Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.4, No.19, 2014

On The Models of Colour Vision.

Stephen D.Songden* and Emeka E. Ike
Department of Physics, University of Jos, PMB 2084 Jos, Nigeria.
* E-mail of the corresponding author: songdenstephen@gmail.com

Abstract

There are three categories of colour vision theory or model; three-components theory, opponent-colour theory and stage theory. Each theory is good in its own way. A colour perception model is proposed. It combines both the trichromatic and opponent theories. It is a modification of colour perception model by Fairchild. The modification basically takes into account the fact that nature generally has a feedback system.

Keywords: Trichromatic, Model, Perception, Feedback, Colour Vision, Colour space

1.0 Introduction

The manner in which the eyes of vertebrates (eyes with image – forming lenses) function was, for centuries, a point of great misconception until in 1625, the German Jesuit Christoph Scheiner (1575 – 1650) performed a classic and irrefutable experiment. He removed the coating on the back of an animal's eye and peering through its transparent retina from behind was able to perceive a small inverted image of the scene beyond the eye. At just about the same time Descartes performed similar experiments (Hecht and Zajac, 1977). Forty years later Mariotte discovered the blind spot as a gap in the visual field. Berkeley's Idealism, advocated a mental process and cast aside any consideration of its problems as dependent upon optics and a physiological organism. It took a hundred years after Berkeley for the next notable step towards the understanding of vision to be made. Photography being born, and with it incidentally a new approach to the study of the eye. Talbot, the father of photography, gave us the flicker method and the law now known by his name, both of which have since figured so largely in the study of vision (Hecht and Zajac, 1977).

Young's first and less well-known paper on physiological optics, 'Observations on Vision', was presented to the Royal Society on 30th May, 1793. He was twenty years old at the time and within a year was elected, on the strength of the paper, a fellow of the Royal Society. Young's 1793 paper might well have passed without much comment had he not insisted on the muscularity of the crystalline lens. It was particularly this aspect of Young's paper which was to start a great revival of interest in this area of optics (Levene, 1977)

It was in the 1840's that electrical methods were first applied to the study of physiology, and thus vision, Du Bois-Raymond, applying the slow-moving galvanometer to a wide variety of animal tissues, discovered the electrical potential between cornea and the back of the eye. The same period saw the birth of modern psychophysics, the attempt at quantitatively relating stimulation and sensation. The regularity discovered by E. H. Weber, the father of this approach, now known as Weber's law, was later applied to vision (Levene, 1977).

During the last few decades, vision has been studied in every conceivable way. The clinician now gives it more detailed examination. The photochemist has given increasing attention to the cycle of changes that occur in the eye in response to light. Psychologists have awakened to a new significance of the visual experience of movement since its study with stationary objects. Cytologists and histologists have laid before us more and more of the minute details of retinal cito-architecture. Comparative anatomists have pushed forward the classification of vertebrate eyes with reference to rod and cone types and populations. Electro – physiologists have begun to tell how the visual apparatus works as a neural mechanism. A new integration of the data available on sensation with those of neurology has begun to take form. Those studying the central nervous system for its own sake have found the retina and the visual pathway a most suitable preparation with which to work (Bartley, 1963). Thus the study of colour vision is an interdisciplinary subject which embraces aspects of physics, biochemistry, neurophysiology, psychology and many more. Abnormal colour vision interests a wide range of people including the millions who realize that their appreciation of colour is 'defective', their families and many more who are responsible for the dangers and other consequences - including industrial and professional implications of the condition. Myopia and its correction has been known since ancient times. This is evident from Aristotelian Corpus which contains an analysis of the habits of short-sighted people. Aristotle was equally appreciative of presbyopia and its differentiation from myopia. 'Why is it,' Aristotle enquires 'that though both short-sighted and an old man are affected by weakness of the eyes, while the later holds it a distance?'

It was not however, until the beginning of the seventeenth century when Maurolyco and Kepler laid the general foundation of physiological optics, that the nature of myopia and presbyopia received an adequate explanation. Francesco Maurolyco (1495-1575), several years before Kepler explained myopia and presbyopia on the bases of analogy with spectacle lenses. A year after being elected to fellowship of the Royal Society (1771), Wells published an essay upon single vision with two eyes. Wells described hypermetropia in his own eyes. As a result of Wells' description of hypermetropia, a further case was reported shortly after by the ophthalmic surgeon, James Ware (1756-1815).

According to Levene (1977), Ware's contribution was significant, in that he not only described hypermetropia as a clinical entity, but he also analysed the relative incidence of myopia in terms of its social implications. Slight defects of myopia were rarely corrected among the lower stations of society, whereas in the higher ranks, fashion possibly more than necessity, led to the use of concave lenses. In three regiments of foot guards, consisting of almost 10,000 men, Ware noted that among the Private rank, myopia was apparently rare and over a period of twenty years, not up to half a dozen men had been discharged nor recruits rejected, on account of their myopia (Levene, 1977).

It is hypothesized that colour vision and opponent processing of colour signals in the visual system evolved as a means of overcoming the extremely unfavourable lighting conditions in the natural environment of early vertebrates (Maximov, 2000). Colours are the basic information carriers of any natural scene (Khan et al, 1994). The loss of information due to inadequate colour decoding prevents or slows down comprehension, increases reaction time and generally lowers the quality of life. Eight percent of men and 0.5% of women have colour deficiency or colour blindness in the developed world. According to the statistics, there were a total of 32.6 million Colour Vision Deficient (CVD) men in USA, Japan and West-Europe (http://www.colourvision.info/, Shuey, 1936). It is more prevalent among the whites than other racial groups (Kilborn,1934).

