

How to Shop on the Web Without Seeing Red

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Abstract

Using the World Wide Web to order goods and services is a rapidly increasing activity. Experience with mail order catalogues has shown that failure of goods to match the catalogue color is a major category of complaint. Ordering colored goods on the web poses even greater challenges. Useful devices to standardise cathode-ray tubes, and other self-luminous displays, are available, but these only address the problem of display set-up. Other relevant problems include the effects of changes in the level of luminance, lack of color constancy of goods with changes in illuminant color, departures from a set of color-matching functions of the spectral sensitivities of acquisition devices, observer metamerism, the effect of the surround on the appearance of the display, and limitations in the gamut and in the resolution of typical displays. The extent to which these factors are likely to be important is discussed, and ways in which some of their effects might be mitigated are considered.

Introduction

The Internet and the World Wide Web are innovations of communication which are making huge changes to the way in which many transactions are made. Ordering services and goods from the web is an option which is rapidly increasing. However, experience with mail order catalogues has shown that failure of goods to match the catalogue color is a major category of complaint. Ordering colored goods on the web poses even greater challenges. It is therefore important to understand the factors that contribute to this problem, and to seek ways in which their effects can be mitigated. One commercially available program makes the following claims. 'The maroon tie your customers see on their computer screen is the same maroon tie they receive in the mail.' The program 'delivers accurate shades and tones across all computer platforms. No downloads. No plug-ins. Your web site visitors simply click their way through a one-time, online set-up process, and that's it. The maroon ties on-screen match the maroon ties in your warehouse. Even better, your online merchandise matches your customers' expectations.' Such a state of affairs is certainly highly desirable, but the program mentioned only addresses one of the many relevant factors.

Factors Affecting Color on the Web

The factors that can affect the colors perceived on the web, relative to those perceived when looking at the actual goods, include the following: differences in luminance level between the actual and displayed colors; the state of the display set-up; illuminant inconstancy of the colors of the goods; camera spectral sensitivities; observer metamerism; the surround to the display; the color gamut of the display; and the resolution of the display.

Luminance Levels

The perceived colors of objects are affected by their luminance levels. Over the majority of the photopic range of vision, there is a steady increase in colorfulness, brightness, and contrast, as luminance levels are increased.[1-3] This requires consideration of what the aim of color on the web should be. Six different color reproduction aims can be postulated.[4]

Spectral (same spectral power distributions).

This is not possible because the spectral power distributions of the displays from the web are usually very different from those of most goods. (*Spectral* is an appropriate aim for mail-order catalogues.)

Colorimetric (same chromaticities and relative luminances).

This is usually inappropriate because the original goods and the display normally have different white-point chromaticities and may have different surrounds. (*Colorimetric* is an appropriate aim for color photocopying, although illuminant and observer metamerisms may complicate its realisation.)

Exact (same chromaticities and absolute luminances).

This is usually inappropriate for the same reasons as given for *Colorimetric*, and in addition it may not be possible for the display to reach the luminance level of the original goods. (*Exact* is an appropriate aim for virtual reality.)

Equivalent (same appearance).

This is an appropriate aim for marketing on the web, whenever possible.

Corresponding (same appearance as that of the original when illuminated at the same level).

This may be an appropriate aim for marketing on the web when the luminance levels of the original and the display are significantly different. (*Corresponding* is an appropriate aim for many applications.)

Preferred (most pleasing).

This is inappropriate if it results in the colors of the displayed goods being significantly different from the actual goods. (*Preferred* is an appropriate aim for portraiture and for consumer photofinishing.)

