Modelling and Application of Contrast Enhancement of Visually Indistinct Colours Using Simple Single Band Image Capture Techniques

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Abstract

The concept of exposure density is used as a general model applied to the recording of two targets. This takes into account the spectral characteristics of all components of the imaging chain and is extended in the form of the *System Exposure Response Difference* (SERD) that is universally applicable to any imaging system. It provides a means for differentiation between two colours that appear identical and are recorded as being identical. Formulae are presented that model the capture and recording of two targets with both differing and with closely similar spectral reflectances. Excellent agreement is obtained between measured pixel differences and calculated (SERD) values. This method provides a means of modelling the required spectral band to be selected in advance of image capture such that the targets can be differentiated and work carried out in these laboratories on a variety of projects is summarised in this paper.

Improvements in image contrast that have been modelled by this approach and applied to medical imaging and related area are included as a case studies. Advantages of this approach in comparison with multiband analysis or with post capture image enhancement techniques are discussed.

Introduction

A major goal of scientific imaging is to record the maximum possible information in the image so that this may be extracted later, often by digital image processing. Colour differences in the scene can be used to differentiate between objects, even when such differences are quite small. It is often assumed that an image captured with a standard three-colour imaging system will record the maximum available information, but it is often the case that a monochrome system, optimised for the particular imaging problem, will yield greater contrast, and hence signal to noise. This has the advantage of simplifying the image capture, whether photographic or electronic, and substan-tially reducing the quantity of data. Although there are moves from recording images in a small number of channels to using increasing numbers of channels in multispectral and hyperspectral imaging, this paper focuses on a simpler technique that uses substantially less data and simpler equipment.

Consider a monochrome system as the simplest type of an imaging system and applying basic principles of imaging science it is relatively easy to explain how the system may be used to improve the contrast between two objects. A monochrome imaging system records differences in lightness between objects in the scene as different shades of grey. The rendering of a particular target area depends not only on its lightness, but also on its colour and the spectral transfer function of the imaging system. The spectral transfer function refers to the weighting that the system gives, at different wavelengths, to the spectral radiant intensity distribution of the target area. Target areas of different colours may, when recorded with a particular system, reproduce as the same shade of grey. Although such areas are perceived as being different in the original scene, this difference is often not apparent in the image.

If one wants to increase the contrast between two target areas then it is a simple matter to alter the system spectral transfer function by the inclusion of a colour filter in the optical path.[1] Such a filter is termed a contrast filter and would be chosen intuitively to be close in colour to one or other of the target areas and has been used from the very early days of photography. If, however, the target areas are of similar colour the choice of filter is not as simple. In this case the effect of different filters and other system parameters on the image contrast between the two areas can be modelled, and the optimum selected from a knowledge of the spectral properties of all the components of the imaging chain shown in figure 1.

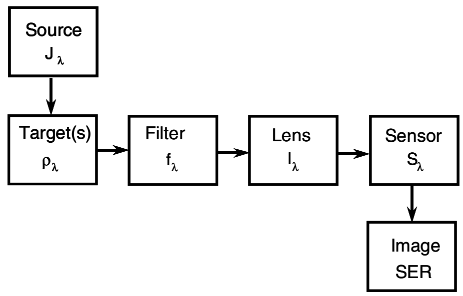

Figure 1. The imaging chain. SER = system exposure response.

The use of filters can then be extended from increasing contrast between markedly different colours, that exhibit little contrast in a monochrome system, to producing contrast between target areas that are perceptually similar in the original scene and are indistinguishable in the image.

It could be argued that increasing the system contrast, for example by thresholding or contrast stretching of a digital image, or high contrast development of a photographic negative, would provide greater differentiation in the image between similar target areas. However, this will also increase the image noise, so that, unless the areas are completely uniform, misclassification of parts of the target areas will often occur. Also overall changes in contrast may result in unacceptable tone reproduction of the scene as a whole.

System Exposure Response (SER), or Exposure Density[2]

The exposure,H, received by any sensor is give by the product of intensity, E, and time, t.

$$H = Et \tag{1}$$

Substituting spectral values for E and taking logs gives:

$$\log_{10} H = \log_{10}\left(\int J_\lambda \rho_\lambda f_\lambda l_\lambda S_\lambda d\lambda\right) + \log_{10} t \tag{2}$$

where the symbols are shown in Figure 1.

