The Effects of Gloss and Viewing Flare on Colour Appearance

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Abstract: In colour management it is often desirable to obtain matching colours across media which impart different gloss characteristics to the image. Furthermore, this matching is often assessed in situations in which there is a high degree of viewing flare. These factors impact colour appearance in a way that is difficult to measure with existing techniques of colorimetry. Recent studies undertaken in evaluating colour difference have suggested to us that this is particularly significant with dark colours. In order to improve prediction of matching colours in real viewing conditions it is necessary to be able to predict viewing flare - and the effects of this when comparing samples of differing gloss in these viewing conditions. This will enable modelling of a correction to colorimetric data to improve appearance predictions in such circumstances. A hypothesis for this model is presented - together with the results of some preliminary work to justify the need for it.

Introduction

Colour management, as currently implemented, generally uses CIE colorimetry as the basis of defining the colour required in a reproduction. However, as is well documented now, (see, for example, Johnson (1995)), such an approach is somewhat simplistic. It is based on the demonstration that all observers who do not suffer from colour "blindness" require very similar mixtures of three widely differing stimuli to match any colour. From that "simple" demonstration a set of stimuli (called XYZ) were standardised by CIE and an international measurement system based on the mixtures of these required to match all spectral stimuli, by an average of 17 observers, was established in 1931. Since the system is based on colour matching observations it tells us that if two colours have the same XYZ tristimulus values they must look the same.

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However, during recent years it has become evident that such a situation is only applicable to limited conditions. The system was derived for isolated stimuli and as viewing conditions differ between samples which are intended to match simple matching of tristimulus values is inadequate. Johnson (1995) summarised much of the earlier work pertaining to this problem and a colour appearance model approved by CIE, CIECAM97s, formally specifies a mathematical procedure to accommodate the situation where conditions of viewing differ between samples that are intended to match. Such a situation is very common when attempting the cross-media reproduction which occurs so frequently in Graphic Arts colour reproduction.

However, the appearance of a coloured surface is not only dependent upon the colour of the sample and the viewing conditions in which it is seen. Other attributes of appearance that are important in assessing a sample are associated with its surface texture – and in particular its gloss. It is our view that in order to predict a match between two samples it is necessary to extend colour appearance measurement to take account of these surface effects when they differ between the samples. In this paper we present the results of some work which was undertaken to confirm this view and introduce a programme of work which is now being initiated in an attempt to quantify this.

In order to set the context for this we will start by introducing the complex mechanisms which are involved when light is reflected by a sample and summarise the main literature pertaining to Graphic Arts that we have found in undertaking this work. This will be followed by a discussion of the preliminary work undertaken to confirm the need for an extended model of appearance when sample textures differ, and our hypothesis concerning the nature of that model.

Surface reflection of incident light

The way light is reflected from a surface depends upon the nature of the colorants (if any), the substrate on which they are applied and the vehicle in which the colorant pigments or dyes are dispersed. It can be rather complex as shown in figure 1.

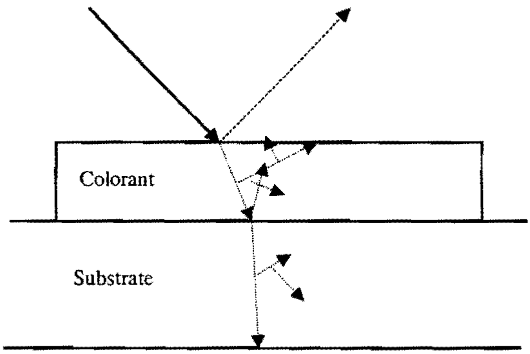


Figure 1 - Some of the options for the nature of the light reflected or transmitted by a medium

A fraction of the light is reflected from the first surface of the medium on which the light is incident while the remainder passes into the colorant medium or reflecting substrate. This light undergoes preferential absorption of certain wavelengths, which imparts its colour, and the remaining light is either transmitted by the medium (if it is non-scattering) or reflected following scattering (in which case the sample is opaque). Many colorant layers exhibit some mixture of reflection and transmission of the incident light, which produces distinct characteristics of opacity or transparency for that media.

Any transmitted (and some scattered) light will strike the substrate and so the characteristics of this layer will also affect the way the light is reflected overall. However, the substrate itself may transmit some of the light incident upon it, particularly if it is a thin layer such as paper, and if so the print will exhibit a degree of translucency. Of course, if the substrate and colorant layer are both transparent, in that they exhibit limited scattering, the materials are transmissive but for the purposes of the issues this paper is concerned with discussion will be restricted to reflecting samples.

Since all of the components of the reflected light are seen simultaneously when the medium is viewed it is the proportions of the light that are reflected in any particular direction that determine the appearance of the medium at that viewing angle. However, the light reflected from the first surface is of particular interest in that it produces the appearance of gloss associated with a surface.

The light reflected from the first surface of a medium will often have the same colour as that incident on it, unlike the light which is transmitted into the media and which will undergo preferential absorption of certain wavelengths. So, it undergoes little change in colour and the effect on the perceived colour of any first surface reflectance is that it typically adds 'white' light to that which is reflected from within the colorant layer. The result of this is that the colour appears lighter and 'desaturated'. For this reason we normally try to avoid looking at any specular component of the reflected light when viewing a surface, at least when the angle at which it is reflected is highly specific.

For a perfectly smooth surface, such as a mirror, any specularly reflected light is emitted at an angle equal and opposite to that at which it is incident, as shown in figure 2. For a good mirror the amount of light reflected specularly is only slightly lower than the amount of the incident light – for most media, however, it is substantially lower.

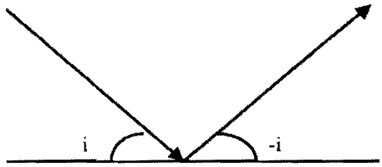


Figure 2 - Light is reflected at an angle equal and opposite to that at which it is incident.

The specularly reflected light also undergoes some degree of polarisation, the degree of which varies with the angle of incidence. It also retains any polarisation present in the incident beam, unlike that which is transmitted into the media.