1.1 Applications Of Colour

Colour has so many applications, one of which is in the area of colour television. It is based on the theory of additive colour mixing: all colours including white can be created by mixing red, green and blue lights. Video (chrominance) signal for red, green and blue information are combined and transmitted along with the brightness (monochrome or luminance) signal. The luminance signal alone serves the need of a monochrome receiver. At the receiver, the three colour signals are separated and fed to the three electron guns of the colour picture tube, the three voltages being proportional to the red, green and blue content of the scanned element (Hutson, 1971). Screen of the picture tube has red, green and blue phosphors arranged in alternate dots. Each gun produces an electron beam to illuminate the three colour phosphors separately on the fluorescent screen. Our eye then integrates the red, green and blue colour information and their luminance to perceive the actual colour and brightness of the picture being televised (Wandell and Silverstein, 2003).

Other applications of colour include:

i. As a key component of information display that is easy to use, for example, in control rooms that enables the algorithmic application of colour in fields such as visualization, illustration, and user-interface design. It combines the principles for using colour in information display, which are based on perceptual models for colour.
ii. Colour as Label: The basic abilities (and limitations) of colour to label, highlight, and group is well understood. Distinctive colours "pop-out" from their background as a preattentive process. That is, it requires no cognitive thought to pick the red numbers out of a field of black ones.
iii. Colour naming to support image reproduction applications
iv. Colour Scales: The effective use of colour to represent progressions of values (colour scales or sequences) has been well articulated, particularly by the cartography community.
v. Hyperchromatic lenses as potential aid for the presbyope,
vi. Real time colour recognition for machine vision systems.
vii. Optometric characteristic of people with reading difficulties who benefit from coloured filters
viii. Decoration of public and private places
ix. Textile industries
x. Chemical analysis
xi. Electronic circuit design and component manufacture
xii. Printing

2.0 Earlier Theories Of Vision

The Greek philosophers (Hippocrates, Aristotle, Plato) provided the first known theories concerning the eye, its function, anatomy and treatment. This background was provided by the work of Kalloniatis and Luu (2008).

Originally, the Aristotelian idea was that rays of light emanated from the eyes to illuminate the world around. When it was dark, the air became murky so the rays could not penetrate but a candle would burn off the opacity in the air allowing sight to penetrate. Aristotle proposed that visual sensation passed from the heart which was at that time considered center of sensation and psychic function. This cardio centric nature of sensation continued into the middle ages, despite the direct experimental evidence of Galen (AD 129-200). Galen, a Greek scientist working within the Roman Empire showed that pressing on the heart in human subjects did not lead to loss of consciousness or loss of sensation but severing the spinal cord in animals abolished sensory responses after brain stimulation. The ideas of the Greeks from centuries BC were perpetuated and preserved by the writings and drawings of the Arab world until well into the middle ages A.D.

Interestingly, the general theory advanced by the majority of Greek anatomists was that the retina, because of its abundant blood vessels, was an organ of nutrition rather than of sight. It was not until the 12th century that a Moor Scientist, Averroes, living in Spain proposed that the retina and not the lens was the visual receptor (Kalloniatis and Luu, 2008). The study of optics is of significance for the understanding of image formation and this flourished in the 13th and 14th centuries. The work of Alhazen (965-1039) became the main source for physical and physiological optics in the medieval west. Even Leonardo da Vinci (1452-1519) based his anatomical sketches of the eye on the older incorrect Arab drawings. He was convinced that the image was formed in the eye but did not know how. It was the early Greek Physicists (Euclid, Archimedes and Ptolemy) that hypothesized concerning the fundamental properties of light: that light travelled in straight lines and could be reflected from polished planes and curved mirrors. Galileo (1564-1642) accepted that light was the agency by which we see: light falls upon an object and is scattered; some of the scattered light enters the eye and there produces the effect known as vision.

Johannes Kepler(1571-1630) understood that the cornea and lens collected and refracted the light rays and that the image was “painted” on the retina as an aggregation of many image points. Kepler was also able to explain presbyopia and myopia. Subsequently, many great Scientists including Rene des Cartes (1596-1650) and Sir Isaac Newton (1642-1727) through their works, put the study of optics and ocular dioptrics on a solid scientific foundation from which stemmed our knowledge of how the eye functions and forms visual image. Perceptual studies of how we see became possible as a result of the development of mathematical technique and other measuring techniques proposed in the early 17th century. They include Newton’s great discovery of the light spectrum which is the foundation for the study of colour vision. Today, the quantum theory of light, based on the wave–particle duality, is an added tool in the study of vision.

According to Lennie (1984), colour vision had attracted scientific attention for more than 275 years, though it was not until the nineteenth century that Scientists began to understand it properly. Since then, Physicists and Psychologists have advanced very precise descriptions of the phenomena of colour vision. Developments in Physiology have also provided much new information on the mechanisms of colour vision. Normal colour vision requires three colour-matching functions for its definition, according to Judd (1966).

2.1 Causes And Attributes Of Colour

Colour is perceived when the wavelengths constituting white light are absorbed, reflected, refracted, scattered, or diffracted by matter on their way to our eyes; alternatively, a non-white distribution of light may be emitted by some system. Fifteen specific physical or chemical mechanisms for producing colour are outlined in table 1 (Nassau, 2003).

We see an object by the light reflected from it. If it looks green in daylight, then this must imply that it is only reflecting the green part of the light back to our eyes. The remainder of the spectrum is absorbed. Different Colour vision tests are necessary for some professions (Squire et al, 2005).