If we consider a perfect white target with spectral reflectance of unity, equation (2) the becomes:

$$\log_{10} H_w = \log_{10}\left(\int J_\lambda f_\lambda l_\lambda S_\lambda d\lambda\right) + \log_{10} t \tag{3}$$

Exposure of a target relative to this white is given by H_{rel}:

$$\log_{10}(H_{rel}) = \log_{10}\left(\frac{H}{H_w}\right) \tag{4}$$

From equations (2) and (3) equation (4) can be written as:

$$\log_{10}(H_{rel}) = \log_{10}\left(\frac{\int J_\lambda \rho_\lambda f_\lambda l_\lambda S_\lambda d\lambda}{\int J_\lambda f_\lambda l_\lambda S_\lambda d\lambda}\right) \tag{5}$$

The *system exposure response* (*SER*) is given by $-\log_{10}(H_{rel})$:

$$SER = \log_{10}\left(\frac{\int J_\lambda f_\lambda l_\lambda S_\lambda d\lambda}{\int J_\lambda \rho_\lambda f_\lambda l_\lambda S_\lambda d\lambda}\right) \tag{6}$$

If we now extend the derivation to the imaging of two targets of spectral reflectances ρ_1 and ρ_2, then the system exposure response difference (SERD) between the two targets is given by:

$$SERD = SER_2 - SER_1 \tag{7}$$

or,

$$SERD = \log_{10}\left(\frac{\int J_\lambda \rho_{1\lambda} f_\lambda l_\lambda S_\lambda d\lambda}{\int J_\lambda \rho_{2\lambda} f_\lambda l_\lambda S_\lambda d\lambda}\right) \tag{8}$$

This simple model enables SERD values to be determined for various imaging systems and situations. It allows a simple calculation of changes in the spectral characteristics of components of the imaging chain (see Figure 1) that would maximise the SERD value and increase the contrast between the specified target areas.

Experimental Verification

Originally this approach was applied to a photographic system in which the SERD value will be proportional to the difference in optical density between the image corresponding to the two target areas, provided they are both recorded on the straight line portion of the characteristic curve. This computational approach was then extended to digital systems.[3]

Spectral Characteristics

Spectral characteristics of all the components of the imaging chain were measured by the procedures previously described.[3] Typical results for some selected components of the imaging chain are shown are shown in Figure 2 and an examples for some of a pair of targets is shown in Figure 6.

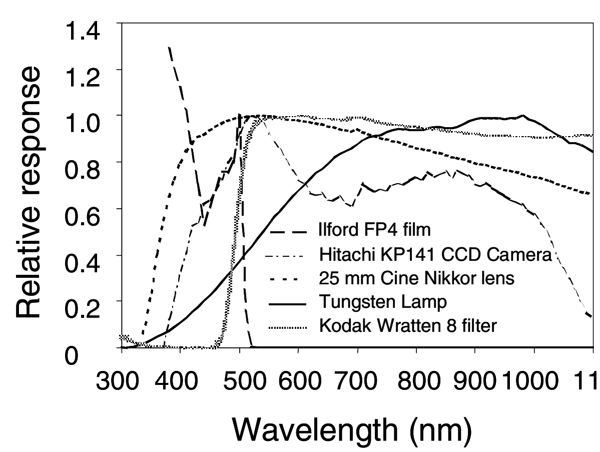

Figure 2. Spectral data for various components of the imaging chain.

Results for a Photographic Image Capture System

A Macbeth ColorChecker Chart was used as the target which was imaged with and without a Kodak Wratten 8 yellow filter. SERD values were determined from equation (8) for the yellow patch relative to the 18 other patches of the chart, using spectral data at 20 nm intervals. This effectively simulates two target areas of yellow patch in combination with the 18 other patches of the chart in one image. The inclusion of the yellow filter is expected to enhance the density differences (and the calculated SERD values) between the yellow patch and other patches of the chart with a high blue content.

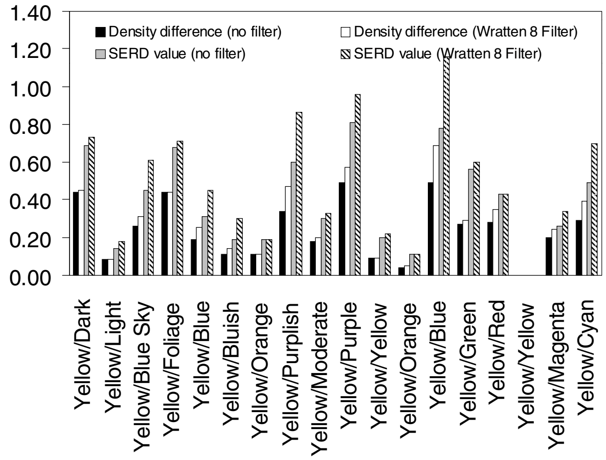

Figure 3. Density differences and SERD values for yellow patch relative other colour patches of the Macbeth ColorChecker Chart, recorded on Ilford FP4 film with and without filtration.

