SMARTDEVICES DEVELOPMENT FOR
VISUAL IMPAIRMENT & COLOUR VISION DEFICIENCY

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Contents

CAPTIONS OF FIGURES:

Table of Content

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ABSTRACT

The research concerns with the development of an app-based system to assist those with vision impairment to better interact with mobile phones and computers achieving maximum advantages. In particular, the system helps to detect colour deficiency and can automatically adjust view screens to increase contrast and arrive at optimal view result. Preliminary results when asking observers to evaluate the system demonstrate the advantages of the developed software system.

1. INTRODUCTION

Colour Vision Deficiency or Colour Blindness affecting 4.5% of the United Kingdom population [1], this can present some huge problems, especially when using a computer. Basic tasks, that a person with normal vision may take for granted such as shopping for clothing or choosing the correct colour font can seriously implicate a sufferer's ability to use a computer correctly. There is currently no known programme that is able to cater to the needs of a person with colour blindness so there is a serious need for one that will enable a person to differentiate between such colours as presented on a screen. The intention of this proposal is to develop an application which is going to help people with Colour Vision Deficiency those who cannot see colours properly and might be without any assistant in ease. This application is working in combination with an analysis software which can come to the scene for further test if required on the actual app on the glass. The observer will be able to call for action to see colour of objects, throw a running application and request for the colour information of that object such as "Red colours outline" or "capture Green", in front of his scene. It will be then highlighted or outlined with stroke line which are suitable to see for colour blind people in common; inside the glass transparent display.

The development field of wearable computing aims to connect computing devices into everyday life. This report focuses on smart glasses technology, one of the categories of wearable computing devices which is very present in the media and expected to be a big market in the next few years. It analyses the differences from smart glasses to other smart devices, introduces many possible applications for different target audiences and gives an overview of the different smart glasses which are available now or should be available in the next few years.

Smart Glasses such as Google Glass are wearable technology devices worn in front of the eyes. Obviously their display moves with the user's head, which leads to the users seeing the display independently of his or her position and alignment. Therefore, smart glasses or smart spectacle are the only devices which can alter or enhance the wearer's vision no matter where the user is physically located and where looks.

2. Literature Review

Visual impairment is a seriously debilitating condition that will, to varying degrees, have an effect upon a person's ability to function normally on a daily basis. As of 2012, throughout the whole world, it has been estimated that approximately 285 million people are affected by visual impairment, with this number growing every year. This statistic is split between 246 million being affected by visual impairment and 39 million being blind [2]. In the UK alone it is estimated that as many as two million people may be living with some sort of sight problem. Of these, around 365,000 are registered as blind or partially sighted [3]. This number is set to increase significantly over the next 35 years with projected figures being forecasted at around 4 million persons by 2050 [4].

These statistics show that there is an urgent need, not just in the UK but across the world, for a program that will enable a visually impaired user to access the same right to information as a user who does not have impairment to their vision, in particular when mobile phone is current prevailing.

2.1 What does the eye look like?

Before we take a look at visual impairment it is important to understand the structure of the eye and how it works. Without this understanding, it would almost be impossible to offer a solution to the concerns that people with visual impairment have.

The eye is a solid object situated inside the bony structure of the eye socket. It is a slightly asymmetrical globe, about an inch in diameter and is made up of several complex components, filled with a jelly like fluid substance called the vitreous humour, which allows a fluid movement [5].

It is controlled using 6 extraocular muscles called the lateral, medial, inferior and superior rectus muscles, and the inferior and superior oblique muscles. The muscles are supplied by the oculomotor nerve, which is situated at the back of the eye, with the exception of the superior oblique, which is supplied by the trochlear nerve, and the

lateral rectus which is supplied by the abducens nerve. Each muscle has its own function, however any defects in these muscles may cause refraction errors in the eye, which are outlined below.

As illustrated in Figure 2.1, the components that make up the eye, that allow for vision include the lens, retina, optical nerve, cornea, iris and pupil, each one having its own 'job'. It is the breakdown in any of these components that may cause a visual impairment, such as a cataract on the lens.
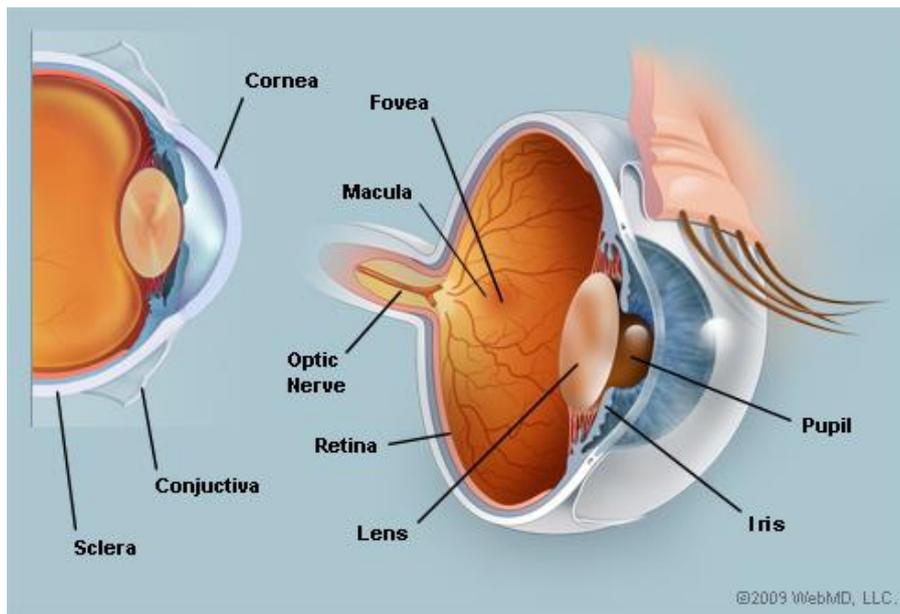
Figure 2.1: Image of the eye, displays back of eye with its components [6]

2.2 How is Visual impairment measured?

According to the World Health Organisation (WHO) [7], the definition of visual impairment is as follows "Reduced vision not corrected by glasses or contact lenses'

Two elements of vision are measured when determining a person's visual impairment - their visual acuity and their visual field. The former refers to the central vision used to look at objects in detail, such as reading a book or watching television. So when a visual acuity score is given as 2/20, it indicates the person in concern can only read at 2 metres away what a person with typical eyesight can read at 20 metres away. Visual field refers to the area that a person can perceive while he/she is looking straight ahead, which is tested using techniques that measure a person's responses to light

stimuli in various parts of their potential visual field. Some people with visual impairment may have poor visual acuity (i.e., 3/60-6/60) but have a full field of view. Others might have relatively good visual acuity (up to 6/18) but a significantly reduced visual field [7].

The World Health Organisation [7] uses the following classification for vision when the vision in the better eye with the best possible corrective lenses is:

- 20/30 to 20/60: is considered mild vision loss, or near-normal vision
- 20/70 to 20/160: is considered moderate visual impairment, or moderate low vision
- 20/200 to 20/400: is considered severe visual impairment, or severe low vision
- 20/500 to 20/1,000: is considered profound visual impairment, or profound low vision
- More than 20/1,000: is considered near-total visual impairment, or near total blindness
- No light perception: is considered total visual impairment, or total blindness[1]

As demonstrated in Figure 2.1 Image of the eye, displays back of eye with its components, a person's sight can be judged upon the Snellen Chart which was created in 1862 by the Dutch ophthalmologist, Herman Snellen. The chart itself shows several rows of letters that grow decreasingly smaller. The Snellen Chart Figure 2.2, although still largely used across the world, has been replaced by the Log MAR chart Figure 2.3 which gives a more accurate estimate of acuity and is able to estimate the visual acuity based upon the Logarithm of the Minimum Angle and Resolution. The Log MAR chart is now commonly used especially in a research environment as it gives a greater degree of accuracy to the visual acuity in comparison to the Snellen Chart.
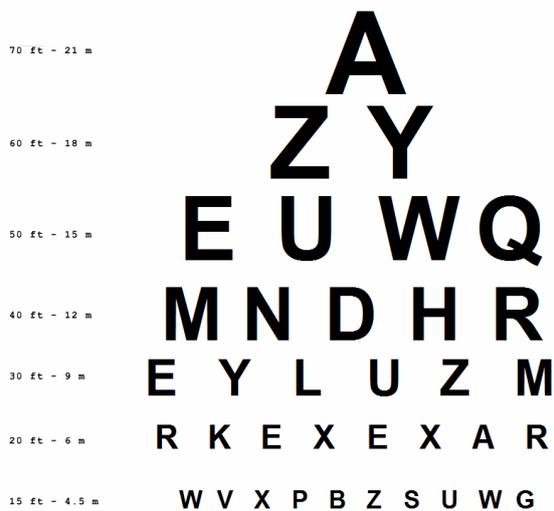
Figure 2.2: Snellen Chart [8]
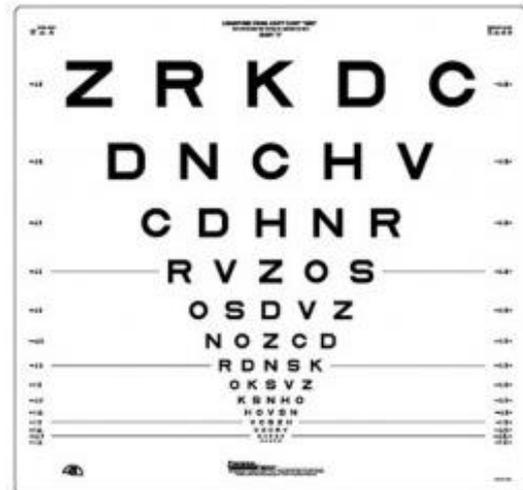
Figure 2.3: Log MAR Chart [9]

2.3 Diseases that cause visual impairment

Across the estimated 2 million people [3] in the UK who suffer from visual impairment there are several diseases and illnesses that are either the main cause of the visual impairment or are a secondary cause. There are several factors that one must take into account when discussing visual impairment. In addition, many diseases of the neurological system may also attribute to the cause of visual impairment, which may come as a secondary symptom due to the neurological effect that the disease may have upon the eyes themselves and the way the eye works. Approximately 90% [3] of all visual impairment cases come from low-income backgrounds with uncorrected refractive errors being the main cause of moderate and severe visual impairment. One could take the opinion that this is down to the lack of health support offered in some of the low-income and third world countries, however the fact still remains that 2 million people in the UK are living with some forms of visual impairment – a country that is far from being classed as being third world.

The 4 conditions outlined below account for 78% of visual impairment cases across the globe. However, the conditions themselves that account for the remaining 22% of cases are limitless as they are often symptoms that have been caused by infections, age related macular degeneration, diabetic retinopathy, corneal clouding, childhood blindness, neurological diseases, trauma to the brain or spinal cord or strokes.

Below are the most common problems known for Visual Impairment:

- Cataracts
- Charles Bonnet syndrome
- Dry eye
- Eye conditions related to diabetes
- Glaucoma
- Nystagmus
- Posterior vitreous detachment
- Retinal detachment
- Retinitis Pigmentosa

2.3.1 Refractive errors

Refractive errors, otherwise known as Ametrophia, make up around 45% of the visual acuity of the 2 million visually impaired people in the UK. A refractive error can be categorised loosely as any type of abnormal vision including but not limited to cylindrical and spherical errors of the eye [4].

Spherical errors occur when the optical power of the eye is either too large or too small to focus light correctly on the retina causing either Myopia (Short sightedness) or Hyperopia (Long sightedness), respectively. Both errors in the vision are usually fairly easily corrected with the use of concave lenses for Myopia and convex lenses for Hyperopia.

Cylindrical errors are slightly more complicated to correct than spherical errors and are generally classified as an astigmatism or presbyopia. Astigmatism is when the optical power of the eye is either too powerful or too weak across one meridian.

Astigmatism can be corrected by using cylindrical lenses to refract the light more in one meridian than the other. Presbyopia is basically the degeneration of the vision due to age. The flexibility of the lens declines causing issues with near vision viewing, however this impairment is generally easily corrected using reading glasses, progressive corrective lens or bi-focal glasses.

Figure 2.4 schematically illustrates these conditions.
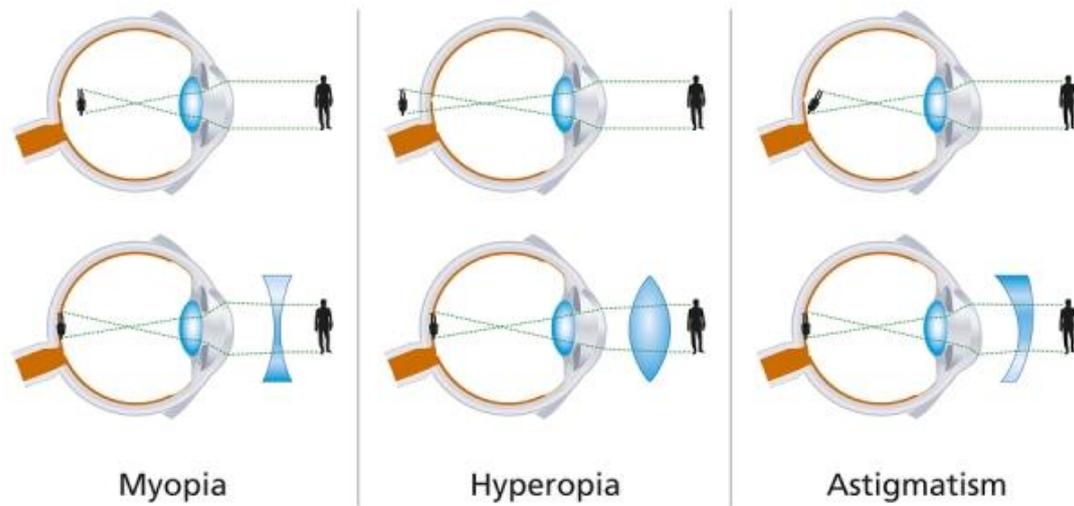
Figure 2.4: corrective lens or bi-focal glasses [10].

It is to be noted that refractive errors are usually caused by either environmental factors or due to the genetics of the individual.

For example, Myopia has been observed in individuals who have a visually intensive occupation such as use upon a computer. It is also worth noting that individuals who are stood within a higher socioeconomic status and who have received a higher level of education are also at a greater risk of Myopia, suggesting that the over-use of the retina at distances that are close have a detrimental effect upon the user's eyesight. The Online Mendelian Inheritance in Man (OMIM) database has 261 genetic disorders listed in which Myopia is one of the symptoms.

2.3.2 Cataracts

In the UK, it is estimated that around 2.5 million people aged 65 or older have some degree of visual impairment caused by cataracts [3]. Figure 2.5 demonstrates the condition of cataracts where the lens covered with many floating objects that block vision to a certain extent as depicted in Figure 2.6.
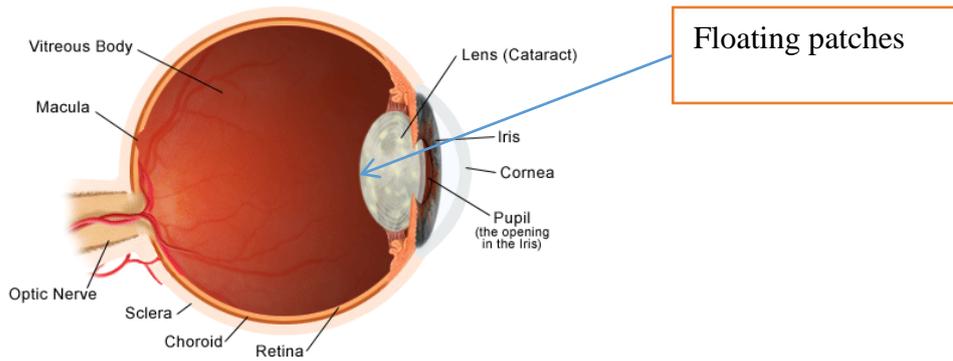
Figure 2.5: Example of Cataract [11]

Cataracts are fairly common in elderly people and cause cloudy patches that develop in the lens of the eye. Causing blurry or misty vision, cataracts can be seriously debilitating as the vision becomes increasingly worse over time.
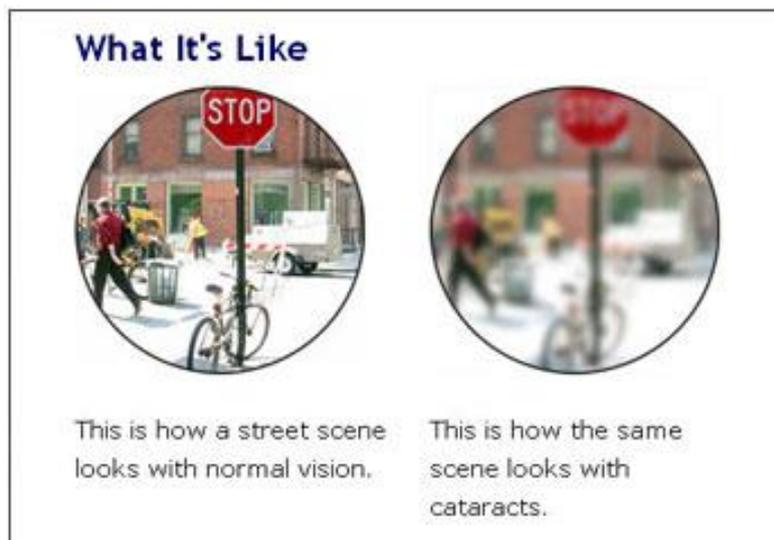
Figure 2.6: Cataract Vision [12]

The cloudy patches prevent light from getting to the back of the eye and thus can reduce the vision to near blindness if left untreated. As cataracts often affect both eyes, although each eye may be affected differently, the vision can become so reduced that the sufferer may find it difficult to see in dim or very bright light, colours may be less clear or double vision may present itself, making seeing clearly difficult. It is thought that cataracts are caused by changes in the proteins of the lens of the eye which cause the structure to change and thus create the 'clouding' that is typical of cataracts. The only current cure is surgery which can be both invasive and painful.

2.3.3 Glaucoma

Another vision condition is glaucoma. Approximately 2% [2] of visually impaired persons are affected by glaucoma's across the world. There are 4 types of glaucoma, which are listed below and illustrated in Figure 2.7.
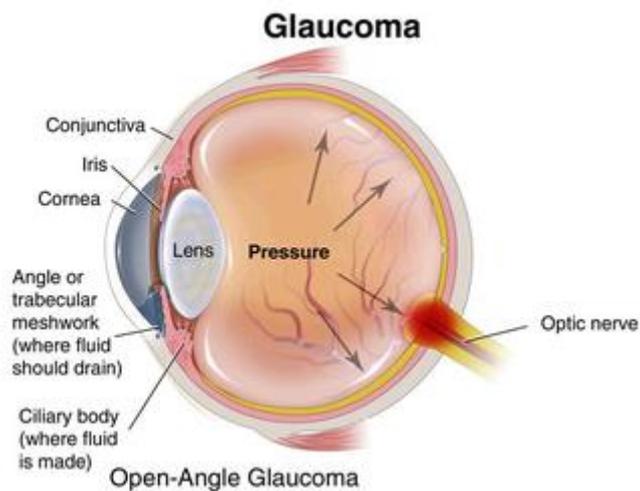
Figure 2.7: Open Angle Glaucoma [13]

1. Chronic open-angle glaucoma

2. Acute angle-closure glaucoma

3. Secondary glaucoma

4. Developmental glaucoma

Each type has its own individual symptoms but the most common one is the chronic open-angle glaucoma, which develops very slowly over a long period of time. There are usually no noticeable symptoms as the first part of the eye to be affected is the peripheral vision. Symptoms usually include seeing 'halo's around the eye, blurriness, double vision and being sensitive to bright lights. Glaucoma's are caused by a build-up of pressure behind the eye, caused by the loss of ability to drain fluid normally away from the eyeball itself [2].