Light reflected specularly from a mirror type surface (such as glass, varnish or water) exhibits the characteristics described above and it is this that provides the gloss we typically associate with such surfaces. The fraction of incident light which is specularly reflected depends upon the refractive index of the material (and that from which the incident light has passed - usually air) and the plane of polarisation of the incident light (if any).

With polarised light the proportion of light reflected specularly from typical pigmented layers can, at angles of incidence close to the Brewster angle (defined as the angle at which the tangent is equal to the ratio of the refractive indices), vary significantly. It can be as low as 1% and as high as 9% depending upon the plane of polarisation.

The proportion of the incident light reflected specularly will increase with the refractive index of the media. For most paint and printed ink films the refractive index is typically similar to glass and this means that about 4% of unpolarised light is specularly reflected for all of these materials. However, that is for angles of incidence up to about 45 degrees. As the angle of incidence increases beyond 45 degrees the amount of light reflected specularly increases significantly. At 90 degrees (grazing incidence) all of the light incident upon the sample is reflected specularly.

At the other extreme there are surfaces which appear to exhibit no gloss. Some of the light is reflected specularly, from the first surface, since it follows exactly the same laws as those defined above. However, the nature of the surface is so uneven (even though this may only be at a micro-level that is not apparent without the aid of a microscope) that the incident light is scattered at all angles. Because of this the reflected light appears to be totally diffuse and inseparable from the light scattered back from the within the media. A theoretical material, known as a Lambertian surface (or perfect diffuser), is one that is such that when illuminated appears equally bright from all angles as shown in figure 3. The luminance of the reflected light L is given by the equation:

$$L = E \cos i / \pi$$

where E is the flux per unit area of the incident beam and i is the angle of incidence.

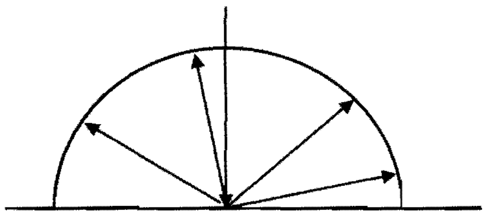


Figure 3. For a Lambertian surface the reflected light is the same at all angles, regardless of the angle of incidence; even though the absolute level of reflected light varies with the angle of incidence.

No real material meets this criterion exactly but it is approximated by media such as pressed barium sulphate or magnesium oxide. For this reason these materials are often used as coatings for integrating spheres. Some translucent glass materials also approximate this behaviour.

Most surfaces encountered in practice are neither perfectly glossy nor perfectly matt and the light reflected from the media has a characteristic typical of that shown in figure 4. It consists of the specularly reflected light mixed with the diffused light from within the media itself. The peak reflectance at the angle equal and opposite to that of the angle of incidence is dominated by the specular reflectance in the example shown in the figure. However, the amplitude and 'spread' of this peak will vary as a function of the glossiness of the material. For glossy materials the peak will be high and narrow, for matt materials it will be low and broader. There is also some evidence, Paul (1994), that the angle of peak reflectance increases with decreasing gloss by as much as 5 degrees.

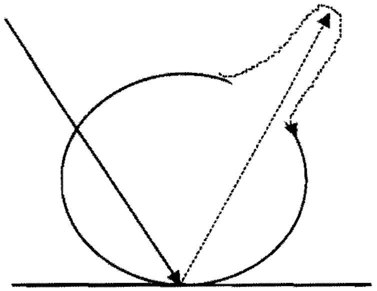


Figure 4. Typical reflectance characteristics of a glossy surface. Note the peak at the angle of specular reflectance

The situation is further complicated when the sample being illuminated has texture. This means that the surface of the sample is not glossy, but is often not matt either. It may consist of a structure in the surface plane which has some distinct geometric property that produces a limited number of surfaces with predominant angles when compared to the illumination and viewing angles. A very simple example is shown in figure 5. Thus, for such media, the reflectance of the specularly reflected light is further complicated.

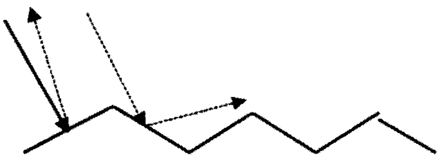


Figure 5. A simple example of texture in which the surface has two predominant angles. It is clear that when illuminated specularly the sample will appear darker on one side of the peak than the other. Which appears lighter or darker will depend on the angle of view.

The complexity of the way light is reflected from a surface has led to various terms being defined to describe the nature and appearance of the surface, such as egg-shell finish, used for paints, and distinctness of image. Table 1, adapted from Hunter and Harold (1987), shows some of the perceived attributes of gloss observed during Hunter's experiments, the method typically used to measure each, and the types of surfaces he considered each applicable to.

Table 1 – Six Types Of Gloss

Types of Gloss	Visual Evaluation	Reflectance Fnctn*	Types of Surface
Specular gloss	Shininess, brilliance of highlights.	G(s) = k(s)S/I	Medium gloss surfaces of paper, paint, etc
Sheen	Shininess at grazing angles (e.g. 85 degrees).	G(sh) = k(sh)S/I	Low gloss surfaces of paint, paper etc.
Contrast gloss, or lustre	Contrast between specularly reflecting areas and other areas.	G(l) = k(l)D/S	Low gloss surfaces of textile fibres, newsprint, bond paper, etc.
Absence-of-bloom gloss	Absence of haze adjacent to reflected highlights.	G(a) = k(a)(D-B)/I	High and semi-gloss surfaces in which reflected highlights may be seen.
Distinctness-of-image gloss	Distinctness and sharpness of mirror images.	G(d) = k(d)δR/δθ	High-gloss surfaces of all types in which mirror images may be seen.
Surface-uniformity gloss	Surface uniformity, freedom from visible non-uniformities such as texture.	Not a function of reflectance	Medium-to-high gloss surfaces of all types.

* S, I and D are the specular, incident and diffuse components respectively; **B** is the component at an angle close to S (approximately 5 degrees from it); R is reflectance; θ is the deviation from the angle of specular reflectance and k is a constant of proportionality.