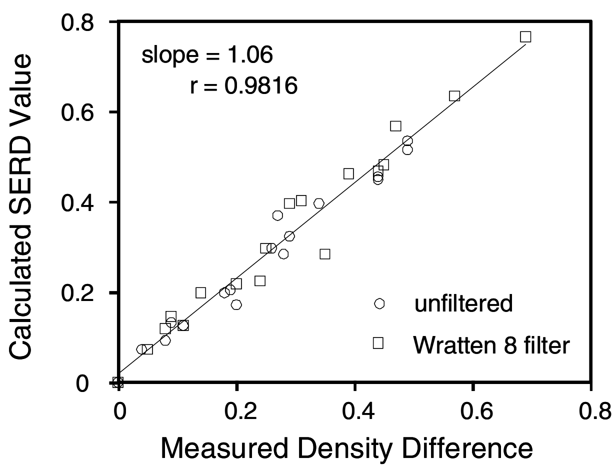

Figure 4. Measured density differences vs calculated SERD values of yellow patches relative to all other colour patches of the Macbeth ColorChecker Chart for the photographic system.

This is clearly shown by the high measured density differences and SERD values for the yellow/blue and yellow/purple patches in Figure 3 and their increased values when a yellow filter is included, whereas the values for the green and red patches against the yellow are little changed by the inclusion of this filter. If the predictive nature of the calculated SERD values is valid then linearity is expected between plots of measured density differences versus the SERD values (see Figure.4).

In Figure 4 the calculated SERD values have been corrected for the contrast of the straight line portion (0.66) of the characteristic curve of the photographic film used as the sensor. The high correlation coefficient (0.9816) and the slope of close to unity indicates the validity of the predictive property of equation (8). However, these results exhibited scatter about the straight line which is due in part to possible experimental errors and that the spectral data was relatively coarse (at 20 nm intervals).

Results for a CCD Image Capture System

To test the application of equation (8) to a CCD based image capture system, images of the Macbeth ColorChecker Chart were captured with the system, both with and without a filter being present. A comparison between the calculated SERD value and the measured pixel difference is shown in Figure 5.

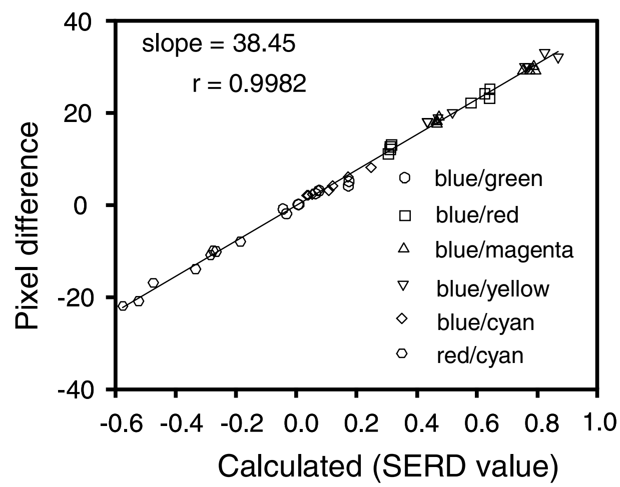

Figure 5. Measured mean pixel value differences vs calculated SERD values of the indicated patches of the Macbeth ColorChecker Chart for the CCD system.

Excellent correlation (r = 0.9982) between the measured and calculated values was found. Pixel values for the patches in all the images were kept within the range 30 to 55, where the transfer function was steepest. The slope of the line in Figure 5 is 38.45, which is close to the slope of the straight line portion (36.05) of the transfer function for the CCD camera (log relative exposure vs pixel value).

In order to test the SERD procedure more critically, two closely similar green patches were used as the target. Figure 6 shows the spectral reflectances of the two green test patches with Natural Colour System (NCS) specifications 1050-G (patch 1) and 1060-G (patch 2). However, it should be noted that in the spectral region 800-1100 nm the CCD sensor system has a sensitivity close to that in the visible region (see Figure 2) and this tended to cause all the test patches to produce similar grey levels in the system.

Also most filters have a significant transmission in this region. Although increased by using filters, the contrast was still not high enough for differentiation, because the small difference in their visible reflectance was swamped by the infra-red signal. The use of an infra-red absorbing filter (Kopp Corning KCF052) increased the contrast between the test patches considerably, and this was confirmed by calculations of SERD values for the system using a number of filters in combination.

