Evaluation of Texture Mapping Algorithms

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Abstract

Five texture mapping algorithms were developed for simulating textures of physical objects on a CRT. Twenty-one thread winding cards with different colours were captured by a digital camera for generating texture profiles which were used to describe the statistical colour distributions of images. A pair comparison method was used to assess the performance of various texture mapping algorithms. A total of 42000 judgements were made by a panel of 10 normal colour vision observers. The results showed that realistic appearance can be achieved by mapping a single set of tristimulus values onto a texture profile specified by the colour distribution only in luminance factor channel.

Introduction

With the recent success on colour communication using calibrated monitors, the images captured by digital cameras are widely used for accurate colour communication and realistic product simulation through the computer network. In order to generate realistic colour texture, techniques of texture mapping have been developed for adding the appearance of surface detail by wrapping or projecting a digitised texture image onto a uniform colour surface. The goal of texture simulation is to generate images of realistic colour texture appearance based on a given set of tristimulus values to define a single colour together with a pre-calculated *texture profile* which stores the detailed colour distribution of a surface.

The authors successfully developed a texture mapping algorithm[1] which was based upon the analysis of colour distributions from limited surface textures of thread winding cards. In this study, four new algorithms were developed and tested together with the previous one. Two sets of materials (thread winding card and woven fabric) were selected and captured by a high resolution digital camera. The simulated images displayed on a CRT were generated using different texture mapping algorithms. A psychophysical experiment was conducted to evaluate the performance of different algorithms in terms of colour matching and texture quality. In addition, the colour region that is the best suit for building texture profile was also investigated.

Texture Mapping Algorithms

A texture mapping algorithm requires the input of a set of tristimulus values to define the desired colour together with a pre-calculated texture profile, which defines the colour distribution in micro-level as a measure of texture. A generic texture mapping procedure is given in equation (1).

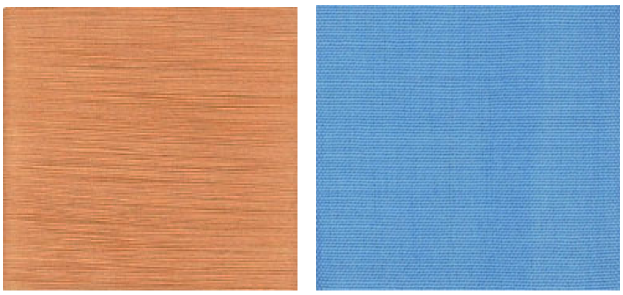
$$D_{Bi} = f(D_{Ai}) = tD_{Ai} + b \qquad (1)$$

where $\boldsymbol{b}$ is the intrinsic colour value of a texture image. $\boldsymbol{D_{Bi}}$ indicates the output colour value for pixel i in a simulated image. $\boldsymbol{D_{Ai}}$ represents the texture profile for pixel i. The profile includes each pixel's colour variation in one or more colour channels and is pre-calculated from a chosen coloured texture image, which is called template image. The $\boldsymbol{t}$ is a function to model the statistical characteristics of a colour channel vary against different colours. The method to determine $\boldsymbol{t}$ will be introduced in the next section.

Texture Feature Extraction

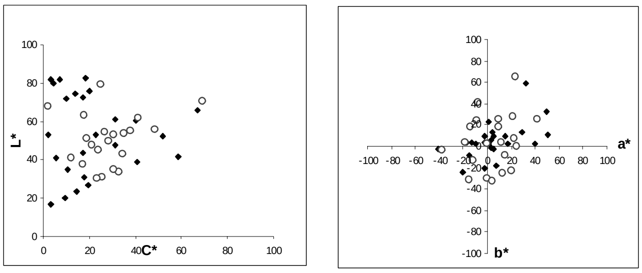
Two sets of textile samples were chosen in this study: forty-five thread winding cards and forty plain woven fabrics as shown in Figure 1. These were chosen to represent a fine and a coarse material. A GretagMacbeth CE7000 spectrophotometer was used to measure all colour samples using large aperture, UV and specula included conditions. The colour distribution of two sets of samples are plotted in CIELAB a*b* and L*C* diagrams as shown in Figure 2.

