The Effect of Reduced Color Depth on the Color Reproduction of Web Images

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Abstract

Accurate color reproduction of images viewed across the Internet can be a difficult task due to problems, which include variable viewing conditions. The standard RGB color space (sRGB) has been proposed to overcome this problem without the need for special software applications. Different graphics adapter bit-depth settings also affect the number of displayable colors on a web browser. For this reason, the 216 colors "web safe" palette has been introduced.

To understand the effect of device characteristics on the process of image reproduction via the web, the characterization of some common devices was carried out. This created a controlled environment whereby experiments could be conducted with reproducible results. Device characterization also enabled the accurate conversion of scanned images to sRGB by using a step-by-step process that followed the specification of the color space.

The investigation of color reproduction on a Cathode Ray Tube (CRT) display under different bit-depth settings has been conducted using a suitable test target, which was converted to the sRGB color space and also to the "web safe" (216 colors) palette. These two images were displayed under the 8-bit and 24-bit depth settings of the graphics card adaptor.

Colorimetric measurements concerning color differences were performed and evaluated. Experimental investigation on the true color (24-bit color depth) image while displayed under 8-bit setting via different browsers followed. The outcome of the investigations was evaluated and combined to determine the relationship between the different parameters described above and their effect on image quality.

Introduction

Color reproduction of images viewed across the Internet is an area of major interest since the developments in technology have made on-line access of image databases fast and easy. There are problems, however, that make accurate color reproduction a difficult task. One of the main reasons is that each viewer accesses on-line images under different viewing conditions. The parameters that affect perceived image quality are many, and the combinations that could describe each user's viewing conditions are numerous.

Users who access on-line images may have computers with different power, modem speed, graphic adaptor's settings and monitor type, to name few. The web site editor cannot know these parameters. The platforms and the software that are used are also unknown. Furthermore, the viewing conditions are also different and they may even vary during the online access of the images.

One of the parameters that affects the reproduced colors while viewing on-line images is the bit-depth setting of the graphics adaptor. The bit depth, which determines the number of displayable colors, can mean that an image may be displayed with fewer colors if the bit depth setting is low. This is a problem for Internet imaging since the web site, or image database creator, does not know under which color depth the image will be viewed. For example, if the display interface card is set to 8-bit color depth (256 colors) then the image, even if it consists of millions of colors, will be presented in only 256 colors. This is achieved by a process called "mapping".[1]

The transformation that occurs because of the decreased color depth of the display interface card has additional limitations. The browsers do not have common 256-color palettes because there are some colors, which are reserved either for the operating system or for the browser.

A solution is provided by a common color palette which was introduced as the "Web safe" palette. This consists of 216 colors, common to most operating systems and browsers.[2-3] A 6x6x6 color cube with Red, Green and Blue colors in increments of 51 pixel values is used to form the palette.[4] Netscape Navigator, Microsoft Internet Explorer and MCSA Mosaic have adopted this palette.[2]

Display conditions also affect accurate color reproduction across the Internet. For this reason, the Standard RGB (sRGB) color space has been proposed for viewing on-line images.[5-6] It is the color space for many applications and hardware and also the default color space for Microsoft Windows 98 and Windows 2000 operating systems. It is useful for images that are not specifically tagged with any other color information.

Table 1. sRGB Reference Display Conditions

Condition	SRGB
Display Luminance Level	80 cd m^{-2}
Display White Point	CIE D65 (x=0.3127, y=0.3291)
Display Model Offset (R, G, and B)	0.055
Display Gun/Phosphor Gamma	2.2

Experimental Details

The aim of this experimental work was to investigate the effect of the reduced color depth of the graphics adaptor's settings and of the use of the "web safe" palette on the color reproduction of images displayed on a Cathode Ray Tube (CRT) display. The host computer was an IBM-compatible Hewlett-Packard Vectra VA with a Matrox Graphics MGA Millennium display interface card. The operating system was Microsoft Windows NT 4.0. Measurements on the CRT faceplate were conducted using a Minolta Chromameter II incident colorimeter with CIE Yxy output. The measuring range of the chromameter was 5.1 – 32700 lux. The X-Rite DTP92L colorimeter was also used.