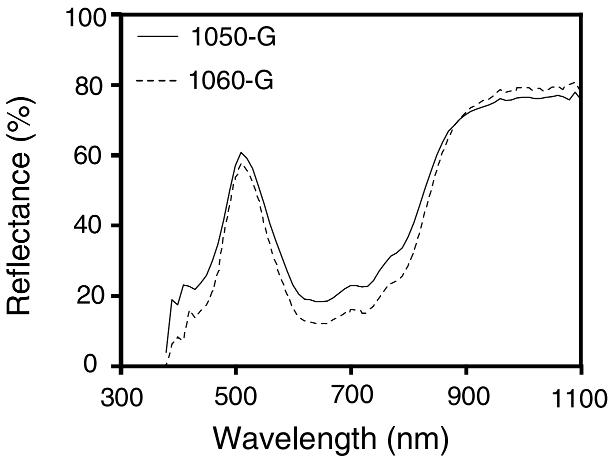

Figure 6. Spectral reflectances of green targets

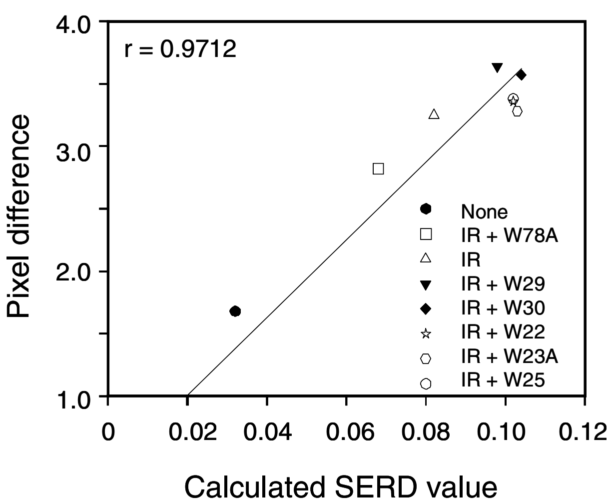

Figure 7. Calculated SERD value vs measured mean pixel value differences for the green targets of Figure 6.

The relationship between the calculated and measured contrasts is shown in Figure 7. The greatest contrast was achieved by the use of the infra-red absorbing filter together with a magenta filter (Kodak Wratten 30, see Figure 7), although some other filter combinations gave similar values. This can be related to the spectral reflection curves of Figure 6 from which it can be seen that the difference between the curves is greatest in the blue and red spectral regions.

Applications

This principle has been successfully applied in the imaging of the bulbar conjunctival vasculature[4] using a photographic image capture system. Figure 8 shows the enhancement in contrast that was achieved via the SERD modelling approach to select the most appropriate filter from a database of spectral transmittances for a number of filters.

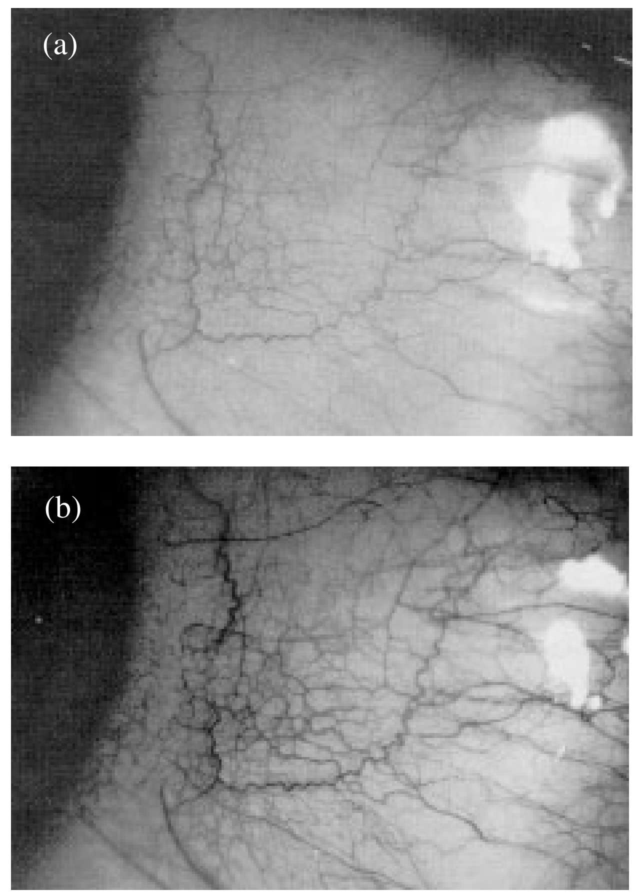

Figure 8. Image of the blubar conjuntiva: (a) without filter (b) with SERD calculated filter.