Of course, for typical viewing situations, the reality of the illumination conditions is very different to the simple examples, with a single angle of incidence, described above. Light striking the object will be a mixture of diffuse and specular illumination at a variety of angles. Diffuse illumination, striking the sample from all angles, will be scattered from other surfaces such as walls and ceilings whereas specular illumination comes from light fittings and windows which illuminate the sample directly. Reflected light, at any specific angle the sample may be viewed at, will then consist of the light reflected from these sources by all the points subtended by the eye. This makes analysis of the perceived reflectance of a sample at any specified angle, and hence its appearance, impossible without defining some 'typical' viewing situation. In practical situations, where it is not possible to be sure exactly how a sample will be viewed, it is not uncommon to choose matt materials to minimise any problems due to gloss causing the appearance of 'glare'. However, where depth of colour is important glossy materials are often chosen and the risk of 'glare' is accepted. This may be an unacceptable approach where the observer cannot move the sample, or themselves, to avoid the glare.

In order to measure the appearance of samples it is normal practice to make separate measurements of the various parameters that impact appearance, such as colour and gloss. Procedures commonly used for the measurement of gloss have been summarised in table 1. For colour measurement two instrument geometries are specified by CIE for reflectance measurement. The first of these is usually abbreviated to 0°/45° (or 45°/0°) and specifies that the sample shall be illuminated with a narrow beam of light at 0 or 45 degrees to the sample. The reflected light is then measured at the alternate angle. The second geometry is 0°/diffuse (or diffuse/0°) and this specifies that the sample shall be illuminated with a narrow beam of light at 0 degrees, and the reflected light integrated by a highly reflecting sphere so that the total reflected light may be measured. Alternatively, the incident light may be diffuse and the reflected light measured at 0 degrees. (In practice it is normal to offset the 0 degrees to 8 degrees, but for most samples this makes no significant effect).

It should be noted that, apart from making use of any polarisation introduced into the incident light, it is generally impossible to completely separate the specular and scattered components during any conventional colour measurement. The diffuse measurement geometry defined by CIE does permit addition of a gloss trap. For a high gloss sample this will essentially include or exclude the specular reflection, but not for samples of lower gloss where the specular component is spread more broadly. It should also be noted that it is not generally possible to convert data obtained from one instrument geometry to that of the other.

Clearly the geometries defined by CIE are not similar to the 'typical' viewing condition described above. However, for many aspects of colorimetry any issues arising from this are of limited importance. Applications such as the control of paper and ink manufacturing are usually limited to internal control within companies, using a restricted range of instruments. Such measurement is primarily concerned with the specification of differences from some approved sample with similar surface characteristics. In such situations the measurement of appearance of a sample is not important – in fact even issues of inter-instrument agreement are not important (apart from between those in use within the company, which are often all of the same type). So long as sufficient care is taken to calibrate the instrument and sufficient measurements are made to minimise sample effects the result obtained is adequate, even if the absolute accuracy achieved by any instrument is fairly low. It is only when data is required to be exchanged that absolute accuracy (or at least high levels of inter-instrument agreement) is required.

However, when we consider issues associated with cross-media matching we are precisely in this situation – even if all the data exchange is still internal to one company. Measurements need to be made of monitors, prints and photographic transparencies, with the objective of defining a colour match between the media.

Usually such measurements will be made with different instruments, and even where it is possible to use a common instrument it will require different illumination and viewing geometries for each media type. As stated above the geometries typically used essentially provide measurements of a flareless condition, whereas most practical viewing situations include some degree of flare, which is likely to be different for each media. Thus any measurement is unlikely to predict appearance such that a match can be guaranteed. It has to be said that models such as CIECAM97s, which are based on visual experiments, do inevitably include some correction for flare, albeit that it is not explicit. However, in our view it would be desirable to see a more specific correction for flare so that the model can be more easily specified for any viewing condition. We anticipate that our work will enable us to achieve this.

Furthermore, in visual assessment a special type of glare, caused by the gloss of the sample itself, may well affect its appearance in a way that is dependent on the illumination incident on the sample and the way it is viewed. Thus, since the geometry used for measurement is rarely similar to that used for viewing, this creates a problem in defining a colour match for samples of differing gloss, when using existing measurement techniques.

If a print on glossy coated paper is viewed such that the gloss is directed into the eye of the observer, the resulting effect is to heavily desaturate the colours being viewed. This is obviously undesirable and needs careful design of the viewing area to avoid it. In practice the problem may be worse with semi-glossy samples since most observers will move their head to avoid the glare from high levels of gloss but may not be so careful where the gloss is less pronounced. As observers of different height view the sample, or it is moved from site to site, each with slightly different designs of viewing areas, the small differences in the specular light included in the viewing of the print may cause a problem. So, as the gloss of any samples that have to match varies from one to another this may introduce a significant source of error in the prediction of a match.

Of course, if samples differ in gloss any colour match can only hold for the conditions of viewing for which the match was made. Change any of these and the match will break down. In this sense it may seem ambitious to even attempt a match in these conditions. However, our industry accepts quite highly metameric matches in producing colour reproductions, in the knowledge that such a match will break down as the spectral power distribution of the illuminant changes. Part of the reason that is acceptable is because of the existence of standard viewing conditions with a well defined illumination source. The situation with varying gloss is very similar. The standard conditions of viewing used in Graphic Arts are well enough defined to make prediction of a match for these conditions a worthwhile exercise. Also it would be convenient to be able to specify by how much any match will breakdown as any such conditions are changed – by means of a viewing index, similar in concept to a metameric index. Thus, our objective in this study is, firstly, to determine the magnitude of the effect of the change of viewing conditions on the appearance of typical samples and, secondly, to produce a model for the measurement of colour that incorporates some aspect of gloss, and define the parametric constants needed in the model for 'typical' viewing conditions.

Literature reviewed

The classic studies of Gloss were those undertaken by Harrison and Hunter. The findings of both of these experts were summarised in books published by each of them which are still required reading for anyone requiring an understanding of the way light is reflected by a sample, and how it impacts appearance (Harrison (1945) and Hunter and Harold (1987)). Much of the discussion in the previous section, including table 1, was summarised from these books.

More recent papers have been written by a small number of workers. Most are largely devoted to the measurement of gloss, and its correlation to visual impressions. Seve (1993) reviewed much of the earlier work in this area, and extended the theoretical analysis of Harrison and Hunter. He discussed the measurement of gloss and questioned the assumptions, largely derived from the work of Hunter, as to why different types of samples require measurement at different angles of incidence. This was not a paper reporting on a lot of new practical work but was intended to provide an improved understanding of the concept of gloss, to promote interest in a topic that the author felt was inadequately covered and define important areas where agreement is required in order to agree on standard methods for measurement.