2.3.4 Cortical Visual Impairment

Cortical visual impairment (CVI) and Neurological Visual Impairment (NVI) and make up the majority of remaining 22% of visual impairment cases across the globe [70]. Cortical Visual Impairment (CVI) and or Neurological Visual Impairment (NVI) are not generally caused by a diseases or illness, but they do cause visual impairment to varying degrees as secondary symptoms. It is worth noting some people can be affected with both cortical and ocular impairment at the same time.

Cortical Visual impairment is an impairment of the vision that is caused by problems with the brain and includes problems [70]. There are many causes of CVI and NVI, including strokes involving the occipital lobe, asphyxia, brain injury, developmental brain defects, hypoxia and infections of the nervous system such as meningitis. As we have discussed above with some of the main reasons for visual impairment, CVI symptoms include double vision, blurriness, halo's in the vision, pain and a dislike of bright or dim lights, colour differentiation, tunnel vision and long or short-sightedness [4, 70].

2.3.5 Children with visual impairments

During a study that was undertaken by the RNIB in 2011/2012 it was shown that nearly 19,000 children under the age of 16 were classed as being partially sighted [4], with 25,000 young persons between the ages of 0-17 being registered as having a visual impairment by 2013 [14], with around half of the registered young people also having a learning disability. The RNIB does note that this statistic is difficult to obtain a true estimate due to the differences in categorisation of sight problems, the definitions of visual impairments and the way data is collection [14].

Visual impairments in children can have a significant effect upon the development of a child due to the obvious fact that they cannot see very well. Most of the learning that a child does during the first 2 years of its life is done through sight alone and it is understandable that a child as young as this may have severe behavioural and emotional development issues as it grows older [4,2,70].

Issues presented may vary considerably from one child to another but a lack of communication with a child can give severe emotional problems including long-standing psychological and emotional problems over time. Issues related to visual impairment are outlined below, along with the implications on a child's development.

2.3.6 Motor Sensory skills

Poor vision may decrease a child's ability to explore what is around them [2,3]. The implications of this may be slow development in walking, talking or crawling. This isn't really surprising, as we have discussed above, children learn primarily from watching when they are very young and not being able to see properly may make a child scared or unsure about new things and places. Figure 2.8 shows an example where a child learns from copying their friend's actions by choosing right pattern.

Figure 1.8: Motor Sensory a child learns from copying the pattern [15]

2.3.7 Sensory development

Sensory development refers to the development of the senses of hearing, sight, smell, taste and touch. The world to a child is a scary place as it is, however, imagine how worse it would be when it can't see properly [15,14]. A child may also have problems with body awareness and may be frightened by loud noises, different smells or a voice that they do not recognise as depicted in Figure 2.9.

Figure 2.9: Sensory Development do not recognise the object [15]

2.3.8 Communication development

Again, as we have discussed above, children primarily learn by sight, especially when it comes to communicating with what is around them. Many conversations begin when people make eye contact or by making some sort of signal, neither of which a young child may be able to recognise. It is therefore paramount that a person approaching a child speaks clearly, soothingly and in a friendly manner so as not to frighten a young child [14,15, 2].

We learn our social skills at a very young age, again, primarily most of these through seeing one another or from watching how others interact. It is therefore understandable that a child with a visual impairment may have issues in later life with communicating and recognising the relevant social interactions that are 'normal' to others. This in itself can cause huge implications, even as the child grows older and is able to learn.

Communication at a very young age is paramount to the development of a child, we communicate 55% of what we mean via body language (this figure is subject to dispute) [65] and it is understandable that if communications are not learnt at a young age that a child may struggle to develop the correct social skills needed in daily life. Children who suffer from a visual impairment may also need help in learning the social skills that are expected during conversations and interactions with another person.

For example, they may need to learn to "look" towards a speaker and when it is appropriate to enter a conversation. They may also need to be taught about the facial

17

expressions or body postures that other people expect from them during a conversation [65].

Research into how to help pre-school children with visual impairments is growing, however, the reliance upon sensory perception and audible guidance is still heavily implemented. Once a child reaches school age, there is more help on offer with braille being offered in some schools and an abundance of learning materials, however to date there are still limited resources that allow a child to use a computer to a standard that is required in today's fast paced technological world. For example, a Braille alphabet as shown in Figure 2.10 can help the visually impaired to use a computer keyboard.
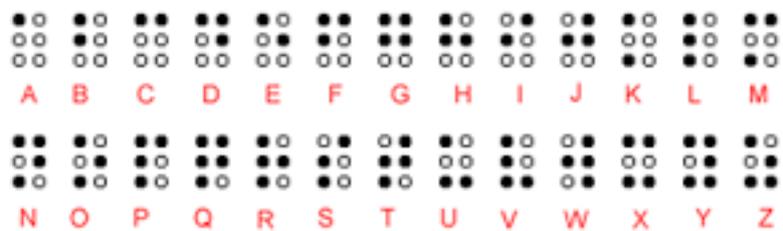
Figure 2.10: Braille alphabet [16]

3. Colour Blindness

Colour blindness is neither a disease nor a secondary physiological symptom of an illness [1,17,18]. It has been given its own sub-heading as colour blindness is not classified as a visual impairment but for the benefit of this project. As the first part of the work of development of an assistant system for the visually impaired, I feel there is a need this should be addressed since that colour blindness or colour vision deficiency (CVD) affects approximately 1 in 12 men (8%) and 1 in 200 women in the world [18]. In the UK, there are approximately 2.7 million colour blind people (about 4.5% of the entire population), most of whom are male. Figure 10 demonstrates what a person with a colour deficiency can see.
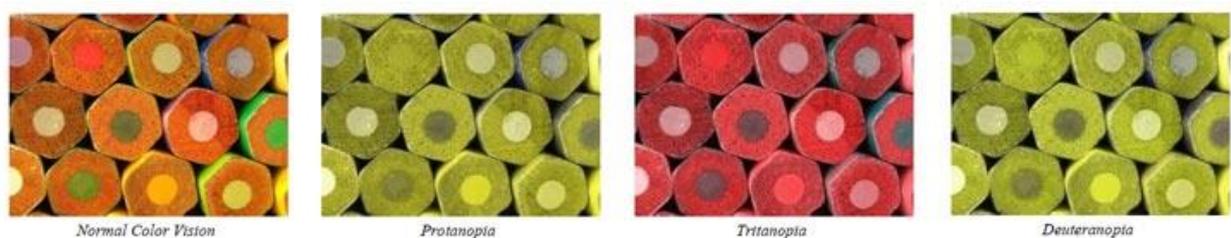
Figure 3.1 Type of CVD [17]

The term colour blind is slightly ambiguous as the word 'blind' is usually used when people cannot see anything or have a very limited amount of vision but in the case of colour blindness, most people affected are not able to fully 'see' **Green**, **Red** or **Blue** light as pointed out in Figure 3.1. Contrary to popular belief most colour blind people are able to see some colours and certainly tones of different colours, although in extremely rare cases true colour blindness will not allow them to recognise any colours at all [1,17,18].
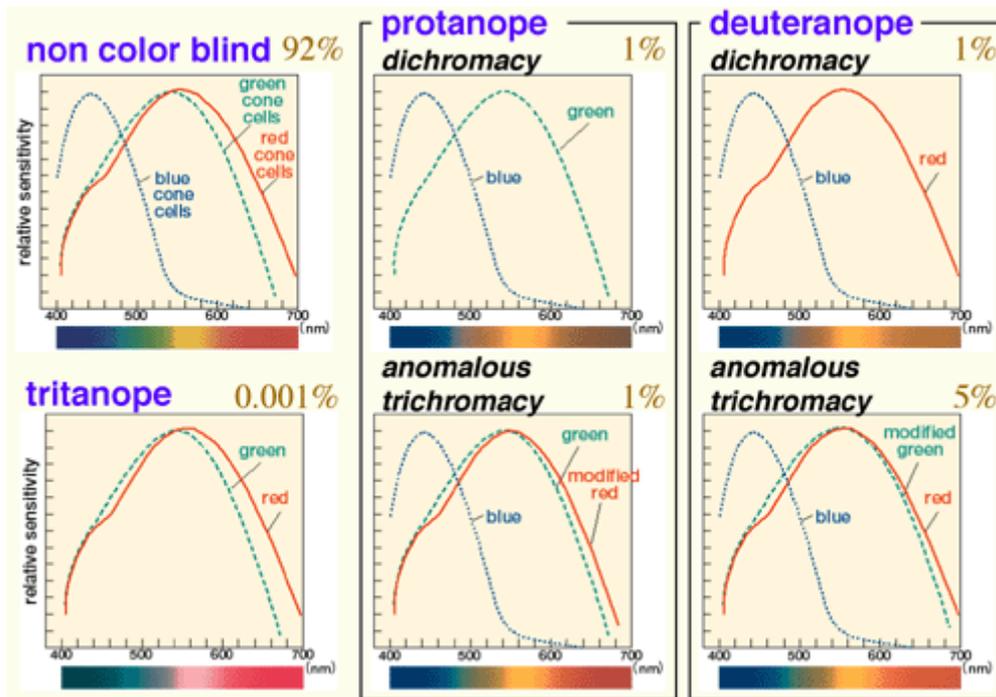
Figure 3.2: CVD in RGB Graph [19]

Colour blindness is generally classed as being a genetic disorder with the deficient gene coming from the mother but it is worth noting that it is not a wholly genetic disorder and there are many causes of CVD that may present as secondary symptoms from another disease [1]. It is the X chromosome that is effected, hence why CVD presents itself in more males than females.

4.   Colour Vision Theory

Colour is an attribute of visual experience and closely related to the other science [20,21,22]. Physics defines light as the electromagnetic radiation in the visible spectrum. Physiologists study the colour receptor mechanisms in the human eye and brain. Colour psychology studies the response of an observer to colour sensations, e.g. whether he or she calls it red or green. Psychophysics is involved in understanding relationships between physical stimulus and subjective response. Mathematics attempts to describe these relationships by numbers and equations. Chemistry is related in two ways: the mechanisms by which light is absorbed in the eye, and the use of dyes and pigments to produce coloured objects [23,24].

The perception of a coloured object ordinarily requires three components: a light source, an object and an observer.

4.1 Light and Wavelength

Colour is a property of light rather than of bodies [22,25]. Without light, colour cannot be sensed. White light, such as sunlight, is not a simple energy, but consists of different colour light travelling at thousands of trillion frequencies each second between the short-wave ultra-violet with high frequency and the long-wave infrared with low frequency. Light can be described by its wavelength for which the nanometre (nm) is a convenient unit of length [26] (One nanometre is 1/1,000,000 millimetre). The light source emits radiant energy well distributed in the spectrum between 380 and 780 nm. When these rays strike the eye simultaneously, the sensation of "white light" is perceived. This remarkable fact was first proved by Sir Isaac Newton at Cambridge in 1666 by means of a triangular glass prism and a beam of sunlight in a darkened room [27]. In this experiment, sunlight was passed through from a small round hole in the window shutter of a darkened room. The beam was directed on to the side of a prism, emerged onto a white surface and altered to a long band consisting of bars of seven different colours. These colours were described as violet, indigo, blue, green, yellow, orange, and red from short to long wavelengths. This coloured band of light is named 'spectrum', the basis of colour science as illustrated in Figure 4.1.

Our eyes are sensitive to light which lies in a very small area of the electromagnetic spectrum labelled "visible light". This "visible light" resembles to a wavelength range of 400 - 700 nanometres (nm) colour range of violet through red.

The human eye is not capable of "seeing" radiation with wavelengths outside the visible spectrum. The visible colours from shortest to longest wavelength are: violet, blue, green, yellow, orange, and red.

Ultraviolet radiation has a shorter wavelength than the visible violet light. Infrared radiation has a longer wavelength than visible red light. The white light is a mixture of the colours of the visible spectrum. Black is a total absence of light.
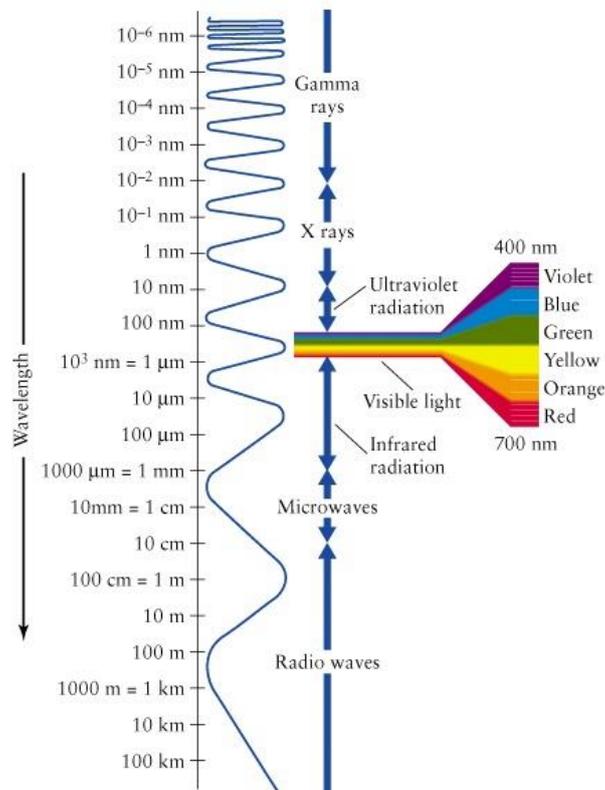
Figure 4.1: Wavelength image from Universe by Freedman and Kaufmann [28]

4.1.1 Violet Light

The visible violet light has a wavelength of about 400 nm. Within the visible wavelength spectrum, violet and blue wavelengths are scattered more efficiently than other wavelengths. The sky looks blue, not violet, because our eyes are more sensitive to blue light (the sun also emits more energy as blue light than as violet).

4.1.2 Indigo Light

The visible indigo light has a wavelength of about 445 nm.

4.1.3 Blue Light

The visible blue light, as pointed in Figure 4.2, has a wavelength of about 475 nm. Because the blue wavelengths are shorter in the visible spectrum, they are scattered more efficiently by the molecules in the atmosphere. This causes the sky to appear blue [28].
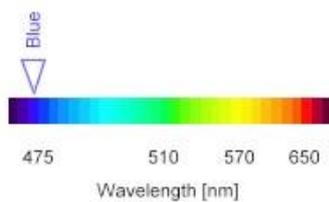
Figure 4.2: Blue light in the wavelength [28].

4.1.4 Green Light
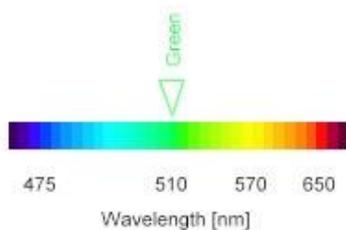
The visible green light has a wavelength of about 510 nm. Grass, for example, appears green because all of the colours in the visible part of the spectrum are absorbed into the leaves of the grass except green. Green is reflected, therefore grass appears green [28].

4.1.5 Yellow Light
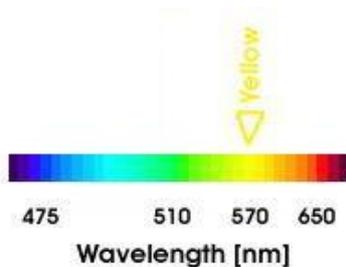
The visible yellow light has a wavelength of about 570 nm. Low-pressure sodium lamps, like those used in some parking lots, emit a yellow (wavelength 589 nm) light [28].

4.1.6 Orange Light

The visible orange light has a wavelength of about 590 nm [28].

4.1.7 Red Light
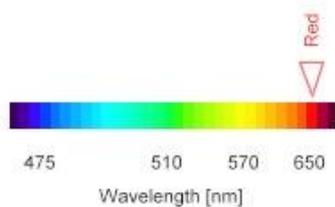
The visible red light has a wavelength of about 650 nm. At sunrise and sunset, red or orange colours are present because the wavelengths associated with these colours are less efficiently scattered by the atmosphere than the shorter wavelength colours (e.g., blue and purple) [28].

4.2 Coloured Objects

When light strikes an object, one or more things pertinent to colour can happen [25,28]. Most objects owe their colour to substances that absorb radiant energy within the visible spectrum. These substances are called colorants: if insoluble, pigments; if soluble, dyes.

4.3 Colour Vision

Colour vision is the result of a system comprising the eye, the nervous system, and the brain. Thomas Young [29] first propounded the trichromatic theory of colour vision including three types of cone receptors (or colour receptors) in the eye, red, green, and violet, following Newton's earlier investigation.

Human colour perception is dependent upon the interaction of all receptor cells with light, and this combination results in nearly Trichromic stimulation. There are shifts in colour sensitivity with variations in light levels, so that blue colours look relatively brighter in dim light and red colours look brighter in bright light. This effect can be observed by pointing a flashlight onto a colour print, which will result in the reds suddenly appearing much brighter and more saturated.

Perceiving colour allows humans (and many other animals) to discriminate objects on the basis of the distribution of the wavelengths of light that they reflect to the eye.

While differences in luminance are often sufficient to distinguish objects, colour adds another perceptual dimension that is especially useful when differences in luminance are refined or non-existent. Colour obviously gives us a quite different way of perceiving and describing the world we live in [28].
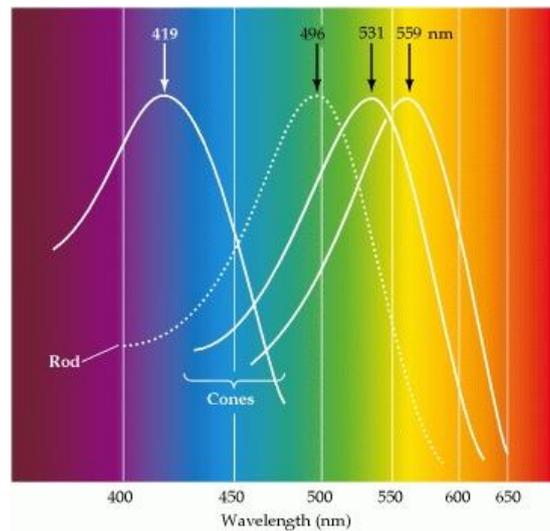
Figure 4.3: Relative Absorbance [19]

The absorption spectra, as illustrated in Figure 4.3, contains four photo pigments in the normal human retina. The solid curves in Figure 4.3 indicate the three kinds of cone opsins; the dashed curve shows rod rhodopsin for comparison. Absorbance is defined as the log value of the intensity of incident light divided by intensity of transmitted light [28].

Furthermore, as three kinds of cones in the human retina. The cones are hosting Young's resonators – the visual pigments. Those which are sensitive for the longest visible wavelengths are called **L-cones or p-cones** (*L for long wavelength or p from Greek proton, "the first"*), those with maximum sensitivity in the middle range are called **M- or d-cones** (*deuteron = "the second"*), and the third ones are called **S- or t-cones**.

These cones supply three primary colours; therefore, human colour vision is supposed to be trichromatic. It is known that birds and also marsupials have tetra-chromatic vision i.e. they have four different cone pigments, while most mammals are dichromate, having only two.