Equivalent color reproduction is the logical aim for marketing on the web, because, ideally, the same appearance is required. If the goods are illuminated at the level that results in the same luminances as on the display, then the signals on the display should be designed to result in the same appearance at that level. In general, however, it must be expected that the original and display luminances will not be the same. The likely differences in luminance level between the original and the display can be estimated as follows. The luminance of whites on displays is typically about 100 cd/m^2, which is equivalent to an illuminance of about 300 lux. Indoor illuminances with artificial lighting are not likely to be outside a range of about 30 to 3000 lux. Indoor daylight illuminances depend on the level of the outdoor illuminance and the *daylight factor*, the ratio of the indoor to outdoor illuminances; assuming a daylight factor of 5% (a typical figure), indoor illuminances of 30 to 3000 lux correspond to outdoor illuminances of 600 to 60 000 lux, covering the range from very dark cloudy weather to bright sunlight. For both artificial and daylight interior illumination, we therefore have a range of likely illuminances not greater than from one tenth to ten times that of the equivalent illuminance of the display. Using the CIECAM97s model of color appearance, these changes of illuminance result in changes of the logarithm of the correlate of brightness, log Q, of about plus and minus 9% (log Q is used because it is more perceptually uniform than Q), in the correlate of colorfulness, M, of about plus and minus 20%, and in changes in contrast, estimated as changes in slope of log Q plotted against log luminance, of about minus 6% and plus 2%. These changes in log brightness and contrast are fairly small, and, although the changes in colorfulness are larger, this attribute is the least critical in imaging because it varies so much in everyday life. Hence, if the goods are most likely to be viewed indoors, as in the case of household goods for instance, then these changes may be sufficiently small to be unimportant in practice, particularly over the more usual luminances in the middle of the range where the changes will be smaller. In this case, equivalent color reproduction assuming no difference in luminance levels is a realistic aim. If, however, these changes are not insignificant, it may be more realistic to regard *corresponding* color reproduction to be the aim, on the assumption that the observer may make some automatic allowance for any differences in color appearance occasioned by the luminance difference. But, if the goods are most likely to be viewed out-of-doors, as in the case of cars for instance, then the luminance level for the actual goods is likely to be very much higher than that of the display, and the same brightnesses will not then be achievable; but an approximation to the same appearance may be improved by increases in the contrast and in the purity of the colors on the display. The differences in luminance levels therefore pose some interesting questions; for practical purposes, it is probably justifiable to assume that, for indoor goods, they will usually be viewed by the customer at a luminance level not sufficiently different from that of the display to be important; however, for outdoor goods it may be desirable to increase contrast and purity to provide closer approximations to equality of appearance.

Display Set-up

The way a display device is set up can make large differences to the color produced by the signals used to generate it. Berns, Motta, and Gorzinski investigated ways of calibrating cathode-ray tube (CRT) displays in order to allow for differences in the chromaticities of the phosphors, and in the settings adopted for gain, offset, and gamma.[5] They found that, by measuring the tristimulus values of the three colors produced by each channel (red, green, and blue) separately, the RGB to XYZ matrix, M, of the system could be determined. They also found that, by measuring the tristimulus values of five neutral colors, and then using the inverse matrix, M^{-1}, to transform the five sets of tristimulus values to the corresponding RGB signals, they could determine the gain, offset, and gamma of each channel using the formula:

$$L/L_{max} = \{k + k'[d/(2^N - 1)]\}^\gamma$$

where L is the luminance produced in the channel, L_{max} is the maximum luminance in that channel, k is the offset, k' is the gain, γ is the gamma, N is the number of bits available in the signal, and d is the value of the digital signal. Because L_{max} occurs when $d = 2^N - 1$, this equation reduces to

$$L/L_{max} = \{k + [1 - k][d/(2^N - 1)]\}^\gamma$$

There are thus only two independent variables in the set-up of each channel, the offset, k, and the gamma, γ.

Although in the early days of display devices there were significant differences between the chromaticities for different sets of phosphors, there has now been considerable convergence.[6] A balance has to be struck between choosing phosphors of high purity, to increase the chromaticity gamut, and high efficacy in light production, to increase colorfulness and brightness and to reduce the effects of ambient light. These conflicting factors have constrained the choice to those now adopted for broadcast television receivers, known as the IR703 set; other display devices, such as monitors and liquid crystal displays (LCDs), have tended to adopt the same reproduction primaries so as to be compatible with broadcast signals. Displays using lasers can have primaries of higher purity, as may also be the case for other displays yet to be developed. But, for the present time and the near future, it is probably reasonable to assume that display devices used for web applications have chromaticities for their primaries which are not significantly different from the 703 set.