There are three ways in which subjective colour sensations can differ and they are called hue, brightness and saturation. Hues, also referred to as chromatic colours are described by words such as red, yellow and green and are dependent primarily on the wavelength of the stimulus. An average observer can distinguish between 150 and 200 hues. Brightness is described by words such as very dim and dazzling and is dependent on the luminance of the stimulus. The relative brightness of different wavelengths changes with luminance; in dim light blue-green colours are brightest whereas in bright light yellow colours are brighter. Saturation refers to the paleness or whiteness of a colour or achromatic colour (names as white, gray, black e.t.c) and depends on the purity of the dominant wavelength in the stimulus. A saturated colour has little white while a less saturated or desaturated colour has more white (Parr ,1978).

2.2 The Eye As An Optical System

The eye is considered an optical instrument.. Its optics, bear a general resemblance to a camera system, but the way in which the retina image is processed into a mental image and stored for later use in the memory is almost infinitely complicated. Of all the instruments made by man, none more closely resembles a part of his system anatomy, in appearance and function, than a camera does the eye. Man has one of the most remarkable vision systems in nature. The human eye's key features include: a highly-corrected optical design, repeatable geometry of materials, control by the brain, processing of retina information, interfacing with the brain from six different levels of sensor cells in the retina, colour vision, compression of data going to the brain, and the highly specific make up and orientation which enable each eye to function and memory of scenes to take place (Deckert, 2008)

The retina is the screen on which the ocular image is formed. It also contains the photosensitive elements that transduce the illumination into nerve impulses. In addition to this, a considerable amount of "image processing" takes place in the retina; that is to say, the nerve pulses travelling from the eye to the brain along the optic nerve are not simply a replica of the illumination distribution on the retina. Instead, this distribution is operated upon by the retina. Operations may include the formation of weighted sums, differencing of adjacent illumination values, and so on. This explains the rather complicated structure of this wonderful organ (Levi, 1980).

3.0 Colour Space Models

There are many colour space models and a colour space is a method by which we can specify, create and visualise colour. As humans, we may define a colour by its attributes of brightness, hue and colourfulness. A computer may describe a colour using the amounts of red, green and blue phosphor emission required to match a colour. A printing press may produce a specific colour in terms of the reflectance and absorbance of cyan, magenta, yellow and black inks on the printing paper. A colour is thus usually specified using three co-ordinates, or parameters. These parameters describe the position of the colour within the colour space being used. They do not tell us what the colour is, that depends on what colour space is being used (Ford and Roberts, 1998).

Different colour spaces are used for different applications. For example some equipment with limiting factors that dictate the size and type of colour space that can be used. Some colour spaces are perceptually linear, i.e. a 10 unit change in stimulus will produce the same change in perception wherever it is applied. Many colour spaces, particularly in computer graphics, are not linear in this way. Some colour spaces are intuitive to use, i.e. it is easy for the user to navigate within them and creating desired colours is relatively easy. Other spaces are confusing for the user with parameters with abstract relationships to the perceived colour. Finally, some colour spaces are tied to a specific piece of equipment (i.e. are device dependent) while others are equally valid on whatever device they are used.

A device dependent colour space is a colour space where the colour produced depends both on the parameters used and on the equipment used for display. For example, specifying the same red, green and blue (RGB) values on two different workstations, the colour produced will be visually different if viewed on side by side screens. Another test is to change the brightness and contrast settings (the offset and gain) on the cathode ray tube (CRT) and see how a displayed colour varies. A device independent colour space is one where a set of parameters will produce the same colour on whatever equipment they are used.

Some device dependent colour spaces are well characterised so that the user can translate between them and some other, device independent, colour space. Typically this characterisation takes the form of specifying the chromaticities of the three primaries as well as the transfer functions for each channel. Such colour spaces are known as device calibrated colour spaces and are a kind of half-way house between dependent and independent colour spaces. The Commission Internationale de l'Eclairage (CIE) has defined a system that classifies colour according to the HVS (the human visual system). Using this system we can specify any colour in terms of its CIE co-ordinates and hence be confident that a CIE defined colour will match another with the same CIE definition. The following are some of the colour spaces (Ford and Roberts, 1998).

Table 1: Examples of the Fifteen Causes of Colour

Group	Physical Mechanism	Example
Vibrations and simple excitations	1 Incandescence	Hot objects, the sun, flames, filament lamps, carbon arcs, limelight
	2 Gas excitations	Vapor lamps, neon signs, corona discharge, auroras, lightning*, lasers
	3 Vibrations and rotations	Blue water and ice, iodine, bromine, chlorine gas, blue gas flame
Transitions involving ligand field effects	4Transition metal compounds	Turquoise, malachite, chrome green, rhodochrosite, smalt, copper patina, fluorescence*, phosphorescence*, lasers*,
	5 Transition metal impurities	Ruby, emerald, alexandrite, aquamarine, citrine, red iron ore, jade*, glasses*, dyes*, fluorescence*, phosphorescence*,
Transition between molecular orbitals	6 Organic compounds	Dyes*, biological colourations*, fluorescence*, phosphorescence*, lasers*
	7 Charge transfer	Blue sapphire, magnetite, lapis lazuli, ultramarine, chromates, Painted Desert, Prussian blue
Transitions involving energy bands	8 Metals	Copper, silver, gold, iron, brass, ‘ruby’ glass
	9 Pure semiconductors	Silicon, galena, cinnabar, vermillion, cadmium orange and yellow, diamond
	10 Doped semiconductors	Blue and yellow diamonds, light-emitting diodes, lasers*, phosphors*
	11 Colour centers	Amethyst, smoky quartz, desert ‘amethyst’ glass, fluorescence*, phosphorescence*, lasers*
Geometrical and physical optics	12 Dispersive refraction, polarization, etc.	Rainbows, halos, sun dogs, photoelastic stress analysis, ‘fire’ in gemstones, prism spectrum
	13 Scattering	Blue sky, red sunset, blue moon, moonstone, Raman scattering, blue eyes, skin, butterflies, bird feathers*
	14 Interference without diffraction	Oil slick on water, soap bubbles, coatings on camera lenses, biological colours*
	15 Diffraction	Aureole, glory, diffraction grating spectrum, opal, liquid crystals biological colours*
		* only in part