A small percentage of humans also has only dichromatic vision, lacking the **L**-(protanopia), **M**- (deuteranopia), or (very seldom) the **S**-cones' pigment (tritanopia) [28,29].
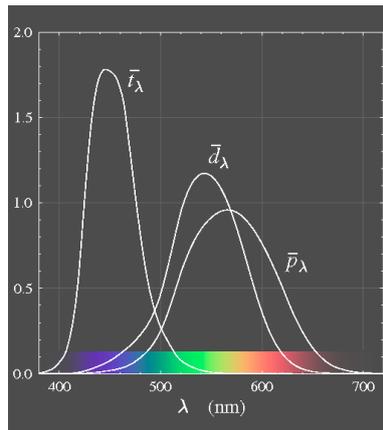
Figure 4.4: Spectral Sensitivity [33]

Average sensitivity curves of the L- (p), M- (d), and S- (t) colour receptor systems. The 1931-CIE colour matching functions supplemented by data on colour deficient persons have been used to generate the functions Figure 4.4. Individual sensitivity curves may be slightly different, but the general appearance is always the same [67].

4.4 When do we see which colour?

Perfect schematic remission curves of a blue, green and red surface Figure 4.5. If only the short wavelengths are strongly remitted (blue line), the S-receptors are stimulated strongly and the M-receptors only weakly, and the resulting sensation is "blue". The primary sensations "green" and "red" arise when the stimulation of the M- or L-cones, respectively, strongly exceeds that of the other ones [29].
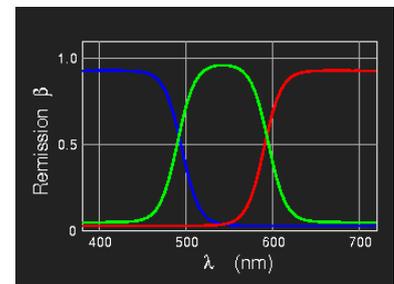
Figure 4.5: Remission B [33]

Perfect transmission curves of layers of inks as used for colour printing (or remission curves of white paper with yellow, magenta or cyan ink on it) Figure 4.6. The yellow ink absorbs strongly the short waves and let's middle and long waves pass, magenta absorbs most strongly in the middle range and cyan in the long-wavelength region. Yellow is, so to say, white minus blue, magenta is white minus green, and cyan is white minus red [29,67].
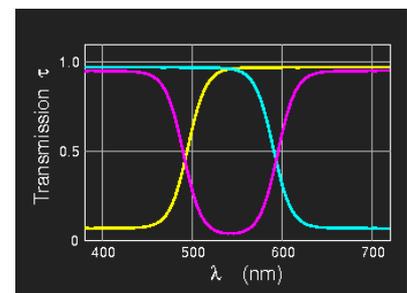
Figure 4.6: Transmission T [33]

5. Colour Models

Colour models are used to categorise colours and to qualify them according to their attributes like hue, saturation, Chroma, Contrast, or brightness. They are further used for matching colours and are valuable resources for anyone working with colour in any in image, or Web. For the reason of my research I will need to explain the ways colour is made accessible to users and look at some of the area that occur when colour is used in computer produced applications.

CIE stands for **Commission Internationale de l'Eclairage** (International Commission on Illumination). The commission was founded in 1913 as an autonomous international board to provide a forum for the exchange of ideas and information and to set standards for all things related to lighting. As a part of this mission, CIE has a technical committee, Vison and Colour, that has been a leading force in colorimetry since it first met to set its standards in Cambridge, England, in 1931 [59].

5.1 The CIE Colour Models

The CIE colour model was developed to be completely independent of any device or other means of emission or reproduction and is based as closely as possible on how humans perceive colour. The key elements of the CIE model are the definitions of standard sources and the specifications for a standard observer [59].

5.2 Standard Sources

A light from any source can be described in terms of the relative power emitted at each wavelength. Plotting this power as a function of wavelength gives the spectral power distribution curve of the light source. The spectral power distribution of a given light source can be measured by a spectro-radiometer.

Colour temperature is another term for specifying light sources. One group of light sources are called blackbodies. When heated, they glow like metals, first a dull red like a hot electric stove, then progressively brighter and whiter like the filaments of incandescent light bulbs. Real blackbodies are hollow heated chambers. Their spectral

power distribution and their colour appearance only depend on their temperature rather than their composition as illustrated in Figure 5.1 The temperature of the blackbody is defined as colour temperature with the unit of Kelvin (K) [30]. If the colour of a real light source (e.g. a fluorescent lamp) does not visually match any of these colours in a blackbody, a correlate of colour temperature can be found. This is defined as the temperature of the blackbody whose perceived colour gives the closest match to that of a given stimulus seen at the same brightness under a set of specified viewing conditions [31].
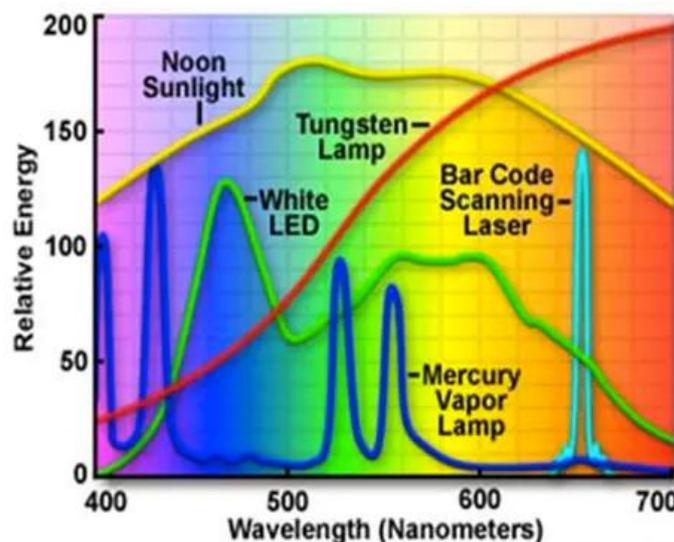
Figure 5.1: Spectral power distribution curves of a few light sources [32].

The following CIE standard sources were defined in 1931 in terms of colour temperature [67].

• Source A

A tungsten-filament lamp with a colour temperature of 2854K

• Source B

A model of noon sunlight with a temperature of 4800K

• Source C

A model of average daylight with a temperature of 6500K

Sources B and C are actually derived from source A through the use of filters that alter their spectral power distribution.

CIE augmented these sources in 1965 with a number of standard illuminates [59]. As mentioned in the Technical Guide, "Basic Colour Theory for the Desktop," illuminates are not physical sources; rather, they are models of light defined by a spectral power distribution. CIE sources A, B, and C are also defined as standard illuminates.

In addition, CIE has defined a series of daylight illuminates called the Daylight D series. Of these Illuminate D65 with a colour temperature of 6500K is the most commonly referenced.

5.3 Standard Observer

CIE has two specifications for a standard observer: the original 1931 specification and a revised 1964 specification. In both cases the standard observer is a composite made from small groups of individuals (about 15-20) and is representative of normal human colour vision. Both specifications used a similar technique to match colours to an equivalent RGB value.

The observer viewed a split screen with 100% reflectance (that is, pure white). On one half a test lamp cast a pure spectral colour on the screen. On the other half, three lamps emitting varying amounts of red, green, and blue light attempted to match the spectral light of the test lamp. The observer viewed the screen through an aperture and determined when the two halves of the split screen were identical. The RGB Tristimulus [34] Figure 5.2, values for each distinct colour could be obtained this way.
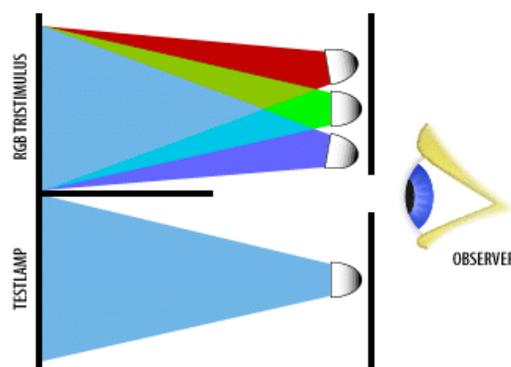
Figure 5.2: The RGB Tristimulus [34]

The significant difference between the 1931 and 1964 standard observers was the field of vision used to view the screens. The 1931 observer had a 2° field of vision (i.e., the amount taken in by the fovea alone). This was later considered inadequate in many cases since it did not take in enough of the observer's peripheral vision. The 1964

specification widened the observer's field of vision to 10° in order to get Tristimulus values that reflect a wider retinal sensitivity.

5.4 CIE Models

Once the RGB Tristimulus [34,59] values were obtained, they were found to be wanting in some regards. Due to gamut restraints, the RGB colour model could not reproduce all spectral light without introducing the effect of negative RGB values (this was done by mixing red, green, or blue light with the test lamp as needed). CIE thought a system that used negative values would not be acceptable as an international standard. Accordingly, they translated the RGB Tristimulus values into a different set of all positive Tristimulus values, called XYZ, which formed the first CIE colour model. From this first model, other models were derived in response to various concerns. Go to the following for a concise summary of each:

CIEXYZ, the original CIE model using the chromaticity diagram adopted in 1931 [67,59].

CIELUV, a model composed in 1960 and revised in 1976. This model uses an altered and elongated form of the original chromaticity diagram in an attempt to correct its non-uniformity [48].

CIELAB, a different approach developed by Richard Hunter in 1942 that defines colours along two polar axes for colour (a and b) and a third for lightness (L) [35].

5.4.1 CIEXYZ

CIEXYZ is the very first mathematical model recommended in 1931 by International Commission on Illumination (CIE) to represent a colour, and is also called CIE 1931 XYZ colour space [67].

The CIE XYZ colour space was derived from a series of experiments done in the late 1920s by W. David Wright and John Guild [68]. If a colour is given by **I(λ)**, and **x(λ)**, **y(λ)** and **z(λ)** are matching functions **Equation 1**, gives the values of X, Y, and Z, which are also called **Tristimulus** values for the colour, whereas **λ** is the wavelength measured in nanometres in below equation.

Equation 1:

$$X = \Sigma I(\lambda)x(\lambda) \qquad Y = \Sigma I(\lambda)y(\lambda) \qquad Z = \Sigma I(\lambda)z(\lambda)$$

5.4.2 CIELUV

In 1976, the CIE defined a new colour space CIELUV to enable us to get more uniform and accurate models. Sometimes, it is also called universal colour space. This colour representation is derived from CIEXYZ. The CIE LUV colour space is a perpetually uniform derivation of a standard CIEXYZ space [48].

5.4.3 CIELAB

Another colour space recommended by CIE is CIELAB [35]. A Lab colour space is a colour-opponent space with dimension L for lightness and a & b for the colour-opponent dimensions, based on nonlinearly compressed CIE XYZ colour space coordinates [35].

5.5 RGB Model

RGB and its complementary CMY form the most basic and well-known colour model [67,48,35]. This model bears closest resemblance to how we perceive colour. It also corresponds to the principles of additive and subtractive colours.

Preservative colours are created by mixing spectral light in varying combinations. The most common examples of this are <u>television</u> screens and <u>computer monitors</u>, which produce coloured pixels by firing red, green, and blue electron guns at phosphors on the television or monitor screen.

More accurately, preservative colour is produced by any combination of solid spectral colours that are optically mixed by being placed closely together, or by being presented in very rapid succession. Under these circumstances, two or more colours may be perceived as one colour.

Red, Green, and Blue are the primary stimuli for human colour perception and are the primary additive colours. The relationship between the colours can be seen in this illustration Figure 5.3.
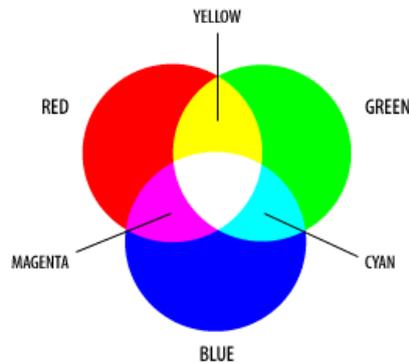
Figure 5.3: RGB Colour Palette

The secondary colours of RGB, cyan, magenta, and yellow, are formed by the mixture of two of the primaries and the exclusion of the third. Red and green combine to make yellow, green and blue make cyan, blue and red make magenta.

The combination of red, green, and blue in full intensity makes white. White light is created when all colours of the EM spectrum converge in full intensity.

The importance of RGB as a colour model is that it relates very closely to the way we perceive colour with the r g b receptors in our retinas. RGB is the basic colour model used in television or any other medium that projects the colour. It is the basic colour model on computers and is used for Web graphics, but it cannot be used for print production [67,48].

6. Type of Colour Vision Deficiency

CVD is split into several types [1], each presenting their own colours issues;

- Monochromacy (achromatopsia);
- Tritanopes; Deuteranopes;
- Protanopia; Dichromacy;
- Anomalous Trichromacy;

Trichromacy with Deuteranopes being the most common and Achromatopsia being the most rare – so rare that only 1 in 33,000 people are affected by it [1,17]. In Achromatopsia, the person can only see tones of black and white, leading to colours presenting themselves as varying tones of grey, black or white.

Red/Green colour blindness or Deuteranopia is the most common form of colour blindness. It is often thought that Deuteranopia suffers mix up red and green colours, this is not true, the whole colour spectrum that includes red or green hues become mixed up, such as orange and purple colours. For example, a person may confuse blue and purple because they are not able to 'see' the red element in the colour purple.

Colour blindness is often difficult to diagnose thanks to its varying degrees of severity for example it is estimated that approximately 40% of people who are colour blind leave secondary education unaware that they are suffers [1,17,18].

The effects of colour vision deficiency can be mild, moderate or severe so, for example, approximately 40% of colour blind pupils currently leaving secondary school are unaware that they are colour blind, whilst 60% of sufferers experience many problems in everyday life.

In Figure 6.1 image contain pen in Red, Purple and Blue which is in Normal Vision, if a person cannot see Red component therefore colour Purple and Blue are alike and Red become Grey Figure 6.2

Figure 6.1: Normal Vision

Figure 6.2: Vision with Deuteranopia

There are some specific differences between the 2 red/green deficiencies [1,17, 18, 20]:

6.1 Protanopia

Protanopes are more likely to confuse:

1. Black with many shades of red
2. Dark brown with dark green, dark orange and dark red
2. Some blues with some reds, purples and dark pinks
3. Mid-greens with some oranges

6.2 Deuteranopes

Deuteranopes are more likely to confuse:

1. Mid-reds with mid-greens
2. Blue-greens with grey and mid-pinks
3. Bright greens with yellows
4. Pale pinks with light grey
5. Mid-reds with mid-brown
6. Light blues with lilac

6.3 Tritanopes

The most common colour confusions for tritanopes are light blues with greys, dark purples with black, mid-greens with blues and oranges with reds.

7. The state of the art of aids

Although it is generally accepted that braille is the main way in which a visually impaired person 'reads', it still has its limits and is mainly aimed at those who are either blind or suffer from severe visual impairments. Audible help is still on offer with plenty of computer packages offering dictation programs to allow a visually impaired user to write on a computer and many web pages now offer an audible function to allow the user to have the content read to them, however the fact remains that one must still have help in accessing these programs and web pages in the first instance. The quest for full independence of a person with visual impairments is still in its infant stages with developments occurring every day but the use of the computer in this day and age is an absolute must, especially that this is obtainable on an independent level. (Gao & Loomes, 2016) [40].

7.1 How can a person with visual impairment be helped?

With a mild visual impairment, the user may still be able to use a computer competently, however again this may have its limits as to what a computer is actually able to offer. Corrective lenses may well help suffers but even with anti-glare spectacles, the user may well still suffer from associated problems such as head-aches and a lack of ability to concentrate due to the glare coming from the screen. In the case of double vision – a problem which has been raised as symptoms of almost all of the main cause of visual impairment – the ability to correct this when using a computer is not as simple.

Corrective lenses again may help the problem to a certain degree, however, it is not always corrected completely which can lead to associated neck problems, caused by the tilting of the head and head-aches from eye strain of the none affected eye having to work harder to counteract the problem. Blurriness can also be helped by the use of corrective lenses but again issues arising from associated problems from the wearing of lenses can cause eye strain at varying degrees.

Looking upon a computer screen itself has been associated with many eye problems, as we have just discussed, the use of corrective lenses helps some refractive errors in the eye but one symptom, the intolerance of bright or dim lighting, has not yet had a solution found.

The problem with using a computer, tablet or even mobile phone when suffering from intolerance to bright lights is that most of the time the screen needs to be lit to allow the user to read what is in front of them.

Although the brightness settings can be altered to a degree, this may present its own challenges, as too dark and the standard black text used may not be seen, yet by raising the colour depth to one of a greater brightness may bring back the previous intolerance to bright lighting, causing head and eye ache.

7.2 Using the Smart Devices with Colour Vision Deficiency

The above brief introduction about this new innovative system, one starts to appreciate the extra ordinary features compared to the normal glasses. It has one head mounted display (HUD) lens at the left side of the glasses which enable one to see and access to every app and features.

This enormous hands free equipment could help people with Visual Impairment and Colour Blindness and benefit them of its features.

The Google Glasses can be used in every place by just wearing them and benefit from its voice command and hands free features.

By developing and using the application that works independently we can process the live scene and define every objects colour in view and show it to the glass application to display to user.

There are different models of how to alter the visual information a wearer observes.

7.3 Virtual Reality (VR)

The goal is to create a fully virtual world for the user to see, interact with and immerse into. The user sees this virtual world only through head mounted glasses Figure 7.1; any other light sources are not affecting the eye. One significant difference to a simple screen is that the actions of the user affect the virtual world. In example movement affects what virtual content the user sees. A famous fictional example of a device creating a virtual world is the Holodeck from Star Trek.

Figure 7.1: Virtual Reality (VR) [37]

7.4 Augmented Reality (AR)

User can see the real world but also perceives virtual content created by a computing device and displayed by an additional light source Figure 7.2 which doesn't prohibit the perception of the real world. Interaction with those virtual objects is a way of communicating with the computing devices.
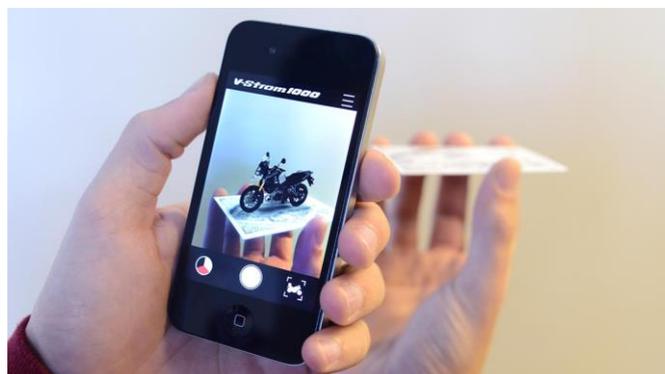
Figure 7.2: Augmented Reality (AR) [38]

Like other smart devices, smart glasses will often also have a camera. Significant differences to other camera devices are that the pictures or videos are taken from the user's point of view, there is no need for the user to hold the device in his hands and the vision of the user is not blocked. This camera can see what the users sees at any time. In combination with eye tracking technology the devices can determine exactly what the user is looking at. This allows the device to get vital information about the user's interests, activities, surroundings and occupation.

Those fundamental differences to other computing devices are what makes smart glasses unique and interesting. They enable new applications which couldn't be as easily realized with other devices.

7.5 Smart Glasses (ex. Google Glass):

Google Glass Figure 7.3 Project is a trial product glasses program developed by Google Inc. for an improved reality head-mounted HUD display the device which will demonstrate information in Smartphone based platform; it is hands free and could interact with applications via voice command.