The test target used for the experimental investigation was the Kodak Q-60R1[7-8] which was scanned with the Hewlett-Packard 6100C flatbed scanner. For columns 1 to 12 each row of the target represents a hue angle. There are three lightness (L*) levels and each one consists of three chroma levels (columns 1-3, 5-7, 9-11). The fourth column (4, 8, and 12) represents the maximum chroma that can be produced by the specific product at that hue angle and lightness level. Columns 13-19 are scales of Cyan, Magenta, Yellow, Neutral, Red, Green and Blue. There are also patches that represent skin colors (columns 20 – 22) and a 22 step neutral scale.

Characterization of the scanner was conducted using the Macbeth ColorChecker color rendition chart [9] and the X-Rite Digital Swatchbook. The images were displayed on a NEC MultiSync M500 15" CRT display with dot pitch 0.25mm and resolution 1024x768 dots at 65Hz.

Calibration and Characterization of the Devices

To understand the effect of device characteristics on the process of image reproduction, the characterization of the flatbed scanner and the display was carried out. This created a controlled environment in which experiments could be conducted. Device characterization also enabled the accurate conversion of scanned images to sRGB.

Colorimetric Characterization of the Flatbed Scanner

Scanner colorimetric characterization has been described in detail in the literature,[1,10-12] and similar methods have been applied for digital camera characterization.[13] Researchers have also worked on scanner characterization procedures for conversion of images to the sRGB color space.[14-15] Scanner colorimetric characterization was performed to determine the transformation matrix from scanner RGB color space to device independent D65 CIEXYZ color space. This procedure was also necessary for the transformation of the images to the sRGB color space.[5-6]

The colorimetric characterization was performed by scanning a Macbeth ColorChecker color rendition chart at 24-bit color depth and 200 dpi resolution. The CIEXYZ values of every patch of the original target were measured using the X-Rite Digital Swatchbook. The scanner RGB values were obtained by measuring the area of each color patch (approximately 10,000 pixels) and computing the average pixel values of each of the 24 patches for the Red, Green and Blue channels. For this purpose, the Scion Image software package was used.

The second step involved the measurement of the CIEXYZ values of all patches of the test target using the X-Rite Digital Swatchbook colorimeter for D65 illuminant. Relative luminance Y of the test target versus scanner RGB pixel values were plotted for the neutral patches. Derivation of the RGB to XYZ transfer matrix was performed by matching the grey balanced RGB valued to the measured CIEXYZ values of the test target using linear regression. The average CIELAB color difference value between the original test target and the scanner response was 5.67.

Characterization of the CRT Display

The CRT display characterization was carried out using special test targets and display software. Tests for focus, convergence and geometry of the monitor showed that good performance was obtained for the central area of the screen. Monitor chromaticity and luminance are expected to vary in different areas of the screen, since it has been shown that spatial characteristics of CRT displays can vary.[16] Since the lack of uniformity for most displays is below the visual system's threshold to low spatial frequencies this problem can be ignored.[17]

The spatial variation of the CRT was investigated by measuring a white patch situated on 12 different areas of the screen. CIELAB Color Difference, ΔE^*_{ab}, was used in this work. ΔE^*_{ab} values were computed across the screen and the results plotted. It was shown that color difference was more uniform in the central area of the screen while the highest differences were at the right side of the faceplate. The stabilisation time[18] of the CRT was also determined by repeated measurements (every 30 sec.) of a white patch covering 50% of the screen for a period of 90 minutes. It was found to be approximately 80 minutes. The display system was set up using special targets and adjusting the brightness and contrast controls, according to the sRGB reference viewing conditions (Table 1). The transfer function of the display system can be expressed according to its luminance output versus the input pixel values[19]:

$$L_i = k_i V_i^{\gamma_i} \quad (1)$$

L: normalised luminance, V: normalised Pixel Values, i: Red, Green or Blue, k: constant for gain

This equation is valid after making the assumption that each electron beam energises only its corresponding phosphor. A more complex model has been proposed by Berns et al.[17] The CRT display system transfer function was found by measuring patches for the red, green and blue channels individually and for the three combined. The patches had 15 pixel values intervals from 0 to 255 and measuring was performed using the Minolta Chromameter II. A suitable power function was applied to the normalised data.

$$y = 0.1366\, x^{2.198} \quad (2)$$

The gamma (γ) for the combination of the three channels (Red, Green and Blue) was equal to 2.2 (Equation 2) and the white point of the display was set to CIE Standard Illuminant D65 which is in agreement with the reference viewing conditions for the sRGB color space. The display system color gamut in the CIE xy color space was found by measuring the peak Red, Green and Blue pixel values of a displayed 5x5 patch in the centre of the screen, with black background.

