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On the Transfer of Painting Style to Photographic Images through Attention to Colour Contrast

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***Abstract*—This paper proposes a way to transfer the visual style of a painting as characterised by colour contrast to a photographic image by manipulating the visual attributes in terms of hue, saturation and lightness. We first extract the visual characteristics in hue, saturation and lightness from a painting. Then, these characteristics are transferred to a photographic image by histogram matching in saturation and lightness and dominant hue spread and relative position mapping along the RYB colour wheel. We evaluated the proposed transfer method on a number of paintings and photographs. The results are encouraging.**

***Keywords*-style transfer; colour contrast; RYB colour space; painting style;**

I. Introduction

In the visual arts, style refers to the aspects of the visual appearance of a work of art. These may involve such things as the content, paint thickness, choice of medium, size of canvas and brushstrokes. One thing informing these aspects is that they have been deliberately arranged according to formal, cultural and personal preferences that even the painter finds difficult to clearly identify and which present a real problem to subject to precise analysis.

In this paper, we are concerned about the chromatic and achromatic aspects of a painting. Their organisation is particular to each artist, with work by that artist showing consistency in its relative contrast values. For an artist the contrast values of a painting constitute its most significant stylistic component. Contrast can itself be further broken down into its chromatic aspects: hue and saturation and its achromatic aspect: lightness. The paper discusses how to transfer such key aspects of a paintings style to a photographic image.

At present, various image processing methods and tools have been proposed to change the look and feel of images. Colour transfer shifts the colour of the image to match the colours of the reference image [1] [2] [3] [4] [5]. These methods only consider the absolute colour values of the source image but not their relative distribution character and relative relationships. Colour harmonisation [6] [7] attempts to enhance the harmony among the colours of a given photograph based on the harmonic rules of hue, saturation and lightness. Colour harmonisation is one operation on colour contrast; however the contrast is based on external harmonic rules. Contrast enhancement [8] [9] [10] seeks to improve the image quality and enhances the visibility. However, it only considers the lightness and saturation channels. The study of the application of brush stroke styles is a major feature of non-photorealistic rendering [11] [12] but this is essentially a mimicry of painting's style, not a learning of the rules that inform it. In contrast to these researches, our work identifies the style of the painting based on the colour contrast through analysis of hue, saturation and lightness distribution and passes the salient attributes of the style of a painting to the photographs. We map the hue of a painting to a RYB (Itten) colour wheel to analyse its colour style as understood in the artists terms. The conversion from RYB to RGB is based on the work of Gosset and Chen [13] with our extension for RGB to RYB mapping. Then dominant hues are extracted in an RYB colour wheel to generalise the global hue contrast. The saturation and lightness distributions are analysed in HSV colour space. Finally the measured hue, saturation and lightness attributes of the painting are transferred to a photographic image through our proposed mapping algorithm. We used the paintings of Vincent Van Gogh (Dutch 1853-1890) and Sir Lawrence Alma-Tadema (English 1836-1912) in our experiments to evaluate our proposal in this paper.

II. Colour Contrast and Colour Space

The style of painting in this paper is considered as an organized arrangement of hue, saturation and lightness which is driven by colour contrast.

A. Colour Schemes and Contrast

A colour scheme can be a preferential combination of colours on a colour wheel. It orders the relationship between

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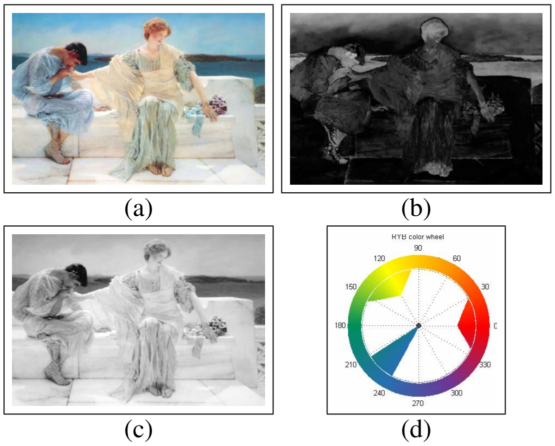


