Colour based image retrieval with embedded chromatic contrast

Xiaohong Gao, Yu Qian, Yuanlei Wang, Anthony White
School of Engineering and Information Sciences, Middlesex University, London NW4 4NT, UK.
x.gao@mdx.ac.uk; ***Tel/fax: +44 208 411 2252.***

Abstract

Due to the over-whelming amount of digital images available in the internet, content-based image retrieval (CBIR) has been developed to complement with the current text-based approach. As such, colour has played a key role in representing image features and has been employed widely in such a development. However a colour appears differently to human eyes when it is viewed against different coloured backgrounds and surroundings, whereas none of existing colour spaces and models has taken this effect of colour contrast into account, leading to a number of unsatisfied retrieved results to a certain extent. This study aims to develop a colour appearance model/space to predict simultaneous colour contrast, which is in turn to be suitable on course to retrieve a collection of museum wallpaper papers. In doing so, a 2-field paradigm is maintained instead of traditionally 3-field one in an effort to model chromatic contrast, which has led to the extension of CIECAM02 into CIECAMcc. Colour based image retrieval is subsequently evaluated using 4 popular colour models and spaces, including CIECAMcc, CIECAM02, HSI, and RGB. Although it is unlikely to judge which method performs better purely based on colour content due to the nature of subjectivity in interpreting images, it can be said that in terms of both brightness and colourfulness contrast between foreground and background, CIECAMcc outperforms the others. In addition, CIECAMcc exhibits potentials in retrieving back images that constitute two shaded patterns the similar way as those depicted in a query image. However this phenomenon can not be simply explained away. Further investigation will be carried out in this regard in the future by including larger collections.

Introduction

Simultaneous colour contrast is a phenomenon that colour appearance changes with the change of its surrounding colours and has played an important part in traditional art and design practices. Due to the advances of computer internet technology, large amount of colour images (both still and motion) are available digitally, especially on the websites of online shopping, the effect of simultaneous colour contrast has to be taken into consideration when correct colours are anticipated to be retrieved back while browsing colourful objects. At present, retrieving images via their contents (colour, texture, shape, etc.), i.e., content-based image retrieval (CBIR), has proven to be an efficient approach complementing the current text-based method, in particular over the internet where huge amount of images are available but not labelled yet apart from their titles. In CBIR, the most popular feature that is extracted to index those images is colour. While colour-based approaches employ colour spaces of mainly RGB, HSV and CIELAB and CIELUB [1], those spaces do not take simultaneous colour contrast into account. Thereby, although a query image and retrieved images have similar physical measures of colour attributes in terms of, say, lightness, colourfulness, or hue, perceptually, they do not match, leading to lots of elaborative efforts of further improvement to these models. In this study, colour contrast is investigated fundamentally and has been attempted on retrieving a collection of wallpaper images. Figure 1 illustrates three typical examples of wallpaper images to be retrieved in the study, whereby 2-field patterns are present showing foreground objects against coloured background. Figure 2 elaborates the effect of chromatic contrast by showing the original image (top leftmost) and the images with its background changed with different colours, i.e., white, green, blue, yellow, cyan, purple, and brown respectively. In particular, the green leaves in the original image can be perceived as different hues in the following pictures of different backgrounds.

Figure 1*. Three examples of wallpaper images to be retrieved in this project.*

To model a colour appearance, CIE (Commission internationale de l'éclairage) has recommended a colour appearance model, CIECAM02 [2] that can predict the change of colour appearance as accurate as an average observer under a number of given viewing conditions. The way that the model describes a colour is similar to subjective psychophysical terms, i.e., hue, colourfulness, chroma, brightness and lightness. Although the viewing conditions can vary from dark to light backgrounds, these models are mainly employed for colours with monochromatic backgrounds/surroundings. On the other hand, colour contrast has been considered being too complex to predict by simply modifying the response of reference white [3]. Nevertheless, this effect has been predicted with a very good match to observers' estimations by building on CIECAM02 with a modification of reference white [4].

The effect of simultaneous colour contrast is usually studied in a centre-surround 3-field paradigm [5] consisted of background, induction field and a test colour and has shown that the change of lightness, colourfulness, and hue of a surrounding colour will all contribute to the change of a perceived colour located in the centre. Since the main goal of this research is for image retrieval with sample pictures given in Figure 1, the induction field is merged with a background as explained in [5]. Hence, this paper constitutes two parts with the first one establishing a colour model that takes simultaneous contrast into account. Subsequently, this developed model is employed on retrieving a collection of wallpaper images, which forms the second part of the paper.