Experiment 1

The first experiment concerned the objective assessment of the color reproduction of images displayed with different color bit-depth. The test target was the Kodak Q-60R1 scanned at 100% magnification. Two copies of this image were converted to the sRGB color space. One of them was converted to the “web safe” palette (216 colors). Both images were scaled by 8x using bicubic interpolation. The final dimensions of the patches were 4x4 cm. Each patch was cropped and displayed in the centre of the screen in black surround. Two settings of the graphics adaptor were applied for image display: 24-bit and 8-bit color depth. This resulted in four image display combinations (Figure 1).

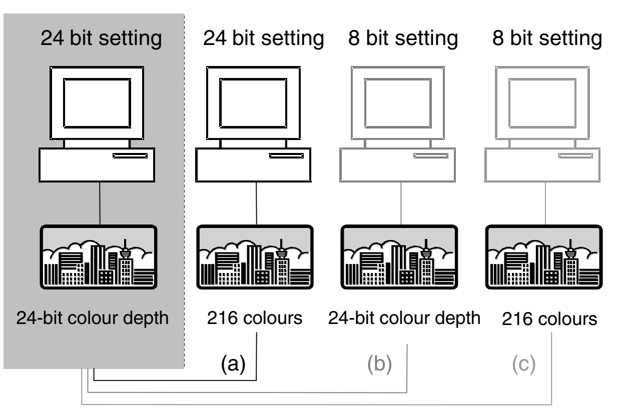

Figure 1. The three cases of image display combined to the reference image (in grey box).

Each patch was measured using the Minolta Chromameter II, which gave CIE Yxy values. These measurements were used to calculate the CIELAB color difference values between the reference image and the images of the remaining three cases.

The primary step was to investigate whether the color differences between the images were perceptible. The Just Noticeable Difference (JND) in the CIELAB color space is 1 ΔE^*_{ab} value.[1] Color differences up to 3 ΔE^*_{ab} values, however, are practically unnoticeable.[14] Color differences higher than 3 ΔE^*_{ab} values had to be further investigated to determine if they occurred randomly or were affected by the color transformation. Some colors showed significantly higher color difference. This could have occurred due to the method of color mapping which might have affected specific patches. Another reason could be error during measurement. The second reason was investigated further by repeating all the measurements using a second colorimeter, the X-Rite DTP92L. That set of measurements showed that the pattern of the graph was the same. The attributes of the colors could be therefore the reason for the high color differences in some patches. Errors that occurred because the luminance of the measured color was out of the colorimeter’s measuring range were taken into account and were excluded from the overall evaluation of the results.

Case (a)

The first case investigated in this experiment was the display of the 216-color image with 24-bit color depth setting of the graphics adaptor. Results showed that the color differences of the test target patches when compared to the reference image were mainly between 0 and 4 ΔE^*_{ab} values (Figure 2).

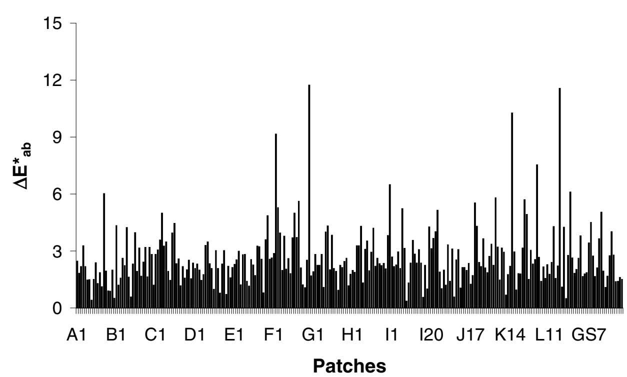

Figure 2. Color differences for Case (a)

The graph showing the frequency of the ΔE^*_{ab} values (Figure 3) confirmed this observation. It also showed that the highest frequency occurred for 2 ΔE^*_{ab} values. There is a relatively high distribution for color differences from 2 to 4 ΔE^*_{ab} values, however. Higher color difference values (over 6 ΔE^*_{ab}) occurred in a few cases.