All the samples were also captured by a Nikon D1X professional digital SLR camera, which features a 23.7x15.6mm RGB CCD panel including 5.33 million pixels for 4024 by 1324 pixel images. The RGB data generated by the camera on each image were then transformed into XYZ values through a 3 by 35 matrix derived using polynomial regression.[2] Then the colour variation statistics of these images were analysed.

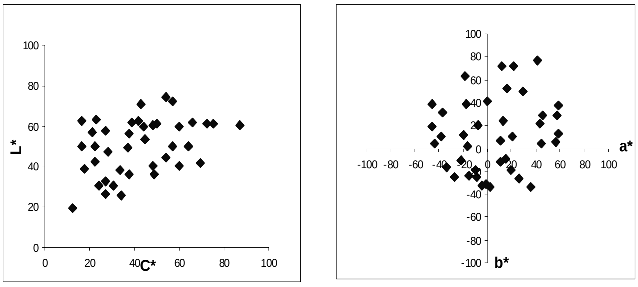


(a) *(b)*

Figure 1. Image samples of thread winding cards (a) and woven fabrics (b)



(a) Thread winding cards



(b) Woven fabrics

Figure 2. Colour distribution of textile samples

The results showed a clear trend between the standard deviation and their corresponding average colour values in X, Y and Z channels for two types of textured images. Figure 3 (a)-(c) shows that for each thread winding card, the mean X, Y and Z plotted against their standard deviation values (dX, dY and dZ) respectively. Figure 3 (d)-(f) are the same plots as the Figure 3 (a)-(c) but based upon the plain woven fabrics. It is clear from all the plots that a higher value of X, Y or Z, a larger colour variation of the texture will be. However, there is a large spread of the data, especially in Z channel, in which the best-fit curves are quite different (see Figure 3)

Defining Texture Mapping Algorithms

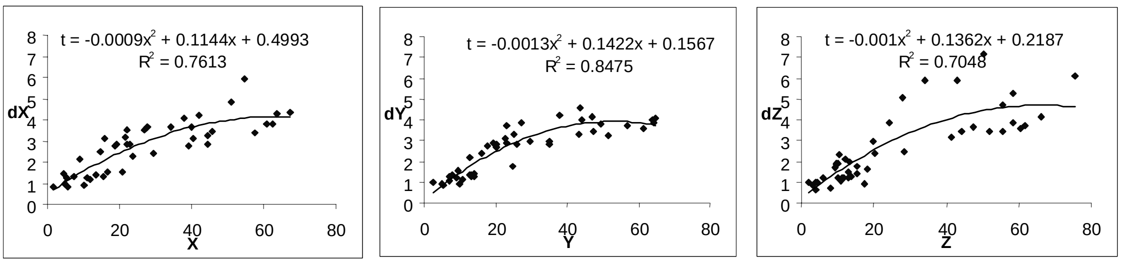
Five texture mapping algorithms were developed in this study. The generic model expressed by equation (1) requires input values (b) of tristimulus values or RGB values as the intrinsic colour values. The tristimulus values form a device independent colour space. The red (R), green (G) and blue (B) form a device dependant space based upon the digital camera responses. Ideally, all colours should be operated in device independent colour space for universal application without restrict to each imaging device. The RGB space is also included in this study because it is still widely used in many imaging tasks.

To develop a texture mapping algorithm requires the following steps:

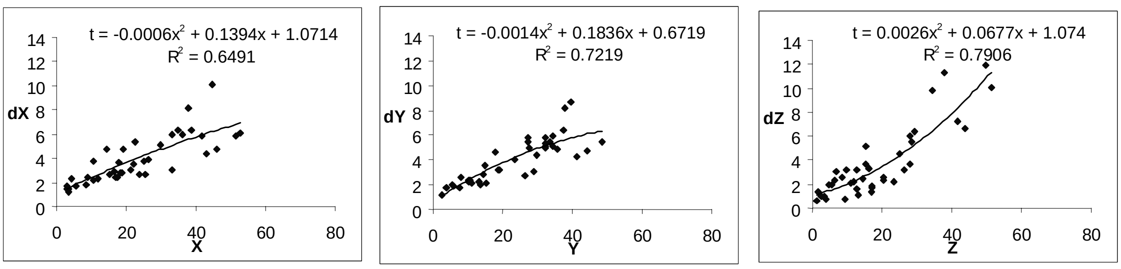
(1) To select a template image from a range of coloured objects with textures. The image should clearly discern the texture details. The colour is important to find template image (see later).

