THE DEVELOPMENT OF AN IMAGE MANIPULATION FACILITY FOR THE ASSESSMENT OF CCD

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1. SUMMARY

The assessment of CCD systems using photosimulation is the tried and tested alternative to performing live observer trials. The greater control over photosimulations allows an increased level of confidence in the results of any comparisons. It also requires less time in the field for a smaller number of personnel. The next step along this route would be a method that required no time in the field. Virtual reality systems, however, do not yet produce the level of realism required. An alternative, perhaps, is to place targets generated by VR software into a scene recorded photographically. Such a system would digitize a slide of a background scene in a controlled manner and allow the realistic implantation of an artificially created target. Reproduction would be achieved using a calibrated film printer. The majority of the reprinted scene would remain identical to the original slide. The methods used to enable the calibration of the equipment used, and the process of comparing information from digital rgb and Lab colour spaces are discussed in this paper.

This image manipulation facility has the potential to bypass the field trial phase of CCD assessment. It could be used to assess CCD more thoroughly by using a variety of background scenes or the same scene at different times of the year. Targets created from CAD models could be assessed. It could be used to determine the effectiveness of potential CCD measures in areas which are not readily accessible. Overall, this system adds a new level of flexibility and completeness to photosimulation.

Keywords: Assessment, photosimulation, imagery, slide, scanner, printer, colour, calibration.

2. INTRODUCTION

The assessment of CCD systems using photosimulation is the tried and tested alternative to performing live observer trials (Ashforth et al., 1991). The greater control over photosimulations allows an increased level of confidence in the results of any comparisons performed in this manner. It also requires less time in the field for a smaller number of personnel. The next step along this route would be a method that required no time in the field. Virtual reality systems would appear to offer this capability. However, they do not yet produce the level of realism required. An alternative, perhaps, is to place targets generated by VR software into a scene recorded photographically. A photosimulation could then be performed on the modified imagery. Such a system would have to digitise a slide of a background scene in a controlled manner. This would then allow the realistic implantation of an artificially created target. Reproduction of the modified scene as a photographic slide would be achieved using a calibrated film printer. In an ideal system, the majority of the reprinted scene would remain identical to the original slide.

The following describes the efforts made by the DCTA towards creating a facility to perform such image manipulation.

3. APPARATUS

The principal components of an image manipulation facility should be a computer capable of handling large image files of 100Mb or more, and a slide scanner and film printer with resolutions close to that of photographic film.

The computer used to control both the slide scanner and the film printer is a Silicon Graphics Indigo2 running the IRIX 6.2 operating system, with 384Mb of RAM. Silicon Graphics computers are designed to manipulate graphics easily, having a very capable graphics card built in as standard.

The slide scanner is a LeafScan-45. It operates by moving the slide between a filtered fluorescent light source and a linear array camera. It can operate at a variety of resolutions up to 5000 dpi. Controlling software called Image Proof is used to set up and calibrate the device, allowing the user a choice of aperture and exposure time combinations. It also incorporates a prescan facility and several adjustment controls for the image. The shadow control affects the brightness of low intensity pixels and the highlight control that of high intensity pixels. The gamma control affects the gamma of the image, in effect the linearity of the dark to light transition. The controls act on the image as a whole and each of the red, green and blue channels separately. These can be used to correct colour discrepancies due to the scanning process prior to a high-resolution final scan.

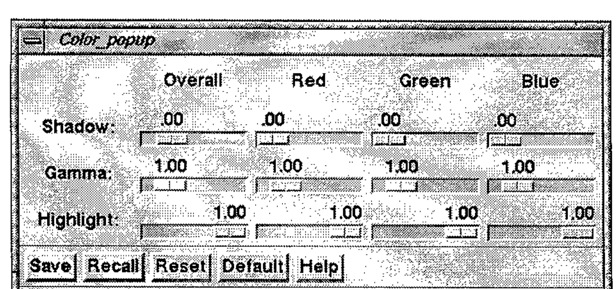


Figure 1 Scanner control window

Paper presented at the RTO SCI Workshop on "Search and Target Acquisition", held in Utrecht, The Netherlands, 21-23 June 1999, and published in RTO MP-45.

The software has the capability to perform a low resolution prescan on a slide. It also allows the user to probe the prescan image for the colour information from each pixel.