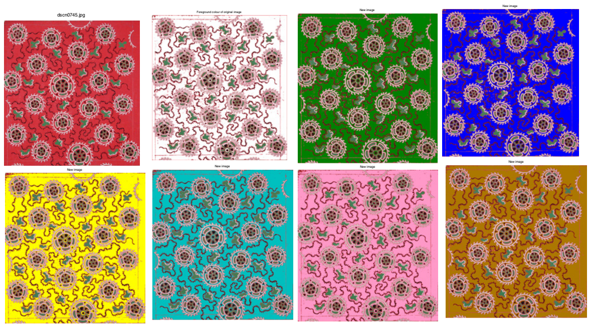

Figure 2. *The effect of simultaneous chromatic contrast by showing the same image with difference backgrounds. Top left, the original images whereas the rest with different coloured backgrounds.*

Experiments for Studying Chromatic Contrast

Psychophysical experiments are conducted on a 19" LCD monitor with illuminant calibrated to D65. Thirty test colours are selected to cover a wider range of colours and are plotted in a CIE chromaticity xy diagram as given in Figure 3, together with sixteen chromatic backgrounds including 3 grey backgrounds, which are chosen with varying luminance levels. Throughout all the experiments, the reference white, reference colourfulness and surrounding colours remain the same. The test field in the centre subtends a visual angle of 2^o at a viewing distance of ~60cm.

Ten subjects with a normal colour vision are selected to conduct the experiments using the approach of magnitude estimation as described in [6] to scale each colour in terms of lightness, colourfulness, and hue. To analyse these subjective data, arithmetic means for hue and lightness are applied as an averaged value between all the observers whereas geometric mean for colourfulness is employed as colourfulness is scaled using an open-end approach.

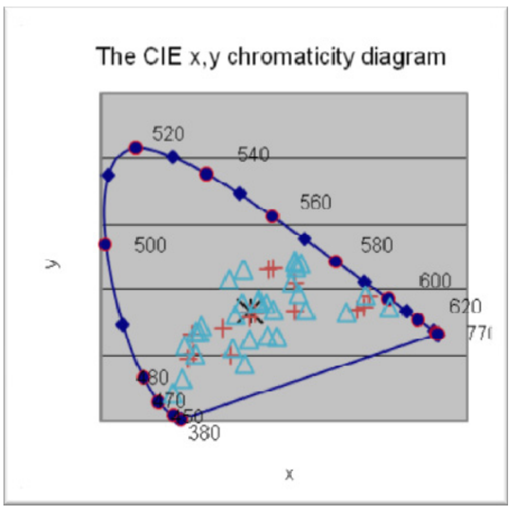

Figure 3. *Sixteen background colours presented on a CIE xy Chromaticity diagram ('+'). The '*' refers to reference white, whereas the colour nearest to the reference white is the grey background. The marks of non-filled-triangles represent 30 test colour samples used in the study.*

Extension of CIECAM02 to CIECAMcc Embedding Chromatic Contrast

Evaluation of the Monitor and Subjects' Data

Minolta Chroma Meter CS-100A has been employed to measure each colour in terms of CIE tri-stimulus values, i.e., x, y, Y and is in the position of observers' view. For each experiment, although the background is different from the other experiments, the reference white (RW) and reference colourfulness (RC) should remain the same though they may be influenced by the luminance level of a background. The averaged colour difference of those measurements in terms of CIELAB for reference white and reference colourfulness is 3 ΔE^*_{ab} units, which is similar to the literature, suggesting the monitor being in a stabled colour condition. On the other hand, to measure the agreement between two group values, the coefficient of variation (CV) is applied. On average, the CV values (in percentage %) are 17, 32, and 15 for the estimation of lightness, colourfulness, and hue respectively, which are considerably reasonable, especially for colourfulness where no scaling is involved in the calculation of CV values since geometric mean is applied. In particular, the estimation of lightness is in very good agreement with [4], suggesting subjects have already considered lightness as a monochromatic concept regardless of coloured backgrounds.