The Glass was primarily made for everybody to share their world with each other and to make life more interactive and generally bring internet access, phone / video calling, GPS as part of our daily routine normal life with ease of access anytime and anyplace.
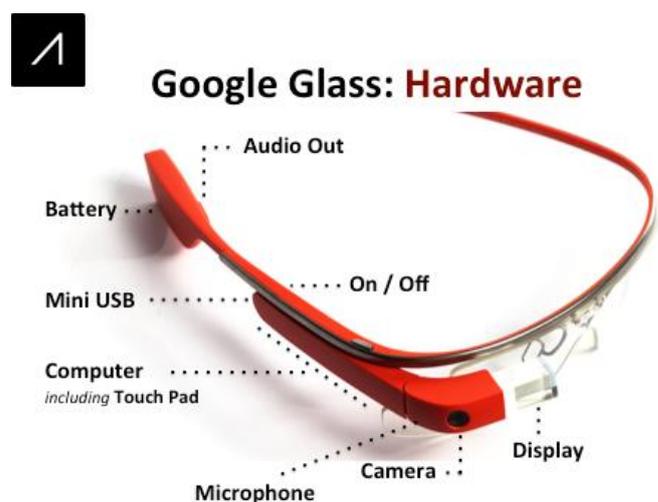
Figure 7.3: Smart Glasses [39]

8. Current progress on assisting the visual impaired

A number of research based on the aforementioned smart devices have been carried out. For example, Gao et al developed a model to enhance images through the application of CIECAM02 colour enhancement model to increase colour contrast for the visually impaired users (Gao & Loomes, 2016) [40].

In the work that is conducted by Ohkubo et al (Tomoyuki Ohkubo & Kazuyuki Kobayashi 2008) [41], a colour compensation vision system for colour blind people is proposed to enable colour-blind people to see the colours of green and red. In order to compensate image colour for colour-blind people, the image in RGB colour space is converted to HLS colour space which enables the defective colour range to be easily avoided.

In addition, helping people with Colour Vision Deficiency by using colour image processing device; is proposed and designed by Ma et al. (Y. Ma, E. Wang & Y. Wang 2011) [42]

Firstly, the image processing algorithms, containing perception simulation and colour adjusting for colour vision deficiency, are developed and tested using the computer. Then an embedded hardware system is designed, which can both exhibit the perception of different types of colour vision deficiency and implement different types of colour transformation algorithms.

With regard to smart phone applications, Schmitt et al [43] propose an advanced Android smartphone solution which fulfils three purposes: (a) it allows to easily diagnose red/green and blue/yellow colour deficiency (b) it supports people suffering from CVD by listing colours, which normally would not be recognizable as soon as the smartphone camera is directed towards any object (c) it provides a simulation mode, which presents any object to people without CVD the way people suffering from CVD would see them. (S. Schmitt, S. Stein, F. Hampe & D. Paulus 2012) [43].

Following this study, 267 volunteers have been checked using both traditional Ishihara plates and a computer system and LCD monitors. The study shows an identical diagnosis results which indicates that the new technologies can replace the traditional clinical tests or can be used for screening purpose in hard testing conditions (N. A. Semary & H. M. Marey 2014) [44].

Considering the substantial population affected by some form of colour-vision deficiency (CVD), reliable traffic control signal head light detection is an important problem for driver-assistance systems. Almagambetov el al [45] present a robust, traffic-standards-based, and computationally efficient method for detecting the status of the traffic lights without relying on Global Positioning System, LIDAR, radar information, or prior (map-based) knowledge. The system can accurately identify the status of the light at 400 ft away from the intersection, reliably detecting solid, faulty, arrow, and high-visibility signal lights. Over 50 h of video (over 2000 intersections) were tested with the system, containing intersections with one to four traffic lights, governing different lanes of traffic, with 97.5% accuracy of solid light detection (A. Almagambetov, S. Velipasalar & A. Baitassova 2015) [45].

Recently, various applications of mobile devices supporting colour vision deficiency are released. However, applications supporting colour vision deficiency may not work as designed performance. Takagi et al focus on how to select visual stimuli's colours using two methods. One method uses colours on a circumference whose centre corresponds to the white point. Another method uses colours on parallel lines to the line passing through primary colours (green and blue) (H. Takagi, H. Kudo, T. Matsumoto, N. Ohnishi & Y. Takeuchi 2014) [46].

9. Methodology and Development

This research aims at the development of an application to assist people with colour vision deficiency to use smart devices such as mobile phones, making most of the functions that a smart phone can offer.

The research intention is to develop application on smart phone to be able to identify and help the colour that is missing to the colour blind person, therefore the user will be able to see that particular colour outlined or highlighted in visible colour for easy recognition.

9.1 Development

The application will work and collaborate on mobile phone or other smart devices such as Smart Glasses if their hardware is able to handle out the process required by the application.

The project App has two main interfaces: 1- **Test and collaborate** 2- **Take Picture and enhance;** through the phone camera and apply necessary filter to the taken photo or choose from library.

The app is developed on Android system based on C# with Xamarin Studio to be compiled for Android (Java platform) computer languages, It will then extend to other platforms such as Apple and Windows.

Essentially in the First section by passing few slides which are on Ishihara test, we realise which colour pattern is suitable for observer. Based on the measurement result from the first section we go to the next part of the application for applying the filters. In second part of application we have option to choose picture from library or take an image capture from phone's camera. By using measurement result collected from previous stage correct filter will apply on the photo, furthermore under captured photo has few adjustment options which can apply to adjust Red Green Blue (RGB). The following Figures 9.1.1,9.1.2,9.1.3 demonstrate the working process of the application.

In initially, a user is asking whether he/she can perceive a number in Figure 9.1.1 and gives the answer at the bottom of the screen as example in Figure 9.1.1 image No 5 displayed and three choices are available 4, 12, 5 to select. Upon this answer application will log and keep the answer based on users input and will be used for second stage of the application. In the second part of the application Figure 9.2 entry of a picture from phones library or to capture from phones camera is requested from application then taken picture will be enhanced and adjusted accordingly for user Figure 9.1.3.

**Visible Colour Test
What do you see in the slide?**

Slide timer: 5 sec

Select Answer

| 4 | 12 | 5 |
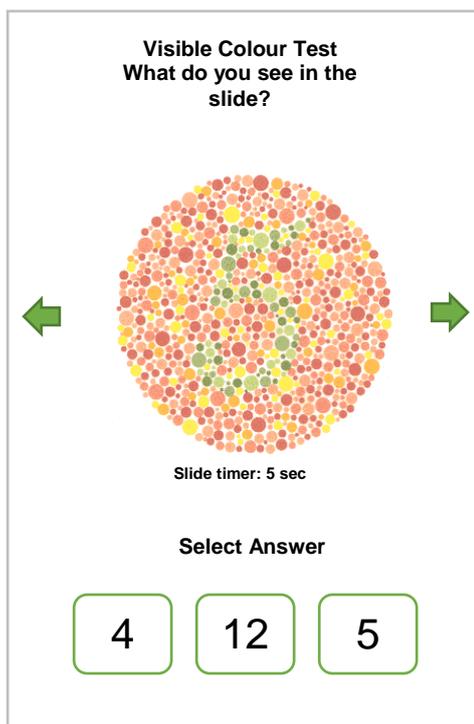
Figure 9.1.1: First Screen of App

Take a Picture
or
Choose from Library
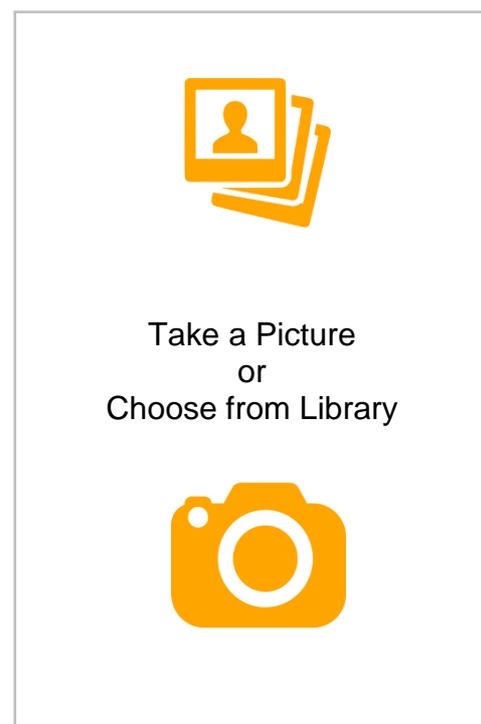
Figure 9.1.2: Second Screen of App

If the user gives the answer other than '5', then he/she might be missing red colour element, the picture is then enhanced mainly using green, blue and yellow primary colours as depicted in Figure 9.1.1 although it has capability to go for previous stage.
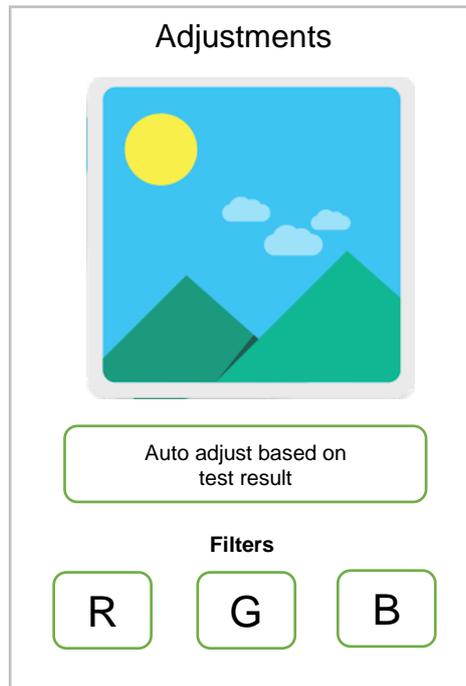
Similarly, the following figures illustrate the interfaces to detect other colour deficiency. In following part, we have overview of the app in Android Studio simulation which present the examination and result.

Figure 9.1.4 Mobile App in Demonstration with result shown in chart.

Figure 9.1.4 Mobile App in Demonstration with result shown in chart.

44
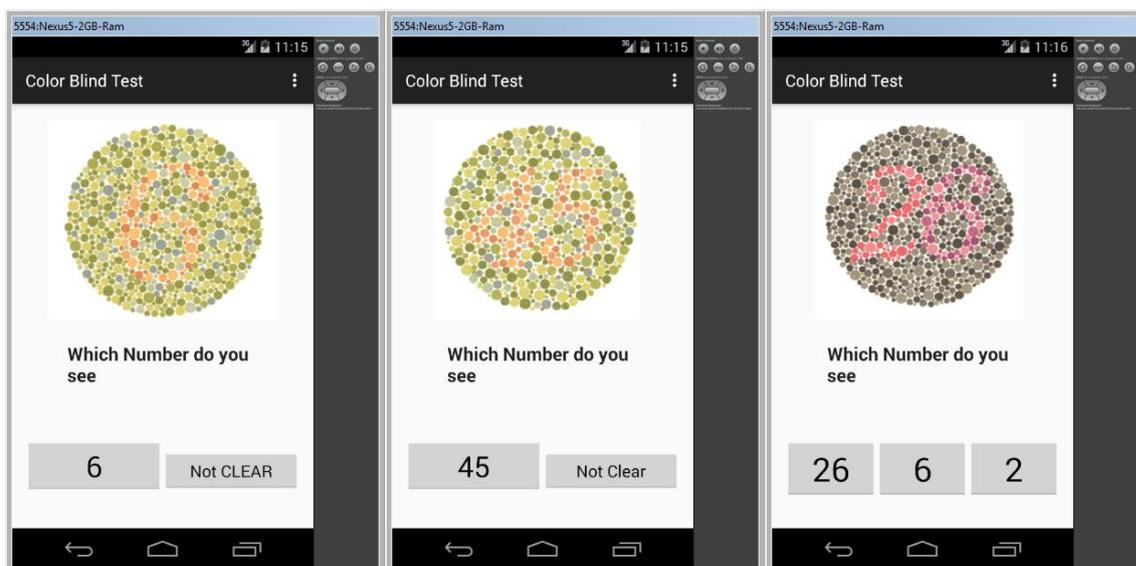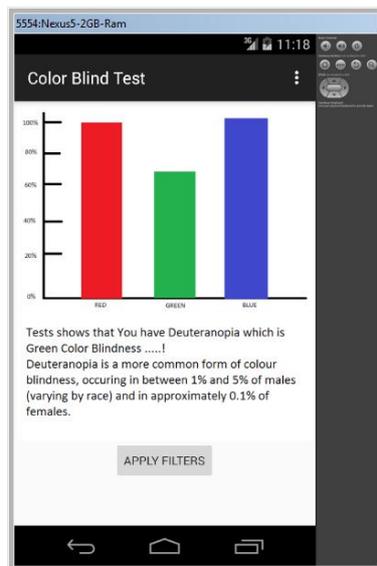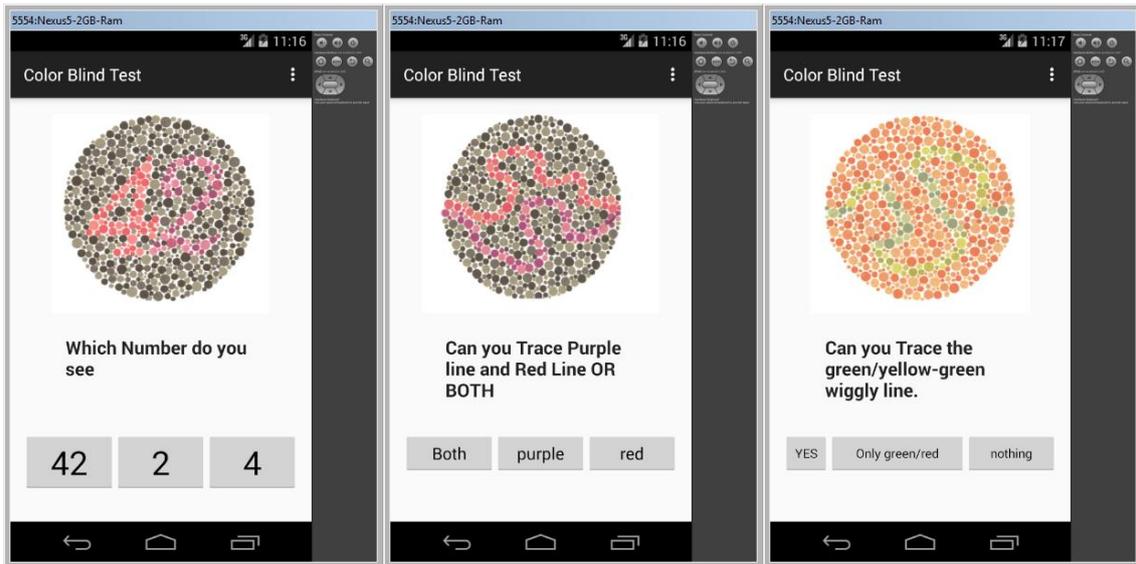
9.2 Data Collection and Analysis

In my developed application I used "Ishihara's" [36] colour palette Figure 9.2.1 to examine and analyse candidates colour vision status, then I have extracted the colour property value of each palette in Hex colour code as well as their RGB values which is demonstrated below, in an attempt to explain the reasons behind detection of missing colour elements details.

The extraction of these information is performed by PHP [Code 1: Extract colour from image by PHP].

The below chart is the extracted RGB values from Figure 9.2.1 Ishihara's Palette which in normal sight display No 26 in Red and Pink colours, In the value clearly shows the amount of "R" (red), "G" (green) and "B" (Blue) values present in the picture. In following colour palette that show "26" we have 40% Red, 30% Green and 30% Blue as displayed in the pie chart.

Hex Colour Code	R	G	B
Green	**0**	**255**	**0**
a89078	168	144	120
606048	96	96	72
787860	120	120	96
d8d8c0	216	216	192
c0c0a8	192	192	168
f0f0f0	240	240	240
a8a890	168	168	144
Red	**255**	**0**	**0**
f09090	240	144	144
a84878	168	72	120
f07878	240	120	120
c07890	192	120	144
c06078	192	96	120
f06060	240	96	96
f00a8a	240	10	136
fffff0	255	255	240
fff0f0	255	240	240
fff0ff	255	240	255
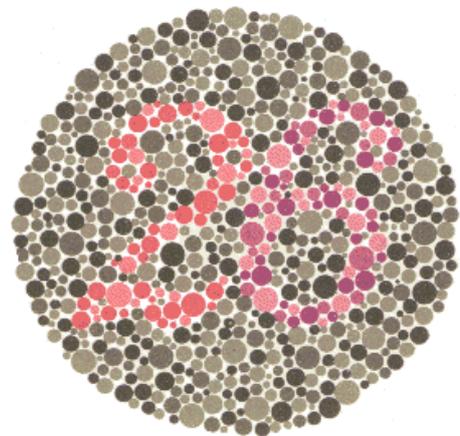
Figure 9.2.1: Ishihara palette test No. 26 used within App
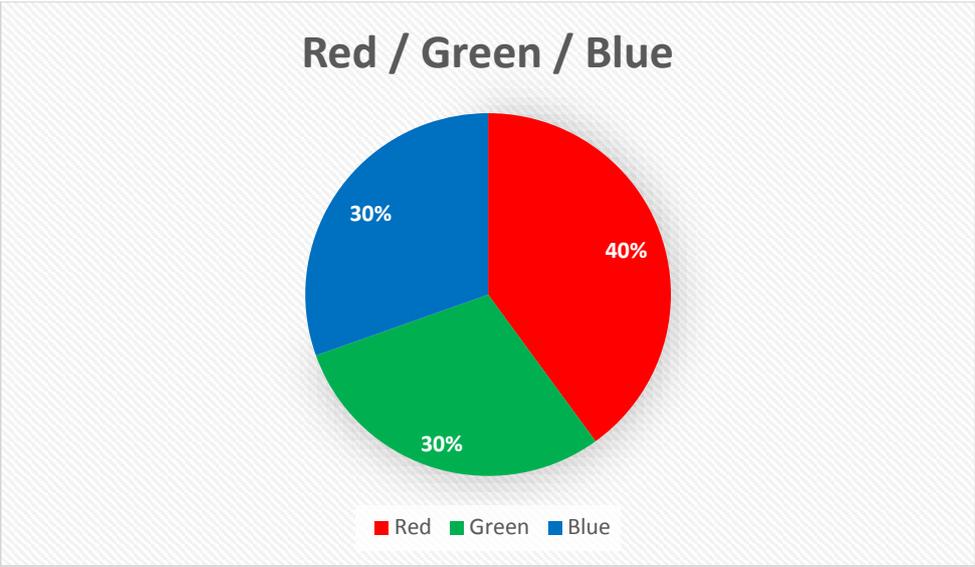
Figure 9.2.2 Red, Green and Blue Ratio pie chart

Figure 9.2.2 The pie chart showing the ratio of Blue, Green and Red contents in the pattern '26' image Figure 9.2.1.