The film printer is a Mirus Galleria. It prints to any type of 35mm film using a film specific look-up table to adjust its output. The look-up table contains details of the resolution required and controls for global contrast and brightness and channel specific brightness. These controls can be used to calibrate the device. It has a maximum resolution of 3333 dpi.

4. COMPARING COLOUR SPACE INFORMATION

It has been mentioned earlier in this paper that it is essential to be able to calibrate both the slide scanner and the film printer. To do this the attributes of the image must be compared before and after both the scanning and printing processes. A convenient start point for the scanning process is the colour information derived from a prescan, with the controls set to the default values, of a slide using the probe function. The aim of this operation is to scan the slide retaining the colorimetric properties of the projected image, therefore these values should be used as the target for the calibration. The film printer's start point is the scanned image, which should have the same colorimetric properties of the projected slide. Its target is the colorimetric properties of the projected image. The devices employed in this facility view and manipulate images in a 24-bit colour system, 8 bits or 256 levels of intensity for each of the red, green and blue channels. This system is derived from the signals required by the digital to analogue converters controlling the voltage to the electron guns for each channel in a colour monitor. However, the projected slide is measured using a telespectroradiometer, which produces a photometric output such as Lab values. It is therefore necessary to be able to convert digital rgb to photometric Lab and vice versa. This transform has two important stages, the transform from a digital rgb system to a photometrically based RGB system and then the further transform to Lab.

4.1. Linearisation of rgb using the gamma function

The relationship between the voltage applied to the electron gun and the luminous output of the screen is known as the gamma function.

$$Y = K(g)^{\gamma}$$

Where

Y is the display luminance $/cdm^{-2}$

g is the pixel grey level value ($g \in [0,255]$)

K is a proportionality constant

γ is the display gamma coefficient

Here, however, the display luminance is not measured but taken from PhotoShop's use of both rgb and Lab colour spaces, L being converted to Y assuming D65 illuminant. The maximums are 255 for rgb and 100 for Y (L is also 100). The mid points are 169 for rgb and 50 for Y (L is 76.07). Two simultaneous equations can be constructed:

$$50 = K * 169^{\gamma}$$

$$100 = K * 255^{\gamma}$$

Solving the above equations gives:

$$K = 0.008810382471$$

$$\gamma = 1.684993781.$$

These values can be put back into original equation to produce the following transforming equations for each of the red, green and blue channels:

$$R = 0.008810382471 * r^{1.684993781}$$

$$G = 0.008810382471 * g^{1.684993781}$$

$$B = 0.008810382471 * b^{1.684993781}$$

Where RGB represent the photometric values and rgb represent the digital values.

The reverses of these transforms are:

$$r = \left(\frac{R}{0.008810382471}\right)^{\frac{1}{1.684993781}}$$

$$g = \left(\frac{G}{0.008810382471}\right)^{\frac{1}{1.684993781}}$$

$$b = \left(\frac{B}{0.008810382471}\right)^{\frac{1}{1.684993781}}$$

It should be stressed that these RGB photometric values are only relevant to this system and do not directly relate to the CIE standard observer.

4.2. Transform from RGB to XYZ

To convert from these RGB values to XYZ tristimulus values, a set of transform equations are required (Hunt 1987). Such as:

$$X = A_1R + A_2G + A_3B$$
$$Y = A_4R + A_5G + A_6B$$
$$Z = A_7R + A_8G + A_9B$$

Where $A_1 - A_9$ are constants.

In order to determine these constants it is necessary to perform the following steps.

The chromaticities (a_1-a_9) of the primaries of European colour monitors are:

	x	y	z
Red	$0.64 = a_1$	$0.33 = a_2$	$0.01 = a_3$
Green	$0.29 = a_4$	$0.60 = a_5$	$0.11 = a_6$
Blue	$0.15 = a_7$	$0.06 = a_8$	$0.79 = a_9$

To proceed further colour matches are represented by equations. These equations are written in the form:

$$C(C) \equiv R(R) + G(G) + B(B)$$

Where the equivalence sign means 'matches', the letters C, R, G and B represent the amount of colour used and the letters in brackets are labels to which the amounts refer

The chromaticity co-ordinates, a_1 to a_9, can be used to represent the amounts of XYZ needed in colour matching equations to match amounts of RGB, as follows:

$$k_1(R) \equiv a_1(X) + a_2(Y) + a_3(Z)$$
$$k_2(G) \equiv a_4(X) + a_5(Y) + a_6(Z)$$
$$k_3(B) \equiv a_7(X) + a_8(Y) + a_9(Z)$$