Figure 1. (a) Lawrence Alma-Tadema (Dutch 1836-1912), "Ask Me No More", 1906. (b) Saturation map (c) Lightness map. (d) Visualization of dominant colours in RYB colour wheel.

dominant colours of a scene based on the contrast within their hue, saturation and lightness values. Johannes Itten identified seven contrasts of colour: hue, light and dark, cool and warm, complementary, simultaneous contrast (i.e. area), saturation, and proportion contrast [14].

Monochromatic colour schemes consist of harmonies built around one single colour, drawing heavily on the light-dark contrast principle. Analogous colour schemes use adjacent colours on the colour wheel with one colour being dominant. Complementary colour schemes describe a more energetic feel by using colours that lie opposite to each other on the Ittens RYB colour wheel, which expresses the complementary contrast. A complementary pairing is also an expression of warm/cool contrast. Additionally, Split-analogous colour schemes, Split-complementary colour schemes and Triadic colour schemes shows the contrast of three dominant hues.

Every painting is a complex expression of these contrast-driven colour schemes which are difficult to measure quantitatively. In [15], the top 10 colours are sampled from Hollywood cinema productions to analyse their colour schemes in films. Even in the research of painting retrieval using artistry concepts [16] [17] [18], measured colours were mapped to semantic art-related concepts and its scheme/contrast was expressed using linguistic representations.

B. Painter's Colour Space

The Lightness and Saturation have absolute values which are easy to obtain and map. Fig. 1(b) and (c) are the saturation and lightness maps of the image in Fig. 1(a). From the map, we can see clearly which regions have high saturation or lightness and which regions have low saturation or lightness. However, hue values present themselves only as relative positions within a colour wheel (as shown in Fig. 1(d)) and as such are difficult to quantativly schematise.

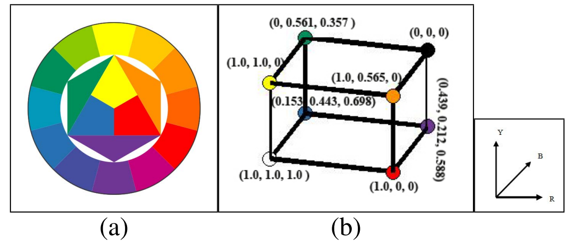


Figure 2. (a) Itten's colour wheel (b) RYB interpolation cube

A painter uses a colour wheel rooted in the perceptive opposites of red/green, yellow/purple and blue/orange [14]. Any two of the RYB primaries can be selectively mixed to produce the orange, green and purple secondary colours. A painter would mix one colour with a small amount of its complementary colour to decrease its intensity (i.e. decreasing saturation). Such a mixing would also darken it as would the addition of a black. To lighten a colour the artist might add white. The colours of an RGB wheel present a different array of opposites that have less perceptual contrast.

III. Proposed Style Transfer Method

The proposed method for style transfer involves the extraction of the hue, saturation and lightness contrast characteristics of a painting and a photograph followed by the mapping of these attributes from the photograph to those from the painting. The hue was measured in RYB colour wheel and dominant hues were extracted to constitute the colour scheme which is driven by colour contrast. The global saturation and lightness contrast is reflected by the saturation and lightness histogram distributions which were measured in HSV space.