As for the 'Green' ish contents, there are three columns showing the contribution of R, G, and B components, which are displayed in the following Figure 9.2.3.
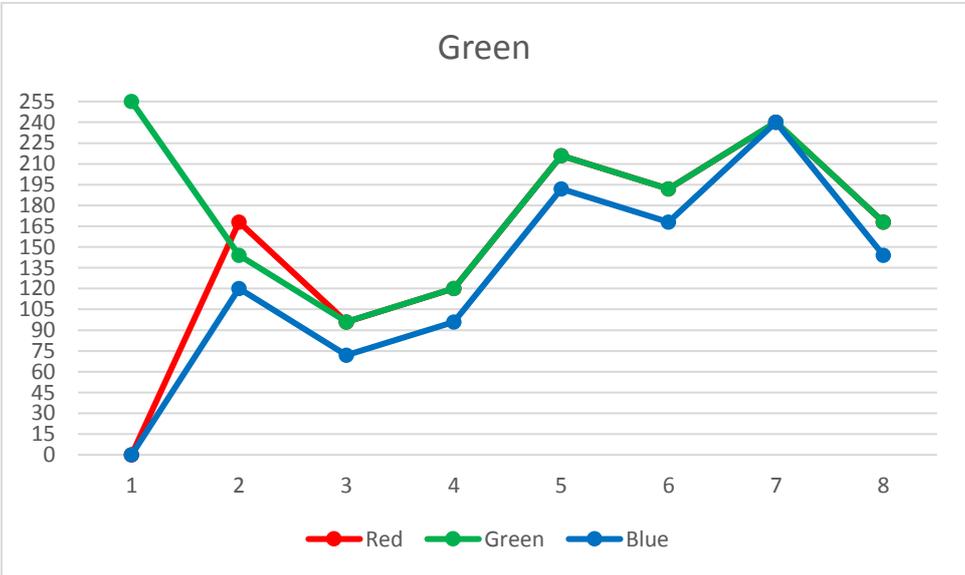
Figure 9.2.3 The Three components of RGB

Figure 9.2.3 The three components of R, G, and B for the content of greenish background Figure 9.2.1 this is demonstrate how much Green colour is available in the image Figure 9.2.1.
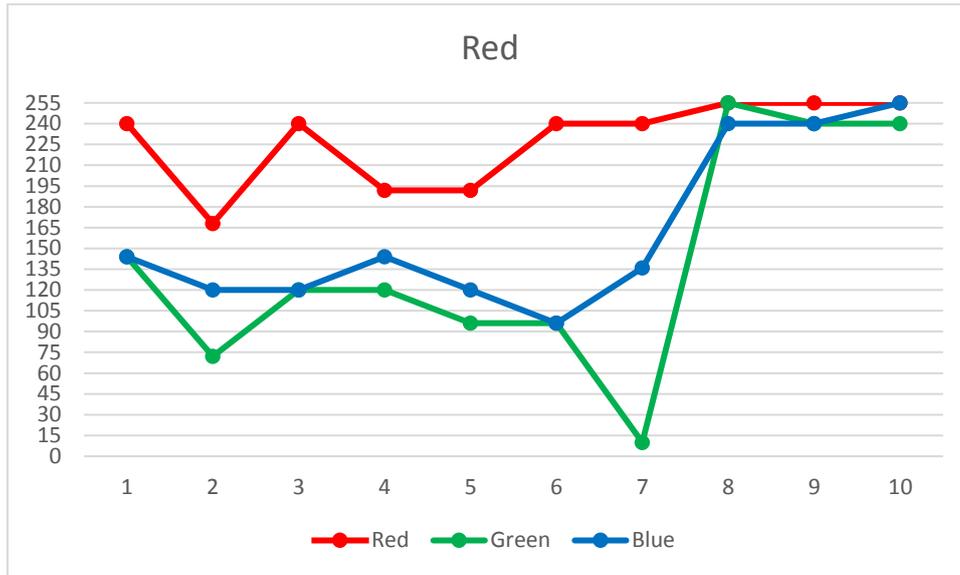
Figure 9.2.4 The Three components of RGB

Figure 9.2.4 Distribution of three components of R, G, and B for the foreground Figure 9.2.1 (Ishihara's palette '26') shows in the chart Figure 9.2.4 the amount of Red value status in the image figure 9.2.1.

The above Figure 9.2.4 clearly depicts that the red element of Red contents stands out from the rest of components from image Figure 9.2.1. Therefore, the red colour should be perceived easily for a normal vision person and cannot be seen if that person has 'Red' colour deficiency.

Similarly, the following data also support the distinguishing 'Red' colour element.

The below chart clearly shows the amount of "R" (red), "G" (green) and "B" (blue) values present in the picture Figure 9.2.5. In following colour palette that show "42" we have 40% Red, 30% Green and 30% Blue as displayed in the pie chart.

Hex Colour Code	R	G	B
Green	0	255	0
ffffff	255	255	255
a89078	168	144	120
604848	96	72	72
787860	120	120	96
a8a890	168	168	144
c0c0a8	192	192	168
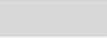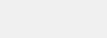
	d8d8d8	216	216	216
	f0f0f0	240	240	240
	Red	**255**	**0**	**0**
	f09090	240	144	144
	a86078	168	96	120
	f0a8a8	240	168	168
	f06060	240	96	96
	f07878	240	120	120
	c07890	192	120	144
	fff0f0	255	240	240
	fffff0	255	255	240
	f0fff0	240	255	240
	ffd8d8	255	216	216
	fff0ff	255	240	255
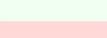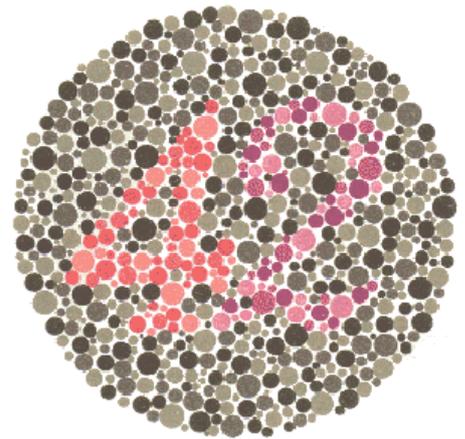
*Figure 9.2.5 Ishihara palette No 42*
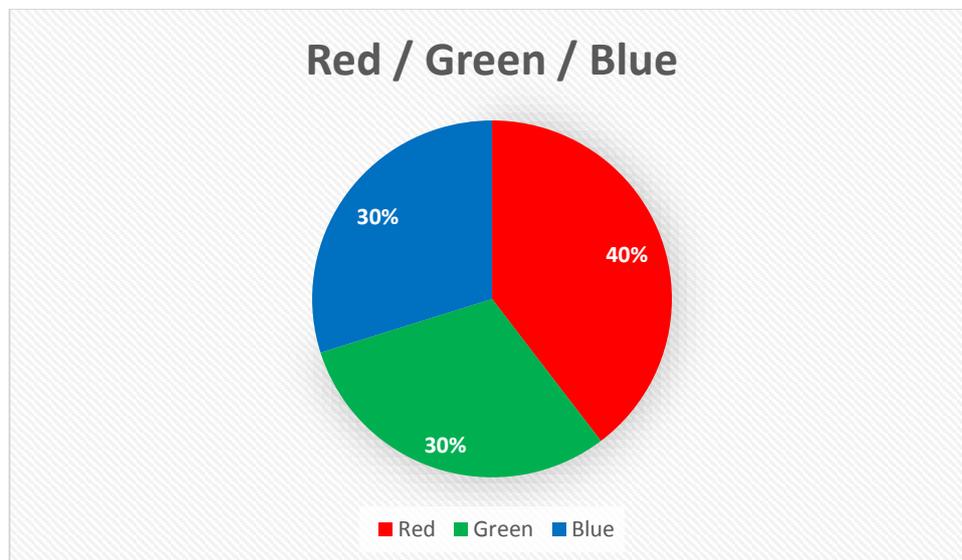
Figure 9.2.6 Red & Green and Blue Ratio pie chart

The pie chart showing the ratio of Blue 30%, Green 30% and Red 40% contents in the pattern '42' image Figure 9.2.5

As demonstrate in graph Figure 9.2.7 as for the 'Green' ish contents, there are three columns showing the contribution of R, G, and B components of Image Background Figure 9.2.5, which are displayed in the following Figure 9.2.7.
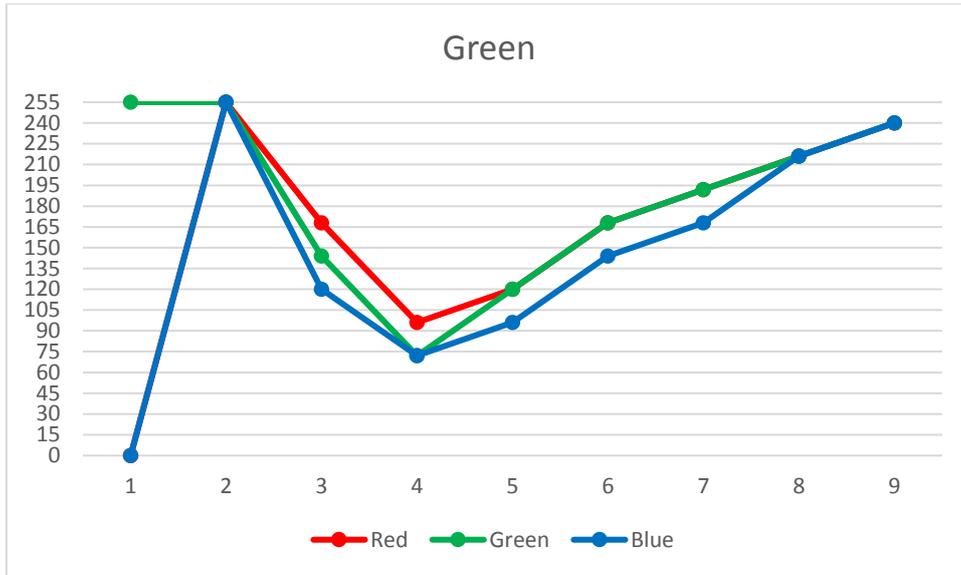
Figure 9.2.7 The Three components of RGB

In the graph Figure 9.2.8 three components of RGB for the content of the background of image Figure 9.2.5 pattern '42' shows the Red colour status in below chart.
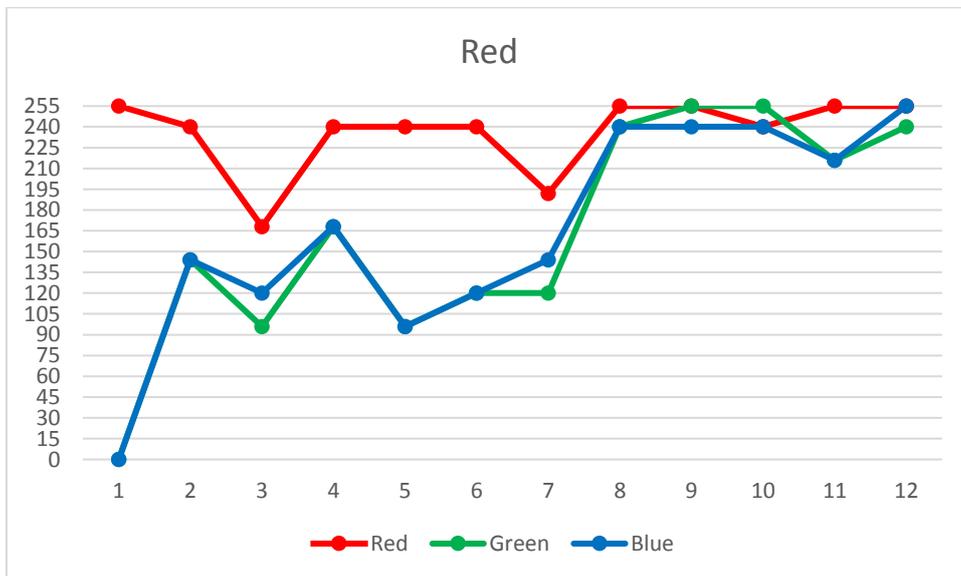
Figure 9.2.8 The Three components of RGB

Distribution of three components of R, G, and B for the foreground of the pattern of '42' Figure 9.2.5 and shows the Red value status in the chart.

In following colour palette Figure 9.2.9 that show "purple swirl" which has 42% Red, Green 32% and 26% Blue as demonstrated in pie chart.

| Hex Colour Code	R	G	B
Green	**0**	**255**	**0**
ffffff	255	255	255
a89078	168	144	120
606048	96	96	72
d8d8c0	216	216	192
787860	120	120	96
c0c0a8	192	192	168
a8a890	168	168	144
Red	**255**	**0**	**0**
f09078	240	144	120
f0f0f0	240	240	240
f06078	240	96	120
c06090	192	96	144
a84878	168	72	120
d890a8	216	144	168
f0a8a8	240	168	168
fffff0	255	255	240
fff0f0	255	240	240
fff0ff	255	240	255
fff0ff	255	240	255
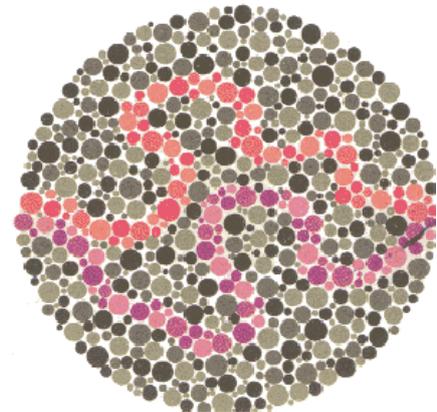
Figure 9.2.9 Ishihara palette Purple Swirl
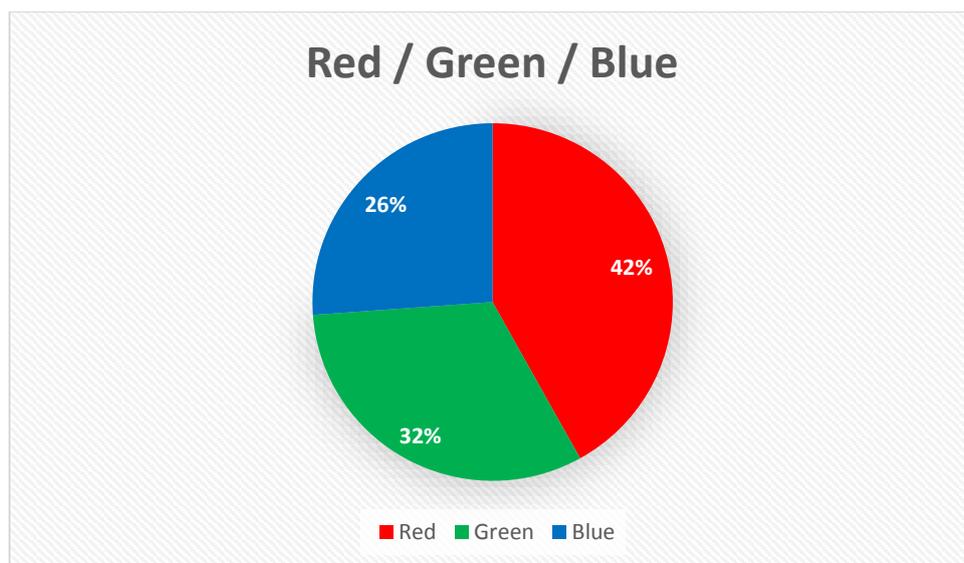
Figure 9.2.10 Red & Green and Blue Ratio pie chart

The pie chart Figure 9.2.10 showing the ratio of Blue 26%, Green 32% and Red 42% contents in the pattern of the 'Swirl' image figure 9.2.9.
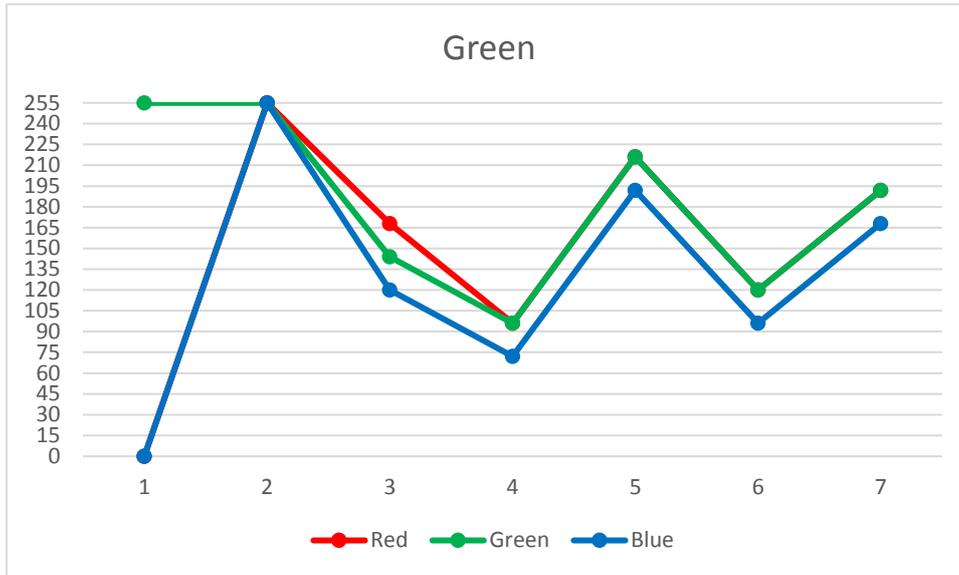
Figure 9.2.11 The Three components of RGB

Figure 9.2.11 showing distribution of three components of R, G, and B for the background 'Swirl' image Figure 9.2.9 of the pattern of 'Swirl' and shows the Red & Green and Blue value status in the chart.
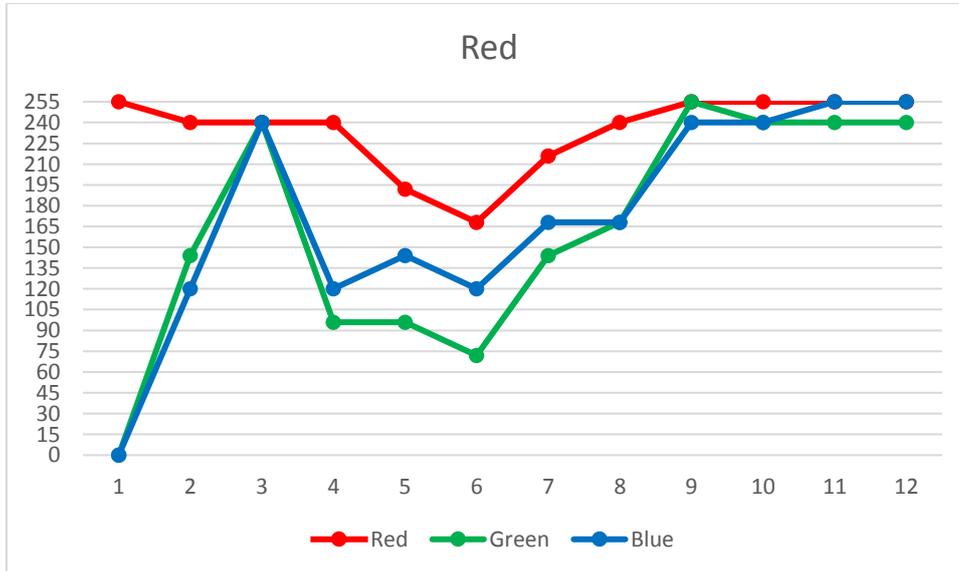
Figure 9.2.12 The Three components of RGB

The above Figure 9.2.12 clearly illustrates that the red element of Red contents stands out from the rest of components in image Figure 9.2.9. Therefore, the red colour should be observed easily for a normal vision person and cannot be seen if that person has 'Red' colour deficiency.

Following colour palette show "greenish swirl" Figure 9.2.13 we have 25% Blue, 40% Red and 35% Green it has clearly show the ratio in the below pie chart.