(Source: Nassau, 2003)

3.1CIE XYZ System

This was established as a coordinate system in 1931(fig. 1) in which chromaticity diagram is two dimensional where in trichromatic units, T,

$$1\ T(R) + 1\ T(G) + 1\ T(B) = 1 \text{ lumen white} \qquad (1)$$

Where R, G and B represent red, green and blue respectively.

Colours can be specified by weighted sums of red, green, and blue

$$C = rR + gG + bB \qquad (2)$$

where r, g, b are the amounts of R, G, B colours, respectively. An experiment was carried out to find the colour-matching functions for RGB primaries; they are obtained by averaging the judgements of a large number of observers. (Ford and Roberts, 1998)

3.2 RGB (Red Green Blue)

This is an additive colour system based on tri-chromatic theory. Often found in systems that use a cathode ray tube (CRT), a mosaic of red, green and blue phosphor dots to display images. RGB is easy to implement but non–linear with respect to the visual perception. It is device dependent and specification of colours is semi–intuitive. RGB is very common, being used in virtually every computer system as well as television, video etc. In a colour receiver, the ultimate requirement at the display device is three voltages proportional to the red, green and blue content of the scanned element (Hutson, 1971)

3.3 CMY(K) (Cyan Magenta Yellow (Black))

This is a subtractive-based colour space and is mainly used in printing and hard copy output. The fourth, black, component is included to improve both the density range and the available colour gamut (by removing the need for the CMY inks to produce a good neutral black it is possible to used inks that have better colour reproductive capabilities). CMY(K) is fairly easy to implement but proper transfer from RGB to CMY(K) is very difficult. CMY(K) is device dependent, non–linear with respect to visual perception and reasonably unintuitive (Ford and Roberts, 1998).

3.4 HSL (Hue Saturation and Lightness)

This represents a wealth of similar colour spaces, alternative names include HSI (intensity), HSV (value), HCI (chroma / colourfulness), HVC, TSD (hue saturation and darkness) etc. Most of these colour spaces are linear transforms from RGB and are therefore device dependent and non–linear. Their advantage lies in the extremely intuitive manner of specifying colour. It is very easy to select a desired hue and to then modify it slightly by adjustment of its saturation and intensity. The supposed separation of the luminance component from chrominance (colour) information is stated to have advantages in applications such as image processing. However the exact conversion of RGB to hue, saturation and lightness information depends entirely on the equipment characteristics. Failure to understand this may account for the sheer numbers of related but different transforms of RGB to HSL, each claimed to be better for specific applications than the others (Ford and Roberts, 1998).

3.5 YIQ, YUV, YCbCr, YCC (Luminance - Chrominance)

These are the television transmission colour spaces, sometimes known as transmission primaries. YIQ (Y is

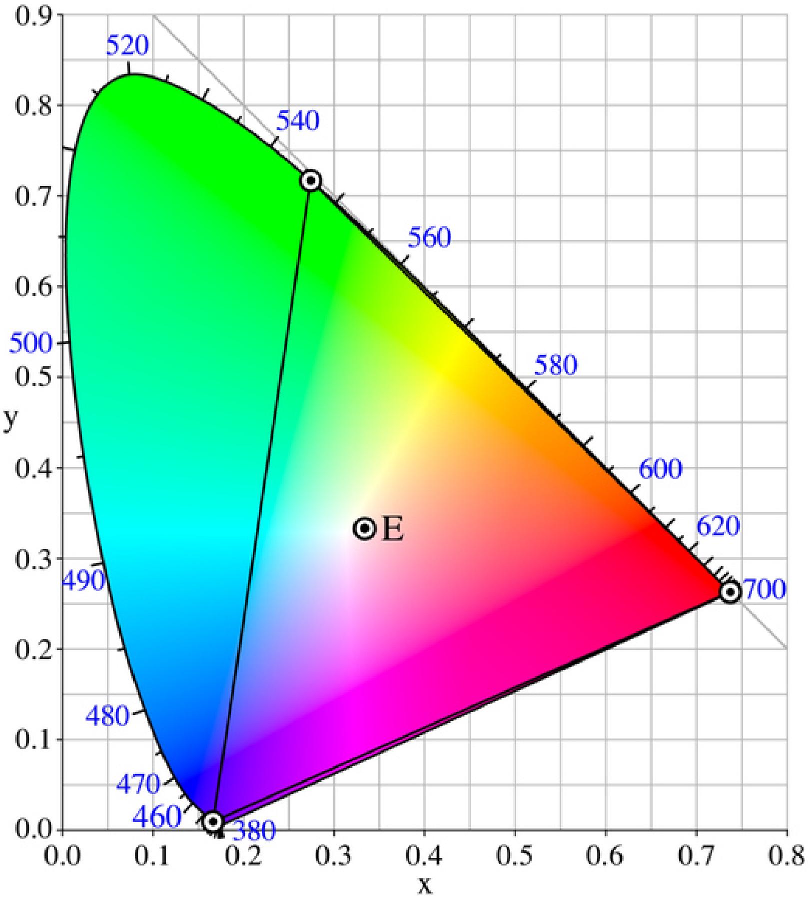

Figure 1: The CIE 1931 Colour Space Chromaticity diagram (http://en.wikipedia.org/wiki/Tristimulus#Tristimulus_values)