A second example of a successful application is the ability of the SERD computation procedure is to enable selection of a filter to enhance the image contrast between two visually identical paint samples using a CCD image capture system. Figure 9 clearly shows that images of two paint samples, NCS register 2020-B50G and the visually matching ICI-Dulux 2020-B50G, become distinguishable through the selection of the appropriate filter on application of equation (8) using the appropriate spectral data and computations from a database of the spectral transmissions of candidate filters. Figure 9 also indicates that if applying image processing techniques to an image only amplifies noise and effective differentiation at primary image capture is essential.

This has obvious application in forensic science and related applications for distinguishing between altered documents, paintings, car re-sprays etc.

Applications of image processing techniques to enhancing images of the same visual appearance do not generally lead to as successful outcomes as those obtained form application of the SERD procedure. Figure 10 compares results for the image processing techniques indicated for a series of closely similar green samples with that of the SERD optical pre-processing method.[5]

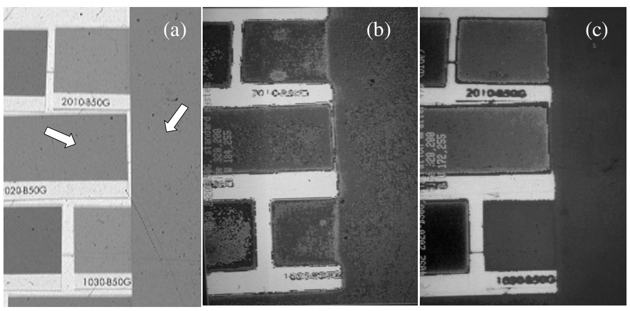

Figure 9. Monochrome versions of two visually identical paint samples indicated by the white arrows. The left hand arrow ICI Dulux 20220-B50G and the right hand arrow NCS register 2020-B50G. (a) Failure to differentiate targets by direct CCD image capture, (b) Failure to differentiate after image processing, (c) successful differentiation using a blue filter suggested by the SERD calculation.

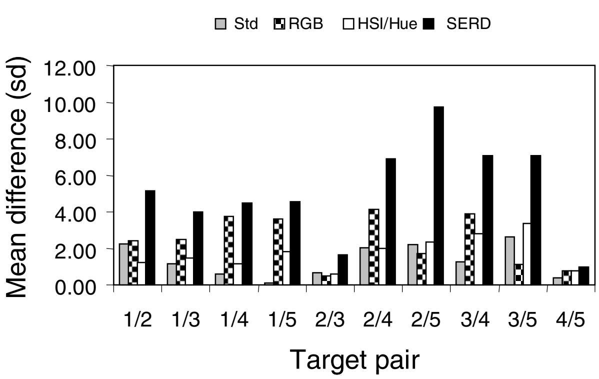

Figure 10. Mean pixel value differences as standard deviations for sample pairs. Std = standard unfiltered image capture system. RGB = optimised principal components transform applied to RGB image. HSI/Hue = hue channel of HSI transformed image. SERD = system filtered according to results of SERD calculation.

In virtually all cases the SERD filtered result was better than any other form of image transformation although the principal component transform generally gave a much improved performance than the standard imaging situation.

Conclusions

Provided that spectral data is available for all the components of the imaging chain the SERD method provides a very useful approach to modelling and quantifying the effects of required spectral bands for simple single band image capture techniques.
This approach provides:

- good predictive modelling
- is universally applicable to any imaging system
- enables enhanced discrimination between targets similar or visually matching in colour
- a means of enhancing colour contrast.

It performs better than digital image processing techniques by providing a form of optical pre-processing of images that can subsequently be used for image processing to improve discrimination even further. The major limitation is that prior knowledge of spectral characteristics of components of the imaging chain are required.

References

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Biography

Ralph Jacobson is a consultant and Emeritus Professor of Imaging Science at the University of Westminster where he has been teaching and researching for 30 years. He is the author and/or co-author of more than 100 papers and contributor to 10 books in the imaging field. He is an honorary Fellow of The Royal Photographic Society and is an Accredited Senior Imaging Scientist (ASIS). His current research interests include the measurement of image quality, techniques for optimising image capture in specific applications and life expectancy and archival proerties of imaging media.