Paul (1994) reported on one of the main issues raised by Seve. His objective was to study whether traditional methods of gloss measurement (typically of specular gloss at varying angles of incidence) correlated well with the visual impression of the sample, and whether an improved measurement method could be derived. His observers were presented with samples of varying gloss in a manner similar to that in which they are measured (i.e. viewed through an aperture, at the specular angle, with 45° incident light). They were then asked to define a gloss category (in the range 0 to 6) for each sample that they were presented with. Paul concluded that a better correlation with the visual assessment of gloss was obtained by taking the logarithm of the ratio of specular to diffuse reflectance (measured at 45 degrees incidence). He also proposed that the actual angle at which the peak reflection was achieved (which he found to be greater than 45 degrees for low gloss samples) should be used as the measure of specular reflectance. A generalised form of this measurement (without restriction on the angle of incidence) is referred to as contrast gloss, or lustre, in table 1 above. He concluded that such a measurement procedure was appropriate to all levels of gloss whereas Hunter had concluded that it was only appropriate to low gloss materials. Work is currently being undertaken by various countries, under the auspices of ISO TC 130, to investigate this further. We have been participating in this work and have not completely confirmed Paul's findings for more normal viewing conditions. However, that work is not the subject of this paper – this will be published later following additional work being undertaken to investigate this further

The work of Paul was directed at a method to determine the measurement of gloss. This is an important appearance attribute but is not the main one of interest to our work presented here. Our objective is to study how differences in gloss impact the appearance of colour and to try to predict this effect on measurement. Work to measure the effect of gloss on colour has been published in two papers. Leekley et al (1978) investigated the change in colour obtained when printing the same ink onto various substrates with differing gloss. They used a polarising reflectometer to separate the specular and diffuse components of the reflected light (measured at the diffuse angle), which was also fitted with colorimetric filters to provide tristimulus values directly. They demonstrated, and quantified, the phenomenon of desaturation and increased lightness associated with surface reflectance described earlier but also showed that with one of their three coloured inks (a magenta) a distinct hue shift was introduced by bronzing. They proposed that a measure of the degradation could be defined, although it is unfortunate that they based the proposed metric on differences calculated in the 1931 CIE colour space. They also showed that there was little correlation between the degradation and 75 degree gloss, which is important to our study – but the question has to be whether this was affected by their choice of colour space and choice of gloss angle. This is an issue that we certainly intend to address in our work.

Dalal and Natale-Hoffman (1999) proposed a simple model for predicting the change in colour of a sample, according to the geometry of measurement and the distribution of its first surface reflections (i.e. gloss) given by:

$$R_{meas}(\lambda,g) = R_{intrinsic}(\lambda) + r(g)$$

where R_{meas} is the measured spectral reflectance, $R_{intrinsic}$ is the light reflected from within the colorant layer, and r(g) is the specularly reflected light.

This model is based on the classic theory for the way light is reflected by a sample described in the early part of this paper, (including the assumption that the specularly reflected light does not undergo any bronzing and that the intrinsic colour is totally diffused). Knowing the refractive index of the media the authors were able to calculate the total first surface reflection and using specular included measurement were able to determine $R_{intrinsic}$. Curve fitting was then used to determine the variation with r(g) as a function of 75° gloss for both 0°/45° and specular excluded diffuse measurement geometries. The model was used to calculate the colour of samples of varying gloss and compared to the measured values for the same samples. Errors found were reasonably small. It is suggested that the profile for r(g) as a function of gloss could be determined for any media using this method, and subsequently used to predict the colour of any sample of known gloss for various instrument geometries.

The papers by Leekley et al and Dalal and Natale-Hoffman come closest to addressing the problem we are addressing in this work. Both attempted to investigate the effect of gloss on colour, and to produce quantitative data. Leekley et al propose a procedure for measuring the change in colour caused by surface reflections for a standard 0°/45° measurement geometry instrument fitted with removable polarising filters. Dalal and Natale-Hoffman provide a procedure for predicting the change in measured colour, as the instrument geometry is altered, by separating the specular reflectance from the intrinsic colour and defining the colour change as the proportion of specular reflectance reaching the detector varies as a function of gloss. However, neither approach totally answers the problem we outlined at the start of this paper – how do we ensure matching colour appearance when samples have differing gloss? Clearly the approach of Dalal and Natale-Hoffman goes part of the way toward this but the problem is more complex than simply separating the intrinsic colour from the specular reflections for known instrument geometries. To predict the effect of the gloss on colour appearance it is also necessary to know the distribution of the light incident upon the sample, and at which angle the sample will be viewed. In general each viewing condition will be different and so no general solution will be simple. Our objective is to establish to what extent the problem affects the prediction of a colour match – and to provide a solution for 'common' viewing conditions.

The problem lies in the fact that most measurement techniques are based on using instrument geometries that are essentially simple and 'flareless' whereas real viewing conditions rarely are. Thus, the approach of Dalal and Natale-Hoffman will allow us to separate the measurements of the diffuse intrinsic colour and that arising from surface reflections. However, to predict the perceived colour it is important to know to what extent the intrinsic colour will be affected by any first surface reflections being directed toward the angle of view for a specific illumination condition.

Hypothesis

Our hypothesis is that the measurement of the colour of a sample can be described by the following model which adds the contributions reaching the eye from the flare, diffuse and specular components.

The total light perceived at each wavelength is given by:

$$L_\lambda = r_{d\lambda} + \alpha r_{s\lambda} + f_\lambda$$

where $r_{d\lambda}$ = diffuse sample reflectance
$r_{s\lambda}$ = specular sample reflectance
f_λ = flare (a constant for each viewing condition)
α is a function of the gloss of the sample and the viewing geometry

Tristimulus values can then be calculated in the normal way by summing the product of the result obtained with the colour matching functions over the range of visible wavelengths.