(2) To determine the texture profile based on the templateimage. The profile includes the differences of the mean and each individual pixel for one of more colour channels. It is known that most of the texture information is embedded in the Y channel. This also means that all pixels in a simulated image have the same chromaticity coordinates (x, y).

(3) To develop the t function in equation (1). The best-fit curves in Figure 3 are the ***t*** functions.



(a) *(b)* *(c)*



(d) *(e)* *(f)*

Figure 3. Plots of Standard deviation in X, Y and Z colour channels against their corresponding mean values

The texture mapping algorithms developed are summarised in Table 1 marked MA1 to MA5. MA1 and MA3 are identical except the use of two sets of ***t*** functions based upon thread winding cards and woven fabrics respectively. (Each algorithm includes three t functions: X, Y and Z, or R, G and B.) MA2 and MA4 are the simplified versions of MA1 and MA3 respectively to express texture information only using the Y channel which carries most of the texture information in an image. In other words, all pixels in each image have the same chromaticity coordinates. MA5 is an algorithm based upon the camera's digital counts (RGB). Note that R, G and B values are ranged from 0 to 255 for a 8-bits per channel in this study. It was found that the statistical characteristics for R, G and B channels are quite different from those of X, Y and Z, The ***t*** function was excluded in MA5 because it introduces obvious defects in the simulated images. The scatter of the R, G and B plotted against standard deviations of them is also much larger than those shown in Figure 3 using X, Y and Z.

Table 1. Summary of the five texture mapping algorithms

Texture Mapping Algorithm	***Description***
MA1	$X_{oi} = \overline{X} + t_X \Delta X_i$ $Y_{oi} = \overline{Y} + t_Y \Delta Y_i$ $Z_{oi} = \overline{Z} + t_Z \Delta Z_i$
MA2	$Y_{oi} = \overline{Y} + t_Y \Delta Y_i$ $x_{oi} = x = \overline{X} / (\overline{X} + \overline{Y} + \overline{Z})$ $y_{oi} = y = \overline{Y} / (\overline{X} + \overline{Y} + \overline{Z})$
MA3	$X_{oi} = \overline{X} + t_X ' \Delta X_i$ $Y_{oi} = \overline{Y} + t_Y ' \Delta Y_i$ $Z_{oi} = \overline{Z} + t_Z ' \Delta Z_i$
MA4	$Y_{oi} = \overline{Y} + t_Y ' \Delta Y_i$ $x_{oi} = x = \overline{X} / (\overline{X} + \overline{Y} + \overline{Z})$ $y_{oi} = y = \overline{Y} / (\overline{X} + \overline{Y} + \overline{Z})$
MA5	$R_{oi} = \overline{R} + \Delta R_i$ $G_{oi} = \overline{G} + \Delta G_i$ $B_{oi} = \overline{B} + \Delta B_i$

Experiment

Twenty-one coloured winding cards were chosen in the experiment. Their CIELAB L*, C* and hue angles are given in Table 2 and plotted in Figure 2(a) using large o symbols. It can be seen that these samples covered a large colour gamut and lightness range. These cards were then captured by a digital camera. The captured images in RGB terms were then transformed by a camera characterisation model including a 35-term polynomial. The images were finally converted to monitor RGB via the GOG monitor characterisation model.[3] Each captured image in monitor RGB was taken as template images. These were analysed and stored as texture profile. For each template image, the colour values of all the other samples were then mapped via five texture mapping algorithms. Therefore, a total of 2100 images [21 texture profiles x 20 colours x 5 algorithms] were generated. In the psychophysical experiment, each simulated image was displayed against their corresponding template image. Ten observers were asked to judge the degree of colour match and texture quality by means of category judgement method. Each observer did experiment twice. Hence, 42000 judgements were made. The categories used to judge the degree of colour match and texture quality are given below.