If standard chromaticities are assumed for the primaries, it is only necessary to standardise the offset and the gamma of a CRT display. In one commercially available program for doing this, the user follows a series of instructions which result in a display calibration being stored in the computer being used and which is accessed by the operating server.[7] This calibration is then automatically brought into play whenever the server is used. The series of instructions are as follows. First, a picture is displayed with a series of dark areas, of gradually decreasing luminance; the 'brightness' control of the display is then set at the point when the darkest of the areas just disappears. Then a picture is shown on which there is a column of red; the column consists of alternate stripes produced by the maximum and the minimum signal; superimposed on this column is a series of small red squares for which the signal gradually increases. The task is then to choose the small square which most nearly blends into the column. This identifies the gamma of the red channel; this is because the stripes, being at the maximum and minimum signal levels, are unaffected by the gamma but the small squares do depend on the gamma. Similar columns and squares are shown in green and blue, to determine the green and blue gammas. The next picture shows a series of red patches having luminances which gradually reduce to the display minimum; the task is then to identify the darkest patch which is just visible; this identifies the red offset. Similar series of patches are used to identify the green and blue offsets. Because the result of the gamma-determining step is affected to some extent by the offset, a further set of columns consisting of stripes and small squares is used to fine-tune the gamma determination; the stripes this time are produced by the maximum signal level and by a medium signal level, and this results in the light parts of the scale being targeted. Columns in red, green, and blue, result in the gammas of all three channels being fine-tuned. Comparison of displayed colors with and without the use of this program show significant differences, and there is no doubt that standardising the display set-up can remove an important source of variability in web marketing activities. However, one factor which always requires consideration is the possible variation of the display with time; for example, cathode-ray tubes change their characteristics as they warm up, and therefore any set-up procedures on them should be carried out only after a suitable warm-up period has elapsed.

If, instead of cathode-ray tubes, other types of display are used, such as liquid crystal displays or plasma displays for instance, then the dynamic response functions are likely to be sufficiently different from those of CRTs for different set-up procedures to be necessary. This further complicates the standardisation of the display set-up for web marketing.

Color Inconstancy with Change of Illuminant

The claim, mentioned earlier, that looking after the display set-up results in colors on the screen matching those of goods in the warehouse and received through the mail, requires examination. No mention is made of the illuminants being used, and the implication is either that the same illuminant is always used throughout, or that such changes in illuminant as may occur do not result in any significant changes in the colors perceived. Neither of these implications is likely to be true. The illuminant in a warehouse is likely to be an artificial source, such as a fluorescent lamp, while the goods when received by a customer through the mail are likely to be viewed under a variety of illuminants, including various aspects of real daylight, domestic fluorescent lamps, and tungsten filament lamps. The result of using these different illuminants is to generate different spectral power distributions for any one object color, and, although the chromatic adaptation of the observer reduces the resulting differences in perceived color, there will usually be significant residual differences. It would be possible for vendors to display on their web sites a series of colors intended to indicate how a particular object will look under the types of light source most likely to be used, such as real daylight of correlated color temperature about 6500K, cool white fluorescent light, compact domestic fluorescent light, and tungsten light. However, vendors may be reluctant to do this, because they may feel that customers might be deterred from purchasing by seeing evidence that the color changes with the light source. An alternative would be to portray only the color for Standard Illuminant D65, and to seek colorisations of goods that have good color constancy for the illuminants most likely to be used. The color constancy of goods then becomes an important attribute for marketing on the web, and happily there is now available a method of deriving a Color Inconstancy Index which can be used to select colorisations which have good color constancy. To derive the Color Inconstancy Index it is necessary to use a Chromatic Adaptation Transform (CAT). This transform is applied to the tristimulus values of a color in a test illuminant, for example Standard Illuminant A, to obtain the Corresponding Color in a reference illuminant, such as D65. A Corresponding Color is that which in the reference illuminant has the same appearance as the sample in the test illuminant. The Color Inconstancy Index is then calculated as the color difference (using an appropriate color difference formula, which must be specified) between the sample in the reference illuminant and its Corresponding Color. A chromatic adaptation transform is incorporated in the Color Appearance Model recommended by the CIE, CIECAM97s, and this transform can be used to compute Color Inconstancy Indices[8]; improved and simpler CATs are being developed by CIE Technical Committee TC1-52. Complete chromatic adaptation is usually assumed (the D factor in the CAT set equal to 1), because only in this way can non-selective whites and greys have Color Inconstancy

Indices of zero, indicating perfect color constancy which such samples are generally regarded as having.