This hypothesis is similar to that defined by Dalal and Natale-Hoffman except that it is extended to include flare and the viewing geometry. Furthermore, since r_s is a function of wavelength it will not assume there is no bronzing Initially we will assume that the intrinsic colour is totally diffused but this will be investigated during this study.

In order to fully define the viewing conditions used in our experiments measurements will be made with a telespectroradiometer from the position of the observer and the sample. This will allow us to define both the goniophotometric distribution of the light reaching the sample and what is seen by the observer. By using samples of varying gloss it is anticipated that the parameters for the above model can be determined explicitly for each viewing condition studied.

It is anticipated that the effects will be most noticeable on dark samples where any flare and specular component can be large compared to the diffuse component and should also be noticeable on high chroma colours where 'white' light de-saturates the sample. We already have evidence of the problem of flare on dark samples reported in our studies of colour difference, Johnson and Green (1999 and 2001).

Preliminary study

It was clear at the outset that the amount of work required to complete this study would be very large. It was therefore felt to be important that a preliminary experiment be carried out to confirm the importance of the problem prior to commencing this work. This was an ideal subject as part of a Masters project, which also studied the measurement of gloss, and the following describes that work.

Our eventual objective is to determine the absolute nature of any change in the colour of a sample as the viewing conditions are changed. However, to achieve this would require rather complex magnitude estimation experiments – and to take account of chromatic adaptation effects. This was beyond the scope of this study and so we decided to limit the work to a comparison of the measured colour difference from a reference, for samples of varying gloss and small to medium colour difference, with a simple estimate of the perceived colour difference for the same samples in various viewing conditions. It was our expectation that if the problem exists as we believe, based on the nature of the change in colour that we anticipate, that it would, at least in part, be revealed by such an experiment and that perceived difference would not have the same correlation with measured difference for all sample types and viewing conditions.

A series of eight coloured samples were produced on three different substrates with surfaces described as glossy, satin and matt. Each 'reference' sample was produced alongside a range of others exhibiting varying colour differences from it. For each colour 'centre', four of these samples, with colour differences from the reference sample that ranged from approximately 1 to 8 (though the range varied between the colours) were selected, in addition to the reference. Observers were asked to assess the magnitude of the colour difference between the reference and each sample when compared to a pair of colours printed on satin paper. The satin samples used in this comparison consisted of the satin reference and another with a colour difference greater than the largest which had been measured on any substrate. The observer was told the magnitude of the difference for the satin pair and asked to judge the difference relative to this.

Three different viewing conditions were used for these assessments. One was a standard viewing booth and the others were a room which was significantly influenced by a large window and the same room in which the window was masked by a blind. Although it contained a number of light sources the latter could be treated as primarily diffuse illumination, whereas the other room geometry and viewing booth each contained a significant specular component.
Unfortunately time limited the number of observers to 3 and the number of colour regions evaluated by all the observers to 4. (The tristimulus values for these samples for a 0°/45°geometry are given in table 2). However, even this limited study was sufficient to show that there seems to be a significant effect on the perceived colour, which is dependent both on the gloss and colour of the sample, as shown in figures 6 to 9.

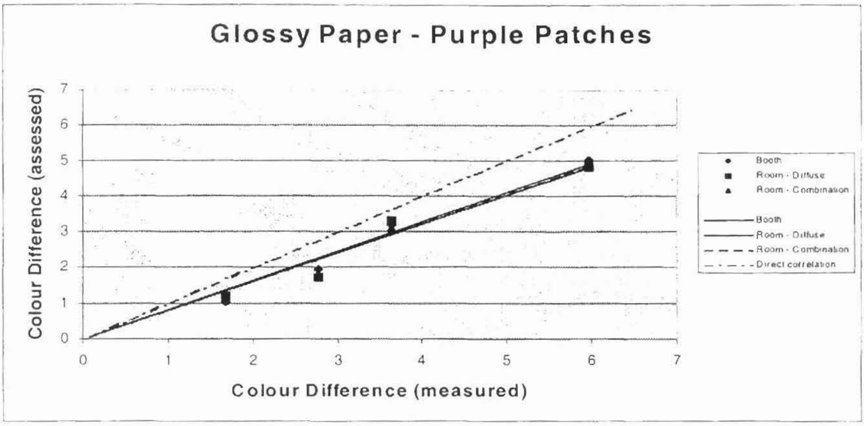
Table 2 – CIELAB values of reference samples used in preliminary study.

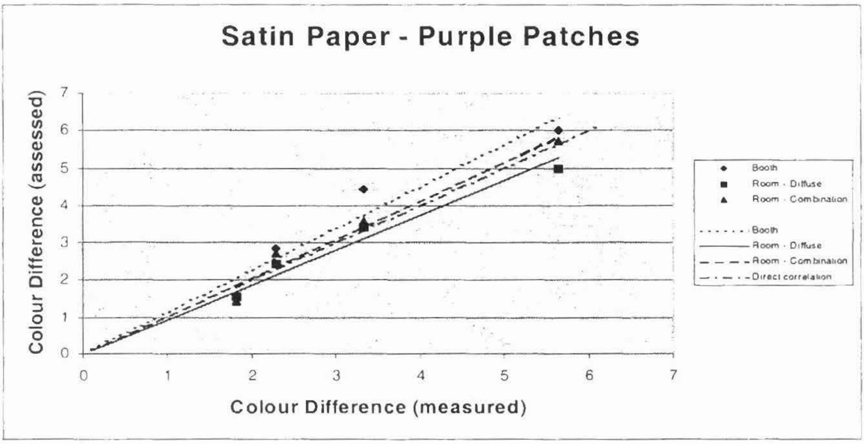
	Purple			**Black**		
Paper	L*	a*	b*	L*	a*	b*
Gloss	22.15	22.25	-29.79	21.48	2.89	-3.30
Satin	22.95	23.45	-31.77	21.58	2.91	-4.38
Matte	27.24	16.53	-23.01	27.31	2.60	-0.74
	Yellow			**Green**		
Paper	L*	a*	b*	L*	a*	b*
Gloss	68.17	-2.55	58.55	44.64	-49.54	20.61
Satin	68.71	-2.06	58.34	44.98	-49.75	19.95
Matte	69.67	2.12	63.42	45.42	-40.37	21.52

Figures 6 to 9 show plots of the data obtained from the experiment for each colour. Each figure has three plots – one for each substrate. The average of the values given by the three observers, for each of the individual samples, under each viewing condition, are shown - and the linear trend lines for these data are also plotted (slightly extended for clarity). These trend lines have been forced through the origin and although there was some evidence that a linear fit was not good for all of these data we restricted our plots to this given the limited number of observations made.