Observation of the percentiles (Table 3) showed that the color differences are above JND (1 ΔE^*_{ab} value) from the 10th percentile and above 2 ΔE^*_{ab} values from the 50th percentile. The median ΔE^*_{ab} value was 2.40. Regarding the specific colors that showed the highest color differences it was observed that they were distributed over the whole test target. Most of the color differences occurred however at columns 1 – 8 which represent low and medium lightness level. Chroma level or hue angle did not seem to have affected the color difference in these columns. There were also high differences for the low lightness blue patches.

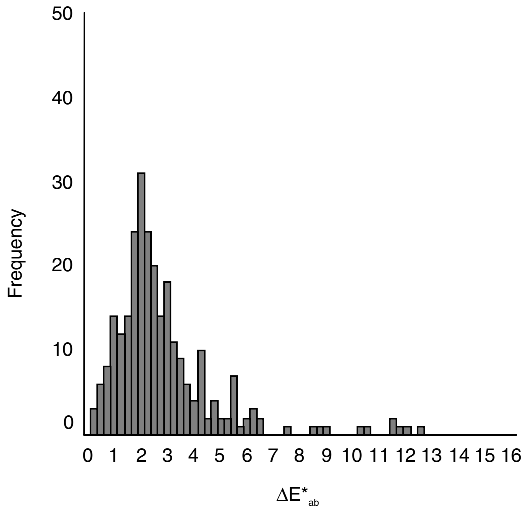

Figure 3. Frequency of ΔE^*_{ab} values for Case (a)

Case (b)

The second case was when a 24-bit color depth image (True Color) was displayed with an 8-bit color depth setting of the graphics adaptor. Comparison of that image to the reference one showed that most of the color difference values were below 2 ΔE^*_{ab} values (Figure 4). A repeated pattern of high color difference values was observed, however, which indicated that they were related to attributes of the color measured. The high values occurred for the dark patches of the test target (columns 2 – 4) and especially for the hue angles 41 to 161. Medium and high lightness columns did not have high color difference values. High error was also measured for magenta, yellow, blue and skin colors.

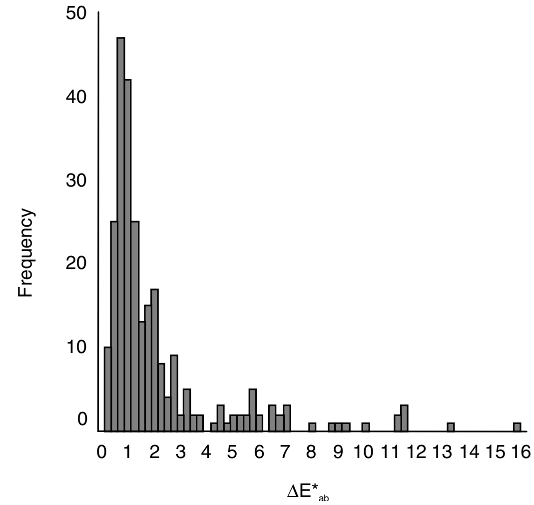

Figure 5. Frequency of ΔE^*_{ab} values for Case (b)

The graph showing the overall ΔE^*_{ab} values' frequency (Figure 5) gave interesting results as well. The highest frequency occurred for up to 3 ΔE^*_{ab} values. Higher values occurred relatively few times. Observation of the percentiles (Table 3) showed good performance as well. The ΔE^*_{ab} value was greater than 1 from the 50th percentile and greater than 3 on the 90th percentile.

Case (c)

The third case referred to a 216-color image displayed with 8-bit color depth (256 colors) setting of the graphics adaptor. In this case the results were closer to the ones in case (a). This was expected since the "web safe" palette was developed to give consistent results when images are viewed with the 8-bit color depth setting of the graphics adaptor. The repeated pattern in color differences pattern was clearer than in case (a). The high color differences occurred mainly for the same patches. More patches with high ΔE^*_{ab} values occurred, however, for the dark patches compared to case (a) (Figure 6).