Effect on Lightness, Colourfulness and Hue

In general, the effects introduced by a chromatic background are different between 3-field and 2-field paradigms. In 2-field patterns, although darker background does make colours appear lighter, which is in consistent with the findings with the literature in [3, 4]. However, the amount of the shift in this study tends to be not significant when comparing with subjects' variations. In other words, the CV values range from 11 to 17 for the lightness shift whereas CV values ranging between 17 to 22 can be perceived within subjects. The reason could be due to the fact that, in a 2-field pattern, the reference white is with a test colour against the same background, which leads a coloured background contributes equally to lightness perception on both reference white and test colours.

Similar to reference white, the reference colourfulness is also displayed on the same background with a test colour. However, the estimation of colourfulness seems to be effected largely by the change of lightness level of a background, i.e., a darker background makes colours appearing more colourful, especially for red background (left column) where colours appear less colourful when the difference of luminance between two backgrounds decreases. Another interesting phenomenon is that a very colourful background out-shines those test colours, making them less colourful, even though the same reference colourfulness sample is applied to all the experiments. For hue estimations, Figure 4 shows the estimated hue data under coloured backgrounds plotted against those under a grey background where all the backgrounds are with similar luminance level at L*=50%. The diagram demonstrates the four opponent hues, i.e., Red (R) against Green (G) versus Yellow (Y) against Blue (B), which is also employed for subjects to estimate a hue during magnitude estimation experiments. The distance of a colour to the origin represents the amount of estimated colourfulness of the same sample. The small dots show the estimated hue values under a grey background where no hue shift is expected, whereas those big square dots are the responses that are estimated under coloured background.

Similar to simultaneous contrast in a 3-field pattern where there is an induction field, a colour shifts to the opponent hue of a background.

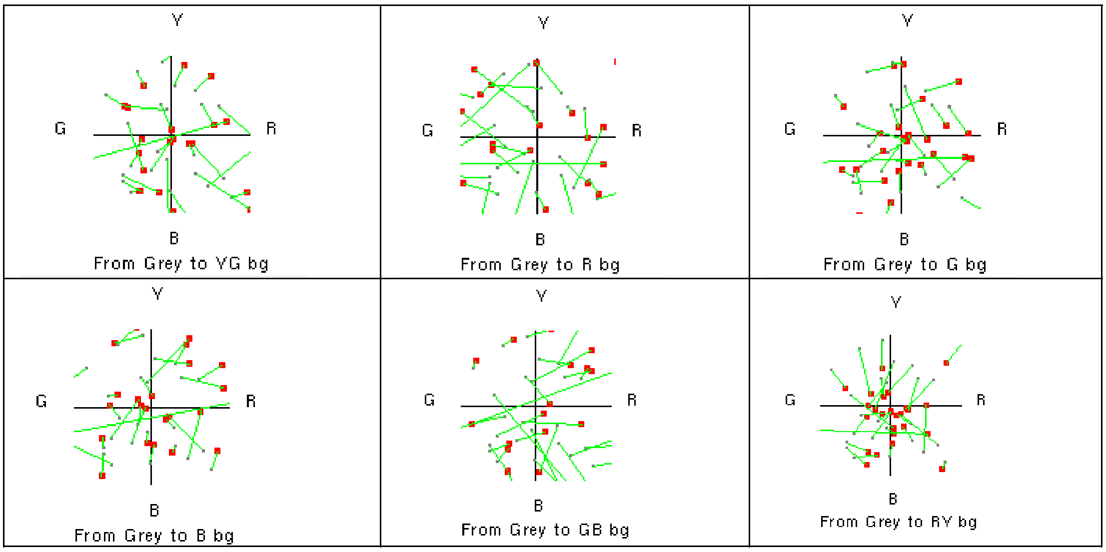

Figure 4*. Response diagram of a colour shift when viewed under different coloured backgrounds, where small and big dots joined by a line representing the response under grey background and coloured background respectively for the same test colour. The distance of each dot to the origin shows the estimated colourfulness for that colour sample.*

Evaluation of CIECAM02 <odels

CIECAM02 has been designed mainly for reflective (surface) colours under grey background. To apply this model to the data obtained under LCD monitors, the parameters of a surrounding is set as f=0.9, c=0.41, nc=0.8 as applied for transparency samples [3], which produces a good match results, where CV values maintain 21, 38, and 22 for lightness, colourfulness and hue respectively.