Discussion of Results

It is clear from these figures that for the Green and Black samples, and to a lesser extent the Purple, the perceived difference is much lower for the glossy samples than for the matt samples – by a factor approaching 2:1 in the worst case. Initially we found this result a little surprising, as it seems to persist for all viewing conditions, but have concluded that even in the viewing conditions in which the specular illumination was believed to be largely avoided in the field of view the influence of the first surface reflection was greater than expected. The alternative explanation would be that the absolute differences in colour between the samples on each type of paper, caused by the nature of the surfaces, has some impact on the results, but we doubt this.





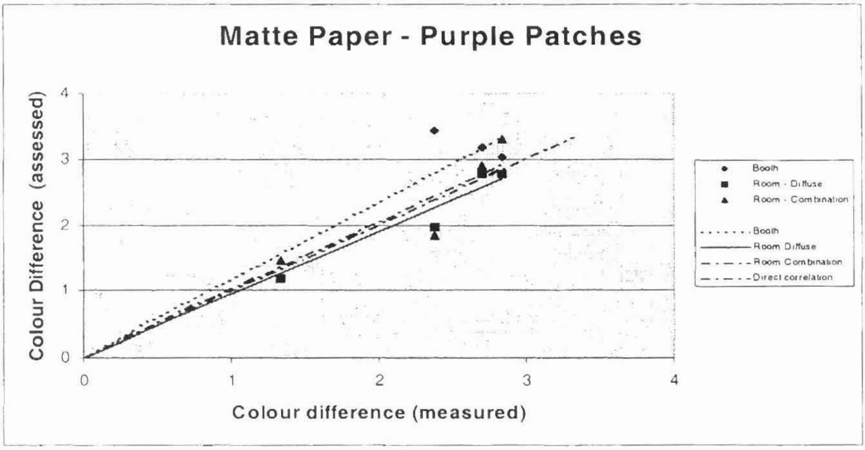
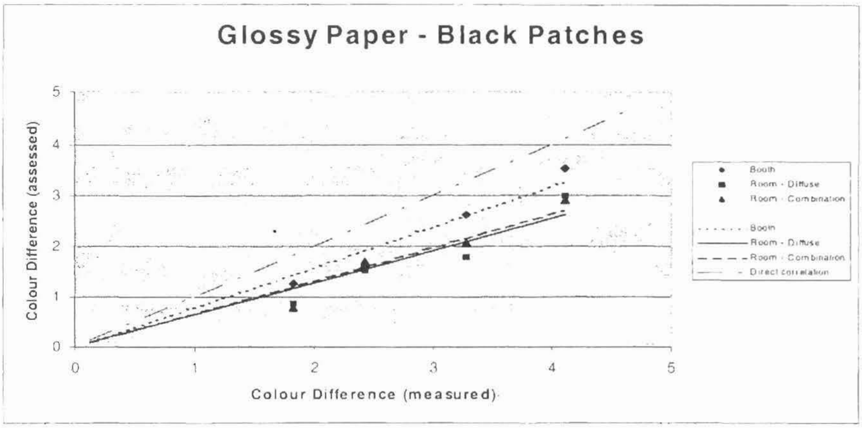
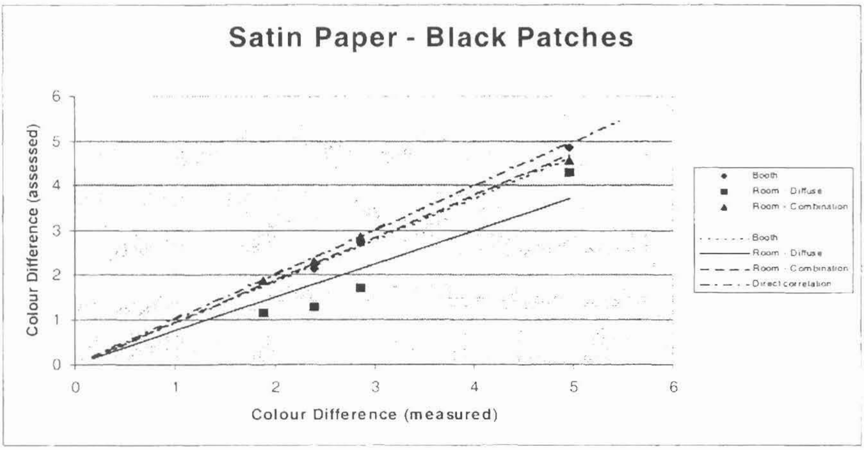


Table 6 – Data and linear trendlines for Purple colour (3 papers).





