular	73,17511	14,50017	22,99103	Specular	57,15175	16,22578	23,03955
	73,14528	14,56708	22,82586		57,2045	16,24886	23,00167
	73,25257	14,63058	22,82519		57,18458	16,26737	22,98785
diffuse	73,18	14,18	22,28	Diffuse	57,15	15,92	22,62
	73,15	14,2	22,29		57,21	15,94	22,58
	73,25	14,26	22,29		57,19	15,96	22,57
Mean	73,19216	14,38964	22,58368	Mean	57,1818	16,09367	22,79984
N3	L	a	b	N6.5	L	a	b
Specular	64,22975	15,06358	22,66905	Specular	54,5524	18,37479	27,22034
	64,1329	15,08516	22,66803		54,49695	18,3862	27,18048
	64,10144	15,10662	22,64972		54,43629	18,39114	27,14299
Diffuse	64,23	14,73	22,2	Diffuse	54,55	18,08	26,84
	64,13	14,75	22,19		54,5	18,09	26,8
	64,1	14,77	22,18		54,44	18,09	26,76
Mean	64,15401	14,91756	22,42613	Mean	54,49594	18,23535	26,99064
N4	L	a	b	N7	L	a	b
Specular	57,35969	16,81439	25,04046	Specular	58,5337	13,69192	19,46795
	57,30548	16,84453	25,00033		58,49249	13,70202	19,4386
	57,2529	16,85018	24,9862		58,4405	13,70534	19,42504
Diffuse	57,36	16,51	24,63	Diffuse	58,53	13,38	19,02
	57,31	16,54	24,59		58,49	13,39	18,99
	57,25	16,54	24,58		58,44	13,4	18,98
Mean	57,30634	16,68318	24,8045	Mean	58,48778	13,54488	19,22026
N5	L	a	b	N8	L	a	b
Specular	59,75403	15,06183	20,16945	Specular	42,31139	14,60481	20,59074
	59,84297	15,08733	20,16086		42,18449	14,59847	20,60753
	59,83739	15,09779	20,14055		42,08342	14,62953	20,65569
Diffuse	59,76	14,75	19,72	Diffuse	42,31	14,36	20,27
	59,84	14,77	19,71		42,19	14,35	20,29
	59,84	14,78	19,69		42,09	14,39	20,33
Mean	59,8124	14,92449	19,93181	Mean	42,19488	14,4888	20,45733

Table 16: L'orela True Match C series

R1C1	L	a	b	C5	L	a	b
Specular	70,07184	14,34594	18,21306	Specular	58,83232	16,19743	20,84365
	70,10629	14,36821	18,24133		58,65954	16,14168	20,71898
	69,43682	14,29553	18,08772		58,82918	16,2026	20,76588
Diffuse	70,07	13,99	17,68	Diffuse	58,83	15,88	20,4
	70,11	14,01	17,7		58,66	15,83	20,28
	69,44	13,94	17,55		58,83	15,89	20,32
Mean	69,87249	14,15828	17,91202	Mean	58,77351	16,02362	20,55475
R2C2	L	a	b	C7	a	b	
Specular	63,80816	14,68544	20,80686	specular	55,35402	18,56984	23,12043
	63,85632	14,74124	20,80307		55,37	18,28	22,69
	63,49595	14,68278	20,70907		Diffuse	55,28	18,25
Diffuse	63,81	14,35	20,33	55,41		18,28	22,73
	63,86	14,41	20,32	55,34		18,28	22,49
	63,5	14,35	20,23	Mean	55,36201	18,42492	22,90521
Mean	63,72174	14,53658	20,53317				
R3C3	L	a	b				
Specular	61,40341	14,26476	18,80645				
	61,80181	14,36736	18,88044				
	61,89067	14,42181	18,87324				
Diffuse	61,4	13,94	18,34				
	61,8	14,04	18,41				
	61,89	14,1	18,4				
Mean	61,69765	14,18899	18,61835				