Hex Colour Code	R	G	B
Green	0	255	0
ffffff	255	255	255
a8a860	168	168	96
d8d878	216	216	120
f0f0d8	240	240	216
c0c078	192	192	120
d8d8a8	216	216	168
Red	255	0	0
d87878	216	120	120
d89060	216	144	96
f0a890	240	168	144
f0a860	240	168	96
f0c078	240	192	120
fff0f0	255	240	240
fffff0	255	255	240
ffd8c0	255	216	192
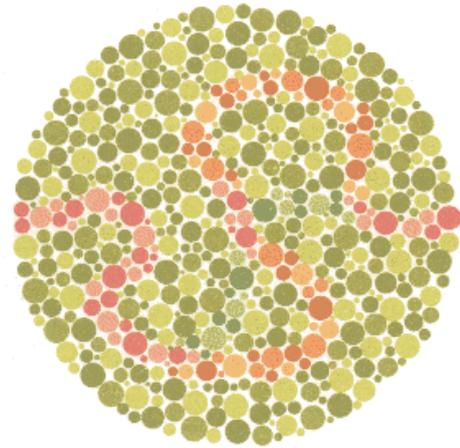
Figure 9.2.13 Ishihara Palette Green Swirl
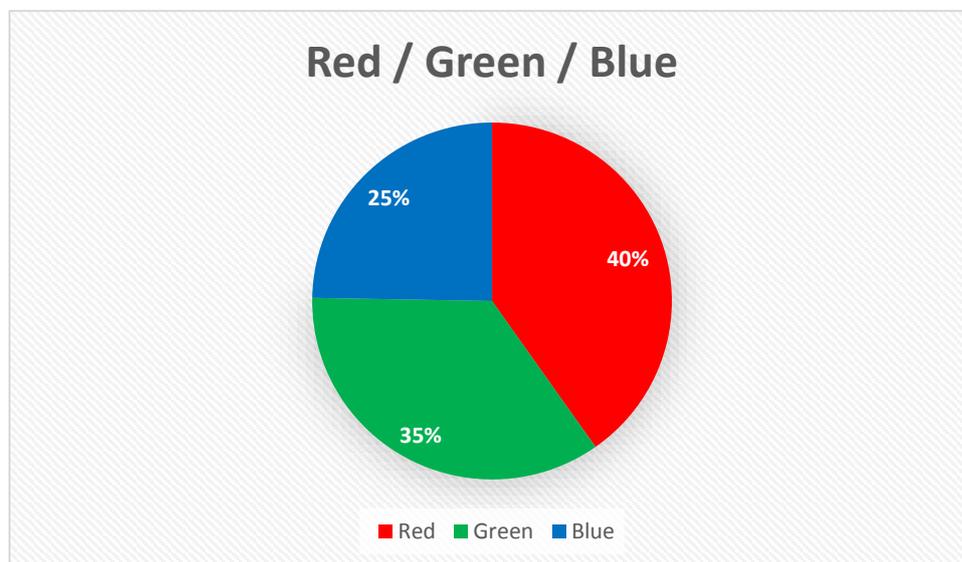
Figure 9.2.14 Red & Green and Blue Ratio pie chart

The pie chart figure 9.2.14 showing the ratio of green, blue and red contents in the pattern Green Swirl image figure 9.2.13.
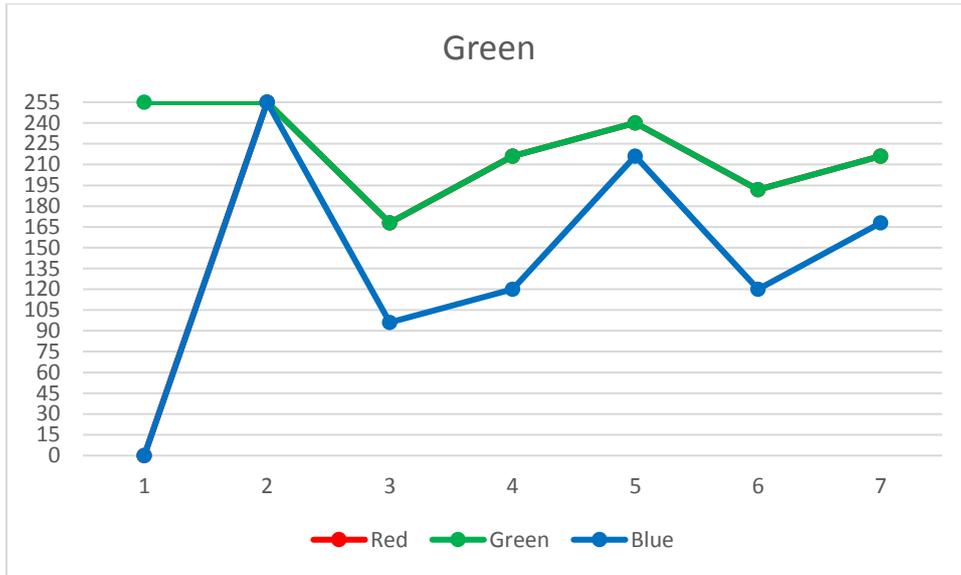
Figure 9.2.15 The Three components of RGB

Figure 9.2.15 Distribution of three components of R, G, and B for the background of 'Green Swirl' Figure 9.2.13 It shows the Green value status illuminated in the chart.
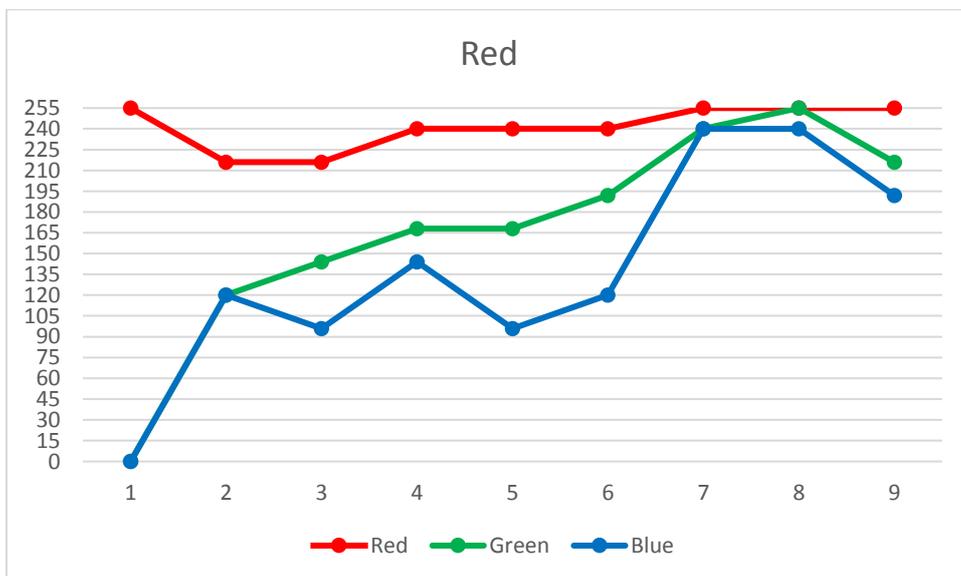
Figure 9.2.16 The Three components of RGB

All those pie chart imply that the red element is always bigger that green one, with a range from 40% to 45%, suggesting that to detect red colour deficiency, the majority component should be red, which is also proofed in the following pattern. Where red, green and blue components are 25%, 35% and 40% respectively.

In following colour palette that shows "6" Figure 9.2.17 we can see three colours are present clearly therefore I demonstrate the values of all three colour which is 37% Red and 34% Green and 29% of Blue.

Hex Colour Code	R	G	B
Green	**0**	**255**	**0**
ffffff	255	255	255
d8d8c0	216	216	192
f0f0f0	240	240	240
c0c078	192	192	120
789048	120	144	72
a8a860	168	168	96
a8d890	168	216	144
609078	**96**	**144**	**120**
78a890	120	168	144
a8c0c0	168	192	192
90c0a8	144	192	168
Red	**255**	**0**	**0**
fffff0	255	255	240
d8a878	216	168	120
f0c078	240	192	120
d89060	216	144	96
c07830	192	120	48
fff0f0	255	240	240
f0fff0	240	255	240
a80000	168	0	0
480000	72	0	0
f0ffff	240	255	255
484848	72	72	72
787878	120	120	120
786060	120	96	96
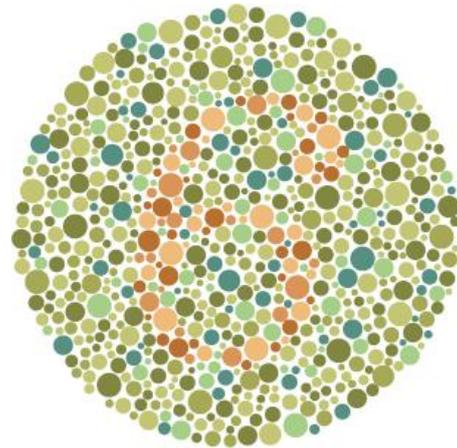
Figure 9.2.17 Ishihara Palette No. 6

54
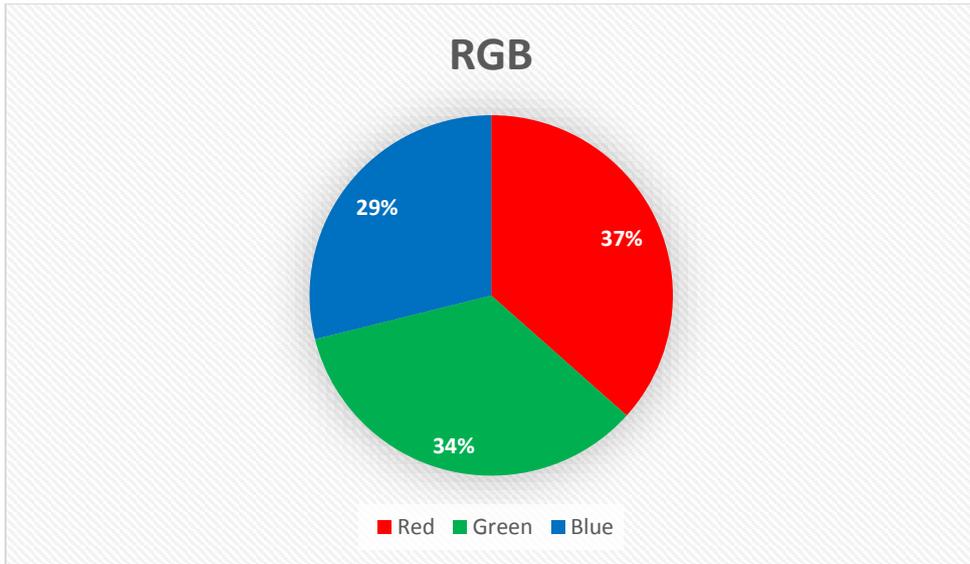
Figure 9.2.18 Red, Green and Blue Ratio pie chart

The pie chart Figure 9.2.18 shows the ratio of three Red 37%, Green 34% and Blue 29% contents in the pattern '6' in the image Figure 9.2.17.
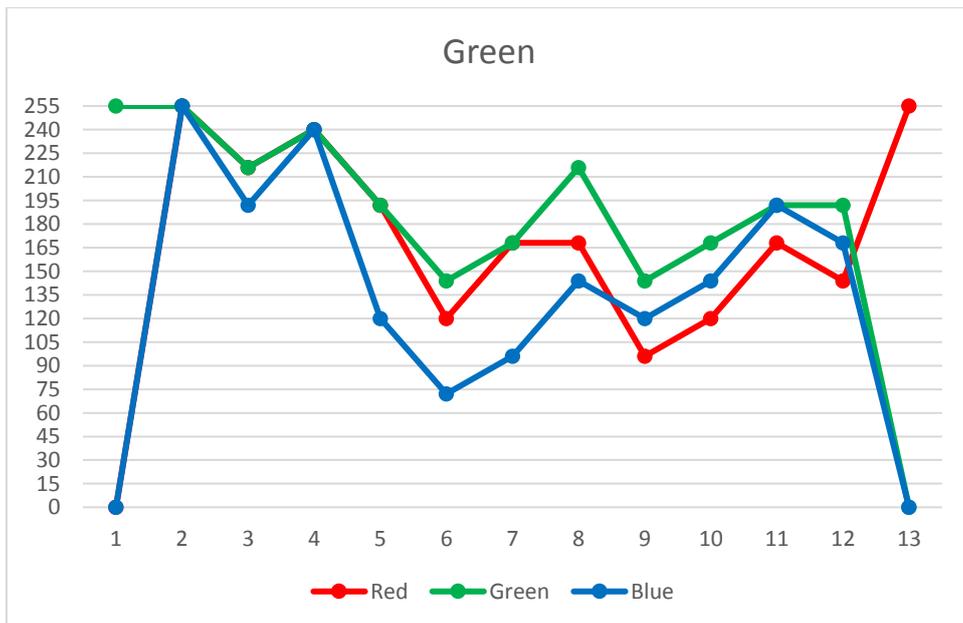
Figure 9.2.19 The Three components of RGB

As for the 'Green' value, there are three components Figure 9.2.19 showing the contribution of R, G, and B, which are displayed in the Figure 9.2.19.
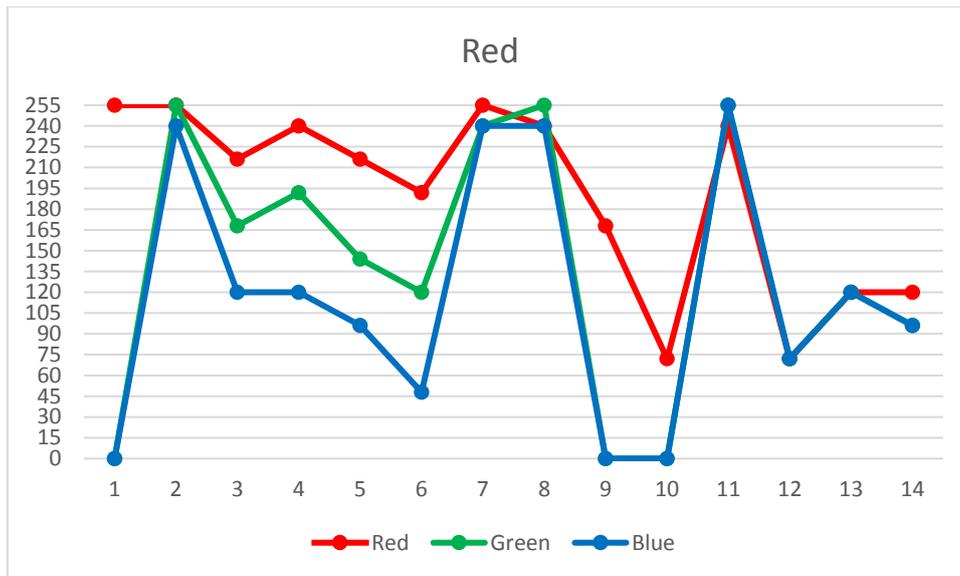
Figure 9.2.20 The Three components of RGB

Distribution of three components of R, G, and B Figure 9.2.20 for the foreground image '6' Figure 9.2.17 and shows the Red value status in the chart.

In the following colour palette that shows "45" Figure 9.2.21 of Ishihara test, clearly shows the amount of "R" (red), "G" (green) and "B" (blue) values present in the picture '45' we have 40% Red and 36% Green and 24% Blue.

Hex Colour Code	R	G	B
Green	**0**	**255**	**0**
ffffff	255	255	255
c0c0a8	192	192	168
f0f0d8	240	240	216
d8d878	216	216	120
d8d8a8	216	216	168
909048	144	144	72
a8a860	168	168	96
a8a890	**168**	**168**	**144**
Red	**255**	**0**	**0**
fffff0	255	255	240
f0c078	240	192	120
fff0f0	255	240	240
d89060	**216**	**144**	**96**
fff0ff	255	240	255
ffc078	255	192	120
f0fff0	240	255	240
f0ffff	240	255	255
f0f0ff	240	240	255
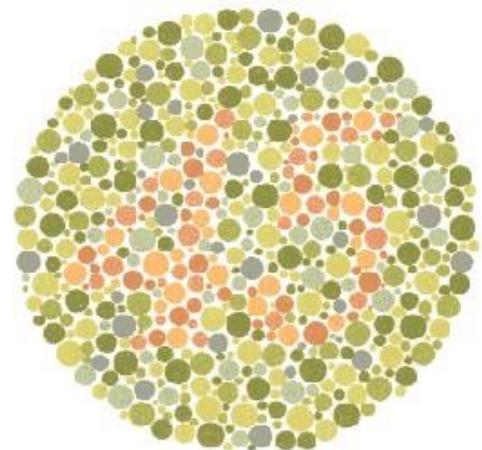
*Figure 9.2.21 Ishihara Palette No 45*

56
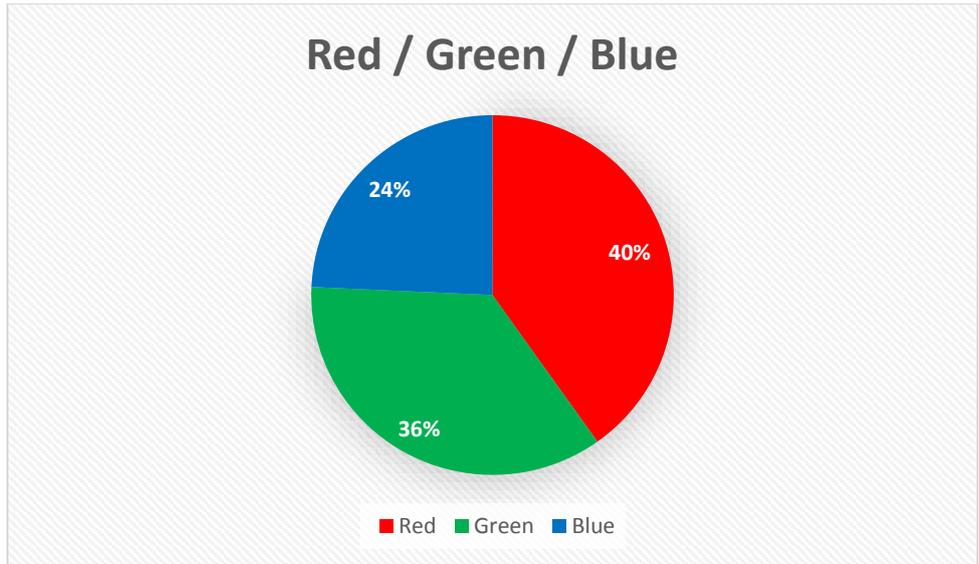
Figure 9.2.22 Red, Green and Blue Ratio pie chart

The pie chart Figure 9.2.22 shows the ratio of Red, Green and Blue contents in the pattern '45' Figure 9.2.21 which is 40% Red and 36% Green and 24% Blue.
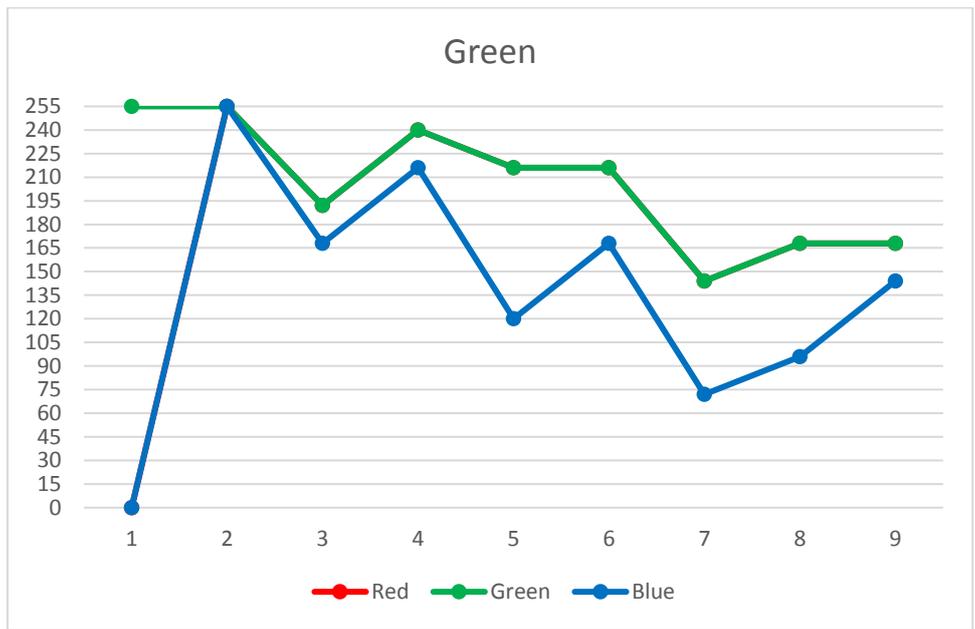
Figure 9.2.23 The Three components of RGB

In the chart Figure 9.2.23 shows the distribution of three components of R, G, and B for the image '45' Figure 9.2.21 It shows the Green value status illuminated in the background of image '45' Figure 9.2.21.
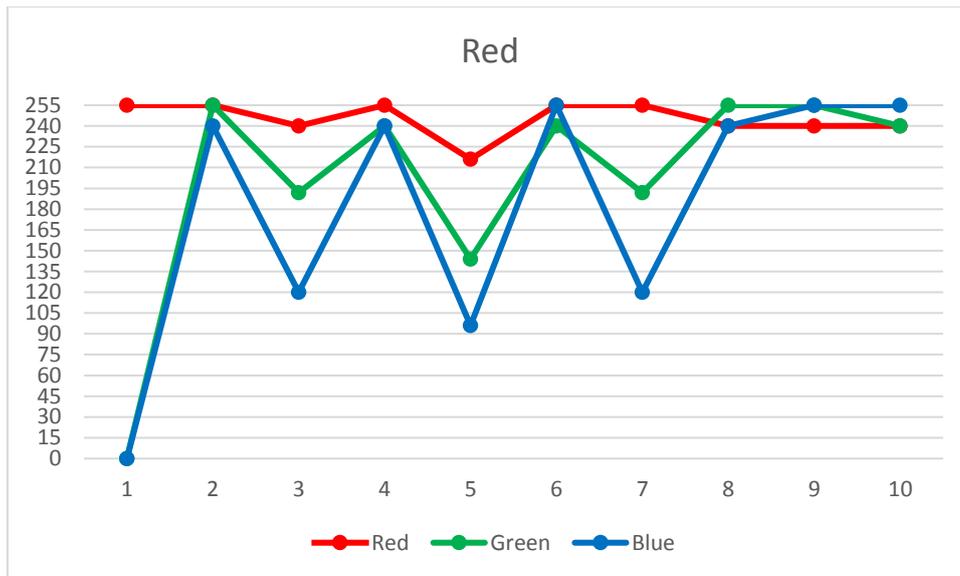
Figure 9.2.24 The Three components of RGB

The above chart Figure 9.2.24 clearly shows the amount of "R" (red) and "G" (green) and "B" (blue) values present in the picture '45' Figure 9.2.21. In the colour palette that show "45" red colour should be perceived easily for a normal vision person and cannot be seen if that person has 'red' colour deficiency.