luminance, IQ in-phase quadrature) and YUV(Y is luminance, UV 2 colour components or chrominance) are analogue spaces for National television systems committee (NTSC) and Phase alteration by line (PAL) systems respectively while YCbCr (where Cb and Cr are chrominance) is a digital standard. These colour spaces separate RGB into luminance and chrominance information and are useful in compression applications (both digital and analogue). These spaces are device dependent but are intended for use under strictly defined conditions within closed systems. Kodak uses a derivative of YCC in its PhotoCD system (Ford and Roberts, 1998).

3.6 CIE

There are two CIE based colour spaces, CIELuv and CIELab. They are nearly linear with visual perception, or at least as close as any colour space is expected to sensibly get. Since they are based on the CIE system of colour measurement, which is itself based on human vision, CIELab and CIELuv are device independent but suffer from being quite unintuitive despite the L parameter having a good correlation with perceived lightness, ab and uv with chrominance and hue. To make them more user friendly, the CIE defined two analogous spaces - CIELhs or CIELhc where h stands for hue, s for saturation and c for chroma. In addition CIEluv has an associated two-dimensional chromaticity chart which is useful for showing additive colour mixtures, making CIELuv useful in applications using CRT displays. CIELab has no associated two dimensional chromaticity diagram and no correlate of saturation (Ford and Roberts, 1998).

4.0 Colour Vision Theory

Colour processing begins at a very early level in the visual system (within the retina) through initial color opponent mechanisms. Opponent mechanisms refer to the opposing colour effect of red-green, blue-yellow, and light-dark in the X and Y cells of the retina. Visual information is then sent back via the optic nerve to the optic chiasm: a point where the two optic nerves meet and information from the temporal (contralateral) visual field crosses to the other side of the brain. After the optic chiasm the visual fiber tracts are referred to as the optic tracts, which enter the thalamus to synapse at the lateral geniculate nucleus (LGN). There are three categories of colour vision theory or model; three-components theory, opponent-colour theory and stage theory.

4.1 Three Components Theory

This theory was briefly stated in 1807 by Thomas Young and was elaborated by Helmholtz about 50 years later. It is also known as the trichromatic theory of colour vision. It assumes the existence of three independent response mechanisms in the normal eye: one predominantly sensitive to long-wave light and yielding the response red; a second predominantly sensitive to middle-wave light and yielding the response green; and a third sensitive to short-wave light and yielding the response violet (Judd, 1966). The theory assumes that yellow is produced by the sum of red and green responses and that white is produced by the sum of equal amounts of red, green and violet responses. The theory fails to explain the way some colour stimuli appear to an observer. Colour vision is possible with two receptor types. However, not all colors can be seen.

4.2 Opponent-Colours Theory

This theory was proposed and explained in detail by E. Hering in 1878. It is based on an analysis of sensations of colour rather than of the stimuli required to evoke them. It assumes that there are six independent unitary colours (red, yellow, green, blue, white and black), no one of which partakes of any other; that is for example, yellow is a basic colour in its own right, not a product of combining red and green. The Hering theory assumes that light is absorbed in the receptors by photopigments, that this absoption starts activity in the rest of the visual system and that this activity is directly responsible for the colours we see. This activity is not found in six separate systems, but in three opposing pairs of processes: black-white, yellow-blue and red-green. Black and white blend to produce gray but equal amounts of yellow and blue and of red and green cancel to zero (Judd, 1966 and Goldstein, 1989). The theory fails to explain certain types of “colour blindness” or deficiencies.

4.3 Stage –theory

This is also called the zone theory of colour vision. The rival theories of trichromatism and colour opponency competed until the stage theory was introduced principally by Muller, which incorporated the two views. The stage theory separates colour vision processing into a series of three stages or zones namely: photopigment stage, cone-response stage and optic-nerve stage. Signals resulting from the reception of light by the photoreceptors are modified at each successive zone often associated with a physiological level. The photopigment stage follows the three components theory based on the Young primaries. The cone-response stage follows an opponent-colours form and the optic-nerve stage is the opponent-colours formulation of Hering with red opposing green and blue opposing yellow. The two-stage theory is based on the retinal photopigment stage and the cone-response stage. There has been a considerable uncertainty as to precisely at what stage of the visual process the signals from the receptors can be said to be organized in opponent colours, whether this is in the retina, the optic nerve, or the occipital lobe of the cortex (Judd, 1966).

Figure 2 illustrates that the first stage of colour vision, the receptors, is indeed trichromatic as hypothesized by Maxwell, Young, and Helmholtz. However, contrary to simple trichromatic theory, the three ‘colour-separation’ images are not transmitted directly to the brain. Instead the neurons of the retina (and perhaps higher levels) encode the colour into opponent signals. The outputs of all three cone types are summed ($L + M + S$) to produce an achromatic response that matches the CIE $V(\lambda)$ curve as long as the summation is taken in proportion to the relative populations of the three cone types. Differencing of the cone signals allows construction of red-green ($L - M + S$) and yellow-blue ($L + M - S$) opponent signals. The transformation from LMS signals to the opponent signals serves to decorrelate the colour information carried in the three channels, thus allowing more efficient signal transmission and reducing difficulties with noise. The three opponent pathways also have distinct spatial and temporal characteristics that are important for predicting colour appearance (Fairchild, 2005).