To predict simultaneous colour contrast, on the other hand, Hunt [7] has proposed a solution to modify the responses of ρ_w, γ_w, β_w for reference white by the inclusion of same responses for both induction field and background using Eq. (1) where subscription *p* and *b* indicating ρ, γ, β signals for induction and background respectively. This equation has been employed to modify CIECAM02 in [4] where 3-field paradigm is employed. The values of *p* depend on the size and shape of an induction field and should be between 0 and -1 for simultaneous contrast. However, in this work, the induction field and a background are merged into one, i.e., p=0, leading to 1 value for Eq.(2), which in turn producing the signals of $\rho_{w'}$, $\gamma_{w'}$, $\beta_{w'}$ being the same as ρ_w, γ_w, β_w, i.e., it is unlikely to predict colour contrast by the modification of reference white when an induction field is merged with background.

$$\rho_{w'} = \rho_w [(1-p)P_\rho + (1+p)/P_\rho]^{1/2} / [(1+p)P_\rho + (1-p)/P_\rho]^{1/2}$$
$$\beta_{w'} = \beta_w [(1-p)P_\beta + (1+p)/P_\beta]^{1/2} / [(1+p)P_\beta + (1-p)/P_\beta]^{1/2}$$
$$\gamma_{w'} = \gamma_w [(1-p)P_\gamma + (1+p)/P_\gamma]^{1/2} / [(1+p)P_\gamma + (1-p)/P_\gamma]^{1/2} \quad (1)$$

where

$$P_\rho = \rho_p/\rho_b; \quad P_\gamma = \gamma_p/\gamma_b; \quad P_\beta = \beta_p/\beta_b \quad (2)$$

To a certain extent, changing a background is analogous to changing to a different chromatic adaptation where a lighting source is switched from one to another [8]. It is therefore in a reasonable attempt to modify chromatic adaptation response in CIECAM02 for a test colour as given in Eq. (3), where $\lambda R_{wr}/Y_{wr}$ is added to CIECAM02 model when it comes to calculate colourfulness and hue (since lightness induces little change with the change of a background as described in Section 3.2), giving rise to the newly modified model as CIECAMcc. In Eq. (3), a background is considered as adopted white and reference white is applied to calculate R_{wr}/Y_{wr}. Figure 5 demonstrates three examples for predictions of colourfulness and hue for YG (cyan), Green and blue backgrounds respectively with L*=50 where λ=1. The top row shows the prediction by CIECAMcc (y) plotted against mean subjects' responses for colourfulness and hue whereas the bottom row gives the original predictions by CIECAM02, demonstrating CIECAMcc gives better match.