Although seeking colorisations that result in good color constancy will help, there are some combinations of objects and illuminants that always tend to have significant inconstancy. For example, compared to their appearance in daylight, in tungsten light red objects tend to look lighter, blue objects tend to look darker, and purple objects tend to look redder. The reason for this is that chromatic adaptation usually operates to equalise the cone responses for white colors, and this provides too little correction for red, blue, and purple colors. This is because, in the spectral band to which the long-wavelength cones are sensitive, the continual increase of tungsten-light power with wavelength enhances the power of red objects more than that of white objects. Similarly, in the spectral band to which the short-wavelength cones are sensitive, the continual decrease of tungsten-light power with wavelength reduces the power of blue objects more than that of white objects. With purple objects both these effects occur, and this makes their hues redder. Color constancy in these cases therefore does not occur.

Hence the only entirely satisfactory answer to color inconstancy with change of illuminant is for the vendor to provide swatches of the actual material, so that the customer can check the color in the various illuminants that will be encountered; this procedure is already adopted in some mail-order catalogue businesses.

Camera Spectral Sensitivities

Only if a camera has a set of spectral sensitivities that are a set of color-matching functions will signals be produced that can result in Colorimetric or Exact color reproduction. Such sensitivities are also desirable for Equivalent and Corresponding color reproduction, for only in this way can all colors that look alike in the original be reproduced the same, and all colors that look different in the original be reproduced different. The most useful set of color-matching functions for acquisition devices is the narrowest possible all-positive set.[9] Photographic films have significant departures from the color-matching-function criterion, although films with red layers having sensitivities at shorter wavelengths have recently reduced these departures somewhat. Electronic cameras usually use a matrixing circuit to approximate the color-matching-function criterion, but residual errors still occur. For ordinary pictorial work, both photographic film and electronic cameras deliver color reproduction that is usually very pleasing. But, for the sale of colored goods, the errors arising from incorrect camera sensitivities will not always be negligible. If the goods are the same color all over, then it is not difficult to adjust the signals prior to broadcasting them so as to obtain the desired result. But, if the goods have complicated colored patterns, then such corrections are much more difficult, or indeed may be impossible, to make.

Observer Metamerism

About 8% of men, and about 0.4% of women, have color vision that is markedly different from normal and are termed *color deficient*; however, the differences are always such as to result in reduced color discrimination, and it is unlikely that a color reproduction that is acceptable to a normal observer would be unacceptable to a color deficient observer. But there are also significant differences between the color vision of normal observers, caused partly by differences in the spectral sensitivities of the cones in the retina, and partly by differences in the spectral transmittances of the ocular media, particularly the macular pigment, and the tendency for these media to become yellower with age. The colors produced on display devices used for viewing images from the web, being additive red, green, and blue mixtures, have spectral power distributions that are almost always very different from those of original goods. This metamerism means that, even for normal observers, there will be the potential for disagreement as to which signal strengths produce a displayed color that matches a particular original color. The extent of this potential problem can be examined by using the CIE Standard Deviate Observer to calculate an Observer Metamerism Index[10] for any color and its displayed reproduction. The way to alleviate observer metamerism is to choose, wherever possible, colorisations that result in only small Observer Metamerism Indices.

The Surround to the Display

The self-luminous devices used for viewing images from the web may be used in surrounds whose luminances are similar to the average luminance of the display (Average surround) or markedly lower (Dim surround). The Average surround condition is typical of monitor environments, while the Dim surround is typical of domestic television receivers. The most important effect of the surround luminance is that the apparent gamma is lowered by the Dim surround to an extent that requires the display gamma to be increased by a factor of about 1.2. It is for this reason that broadcast television signals are gamma-corrected by being raised to the power of 1/2.2, so that with a cathode-ray tube having a gamma of 2.65, the overall system gamma becomes 1.2. Monitors usually have a gamma of about 2.2, so that with signals of gamma 1/2.2 the system gamma is 1.0, which suits the Average surround viewing. The sRGB default color space widely used in color management systems also uses a gamma of approximately 1/2.2. If the signals used on the web have a gamma of 1/2.2, they will therefore suit both domestic television viewing and monitor viewing. However, because the relationship between the display set-up, and the appearance produced by it, is dependent on its type of surround, the type of display set-up procedure described earlier should allow for this dependency; one way of doing this would be for the user to be asked whether the display being used is a television receiver (normally viewed with a Dim surround) or a monitor (normally viewed with an Average surround).