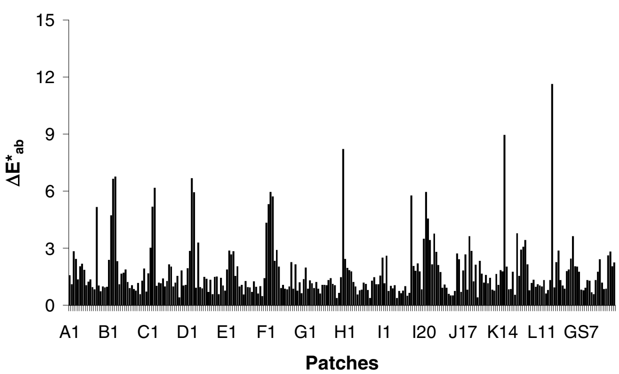

Figure 4. Color differences for Case (b)

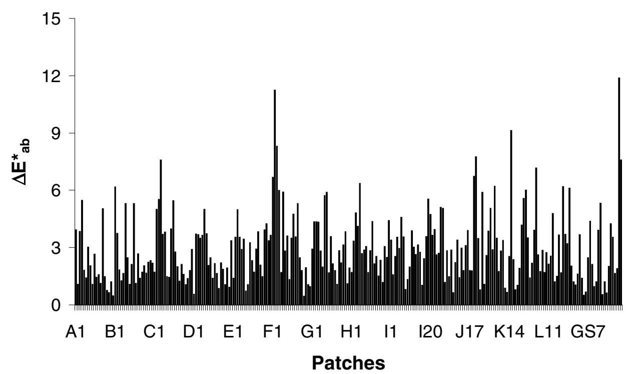

Figure 6. Color differences for Case (c)

The frequency of the ΔE^*_{ab} values had a wider distribution between 0 and 4 ΔE^*_{ab} values (Figure 7). The percentiles (Table 3) showed similar attributes to case (a) with respect to the increase in ΔE^*_{ab} values.

Summarising the results, it can be seen that the lowest ΔE^*_{ab} values were obtained when the 24-bit color depth image was displayed at 8-bit graphic adaptor's setting. The effect on ΔE^*_{ab} when the 216-color image was displayed at 8-bit and 24-bit color depth was similar, which was an expected result. Some large ΔE^*_{ab} values, where color difference would be perceptible, were observed for certain colors. Measurements of specific dark patches (F1-F2, I20, J2-J4, J21, L16, L19) were excluded from the evaluation because their luminance level was out of the colorimeter's measuring range, introducing error. Case (b) showed an overall better performance since the color differences were lower and the median ΔE^*_{ab} value was 1.30, lower relative to cases (a) and (c). The color difference, however, was greater than in cases (a) and (b) for the 90th percentile.

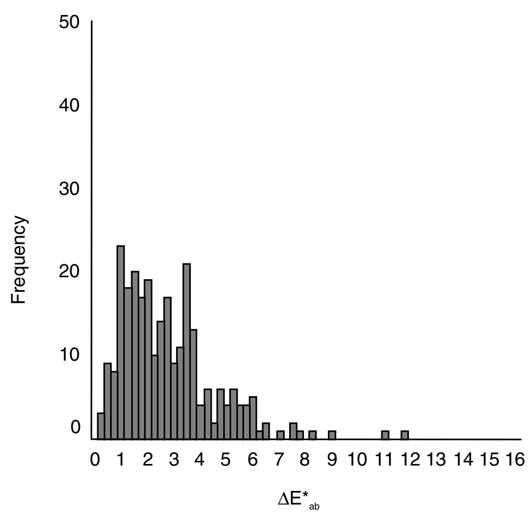

Figure 7. Frequency of ΔE^*_{ab} values for Case (c)

Table 2. Descriptive Statistics for the Three Cases

Case	Median (ΔE^*_{ab})	Minimum (ΔE^*_{ab})	Maximum (ΔE^*_{ab})
(a)	2.40	0.36	12.74
(b)	1.30	0.36	15.96
(c)	2.59	0.45	11.89

Table 3. Percentiles for the Three Cases

	Percentiles (ΔE^*_{ab})						
Case	**5**	**10**	**25**	**50**	**75**	**90**	**95**
(a)	0.90	1.18	1.86	2.40	3.47	5.45	6.60
(b)	0.55	0.68	0.92	1.30	2.39	5.93	7.17
(c)	0.78	1.06	1.62	2.59	3.74	5.39	6.18

Experiment 2

The second experiment aimed to investigate the color differences between the two most popular Internet browsers when 24-bit color depth images are displayed with 256-color graphics adaptor setting. The versions of the web browsers used were Microsoft Internet Explorer 5 and Netscape Navigator 6. The reason for this experiment was to investigate any differences due to different mapping of the image colors to the reduced 216-color palette. Results would show whether the use of different browsers had an effect on the color reproduction of web images.