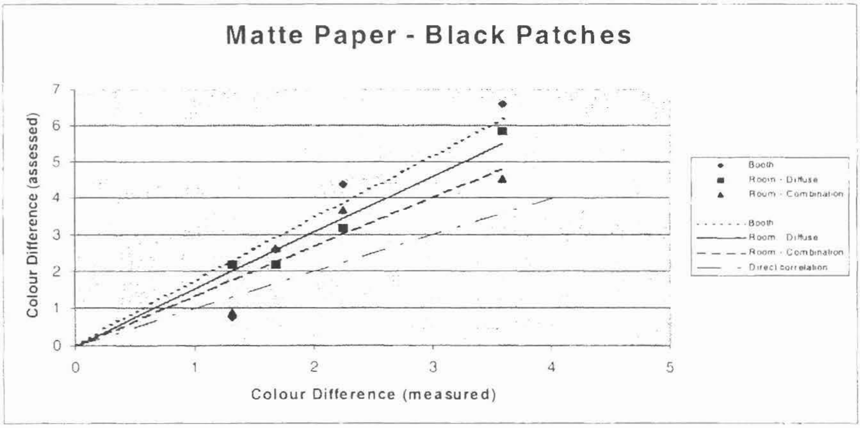
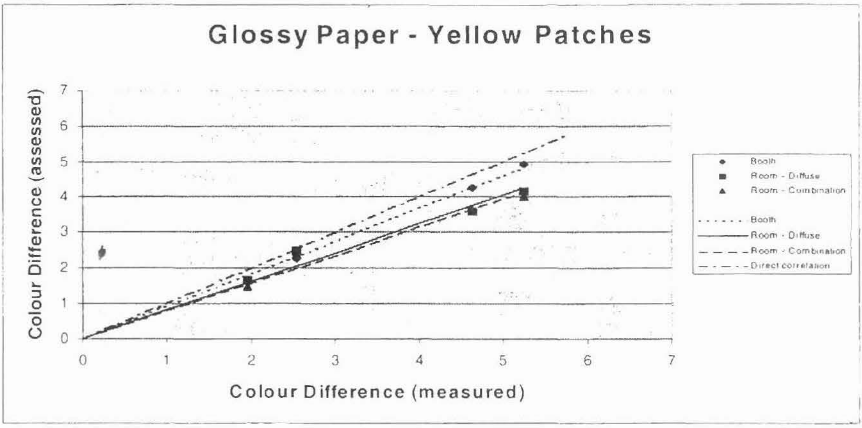
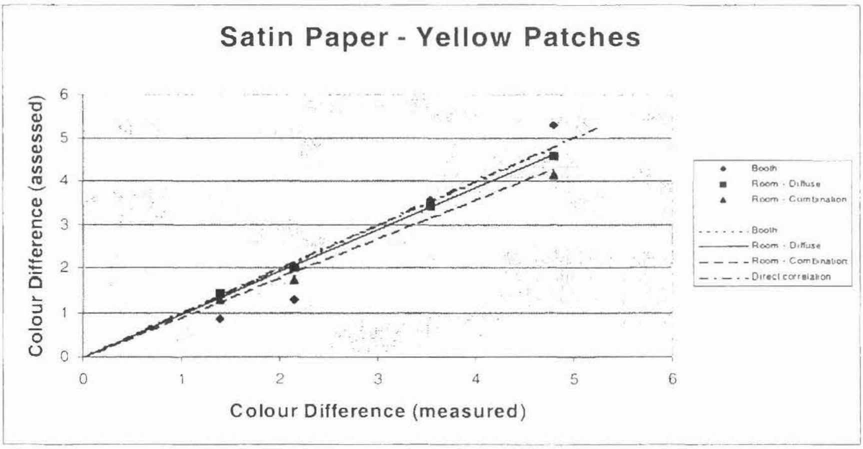


Table 7 – Data and linear trendlines for Black colour (3 papers).





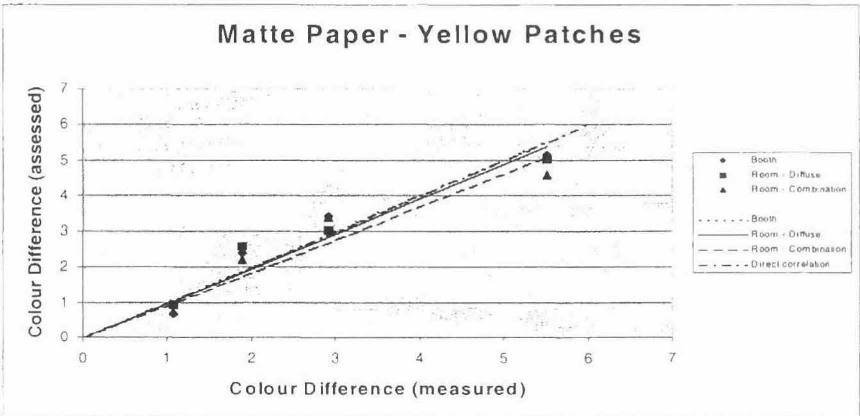
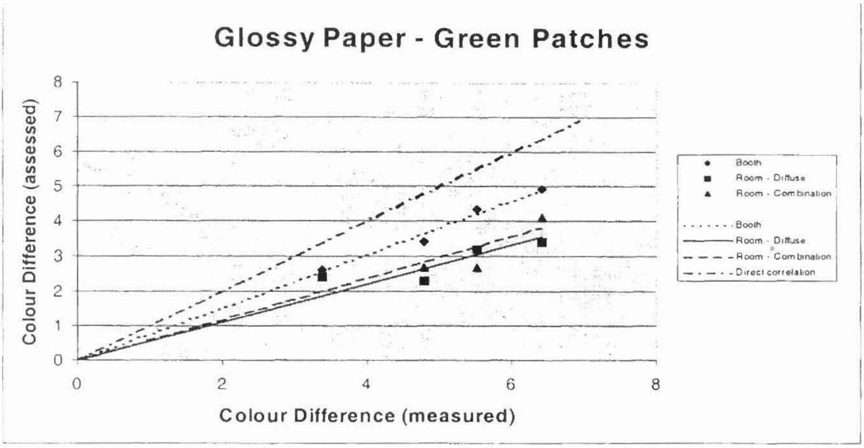
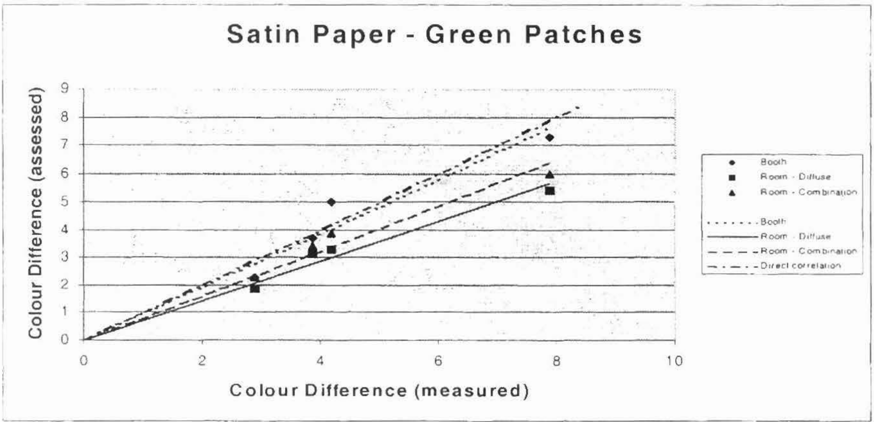


Table 8 – Data and linear trendlines for Yellow colour (3 papers).