$$R_c = R\,[\,D\,(Y_w/R_w)\lambda(R_{wr}/Y_{wr}) + 1-D] \quad (3)$$

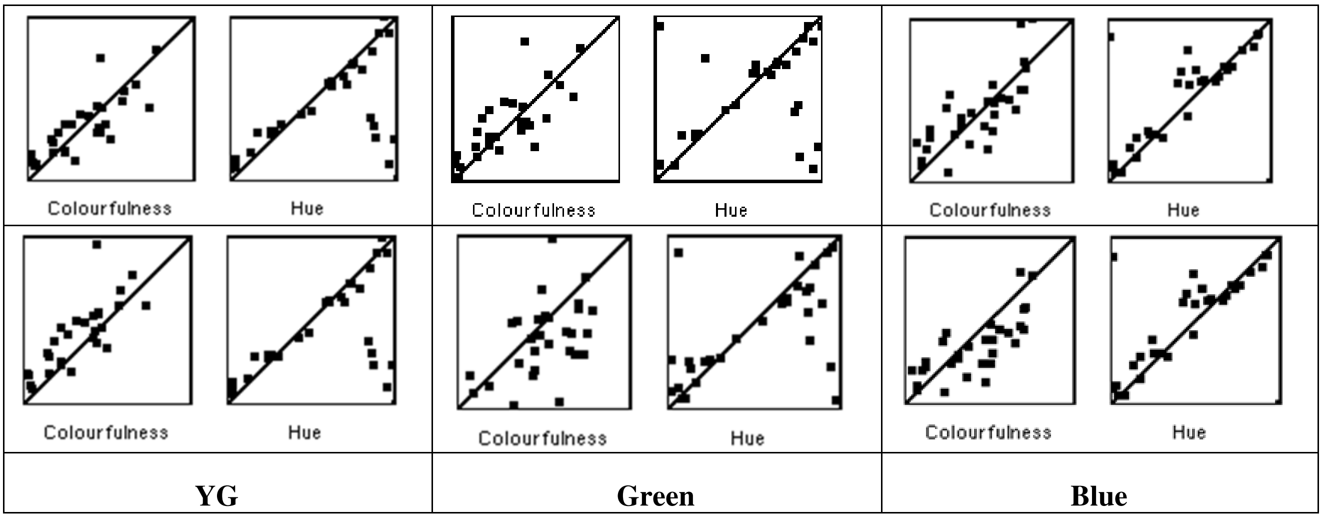

Figure 5. *Modified (top row) CIECAM02 (y) plotted against mean responses of colourfulness and hue for YG (left), Green (middle) and blue (right) backgrounds where L*=50. The bottom row shows the original predictions by CIECAM02.*

Image Retrieval with Entailed Chromatic Contrast Model CIECAMcc

Based on CIECAMcc that taking simultaneous contrast into account, image retrieval is carried out on a collection of 341 wallpaper pictures obtained from Museum of Domestic Design & Architecture (MoDA) at Middlesex University (www.moda.mdx.ac.uk). MoDA accommodates one of the world's most comprehensive collections of decorative arts for the home including a collection of wallpapers and textiles dating from the 1870s to the 1960s, as illustrated in Figure 1. Among around 40,000 designs, many of them have been digitised and indexed using keywords annotated by the curators at MoDA.

In addition to employing CIECAMcc, three other most commonly used colour spaces are also compared, which are CIECAM02, HSI, and RGB. HSI (*Hue, Saturation* and *Intensity*) [9] colour space becomes popular in the computer vision field due to its simplicity while incorporating human vision systems. It bases on human colour perception and gives better uniformity than a few CIE standard colour spaces (e.g, CIELab and CIELuv, which are also based on human perception). On the other hand, primary colours, Red, Green and Blue (RGB), are the three colours that are built-in in the computer hardware and software systems to generate colours by mixing the required amount of each of them. In this way, when an image is uploaded to a computer, the image is firstly represented using RGB space before converting into any other spaces. As such RGB space has widely been applied in computer vision research even though it is a device dependent space.

When CIECAMcc and CIECAM02 are applied, background colours are found out first using colour histogram map, by which a certain number of bins (e.g., 100) are allocated, whereby the bin number with the peak is assumed to be the colour of the background. For CIECAM02, only the intensity level of the background attributes to the subsequent calculations. With regard to chromatic contrast, for CIECAMcc, the chromatic adaption is calculated using Eq. (4) that is developed in the first part of this study. Whereas in CIECAM02, Eq. (5) remains to be employed.

$$R_c = (D\,(Y_b/R_b)\,\lambda\,(R_w/Y_w) + 1 - D)\,R;$$
$$G_c = (D\,(Y_b/G_b)\,\lambda\,(G_w/Y_w) + 1 - D)\,G; \qquad (4)$$
$$B_c = (D\,(Y_b/B_b)\,\lambda\,(B_w/Y_w) + 1 - D)\,B;$$

Where Y_b, R_b, G_b and B_b are the luminance, R, G, and B values for the background and Y_w, R_w, G_w and B_w are for the reference white, red, green, and blue receptors resplectly, and λ =1.0.

$$R_c = (Y_w\,(D/R_w) + 1 - D)\,R$$
$$G_c = (Y_w\,(D/G_w) + 1 - D)\,G; \qquad (5)$$
$$B_c = (Y_w\,(D/B_w) + 1 - D)\,B;$$

Distance Calculation

All images in the dataset are first converted into CIECAMcc, CIECAM02, and HSI from RGB colour space respectively. LCH (lightness, colourfuless and hue that are calculated from CIECAMcc and CIECAM02) and HSI colour spaces are then quantized into 300 bins (i.e., L or I =5 bins, C= 6 bins and H = 10 bins), RGB colour space are quantized into 216 bins (R=G=B=6 bins). Then colour histogram in four colour spaces are calculated respectively. In this way, colour noises or small amount of colours can be restricted into a limited extent. When a query is submitted, a distance function named histogram intersection is subsequently utilised to compare colour histograms between a query images *Q* and an image I from a database and formulated as Eq.(6).

$$D(Q, I) = \Sigma \min (Q, I) \qquad (6)$$

where *i* represents each bin in a histogram and I the image in a database and circulates to all the images one by one, i.e., 341 images. As a result, bigger value of *D* indicates more similar between images of query Q and *I*.