By treating this set of three equations as a matrix the subject of them can be changed to:

$$1.0(X) \equiv c_1 k_1(R) + c_2 k_2(G) + c_3 k_3(B)$$
$$1.0(Y) \equiv c_4 k_1(R) + c_5 k_2(G) + c_6 k_3(B)$$
$$1.0(Z) \equiv c_7 k_1(R) + c_8 k_2(G) + c_9 k_3(B)$$

Where the values of c are gained by inverting the 3x3 matrix containing the values of a:

$$c_1 = 2.06 \quad c_2 = -1.14 \quad c_3 = 0.08$$
$$c_4 = -0.94 \quad c_5 = 2.21 \quad c_6 = -0.27$$
$$c_7 = -0.32 \quad c_8 = 0.05 \quad c_9 = 1.27$$

The colour matching equations for the chosen reference white, to which the amounts of RGB previously stated produce, are:

$$k_4(W) \equiv H_1(R) + H_2(G) + H_3(B)$$
$$k_4(W) \equiv J_1(X) + J_2(Y) + J_3(Z).$$

Where H_1, H_2, H_3 are the amounts of (R), (G), (B), needed to match the white, and J_1, J_2, J_3 are proportional to the x, y, z chromaticity co-ordinates of the white. J_2 is equal to the luminance factor of the white.

Substituting for X, Y and Z in the above equation gives:

$$\begin{aligned} k_4(W) \equiv\ & J_1c_1k_1(R) + J_1c_2k_2(G) + J_1c_3k_3(G) + \\ & J_2c_4k_1(R) + J_2c_5k_2(G) + J_2c_6k_3(G) + \\ & J_3c_7k_1(R) + J_3c_8k_2(G) + J_3c_9k_3(G) \end{aligned}$$

This enables the derivation of H_1, H_2 and H_3:

$$H_1 = (J_1c_1 + J_1c_4 + J_1c_7)\ k_1$$
$$H_2 = (J_2c_2 + J_2c_5 + J_2c_8)\ k_2$$
$$H_3 = (J_3c_3 + J_3c_6 + J_3c_9)\ k_3$$

And hence the equations for k_1, k_2 and k_3:

$$k_1 = H_1 / (J_1c_1 + J_1c_4 + J_1c_7)$$
$$k_2 = H_2 / (J_2c_2 + J_2c_5 + J_2c_8)$$
$$k_3 = H_3 / (J_3c_3 + J_3c_6 + J_3c_9)$$

Using D_{65} as the standard white gives J_1=95.04, J_2=100, J_3=108.89 and H_1=H_2=H_3=100. The above equations can now be resolved.

$$k_1 = 1.49$$
$$k_2 = 0.85$$
$$k_3 = 0.84$$

Returning to the earlier set of equations:

$$k_1(R) \equiv a_1(X) + a_2(Y) + a_3(Z)$$
$$k_2(G) \equiv a_4(X) + a_5(Y) + a_6(Z)$$
$$k_3(B) \equiv a_7(X) + a_8(Y) + a_9(Z)$$

They can be rearranged to give:

$$1.0(R) = a_1/k_1(X) + a_2/k_1(Y) + a_3/k_1(Z)$$
$$1.0(G) = a_4/k_2(X) + a_5/k_2(Y) + a_6/k_2(Z)$$
$$1.0(B) = a_7/k_3(X) + a_8/k_3(Y) + a_9/k_3(Z)$$

By substituting this into the generic colour matching equation:

$$\begin{aligned} C(C) \equiv\ & Ra_1/k_1(X) + Ra_2/k_1(Y) + Ra_3/k_1(Z) + \\ & Ga_4/k_2(X) + Ga_5/k_2(Y) + Ga_6/k_2(Z) + \\ & Ba_7/k_3(X) + Ga_8/k_3(Y) + Ba_9/k_3(Z) \end{aligned}$$

The RGB to XYZ transform equations can then be derived:

$$X = (a_1/k_1)R + (a_4/k_2)G + (a_7/k_3)B$$
$$Y = (a_2/k_1)R + (a_5/k_2)G + (a_8/k_3)B$$
$$Z = (a_3/k_1)R + (a_6/k_2)G + (a_9/k_3)B$$

The values for the constants can be inserted, hence:

$$X = 0.64/1.49R + 0.29/0.85G + 0.15/0.84B$$
$$Y = 0.33/1.49R + 0.60/0.85G + 0.06/0.84B$$
$$Z = 0.03/1.49R + 0.11/0.85G + 0.79/0.84B$$