The importance of the transformation from trichromatic to opponent signals for colour appearance is reflected in the prominent place that it finds within the formulation of all colour appearance models. Figure 2 includes not only a schematic diagram of the neural ‘wiring’ that produces opponent responses, but also the relative spectral responsivities of these mechanisms both before and after opponent encoding.

4.4 The Decoding Model.

There are many improved versions of the stage theory (Hunt, 1982 and 1987). Yet, the answers are still unclear as to why and how colour signals are processed and how colour vision has been evolving. To answer these questions better, Lu, (1986 and 1989) built a model of colour vision named the decoding model (fig.3). The decoding model can also be said to be a new version of the zone model, but it is quite different from others. Compared with a popular zone model, the decoding model adopts fuzzy logical operations but not arithmetical operations; it is strictly symmetrical and produces three pairs of chromatic signals: blue-yellow, green- magenta and red-cyan instead of the two pairs: blue-yellow and red-green used in a popular zone model. The "red" and "green" in the Hering theory as well as in the popular zone model are different from "red" and "green" in the Young- Helmholtz theory. In terms of the Young-Helmholtz theory or of the industry of colour television, "red-green" in opponent theory means a colour between red and magenta, and "green"" is a colour between green and cyan. The difference in names of the colours are not important; the important issue is whether three pairs of unique colours possibly exist. First, according to this model, it is not the final conclusion that only four unique colours exist; some people still insist that there should be more unique colours than four (Hardin, 1985). Second, more than two kinds of chromatic opponent signals in monkey retina was found by physiological experiments. Third, a model possessing symmetry seems better in theory; a symmetrical model of colour vision needs six unique colours. Fourth, colour vision is evolving; we can image that the number of unique colours is increasing from four to six. Even if there are some similarities between red and magenta order to demonstrate the process of colour signals both in the retina and in the cortex, a complete physical model of colour vision is built.

The physical model suggests that, in the cortex, there are seven colour cells, which receive white and six unique colour signals; the brain produces brightness and colourfulness by simple addition, and turns out hue and saturation by the method of weighing. Perhaps there are also some processes of colour signals on lower levels; for example, some white cells probably receive faster conducting signals directly from cones and rods. The decoding model does not cover this subject.

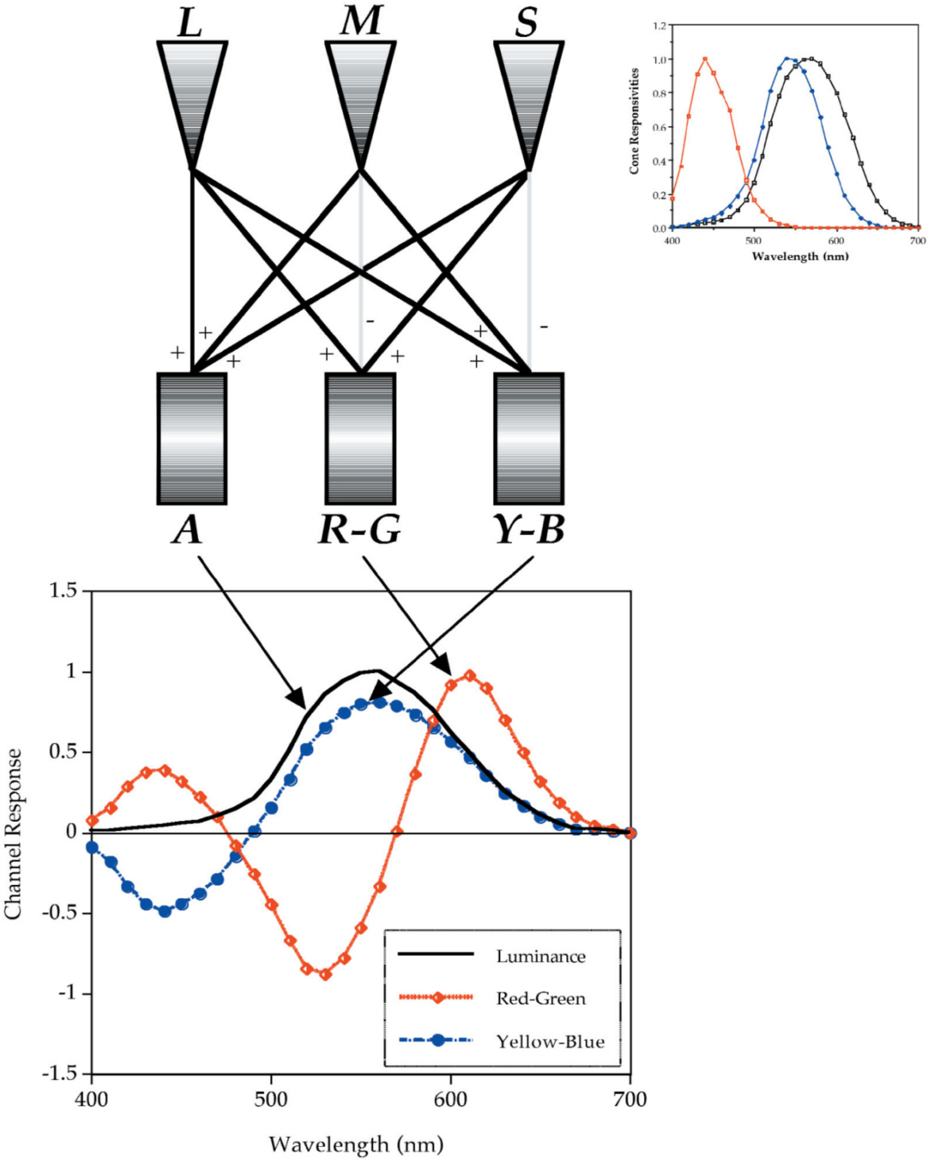

Figure 2: Schematic Illustration of the Encoding of Cone Signals into Opponent Colours Signals in the Human Visual System (Fairchild, 2005).