The test target used for this experiment was the Kodak Q-60R1 scanned at 100% magnification in BMP format. It was converted to the sRGB color space and scaled by 8x using bicubic interpolation. Each patch was cropped and imported in a web page. It was then displayed in the centre of the screen with a black surround. Measurements were performed using the X-Rite DTP92L colorimeter, which was firmly attached to the screen, to measure the same area.

Results showed that the color differences were under 2 ΔE^*_{ab} values for most of the patches. Some high color differences were observed for light patches (Figure 8).

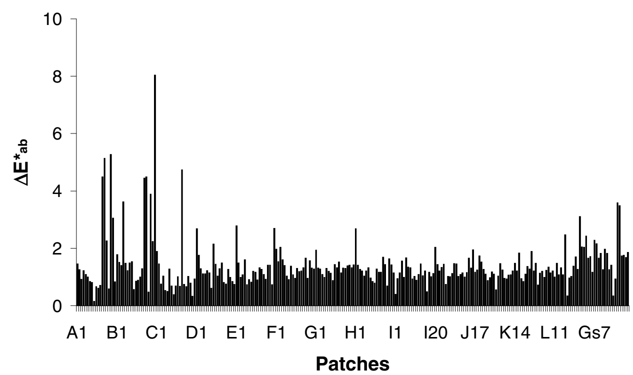

Figure 8. Color differences between the two browsers

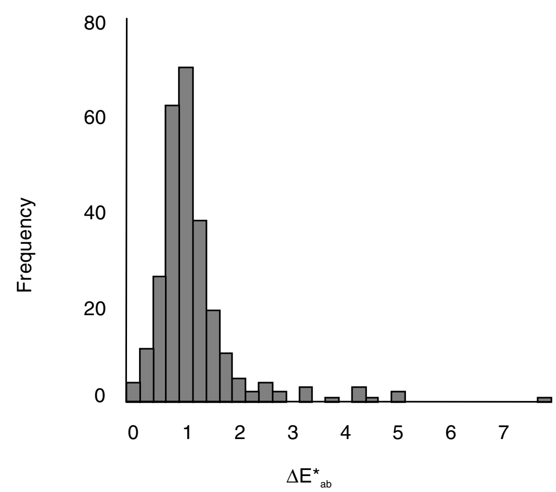

Figure 9. Frequency of ΔE^*_{ab} values for the two browsers

The frequency diagram (Figure 9) showed the distribution of the ΔE^*_{ab} values. Most of them occur within 0 to 2 ΔE^*_{ab} values which meant that the differences were practically unnoticeable.

From table 5 it can be observed that ΔE^*_{ab} values only rose above 2 at the 90th percentile.

Table 4. Descriptive statistics

	ΔE^*_{ab}
Median	1.21
Minimum	0.15
Maximum	8.04

Table 5. Percentiles

Percentiles (ΔE^*_{ab})						
5	**10**	**25**	**50**	**75**	**90**	**95**
0.59	0.74	0.99	1.21	1.48	2.03	2.98

Conclusions

Reduction of the image colors to the 216 color "web safe" palette can result in high color differences for specific colors and especially for dark ones.

Displaying a True Color image (24-bit color depth) with the 8-bit graphics adaptor setting gave better color reproduction. If a consistent result for both settings is needed, however, the web safe palette should be chosen.

Some specific colors cannot be reproduced well using the 216-color palette. The web designer needs to know in advance about the possible high error when the image is transformed to the reduced palette in case these colors are critical for the designer's application.

Use of different web browsers was shown that does not affect the color of the reproduced images except of some specific colors.

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Biography

Efthimia Bilissi graduated with a degree in Photography from the Technological Educational Institute (T.E.I) of Athens, Greece in 1995. She has worked as a photographer and as an editor in several photographic publications.

She completed her MSc in Digital Imaging at the University of Westminster in 1999. Since then she has been a postgraduate research student in the University of Westminster's Imaging Technology Research Group, working on a project concerned with image quality on the Internet.