10. Data Collection and Evaluation

Data collection and evaluation takes place with a series of structured interviews with total of **35 people** which are in **Normal vision**, **Visual Impaired** and **Colour Vision Deficiency**, series of data collected by phone application in person and online colour impairment test [71]. Some people in hospital and few local areas in the Borough of Barnet. To supplement the interviews, the majority of the questions asked were also formatted as a simple and targeted questions about their vision condition by all the volunteers.

10.1 Sight levels reported by participants

At the beginning I asked to participate of **10 volunteers** for their sight level acuity, there is people with normal vision and people with not knowing if they have any kind of Colour Blindness which I wanted to know the proportion of them. By using online Test [71] to measure and understand the ratio of the people with minor or major colour deficiency issues, this is developed in conjunction with this research including normal (right), enhanced using CIECAM02 [58] model (left) and enhanced using RGB model (middle).

The observers are asked which pattern on each row appear the most-clear to them. Table 1 lists the result of this interview, whereas **Table 2** specifies the visual conditions that described by these participants. In total, there are **10 volunteer** observers with 4 males and 6 females. Table 3 gives a brief story by each observer in relation to their vision conditions.
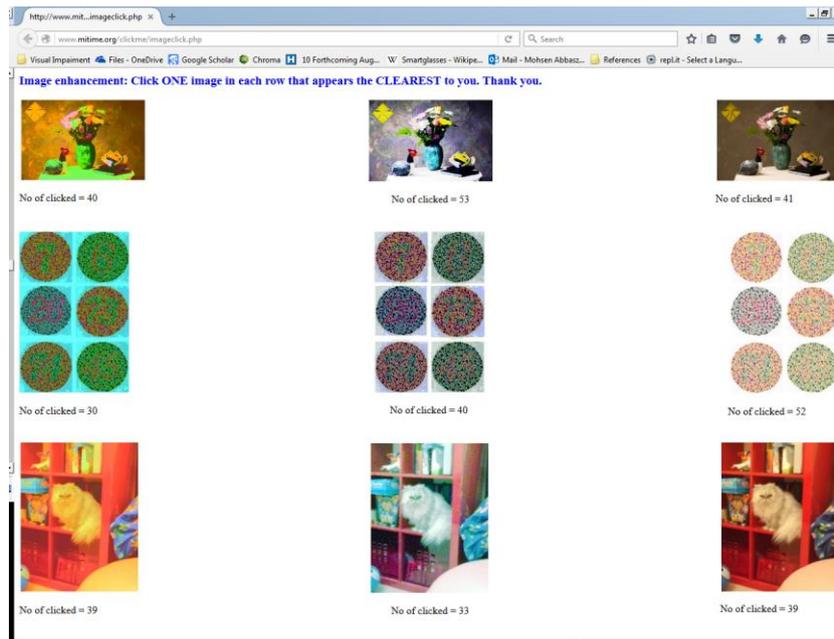
Figure 10.1 Online Test to find observer's vision condition and their Colour Blindness level [71]

Table 1- **Normal and Colour Blindness**

No	Clear 1 to 10	Objects	Colours	Sex	Age	Origin
1	**6**	Y	Y	M	38	UK
2	**7**	Y	N	F	51	UK
3	**8**	Y	Y	F	45	Europe
4	**5**	N	N	M	76	Europe
5	**9**	Y	Y	M	40	UK
6	**10**	Y	Y	F	42	UK
7	**8**	Y	Y	F	56	UK
8	**9**	Y	Y	M	65	Asian
9	**6**	Y	N	F	70	Asian
10	**5**	Y	N	F	75	Asian

I have collected data from volunteers shows in **Table 1**, with their Age, Ethnicity and their Gender with their answer If they are able to see and recognise object in the test [71]
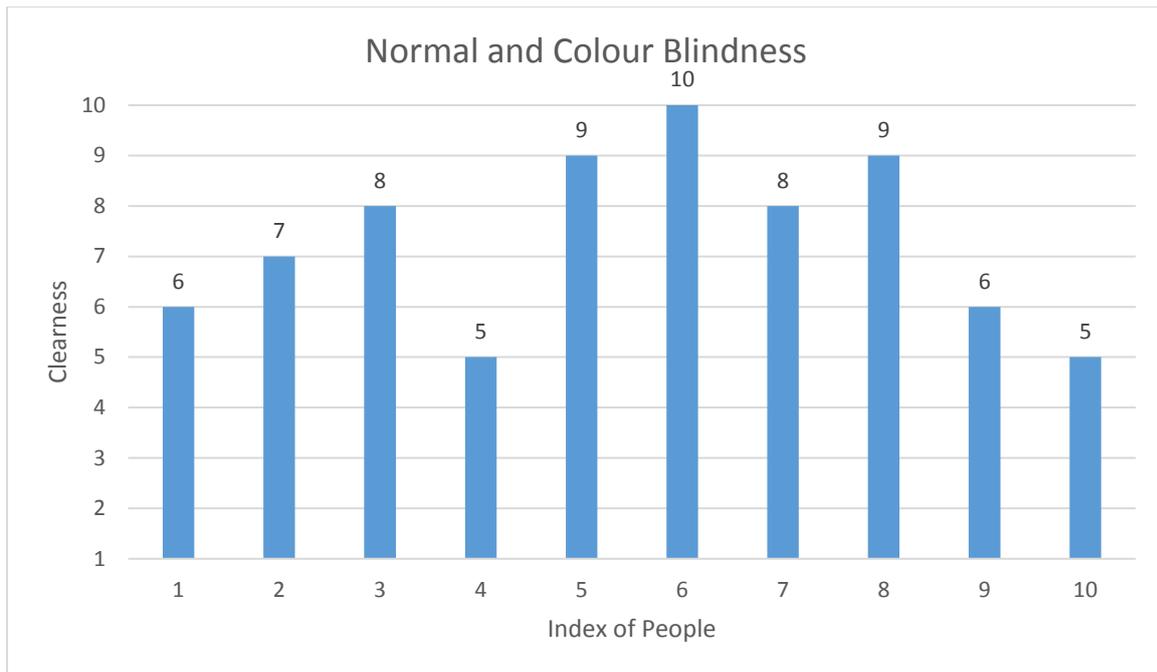
Figure 10.2 Normal and Colour Blindness, Clearness Chart

In the above chart figure 10.2 which demonstrates the clearness of **10 volunteers** interviewed for their **vision condition**. It clearly shows people with clearness and colour blindness result in chart.
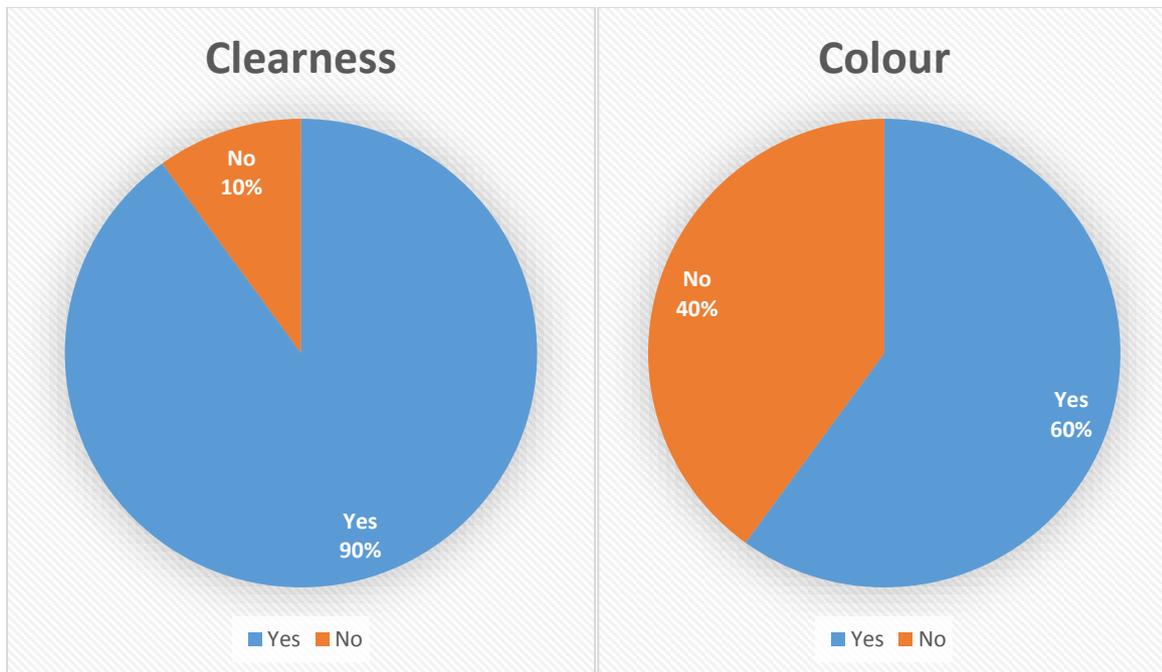
Figure 10.3 Normal and Colour Blindness, Clearness vs Colour fullness pie chart

In the left pie chart Figure 10.3 showing 10% of interviewed people with clearness issue and 90% with good clearness condition. And in the right pie chart we have colour

measurement with 40% of candidates unable to see the coloured image(s) properly and 60% with good colour vision.

Below chart Table 2, shows **10 volunteers** participated in **Visual Impairment** test. They explained about their condition, I also captured their Ethnicity, Age and Gender collected for my statistics.

Table 2- Visual Impaired

Visual Impaired Volunteers	No	Sex	Age	Origin
Half of my left eye is black and cannot adjust both eyes to see properly	1	M	68	Asian
No light awareness	1	F	75	Wales
A thick layer has come on my both eyes that effected and decreased my vision more about 60%	2	F	70,65	Europe
In day light I can identify the big objects	1	M	72	Europe
I can see normal in day light but in dusk time before complete darkness I can see no more than 20% and should wait until complete darkness	1	F	45	Asian
Half of my Right eye horizontally is dark/black	2	F	62	Asian
I cannot see around of my eye clearly	1	M	50	UK
Above my eyes is blurry and it looks like sparkle in my eye	1	M	38	UK
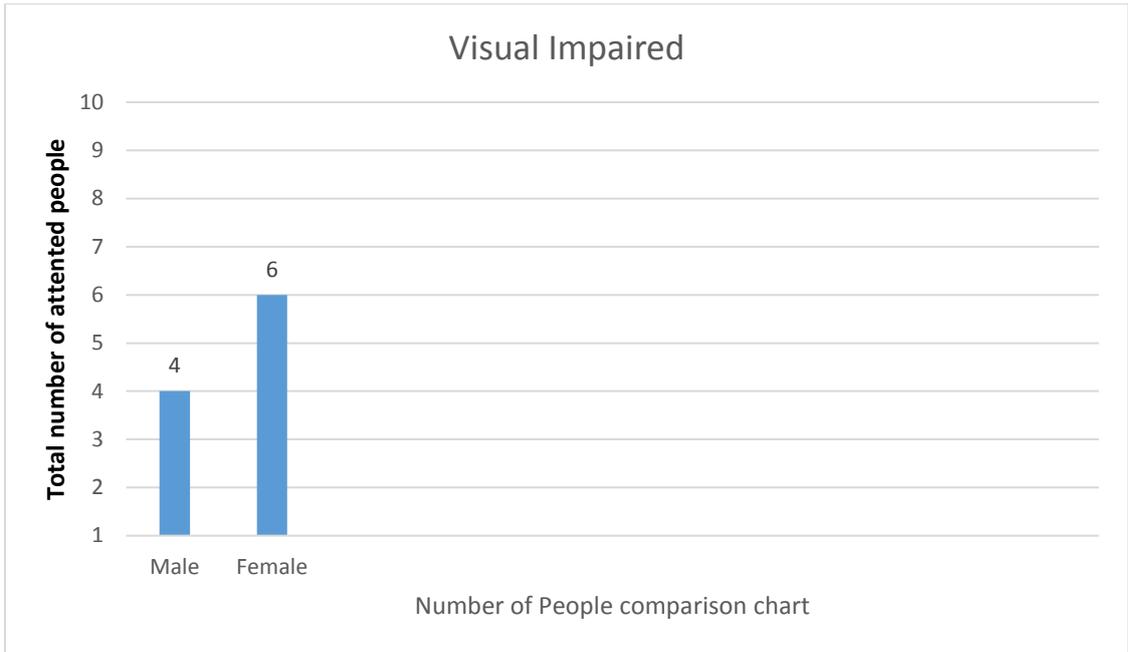
Figure 10.4 Visual Impaired, Number of People Chart

In the chart Figure 10.4 demonstrates **10 volunteers** interviewed for their Visual Impairment vision condition the result shows 4 Male and 6 Female result in chart.
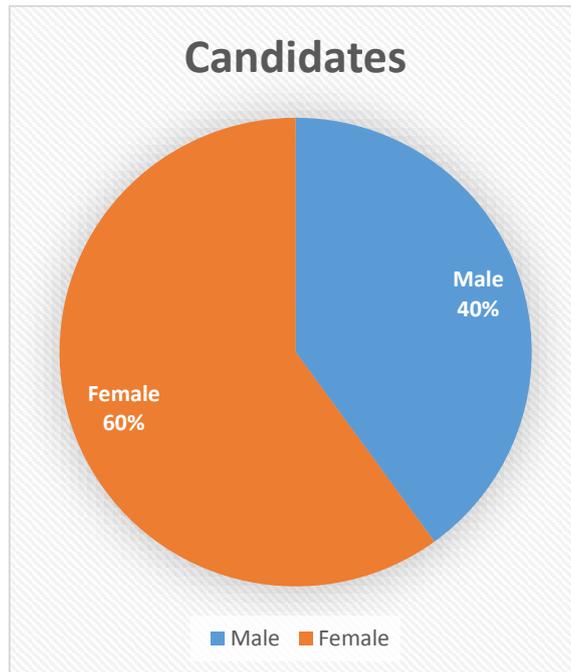
Figure 10.5 Visual Impaired Candidates percentage pie chart

The above pie chart Figure 10.5 showing the ratio of both male and female volunteers for Visual Impairment test. With regards to the data collected and comparison Figure 10.4. from candidate in result of 40% for male and 60% female, clearly shows that female is more likely to suffer from visual impairment.

Below chart Table 3, shows **15 volunteers** participated in Colour Blindness test. They explained about their condition as well as I captured their Ethnicity, Age and Gender collected for my statistics.