A similar method can be used to find the reverse transform:

$$R = 2.06*1.49X - 0.94*1.49Y - 0.32*1.49Z$$
$$G = -1.14*0.85X + 2.21*0.85Y + 0.05*0.85Z$$
$$B = 0.08*0.84X - 0.27*0.84Y + 1.27*0.84Z$$

4.3. Transform from XYZ to Lab

The conversion from XYZ to Lab is more routine:

$L = 116(Y/Y_n)^{1/3}-16$
$a = 500[(X/X_n)^{1/3}-(Y/Y_n)^{1/3}]$
$b = 200[(Y/Y_n)^{1/3}-(Z/Z_n)^{1/3}]$

This is only complicated when looking at dark areas of a scene. If any of the ratios X/X_n, Y/Y_n or Z/Z_n is equal to or less than 0.00856, it is replaced in the above formula by:

$7.787F + 16/116$

Where F is X/X_n, Y/Y_n or Z/Z_n as appropriate

These transforms can be performed in the reverse direction to turn Lab into XYZ:

$$Y = Y_n\left(\frac{L+16}{116}\right)^3$$

Or if $Y/Y_n \le 0.008856$

$$Y = Y_n\left(\frac{\left(\frac{L+16}{116}\right)^3 - \frac{16}{116}}{7.787}\right)$$

$$X = X_n\left(\frac{a}{500} + \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right)^3$$

Or if $X/X_n \le 0.008856$

$$X = X_n\left(\frac{\left(\frac{a}{500} + \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right)^3 - \frac{16}{116}}{7.787}\right)$$

$$Z = Z_n\left(\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \frac{b}{200}\right)^3$$

or if $Z/Z_n \le 0.008856$

$$Z = Z_n\left(\frac{\left(\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \frac{b}{200}\right)^3 - \frac{16}{116}}{7.787}\right)$$

If $Y/Y_n \le 0.008856$ then it should be replaced in the above four equations by $7.787\ Y/Y_n + 16/116$.

These equations are best combined in the form of a short program to perform the Lab to rgb and rgb to Lab conversions more easily.

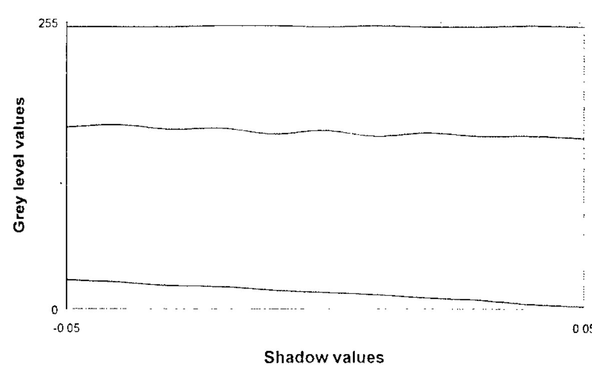
5. CALIBRATION

With these conversions accomplished, it is possible to compare the input and output of the scanning and printing processes. The next stage is to model the effects of the scanner and printer control functions. This will enable the prediction of the settings required to retain accurate colour registration through the system.

Firstly the effect of each of the scanner controls needs to be measured. The values obtained from a test slide scanned on the default settings are recorded. Then the controls are individually changed through small increments and the new values recorded. This data can be examined to determine the type of function that each control is.

Figure 2 Shows how the shadow control changes the grey level values.

Through inspection it can be seen that as the value of the shadow control increases the grey level values decrease by an amount proportional to the difference between the maximum value of 255 and the original grey level. This indicates that the



shadow control is the following function type:

$$new \approx 255 - \left(\frac{255 - old}{1 - shadow}\right)$$

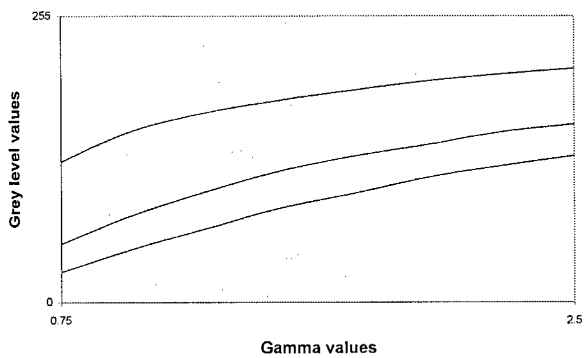


Figure 3 Shows how the gamma control changes the grey level values.