Results and Discussion

The retrieved results are illustrated in Figures 6 to 10 that display several query samples covering various coloured backgrounds. The top left in each figure is the query image, whereas the leftmost in the 2^{nd} row shows the background colour of the query image which is extracted by using histogram map. The remaining 5 columns in each figure illustrates the top 5 relevant images retrieved back from each of four approaches, which are CIECAMcc (row 1), CIECAM02 (row 2), HIS (row 3) and RGB (row 4) respectively. Since the retrieved results are very much subjective, it is quite unlikely to define a ground truth. For example, some users might like the combination of both colour and geometric patterns whereas the others might prefer semantics, such as with flowers or children. Therefore it is not in the intension for this paper to promote each method rather than to include more features. Apparently, each approach has its own pros and cons. It is the direction that this paper gives by taking into consideration of chromatic contrast that matters, especially for art images whereby certain period shows differentiated colour contrast , which is in the hope to lead more semantic retrieval in the future. From colour point of view, CIECAMcc gives retrieval results that with similar hues and at the same time with similar brightness and colourfulness contrasts between foreground and background. For example, Figure 6 presents that CIECAMcc depicts more similar brightness contrast to that in the query sample than the other three methods. Although r1-c3 (i.e., row 1 and colume 3), r2-c2, r3-c2, and r3-c3 are all composed of black and white with similar patterns, r2-c2 resembles more strikingly in terms of brightness contrast than the other three images when compared with the query. Likewise, similar trend can also been seen in the other figures. In terms of colourfulness, CIECAMcc also appears to match better as well with retrieved results more similar to the colourfulness of foreground patterns than that by the other three approaches. Figure 7 exemplifies the effect, e.g., rows 2 and 4 demonstrate less colourful foreground whilst row 3 shows more colourful than that in the query image, whereas row 1 agrees better with the query.

The most interesting phenomenon appears in Figure 10 where a query shows two shaded patterns. CIECAMcc is able to retrieve 3 out 5 patterns (i.e., r1-c2, r1-c2, and r1-c5) with duo contrasted patterns although it can not be simply explained away. On the other hand, CIECAM02 also retrieves back one such pattern as given in r2-c5.

Figure 6. Image retrieval results by four methods. Top row: query with its background colour; 1^{nd} column: CIECAMcc, 2^{rd} column: CIECAM02; 3^{th} column: HIS; 4^{th} column: RGB.

Figure 7. Image retrieval results by four methods. Top row: query with its background colour; 2nd row: CIECAMcc, 3rd row: CIECAM02; 4th row: HIS; 5th row: RGB.