Table 2. CIELAB values for the samples used in the texture mapping experiment

Colour Names	L*	C*	h
1	68.0	2.3	98
2	79.4	25.3	359
3	56.0	48.5	31
4	41.1	12.2	15
5	44.9	24.1	19
6	54.2	27.1	70
7	47.6	21.2	62
8	53.5	34.9	52
9	70.3	69.3	70
10	50.8	18.7	168
11	61.7	41.4	101
12	55.0	37.8	185
13	31.0	25.9	109
14	29.9	23.5	128
15	63.4	17.7	227
16	43.1	34.7	245
17	53.0	30.5	270
18	33.7	32.8	278
19	37.5	17.2	329
20	49.7	28.4	298
21	34.9	30.8	312

Grade	Degree of match
1	Complete mismatch
2	Very bad match
3	Bad match
4	Acceptable match
5	Good match
6	Very good match
7	Perfect match

Results and Discussions

Observer Variations

Observer variations were first analysed. Each observer's two repeated results were compared in terms of the PF/3 measure to represent the typical repeatability performance. (The PF/3 is called performance factor developed by Luo and Rigg[4] to indicate the agreement between two sets of data. It combines three different statistical measures. A PF/3 of 0 means a perfect agreement and a PF/3 of 30 represents a 30% disagreement between two data sets. Observer accuracy was calculated by comparing each observer's data with the mean visual data from all observers again using the PF/3 measure. Both repeatability and accuracy results for each observer are summarised in Table 3.

The results show about 5 PF/3 units higher for observer repeatability than observer accuracy, and 4 PF/3 units higher for judging texture quality than colour fidelity. The overall observer variation is about 30 PF/3 units, or 30% disagreement between observers. This degree of variation is considered to be reasonable.

Performance of Different Texture Mapping Algorithms

As mentioned earlier texture mapping was carried out based on 21 template images in the experiment. For each template image, there were twenty different colours were mapped via the five texture mapping algorithms developed.

Table 3. Observer accuracy and repeatability

	Observer Accuracy		Observer Repeatability	
Observer	**Colour matching**	**Texture quality**	**Colour matching**	**Texture quality**
1	30	27	46	43
2	17	20	20	19
3	40	47	46	46
4	17	36	19	33
5	39	38	45	42
6	25	21	30	27
7	20	24	22	29
8	20	21	20	23
9	22	32	28	42
10	18	21	24	3
Mean	**25**	**29**	**30**	**34**

The judgements given by all observers on these twenty simulated images against their corresponding template image were averaged and the results are given in Table 4 in terms of colour matching and texture quality. A larger value of the result indicates a higher colour fidelity or image quality of the simulated images against the template image**.**

Table 4. Performance of five texture mapping algorithms

(a) Colour fidelity

Template image	**MA1**	**MA2**	**MA3**	**MA4**	**MA5**
1	5.07	4.93	4.69	4.86	5.02
2	4.73	4.85	4.34	4.83	4.45
3	4.26	4.86	4.24	4.76	4.52
4	4.85	4.92	4.29	4.81	4.74
5	4.63	4.50	4.36	4.48	4.44
6	4.58	4.56	4.10	4.46	4.55
7	4.29	4.53	4.19	4.68	4.41
8	4.47	4.89	3.90	4.79	4.58
9	4.21	4.85	3.85	4.86	4.48
10	4.70	4.87	4.24	4.85	4.20
11	4.12	4.36	3.78	4.20	3.92
12	4.40	4.57	3.78	4.42	2.94
13	4.06	4.13	4.08	4.45	3.41
14	4.35	4.44	4.23	4.62	3.34
15	4.53	4.66	4.23	4.57	4.67
16	4.12	4.63	3.89	4.58	2.70
17	4.50	4.71	4.03	4.53	3.15
18	4.55	4.59	4.24	4.68	3.92
19	4.59	4.60	4.22	4.57	4.46
20	4.79	4.67	4.49	4.55	4.49
21	4.73	4.61	4.16	4.62	4.60
Mean	**4.50**	**4.65**	**4.16**	**4.62**	**4.14**