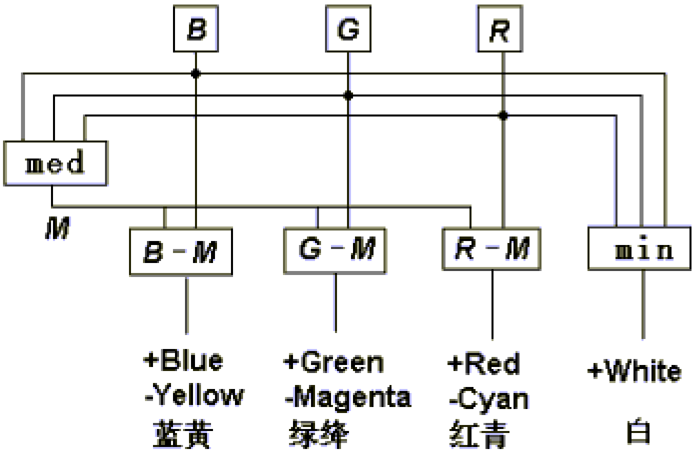

Figure 3: Symmetrical opponent process in the decoding model (Lu, 1989)

4.5 A Proposed Modified Colour Perception Model

A proposed modified colour perception model is hereby presented based on that designed by Fairchild (2005) already seen in Fig.2, which combined both the trichromatic and opponent theories. The modification basically takes into account the fact that nature generally has a feedback system. According to Walderr et al (2008) biological experiments and theoretical analyses have shown that cellular systems make use of feedback circuits to achieve a wide range of goals that are important for a living organism, such as robustness against perturbations and the closely connected signal sensitivity or optimality of their function with respect to relevant performance criteria. Cinquin and Demongeot (2002) had stated that both positive and negative feedback are important enhancers of the properties of biological systems. So a feedback loop is incorporated to take care of the various colour deficiencies that exist and perhaps those that are yet to be discovered (Fig. 4). A portion of the output is feedback into the input, modifying the input and hence the output depending on the feedback output. The three cone types L, M and S respond to long wavelength (red), medium wavelength (green) and short wavelength(blue). The outputs of the three are summed (L+M+S) to produce an achromatic response A or black-white (B-W), while differencing of the cone signals (L-M+S) produce red-green (R-G), (L+M-S) produce yellow-blue(Y-B). It is supposed that the neurons of the retina or higher levels encode the colour into opponent signals before transmitting to the brain. The two faint lines on the model indicate inhibition while the others indicate excitation. A feedback loop, a factor proposed that takes care of the deficiencies associated with colour vision (Fig. 4).

5.0 Conclusion

It is interesting to note that nature is both simple and complex. The solution of certain complex problem ended being very simple while the solution of certain simple problem ended being very complex. This is simply the beauty of our proposed model.