Although the contrast-lowering effect of the Dim surround results in the same perceived gamma for displays having gammas of 2.65 viewed in Dim surrounds, and for displays having gammas of 2.2 viewed in Average surrounds, the perceived reproduction of colors will not necessarily be the same. The increase in gamma results in increases in the purities of colors, and, although the dim surround results in some reduction in perceived color saturation, the two effects cannot be expected to be exactly compensating. The CIECAM97s color appearance model[11] allows for the contrast lowering effect of a Dim surround, and, by setting its factor N_c equal to 0.95 (instead of 1.1 as originally published) the saturation-decreasing effects of a Dim surround can also be allowed for[12]; hence both the effects of the surround can be computed.

The Color Gamut of the Display

The chromaticities that can be produced on a display are limited to those within the triangle formed in a chromaticity diagram by the points representing the chromaticities of the red, green, and blue primaries used. This limited gamut means that there are colors that exist in the real world which cannot be reproduced; in particular some saturated reds, cyans, and magentas. This could be an embarrassment, for instance, in the case of some red cars, turquoise clothing, and magenta furnishings. Some increases in apparent saturation could be achieved by surrounding the image of the object with a background of the complementary color, but this would probably be a rather hazardous ploy. There may be no alternative at present to simply omitting from the presentation all goods having out of gamut colors. If displays having wider gamuts are used in the future, some such goods could then be included, but it would be necessary for the broadcast signals to carry negative as well as positive components, and the display would have to re-matrix the signals to suit the different display; the re-matrixing should be carried out on linear signals so that circuits would be required that first raised the signals by a power of 2.2, then carried out the rematrixing, and then lowered the signals to the power of 1/2.2 again.

If a limited number of different colors is used, such as a palette of 256, then even original colors that lie inside the limits of the reproduction gamut will be reproduced with errors unless they happen to be exactly the same as one of the palette colors. Desktop computers usually have 8-bit graphics facilities, providing $6 \times 6 \times 6 = 216$ colors in a *browser-safe palette*, the remaining 40 colors being reserved for special use, such as producing the colors of particular market items.[13] If the number of colors is increased by dithering, resolution is reduced, and display artefacts may become apparent especially for textured goods such as clothing.

The Resolution of the Display

Conventional broadcast television has either 483 active lines of 720 pixels (in a 525-line system) or 575 active lines of 860 pixels (in a 625-line system). But if the display device is a shadow-mask tube, its dot structure may consist of only 520 lines of 690 holes (in 525-line systems) or 575 lines of 770 holes (in a 625-line system); furthermore, the electron beam diameter is such that more than one line of holes is irradiated so that the effective definition is restricted even more. High definition television (HDTV) displays may have 1080 active lines and 1920 pixels per line. Monitors may have up to 2000 or more lines of holes, and these extra lines are useful in reducing the incidence of jagged edges in the displayed images. To reduce the bit requirement in web images it is customary to use compression techniques such as the JPEG algorithm.

When showing goods of uniform color, the limited resolution of the systems used for the web are usually unimportant. But for goods with texture, or fine patterns, there can be many problems. Fine detail may be lost because of being below the resolution of the system, and aliassing can produce texture patterns that are not on the goods at all. The best solution to these problems is to show both general views of the goods to give an overall impression, and such close-ups as may be necessary to show detailed parts. This is normal practice in broadcast television where three cameras are commonly used in studios to provide both general and close-up views, the provision of zoom lenses increasing the variety of views very greatly.

Conclusions

So, how to shop on the web without seeing red? One solution is to confine one's shopping to services, such as travel, banking, or insurance, for instance, where there are no actual goods involved. If goods are to be bought, one could restrict one's purchases to items where color is unimportant, such as tools, electronic equipment, or recordings of music, for instance. If goods are to be bought where color is important, such as clothing, or furnishings, for instance, the use of a display set-up program is helpful, but the best safeguard is to ask for a swatch before placing an order.

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