Similarly, it can be seen that as the value of the gamma control increases the grey level increases by a proportionally smaller amount. This indicates that the gamma control is the following function type:

$$new \approx old^{(1/gamma)} * 255 / 255^{(1/gamma)}$$

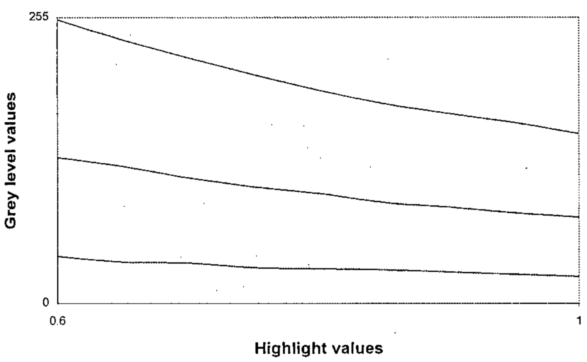


Figure 4 Shows how the highlight control changes the grey level values.

Again, it can be seen that as the value of the highlight control decreases the grey level increases proportionally with its inverse value. This indicates that the highlight control is the following function type:

$$new \approx old / highlight$$

The functions for the individual controls then need to be integrated into a single function to mimic their interaction.

$$new \approx \left(\frac{255 - \left(\frac{255 - old}{1 - shadow} \right)}{highlight} \right)^{\left(\frac{1}{gamma} \right)} * \frac{255}{255^{\frac{1}{gamma}}}$$

This is still only an approximation, requiring the addition of constants of proportionality to enable it to replicate the function of the calibration controls accurately. The values of these constants are best determined by fitting the function to a set of data from a variety of control settings. As this function is likely to require truncating at either end of the 0 – 255 scale at various stages, it will probably take the form of a small program.

This creates another problem, in that a number of data-fitting software packages that allow user defined functions will not accept conditional statements. It is therefore necessary to write a program to fit the function to the data. An adapted version of the Amoeba minimisation routine (Press et al., 1986) has proved satisfactory for this purpose.

With the fitting complete, the variables become constants and the function can be used to predict the setting of the controls.

If the scanner has been calibrated successfully, the printer calibration should be a single set up for a suitable type of film, simply tuning the film and printer to the computer output. Small differences between the projected slide and the scanned image can be corrected using the printer controls.

The modelling of the printer controls follows the same steps as the scanner: establishment of the type of function and then fitting it to a set of sample data using the same methods.

It is important to note the importance of film type at this point. All films used in the printer are likely to achieve the required extremes of scale, white and black, however the response of the film at intermediate levels should also be close to that required. A slow film will make most of the image too dark and a fast film will make most of the image too bright. With this particular printer, a 200ASA film is used to start close to the required response.

The system should now be capable of reproducing a slide perfectly. However, by using the photometric properties of objects in the scene, rather than those of the projected slide, it should be possible to produce an image that has similar colours and contrast levels to the original scene, removing the changes introduced by the photographic process that recorded it.

6. CONCLUSION

Between the scanning and printing phases, this system can be used in the creation of imagery for assessment. It is at this point that targets can be inserted into the scene. It should be obvious that great care should be taken to ensure that colour registration between the target and background is carefully controlled. It is essential that any target inserted should be as appropriate as possible in size, colour and contrast terms. To this end, capture of the base scene will need to be accompanied by measurement of the dimensions of key objects and the spectral distribution of the illumination when the imagery is taken. If a target is obtained photographically, its true reflectance should be recorded as well as the spectral distribution of the illumination. This will allow the target to be tuned to the background scene and inserted using an image manipulation software package. These details will also be required if a 3D modelling package is used to provide the target.

This type of image manipulation facility has the potential to bypass the field trial phase of CCD assessment, thus saving time and money. It could also be used to assess CCD more thoroughly by using a variety of background scenes or the same scene at different times of the year. Targets that do not exist in the real world could be assessed, targets being created from CAD models. It could be used to determine the effectiveness of potential CCD measures in areas that are not readily accessible for field trials. Another use may be to remove some of the effects on colour and contrast due to the nature of the photographic media and its projection. Images corrected in this way might appear more realistic than a standard slide.

Overall, this system adds a new level of flexibility and completeness to photosimulation.

7. REFERENCES

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