## D Matlab scripts

---

```

clear all
clc

% reading the folder containing the skin photos of the experiment
path = 'photos/';
photos = dir(fullfile(path, '*.png'));
photos = {photos.name};

%Initializing
Ascending_deltaE=zeros(1,20);
Str=['C7 ','C5 ','R3C3','R2C2','R1C1','N8 ','N7 ','N65 ','N6 ','N5 ','N4 ','N3 ','N1
    ','D8W8','D7W7','D5W5','D4W4','D3W3','D2W2','D1W1'];

%Creating a string cell for displaying the suggestion in the end
Foundation=cellstr(Str);

%Seperating the colorspace channels in a 2D Matrix
L= mode(mode(img(:, :, 1)));
a= mean(mode(img(:, :, 2)));
b= mode(mode(img(:, :, 3)));

L1= mode(mode(img1(:, :, 1)));
a1= mode(mode(img1(:, :, 2)));
b1= mode(mode(img1(:, :, 3)));

L2= mode(mode(img2(:, :, 1)));
a2= mode(mode(img2(:, :, 2)));
b2= mode(mode(img2(:, :, 3)));

L3= mode(mode(img3(:, :, 1)));
a3= mode(mode(img3(:, :, 2)));
b3= mode(mode(img3(:, :, 3)));

L4= mode(mode(img4(:, :, 1)));
a4= mode(mode(img4(:, :, 2)));
b4= mode(mode(img4(:, :, 3)));

L5= mode(mode(img5(:, :, 1)));
a5= mode(mode(img5(:, :, 2)));
b5= mode(mode(img5(:, :, 3)));

%Creating a Matrix of the ground truth color values for 20 foundations
C7=[55.36589907 20.92994069 16.70891002];
C5=[58.77350638 16.02361747 20.55475064];
R3C3=[61.69764853 14.18898798 18.6183539];
R2C2=[63.72173894 14.53657582 20.53316772];

```

```

R1C1=[69.87249288    14.15828037    17.91201847];

N8=[42.19488358  14.48880062  20.45732606];
N7=[58.48778077  13.54487925  19.22026397];
N65=[54.49593933    18.2353544    26.99063532];
N6=[57.18180488  16.09366811  22.79984461];
N5=[59.81239915  14.92449224  19.93180896];
N4=[57.30634496  16.68318313  24.80449796];
N3=[64.15401418  14.91755909  22.42613307];
N1=[73.19216163  14.38963734  22.58368109];

D8W8=[51.40753979    14.77074947    21.15682495];
D7W7=[54.36112406    16.32076735    22.33159109];
D5W5=[58.90891992    15.7203568    19.74109472];
D4W4=[60.2478856    15.41647033    25.66163673];
D3W3=[62.59871833    13.96665348    22.73476916];
D2W2=[69.47339449    13.45966354    27.90770386];
D1W1=[71.08087449    15.42007455    26.52408283];

F=cat(1,C7,C5,R3C3,R2C2,R1C1,N8,N7,N65,N6,N5,N4,N3,N1,D8W8,D7W7,D5W5,D4W4,D3W3,D2W2,D1W1);

%Calculating the characterization Vector from the reference foundation and
%the ground truth value
V1=[(C7(1) - L1),(C7(2) - a1), (C7(3) - b1)];
V2=[(C5(1) - L2),(C5(2) - a2), (C5(3) - b2)];
V3=[(R3C3(1) - L3),(R3C3(2) - a3), (R3C3(3) - b3)];
V4=[(R2C2(1) - L4),(R2C2(2) - a4), (R2C2(3) - b4)];
V5=[(R1C1(1) - L5),(R1C1(2) - a5), (R1C1(3) - b5)];

Ls=Mode([V1(:, 1),V2(:, 1),V3(:, 1),V4(:, 1), V5(:, 1)]);
as=Mode([V1(:, 2),V2(:, 2),V3(:, 2),V4(:, 2), V5(:, 2)]);
bs=Mode([V1(:, 3),V2(:, 3),V3(:, 3),V4(:, 3), V5(:, 3)]);

V=cat(2,Ls,as,bs);

% Restore the participant's skin color to the real value using the
% calculated vector above
R=[(L+V(1)), (a+V(2)),(b+V(3))];

%Calculating the color difference value (CIEdeltaE) between the face
%skin color and all the 20 shades
for i=1:20

    DeltaE(i)=sqrt((abs(F(i,1)-R(1)).^2 + (abs(F(i,2)-R(2))).^2 +
        (abs(F(i,3)-R(3))).^2));

end

%Sorting the deltaE array in ascending order to have access to the 3 minimum element

```

```
[ascending_deltaE,index]=sort(DeltaE);  
  
% Displaying the True match suggestion  
disp(Foundation(index(1)));  
disp(Foundation(index(2)));  
disp(Foundation(index(3)));
```

---