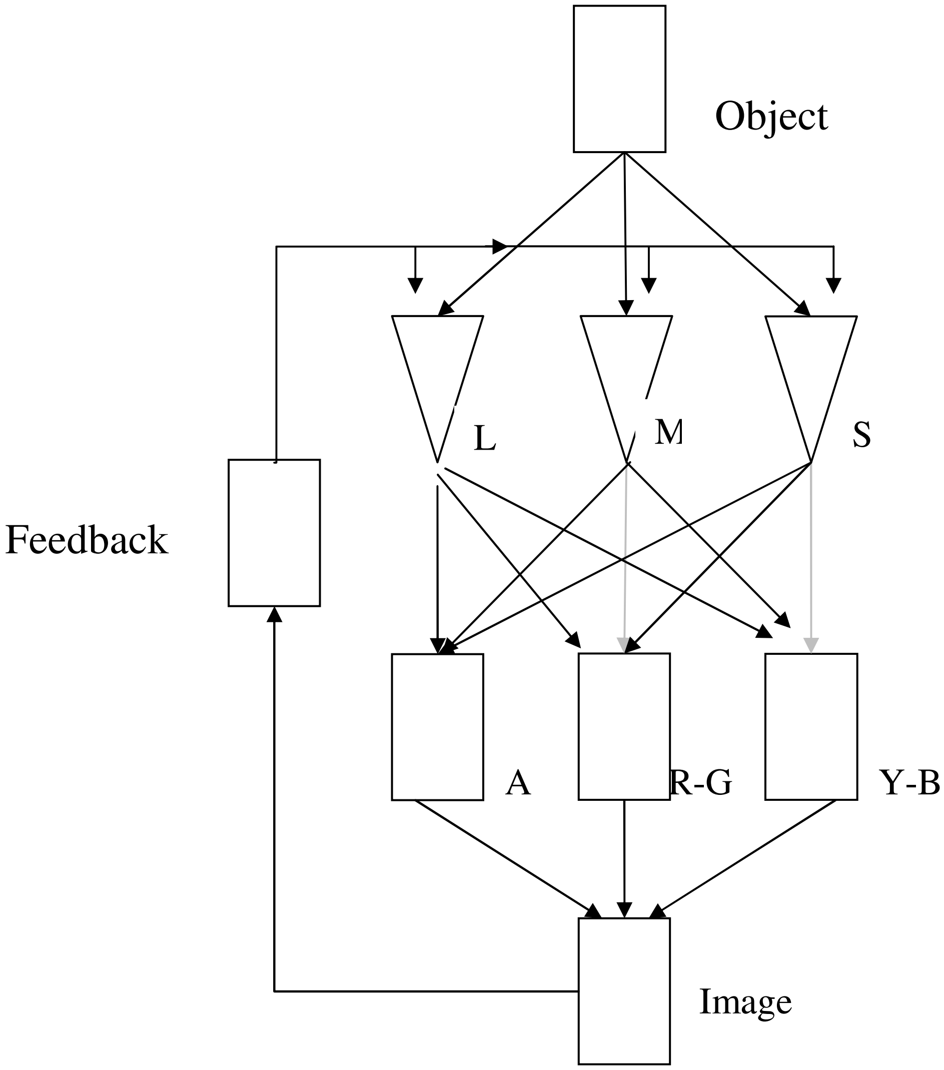

Figure 4: Proposed Colour Perception Model

REFERENCES

Cinquin O.and Demongeot J. (2002) Roles of Positive and Negative Feedback in Biological Systems. *Comptes Rendus Biologies*. 325 1080-1095.

Deckert C. (2008) http://www.eyedesignbook.com/ch3/eyech3-i.html#I.%20Human (Retrieved 7th May 2008)

Deckert C. (2008) http://www.eyedesignbook.com/ch2/eyech2-abc.html#Chapter%202. (Retrieved 7th May 2008)

Fairchild M.D. (2005 Colour Appearance Models Second Edition. Pp 18-19, John Wiley & Sons, Ltd, USA

Ford A. and Roberts A. (1998) Colour Space Conversions. http://www.poynton.com */PDFs/coloureq.pdf*

Goldstein E.B. (1989) Sensation and Perception. 3rd Edition. California, USA. Wadsworth Publishing Company, Inc. pp 122-125.

Hardin C.L.(1985) The resemblances of colours. *Philosophical Sudies*. **48**, 35-47

Hecht E. and Zajac A. (1977) Optics,. Addison-Wesley Publishing Company, Inc. USA. Pp 18 ,138.

Hutson G. H. (1971) Colour Television Theory. McGraw-Hill Publishing Company Limited, Great Britain. Pp14,15, 24.

Hunt, R. W. G. (1982: A model of colour vision for predicting colour appearance, *Colour Research Applications.* **7,** 95-112

Hunt, R. W. G (1987): A model of colour vision for predicting colour appearance in various viewing conditions, *Colour Research Applications*. **12**, 293-31

Judd D. B. (1966) Fundamental Studies of Colour Vision from 1860 to 1960. *Proceedings of the National Academy of Sciences of the United States of America.* **55** (6) 1313-1330.

Kalloniatis M. and Luu C. (2008) http://webvision.med.utah.edu/Psych1.html

Khan A.A., Rizvi A.A, and Zubairy M.S.(1994) Coloured Pattern Recognition with a neural network model. *Applied Optics* **33** (23), 5467-5471.

Kilborn L.G. and Beh Y.T.(1934). The incidence of Colour-Blindness among the Chinese. Science.**79** (2037), 34.

Levene J.R.(1977) Clinical Refraction and Visual Science. Butterworths & co, Ltd London. Pp 35-50, 124.

Lennie P. (1984) Recent Developments in the Physiology of Colour vision. *Trends in Neuroscience*.**7**, (117) 243-248.

Levi L. (1980). Applied Optics. A Guide to Optical System Design. volume 2 John Wiley & Sons, New York. pp 345,357

Lu, C.G.: (1986) New Theory of colour vision and simulation of mechanism, *Developments in Psychology in China,* ***14*****,** 36 45.

Lu, C. G.: (1989) Decoding model and its verification, *Acta Optica Sinica*, **9**, 158-163.

Maximov V.V. (2000). Environmental Factors which may have led to the appearance of Colour Vision. *Philosophical Transactions of the Royal Society of London.* **355** (1401), 1239-1242.

Nassau K. (2003) The Physics and Chemistry of Colour: The 15 Mechanisms. In: The Science of Colour. 2nd Edition, edited by Shevell S.K. Optical Society of America. Chapter 7 pp 247-280.

Parr J. (1978) Introduction to Ophthalmology. Oxford University Press, New Zealand. Pp 42-43,67

Shuey A.M.(1936) The Incidence of Colour-Blindness among Jewish males. Science. **84** (2175), 228.

Squire T.J., Rodriguez-Carmona M., Evans A. D. B. and Barbur J. L. (2005) Colour Vision Tests for Aviation: Comparison of the Anomaloscope and Three Lantern Types. *Aviation, Space and Environmental Medicine.* **76** (5), 421-429.

Walderr S., Eissing T., and Allgower F. (2008) Analysis of Feedback Mechanisms in Cell- biological Systems. *Proceedings of the 17th World Congress. The International Federation of Automatic Control. Seoul, Korea, July 6-11.*

Wandell B.A. and Silverstein LD. (2003) Digital Colour Reproduction. In: The Science of Colour. 2nd Edition, edited by Shevell S.K. Optical Society of America. Chapter 8 pp 281-316.

http://www.colourvision.info/colour_vision_deficiency_correction_about_colour_ deficiency and colour_blindness.htm (Retrieved 8th Nov 2007)

http://en.wikipedia.org/wiki/Tristimulus#Tristimulus_values (Retrieved 27th May 2008)