(b) Texture quality

Template image	**MA1**	**MA2**	**MA3**	**MA4**	**MA5**
1	4.24	4.21	4.11	4.11	4.15
2	4.14	4.35	4.09	4.18	3.93
3	3.89	4.20	3.87	4.20	4.02
4	4.44	4.40	4.19	4.27	4.25
5	3.91	3.97	3.83	3.86	3.77
6	3.89	4.01	3.85	3.95	3.96
7	4.30	4.46	4.26	4.40	4.39
8	3.96	4.01	3.74	3.93	3.83
9	3.87	4.12	3.83	4.06	3.96
10	4.22	4.43	3.99	4.22	3.79
11	3.90	4.09	3.80	3.93	3.74
12	4.19	4.20	3.90	4.10	3.62
13	3.37	3.43	3.46	3.61	3.12
14	4.16	4.28	4.16	4.38	3.44
15	4.01	4.01	4.03	4.03	4.08
16	3.86	4.18	3.82	4.01	3.09
17	3.87	4.16	3.69	4.03	3.08
18	3.79	3.97	3.81	4.14	3.47
19	4.00	3.92	3.77	3.89	3.71
20	4.22	4.15	4.21	4.00	4.01
21	4.54	4.52	4.26	4.41	4.34
Mean	**4.03**	**4.14**	**3.94**	**4.08**	**3.80**

The mean performance of each texture mapping algorithm for each template image are summarised in Table 4. The results show that, in the case of colour matching, all five algorithms can simulate images with acceptable colour matching quality (category 4 or above).

Amongst these algorithms, MA2 and MA4, which used Y channel only, performed better than the others. From the equations given in Table 1, it can be seen that the chromaticity coordinates (x, y) of each pixel on a simulated image were kept constant when the MA2 and MA4 were used to simulate images. This means that dominant wavelength and excitation purity of the colour of the simulated images are constant.

A similar trend as colour fidelity was found for assessing texture quality. The better performance of MA2 and MA4 proved that the most important texture information of images is embedded in Y channel. Adding texture information from X and Z channels into the texture mapping algorithms would not improve the texture quality of simulated images.

Comparing MA1 with MA3, which are the algorithms applying texture information from all three channels, the results show that there was little difference between ***t*** functions derived from card and fabric. The same conclusion was found by comparing MA2 and MA4. When the ***t*** functions derived from different textures were applied in image texture mapping, MA2 and MA4 are preferred comparing to MA1 and MA3. This implies that using texture information embedded in Y channel only can generate more realistic colour appearance of simulated images than using texture information from all X, Y and Z channels. Image simulation using MA5 using RGB colour values and the texture characteristics inherited in RGB channels gave somewhat poorer performance. In particular, texture quality of the simulated image using MA5 was lower than category 4, the level of acceptance. This is caused by the exclusion ***t*** function, which was introduced into the other algorithms to describe the change of image's colour variations as the colour varies. As mentioned earlier, there was no clear trend between the standard deviation and their corresponding average colour values existed in R, G and B colour channels. It could result in artefacts on the simulated images when MA5 was used.

The experimental results shown in Table 4 also indicate that using a light-grey sample (Colour 1) as the template image to build texture profile performed better than the other coloured texture images. In particular, a light-grey template image assures a better colour match than the other colours. The texture quality of the simulated images could be poor when a template image with low Y value was chosen. It can be seen that for Colour 13 in Table 4 (a dark green) with a Y of 31, the texture quality of this colour sample using five mapping algorithms was the worst amongst all the colours investigated. The image with a darker colour causes a loss of texture details when transform between camera RGB and XYZ.

Conclusions

Five texture mapping algorithms were developed and evaluated in this study. The experimental results show that the realistic colour appearance could be generated by mapping a set of tristimulus values onto a texture profile that stores the texture information in Y channel. The advantage of this texture mapping algorithm is that the chromaticity coordinates of the simulated image will be reserved. Different ***t*** functions derived from textile samples with different texture patterns had little effect on image texture simulation.

References

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Biography

Bing Han received her MSc. degree in Colour Imaging Science from Colour and Imaging Institute (CII) at University of Derby in 2000 and currently is a research student in CII. Her Ph.D. project has focused on the texture simulation of coloured object on CRT display. Models for texture mapping will be developed and based on different materials such as textile samples and metallic paint.