Table 3- Colour Vision Deficiency

Colour Blindness Volunteers	No	Sex	Age	Origin
In day light I can see and recognise green colour but at dusk I cannot see it or seeing it in grey	1	M	Under 30	Europe Italy
Two Brothers born with CVD and those are Red, Green Colour Blind	2	M	24, 30	UK Asian Background
I can see the colours but only in light colours always lived with this and now get into the habit	2	F	55	Europe
Since I have problem with my eyes it seems I can see everything in monochrome.	1	M	78	Europe
Normal Vision with no Colour Vision Deficiency	5	F		Unknown
Normal Vision with no Colour Vision Deficiency	4	M		Unknown
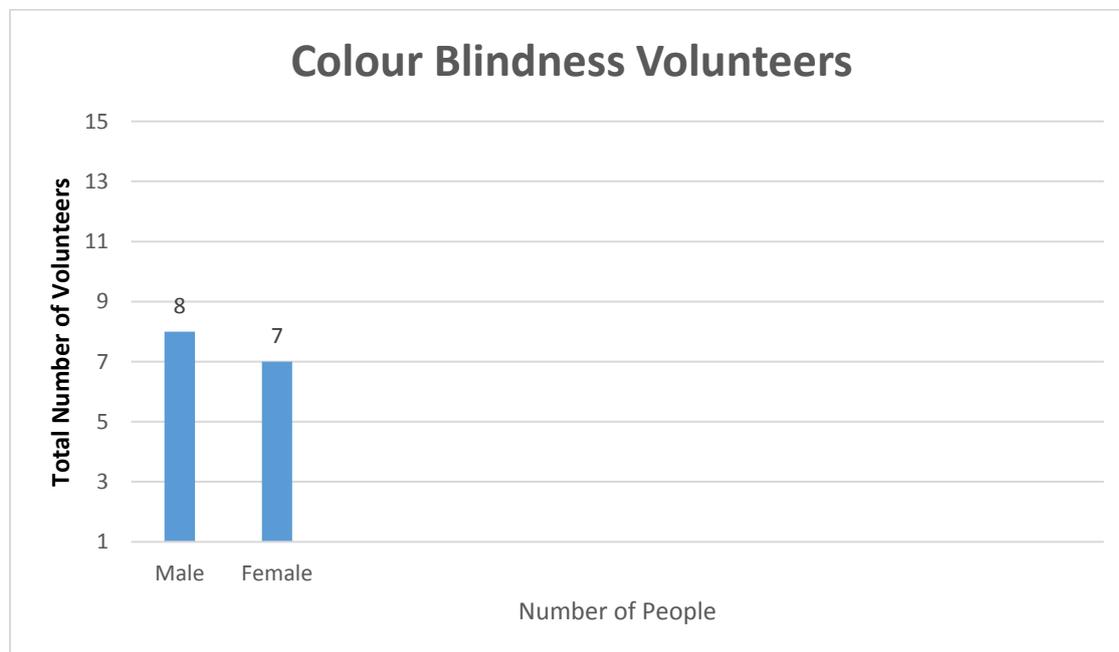
Figure 10.6 Colour Blindness Volunteers, Chart

In the chart figure 10.6 demonstrates 15 volunteers interviewed for their colour vision deficiency condition if exist. It shows 8 Male and 7 Female are participated in chart.
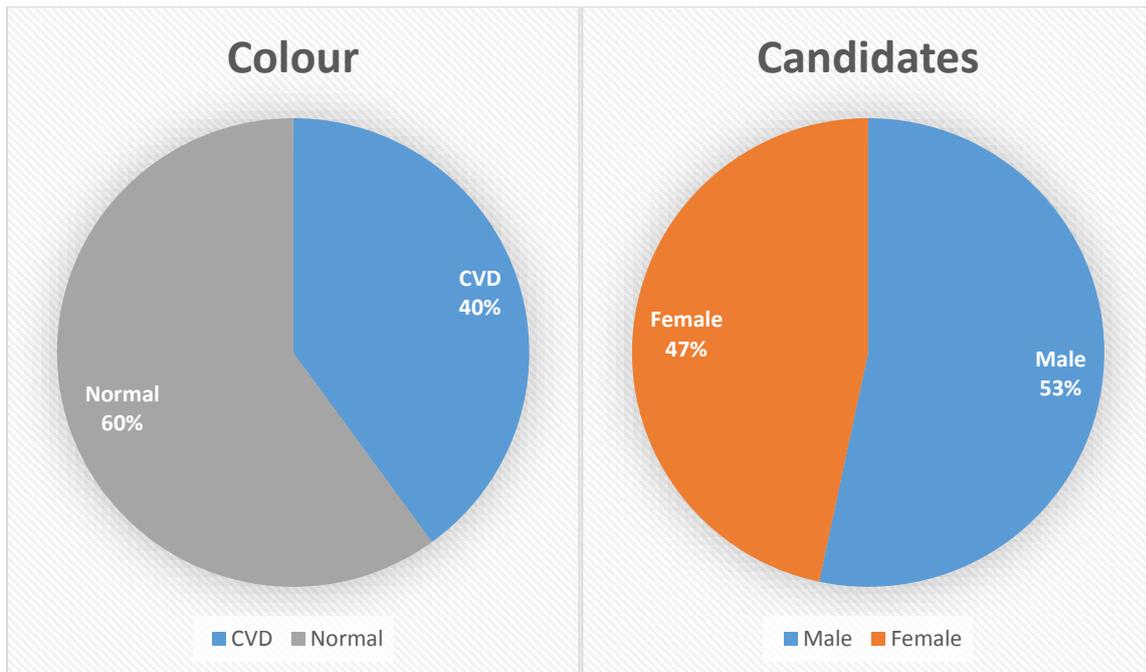
Figure 10.7 Colour Blindness Volunteers, Colour vs Candidates pie chart

The above pie chart figure 10.7 shows the ratio of both male and female volunteers for colour blindness examination. In the right pie chart, we have ratio of 53% for male and 47% female attended for their analysis, whereas 'left pie chart' shows 60% of the candidates with normal colour vision and 40% of them with some sort of colour vision deficiency.

11. Discussion and future directions

In this study, I have developed an application for smart mobile phones as explained in details in chapter 9 section 9.1 to help colour deficiency users to view their photographs while using mobile phones. This system is developed on Android system using Android SDK library by using Android Studio v.2.1 and Eclipse. By collecting data and analysing them as explained in chapter 10 section 10.1 from volunteers and patents' evaluation, It is show that this system can help patents view pictures more clearly.

Further modules such as **Colour Differentiation mode** can be implemented as features of the App this can be added to the project as future expansion. Here I have taken a picture in the motorway and by using Adobe Photoshop software edited and highlighted the Red colour in the scene Figure 11.1 and 11.2, in this mode user with Colour Vision Deficiency can choose any of the Colour mode that he suffers from or chooses to be filtered and that colour could be outlined or highlighted automatically. It can be in live scene such as football match or traffic light or in motor way with traffic as exemplified in Figures 11.1 and 11.2 for the user to identify missing colour.

Figure 11.1: Traffic light in motor way highlighted and outlined to be identified by observer.

Figure 11.2 Red colour identified and outlined for better recognising in Football Ground.

In addition, for the future expansion of the developed application as explained in chapter 9. The app can be tailored and developed for number of professionals to assist their work up to their best standards.

As an example **Painter and decorator as demonstrated in Figure 11.3.** Painters may be required to mix colours to match a sample colour or an existing colour. [66].

No formal colour vision standard.   Normal colour vision desirable.

Figure 11.3 Painting example for the Painter that can differentiate the colours. [66]

Below as example we can see how future expansion of application could help professions and careers include transportation (maritime, aviation, railway and road drivers, Figure 11.4.), defence and security forces (armed forces, police, Fire and rescue services), electricians (Figure 11.5) as well as medical professionals, e.g. dentists, cooks, and fruitiest to use Colour Differentiation mode to have their best progress in work.

Figure 11.4 An example of Traffic on Road with colour deficiency. [66]

Industrial drivers are often subject to colour vision test. Very few authorities have a colour vision standard for private drivers or commercial drivers. Those drivers with severe colour vision deficiency should be informed the risk of making mistakes with recognising signal lights, specifically those with "Protan" or red colour blindness.

Communication cables are colour coded with 10 or more colours, for example Electrical cables are coloured coded but usually with a limited number of colours Figure 11.5 (green, black, red, blue but sometimes orange or brown). So there is a risk of mistake if the colours are confused by the colour blind electrician.
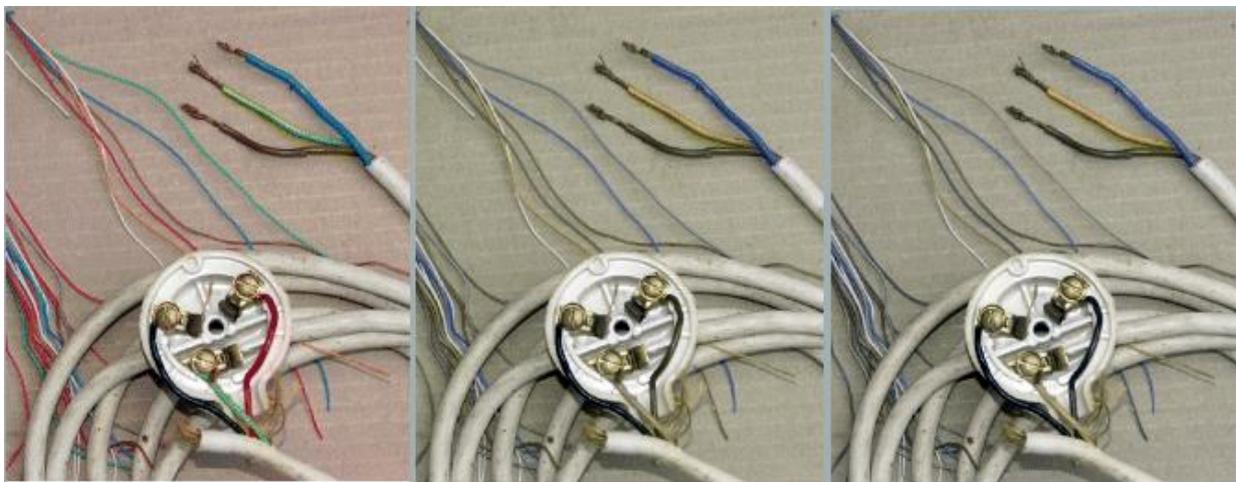
Figure 11.5 Colour Blindness example in Electrician View [66]

Figure 11.6 and 11.7 shows how colour is important to judge the ripeness and quality of foods and fruits. Colour indicates how well meat is cooked. About 22% of people [66] with abnormal colour vision report that they have problems recognising when meat is cooked Figure 11.7.

Figure 11.6 Fruiterers could identify ripeness and quality of the fruits [66]

Figure 11.7 Recognising cooked food in CVD [66]

12. Conclusion

For my research aim I have developed an application to help individuals with colour vision deficiency to be able to use smart devices such as mobile phones in ease to identify their missing colour, this is making the majority of the capacities that a smart phone can offer to people with colour blindness.

In my development I used "Ishihara's" [36] colour palettes to examine and analyse candidates colour vision acuity status, then by using PHP code I have extracted the colour properties value of each palette in Hex and RGB values, in an attempt to explain the reasons behind detection of missing colour elements details.

I also evaluated and collected series of structured information from 35 volunteers people which were in **Normal vision**, **Visual Impaired** and **Colour Vision Deficiency**, series of data collected by phone application in person and online colour impairment test [71]. Some people in hospital and few local areas of my living area. To supplement the interviews, the majority of the questions asked were also formatted as a simple and targeted questions about their vision condition by all the volunteers.

There are a lot of interesting applications which can lot easier be used and instigated with smart devices than with traditional computing devices. It is probable that there will be large investments into research and development of smart glasses because the entertainment industry, military and businesses can benefit from smart glasses and there might be a high consumer demand for them soon. The hardware that will be available in the near future still has its pitfalls and will probably need a few years and iterations to be fixed. Nevertheless, the prototypes available today are very promising and it might happen that smart glasses will be a part of our future everyday life. Be it in cinemas, at the workplace, in our entertainment systems or as always connected companion device.

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14.Appendix

14.1 Code 1: Extract colour from image by PHP.

Code description: following code extract and get most common colours in an image and return their colour values in Hex format.

```php
<?php
/**
 * This class can be used to get the most common colours in an image.
 * It needs one parameter:
 *     $image - the filename of the image you want to process.
 * Optional parameters:
 *
 *     $count - how many colours should be returned. 0 means all. default=20
 *     $reduce_brightness - reduce (not eliminate) brightness variants?
default=true
 *     $reduce_gradients - reduce (not eliminate) gradient variants? default=true
 *     $delta - the amount of gap when quantizing colour values.
 *             Lower values mean more accurate colours. default=16
 */
class GetMostCommonColors
{
        var $PREVIEW_WIDTH    = 150;
        var $PREVIEW_HEIGHT   = 150;

        var $error;

        /**
         * Returns the colors of the image in an array, ordered in descending order,
where the keys are the colors, and the values are the count of the color.
         *
         * @return array
         */
        function Get_Color( $img, $count=20, $reduce_brightness=true,
$reduce_gradients=true, $delta=16 )
        {
                if (is_readable( $img ))
                {
                        if ( $delta > 2 )
                        {
                                $half_delta = $delta / 2 - 1;
                        }
                        else
                        {
                                $half_delta = 0;
                        }
                        // WE HAVE TO RESIZE THE IMAGE, BECAUSE WE ONLY NEED THE MOST
SIGNIFICANT COLORS.
                        $size = GetImageSize($img);
                        $scale = 1;
                        if ($size[0]>0)
                        $scale = min($this->PREVIEW_WIDTH/$size[0], $this-
>PREVIEW_HEIGHT/$size[1]);
                        if ($scale < 1)
                        {
                                $width = floor($scale*$size[0]);
                                $height = floor($scale*$size[1]);
                        }
                        else
                        {
                                $width = $size[0];
```

```
                              $height = $size[1];
                      }
              $image_resized = imagecreatetruecolor($width, $height);
              if ($size[2] == 1)
              $image_orig = imagecreatefromgif($img);
              if ($size[2] == 2)
              $image_orig = imagecreatefromjpeg($img);
              if ($size[2] == 3)
              $image_orig = imagecreatefrompng($img);
              // WE NEED NEAREST NEIGHBOR RESIZING, BECAUSE IT DOESN'T ALTER
THE COLORS
              imagecopyresampled($image_resized, $image_orig, 0, 0, 0, 0,
$width, $height, $size[0], $size[1]);
              $im = $image_resized;
              $imgWidth = imagesx($im);
              $imgHeight = imagesy($im);
              $total_pixel_count = 0;
              for ($y=0; $y < $imgHeight; $y++)
              {
                      for ($x=0; $x < $imgWidth; $x++)
                      {
                              $total_pixel_count++;
                              $index = imagecolorat($im,$x,$y);
                              $colors = imagecolorsforindex($im,$index);
                              // ROUND THE COLORS, TO REDUCE THE NUMBER OF
DUPLICATE COLORS
                              if ( $delta > 1 )
                              {
                                      $colors['red'] =
intval((($colors['red'])+$half_delta)/$delta)*$delta;
                                      $colors['green'] =
intval((($colors['green'])+$half_delta)/$delta)*$delta;
                                      $colors['blue'] =
intval((($colors['blue'])+$half_delta)/$delta)*$delta;
                                      if ($colors['red'] >= 256)
                                      {
                                              $colors['red'] = 255;
                                      }
                                      if ($colors['green'] >= 256)
                                      {
                                              $colors['green'] = 255;
                                      }
                                      if ($colors['blue'] >= 256)
                                      {
                                              $colors['blue'] = 255;
                                      }

                              }

                              $hex = substr("0".dechex($colors['red']),-
2).substr("0".dechex($colors['green']),-2).substr("0".dechex($colors['blue']),-2);

                              if ( ! isset( $hexarray[$hex] ) )
                              {
                                      $hexarray[$hex] = 1;
                              }
                              else
                              {
                                      $hexarray[$hex]++;
                              }
                      }
              }

              // Reduce gradient colors
              if ( $reduce_gradients )
              {
                      // if you want to *eliminate* gradient variations use:
                      // ksort( &$hexarray );
```

80

```php
                        arsort( $hexarray, SORT_NUMERIC );

                        $gradients = array();
                        foreach ($hexarray as $hex => $num)
                        {
                                if ( ! isset($gradients[$hex]) )
                                {
                                        $new_hex = $this->_find_adjacent( $hex,
$gradients, $delta );

                                        $gradients[$hex] = $new_hex;
                                }
                                else
                                {
                                        $new_hex = $gradients[$hex];
                                }

                                if ($hex != $new_hex)
                                {
                                        $hexarray[$hex] = 0;
                                        $hexarray[$new_hex] += $num;
                                }
                        }
                }

                // Reduce brightness variations
                if ( $reduce_brightness )
                {
                        // if you want to *eliminate* brightness variations use:
                        // ksort( &$hexarray );
                        arsort( $hexarray, SORT_NUMERIC );

                        $brightness = array();
                        foreach ($hexarray as $hex => $num)
                        {
                                if ( ! isset($brightness[$hex]) )
                                {
                                        $new_hex = $this->_normalize( $hex,
$brightness, $delta );

                                        $brightness[$hex] = $new_hex;
                                }
                                else
                                {
                                        $new_hex = $brightness[$hex];
                                }

                                if ($hex != $new_hex)
                                {
                                        $hexarray[$hex] = 0;
                                        $hexarray[$new_hex] += $num;
                                }
                        }
                }

                arsort( $hexarray, SORT_NUMERIC );

                // convert counts to percentages
                foreach ($hexarray as $key => $value)
                {
                        $hexarray[$key] = (float)$value / $total_pixel_count;
                }

                if ( $count > 0 )
                {
                        // only works in PHP5
                        // return array_slice( $hexarray, 0, $count, true );

                        $arr = array();
                        foreach ($hexarray as $key => $value)
```

```
                              {
                                      if ($count == 0)
                                      {
                                              break;
                                      }
                                      $count--;
                                      $arr[$key] = $value;
                              }
                              return $arr;
                      }
                      else
                      {
                              return $hexarray;
                      }

              }
              else
              {
                      $this->error = "Image ".$img." does not exist or is
      unreadable";
                      return false;
              }
      }

      function _normalize( $hex, $hexarray, $delta )
      {
              $lowest = 255;
              $highest = 0;
              $colors['red'] = hexdec( substr( $hex, 0, 2 ) );
              $colors['green']  = hexdec( substr( $hex, 2, 2 ) );
              $colors['blue'] = hexdec( substr( $hex, 4, 2 ) );

              if ($colors['red'] < $lowest)
              {
                      $lowest = $colors['red'];
              }
              if ($colors['green'] < $lowest )
              {
                      $lowest = $colors['green'];
              }
              if ($colors['blue'] < $lowest )
              {
                      $lowest = $colors['blue'];
              }

              if ($colors['red'] > $highest)
              {
                      $highest = $colors['red'];
              }
              if ($colors['green'] > $highest )
              {
                      $highest = $colors['green'];
              }
              if ($colors['blue'] > $highest )
              {
                      $highest = $colors['blue'];
              }

              // Do not normalize white, black, or shades of grey unless low delta
              if ( $lowest == $highest )
              {
                      if ($delta <= 32)
                      {
                              if ( $lowest == 0 || $highest >= (255 - $delta) )
                              {
                                      return $hex;
                              }
                      }
              }
```

82

```
                else
                {
                        return $hex;
                }
        }

        for (; $highest < 256; $lowest += $delta, $highest += $delta)
        {
                $new_hex = substr("0".dechex($colors['red'] - $lowest),-
2).substr("0".dechex($colors['green'] - $lowest),-
2).substr("0".dechex($colors['blue'] - $lowest),-2);

                if ( isset( $hexarray[$new_hex] ) )
                {
                        // same color, different brightness - use it instead
                        return $new_hex;
                }
        }

        return $hex;
}

function _find_adjacent( $hex, $gradients, $delta )
{
        $red = hexdec( substr( $hex, 0, 2 ) );
        $green  = hexdec( substr( $hex, 2, 2 ) );
        $blue = hexdec( substr( $hex, 4, 2 ) );

        if ($red > $delta)
        {
                $new_hex = substr("0".dechex($red - $delta),-
2).substr("0".dechex($green),-2).substr("0".dechex($blue),-2);
                if ( isset($gradients[$new_hex]) )
                {
                        return $gradients[$new_hex];
                }
        }
        if ($green > $delta)
        {
                $new_hex = substr("0".dechex($red),-2).substr("0".dechex($green
- $delta),-2).substr("0".dechex($blue),-2);
                if ( isset($gradients[$new_hex]) )
                {
                        return $gradients[$new_hex];
                }
        }
        if ($blue > $delta)
        {
                $new_hex = substr("0".dechex($red),-
2).substr("0".dechex($green),-2).substr("0".dechex($blue - $delta),-2);
                if ( isset($gradients[$new_hex]) )
                {
                        return $gradients[$new_hex];
                }
        }

        if ($red < (255 - $delta))
        {
                $new_hex = substr("0".dechex($red + $delta),-
2).substr("0".dechex($green),-2).substr("0".dechex($blue),-2);
                if ( isset($gradients[$new_hex]) )
                {
                        return $gradients[$new_hex];
                }
        }
        if ($green < (255 - $delta))
        {
```

```php
                $new_hex = substr("0".dechex($red),-2).substr("0".dechex($green
+ $delta),-2).substr("0".dechex($blue),-2);
                if ( isset($gradients[$new_hex]) )
                {
                        return $gradients[$new_hex];
                }
        }
        if ($blue < (255 - $delta))
        {
                $new_hex = substr("0".dechex($red),-
2).substr("0".dechex($green),-2).substr("0".dechex($blue + $delta),-2);
                if ( isset($gradients[$new_hex]) )
                {
                        return $gradients[$new_hex];
                }
        }

        return $hex;
    }
}
?>
```