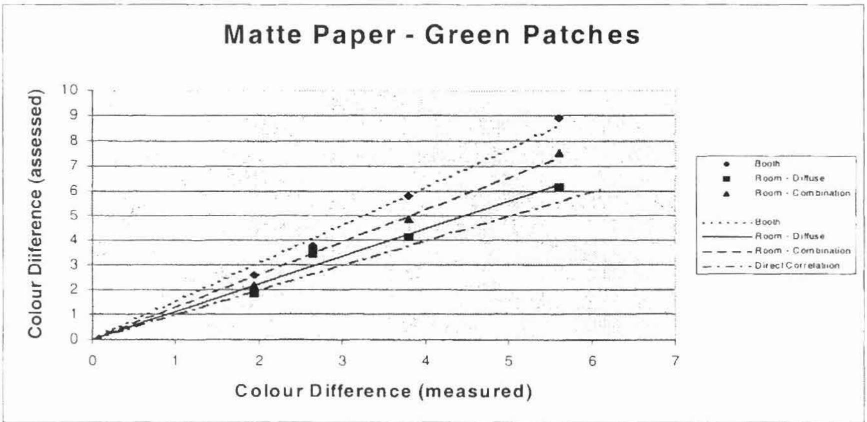


Table 9 – Data and linear trendlines for Green colour (3 papers).

The fact that there appears to be some difference between the various viewing conditions may be over or understated because of the nature of the experiment as discussed below. Nevertheless, there is evidence to the effect that the viewing condition does have some influence on the perceived colour difference – and that it may be non-linear. However, the data is really insufficient to be specific about this at this time and this will represent an important part of our future work.

The experimental procedure utilised in this study is inadequate to allow us to fully differentiate the effects of the different viewing conditions. By normalising the visually assessed colour difference to the measured value of a specific satin paper sample in each viewing condition it is not possible to properly compare the viewing conditions one with another, nor to compare one colour with another. This was a deliberate restriction as time precluded the far more complex magnitude estimation experiment needed to fully account for these. However, it is noteworthy that there is sufficient evidence of there being a significant problem in assessing differences, when the gloss of the media varies, that justifies further work. The fact that for two of the colours the perceived difference is significantly different to that measured – as the gloss of the substrate differs - is an important result.

Future Work

As reported in an earlier TAGA paper, Johnson and Green (1999), we have printed, by lithography, a large number of colours (approximately 60 in total) on a variety of substrates of varying gloss. Each sample is approximately 2.5cm square and has been printed together with similar samples that differ slightly from the 'aim' colour with a difference of approximately 1, 2, 3, 4 and 5 units of difference in each of hue angle, chroma and lightness from the aim colours. Some additional colours, with a larger difference, were also added to ensure we had samples that were clearly visually different from the aim colours.

A number of these colours will be selected for comparison across the substrates. These vary in gloss significantly as the substrates range from Newsprint, through a matt-coated paper to a high gloss coated paper. Spectrogoniophotometric measurements, carried out at 45° incidence on a printed sample of each substrate type, are shown in figure 10. It is clear that two of the papers have similar gloss and there is a range of gloss which is not represented. Nevertheless, the range of samples printed does provide a good range of gloss. We also note that a degree of asymmetry appears with the data shown. This requires further exploration.

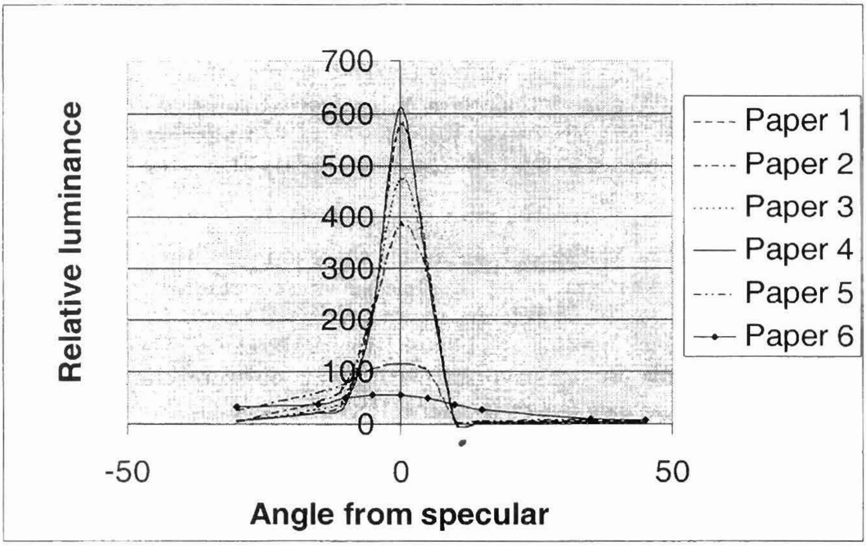


Figure 10 – Goniophotometric properties of 6 papers

Observers will be asked to make a difference assessment to a reference sample, similar to that described above – however, they will also undertake magnitude estimation to evaluate the hue, chroma and lightness of the reference samples presented, and also describe the difference to the reference sample in terms of these parameters.

Colour measurements of all the samples will be made using telespectroradiometry and spectrophotometry with the standard CIE geometries. Spectrogoniophotometric measurements will also be made on the samples to determine various gloss attributes. As stated earlier we also plan to define the distribution of illumination for the viewing conditions used in the experiments, to verify parameters for our model to 'correct' colorimetric data to compensate for both viewing flare and differences in gloss between media. Such information will be useful in the definition of colour appearance when combined with the corrections specified in CIECAM97s.

Conclusions

Our preliminary study has confirmed that the assessment of a colour match, when samples differ in gloss, cannot be predicted by simple colorimetry. High gloss samples showed a smaller perceived difference when compared to measured differences than low gloss samples – for three different viewing conditions. It follows that in order to properly predict colour appearance it is necessary to take account of the gloss and the conditions of viewing as well as the colorimetry. A hypothesis for this has been presented and work described that will attempt to verify this and provide data for the most common viewing conditions.

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