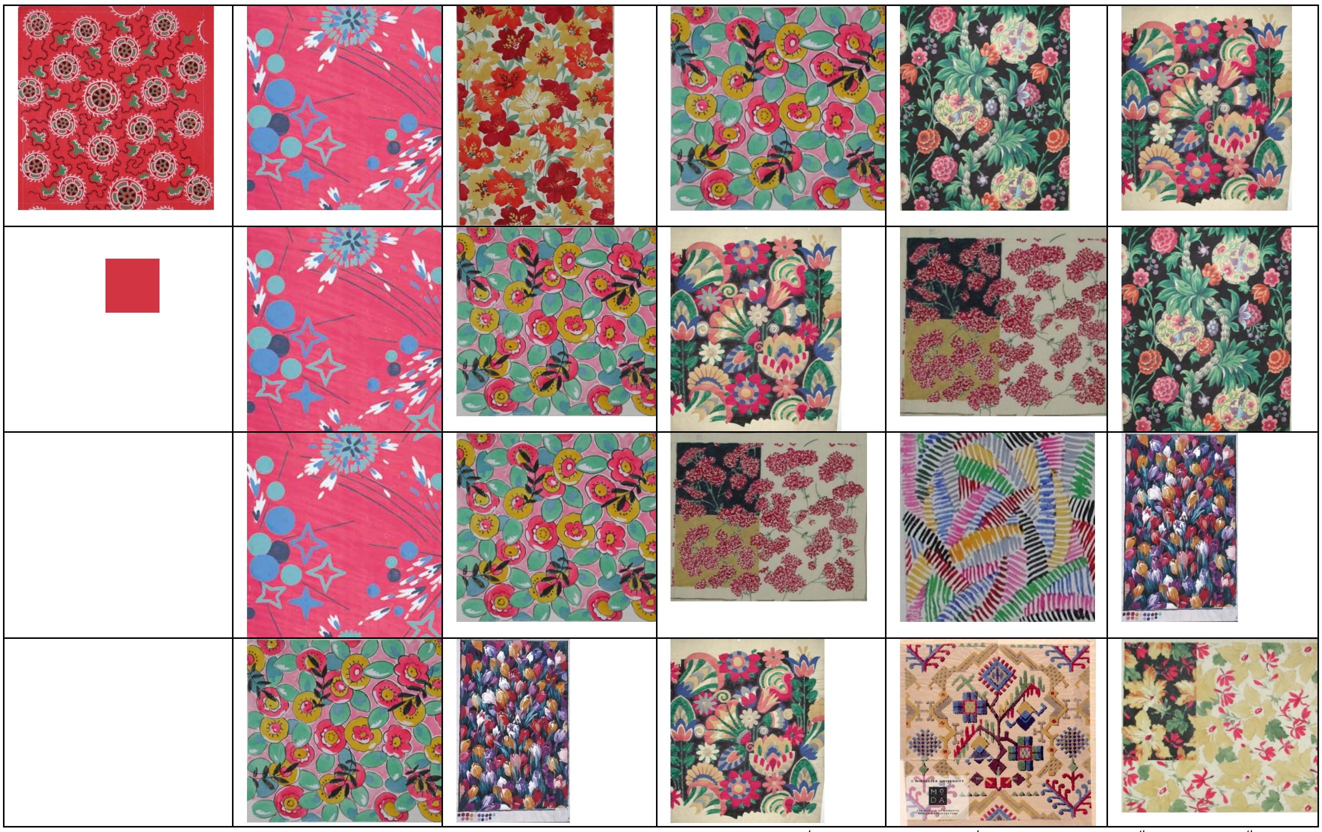

Figure 8. Image retrieval results by four methods. Top row: query with its background colour; 2nd row: CIECAMcc, 3rd row: CIECAM02; 4th row: HIS; 5th row: RGB.

Figure 9. Image retrieval results by four methods. Top row: query with its background colour; 2nd row: CIECAMcc, 3rd row: CIECAM02; 4th row: HIS; 5th row: RGB.

Figure 10. Image retrieval results by four methods. Top row: query with its background colour; 2nd row: CIECAMcc, 3rd row: CIECAM02; 4th row: HIS; 5th row: RGB.

Conclusion

The effect of colour contrast has been investigated in details in this study with the aim to develop a colour model for colour-based image retrieval. CIECAM02 has been evaluated to predict the effect and has shown potentials in doing so. Further investigation is worth continuing to further the modification and evaluation.

It is very knowledgeable that colour-based retrieval can vary widely between users depending on what content users are interested in. While global colour is one of the most popular components that many users are focusing on, perceived hue changes with the change of its chromatic background. This study extends the current colour appearance model, CIECAM02 into CIECAMcc by taking into account of chromatic contrast. The subsequent application of CIECAMcc on image retrieval on a collection of over 340 wallpaper images has shown that CIECAMcc retrieves back more similar images in terms of both brightness and colourfulness contrast between foreground and background patterns than the other three commonly applied colour spaces, i.e., CIECAM02, HSI, and RGB. More interestingly, CIECAMcc can also retrieval double patterned images to match that in a query, though it is kind of unaccounted for at the moment due to the limited number of images studied in the research, which will be further investigated in the future. Future work also includes semantic based retrieval incorporating image descriptions scripted by curators.

With regard to Eq. (4), in-depth investigation and evaluation are in need to study the constant factor value of λ that is currently set to 1.

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Author Biography

Dr. Xiaohong W. Gao is a Reader in Computer Vision and Imaging Sciences at Middlesex University, UK, and has wider experience on colour sciences. Her PhD work on Modelling of Colour Appearance has led the standardization of colour appear model, CIECAMs97 and later CIECAM02.

Dr. Yu Qian is a researcher fellow in Middlesex University. Her PhD research worked on image retrieval of wallpaper images.

Mr. Yuanlei Wang has obtained his MSc degree by research at Middlesex University, UK in 2011. His master work was concerned with colour contrast.

Prof. Anthony White is a Professor of Software Engineering. His research ranges from software management to imaging sciences.