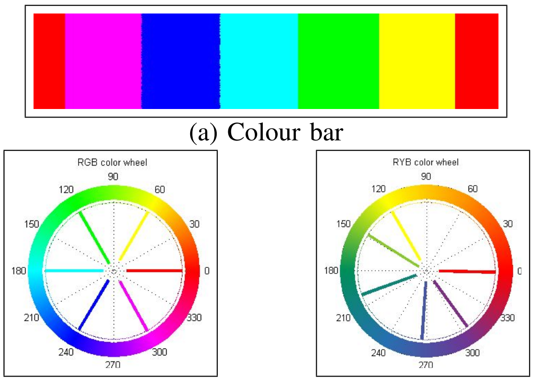
A. Hue Mapping

1) RGB to RYB Conversion: RYB, being a painters subjective colour space, is subject to no standard mathematical conversion to and from RGB colour space. However, Gosset and Chen have proposed a reasonable approximation of the conversion from RYB to RGB using tri-linear interpolation [13]. In order to be coherent with Itten's colour wheel shown in Fig. 2(a), we corrected the values of the eight corner colours of the cube (in Fig. 2(b)). Based on the conversion model using linear interpolation, we obtained the RYB colour wheel (see Fig. 3). The obtained RYB colour wheel is clearly coincident with Itten's colour wheel in Fig. 2(a).

To process an RGB digital image in RYB colour, it needs to be converted from RGB space to RYB. The conversion from RGB to RYB was achieved using Newton's Method [19] based on the conversion model from RYB to RGB. The conversion from RGB space to RYB is an out of range mapping. We moved the colours that are out of range to the nearest colours in an RYB wheel. For

(a) (b)

Figure 3. Continuous RYB colour wheel (left) and 12-hue colour wheel (right). The values are coincident with Itten's 12 hue colour circle.



(a) Colour bar

(b) Hue map in RGB space (c) Hue map in RYB space

Figure 4. Conversion of the six pure colours in RGB to RYB space.

example, pure blue in RGB is (0, 0, 1.0). When converted to RYB, it is (-0.47, -1.70, 1.04). The normalisation process begins by subtracting the smallest value and hence we have $v_1 = (-0.47, -1.70, 1.04) - (-1.70, -1.70, -1.70) = (1.23, 0, 2.74)$. If the largest value of v_1 is bigger than 1.0, then v_2=v_1/max(v_1)=$(0.44, 0, 1.00)$. As the normalisation was linear, so the hue value remained unaffected.

Fig. 4 illustrates the conversion using one fully saturated colour bar in RGB space. The mapped hue shows that the relative position of colours in RYB is slightly different from that in RGB. Pure green in RGB is biased towards yellow in RYB, and pure blue in RGB is biased towards purple. Generally, the hue map is coherent with perception.

The RYB cube model is similar to the RGB cube model, so we adopted the function of the conversion from RGB to HSI to calculate the hue in RYB.

$$\theta^\circ = cos^{-1}\left\{\frac{0.5[(R-Y)+(R-B)]}{[(R-Y)^2+(R-B)(Y-B)]^{0}.5}\right\} \quad (1)$$

$$H = \begin{cases} \theta^\circ & if B \leq Y \\ 360^\circ - \theta^\circ & if B > Y \end{cases} \quad (2)$$

2) Dominant Hue Extraction: The complementary contrast, warm and cool contrast, and hue contrast all can be expressed by the relative position of dominant hues in the form of colour schemes within the colour wheel. In our work we didn't consider the simultaneous and proportional contrasts which depend more on the content of the image. A painting is combinations of many kinds of contrast. Complementary contrast and warm and cool contrast are linear combinations of two factor level means. For normal hue contrast, three dominant hues are sufficient to express most of the relationship in the colour wheel. So three dominant hues were extracted in the measure of global hue contrast in RYB colour wheel, and the three dominant hues constituted the colour scheme used in the painting.

In the dark areas of a painting the colour is difficult to see, as is the colour in very light areas. In black and white areas there is evidently no colour, likewise in grey areas. The saturation value of the painting accounted for all these 'colour ignore' exceptions. For this reason, pixels with saturation less than a threshold rate (e.g. 10%) of the maximum saturation of the painting were ignored in the dominant hue extraction of paintings. However, this step is not necessary in the dominant hue extraction of photographs.

There is a lot of variation of value within one area of a painting caused by such things as differences in canvas absorbance, canvas primer, colour brush technique and colour layering. However, in a photograph it is visually merged as one perceived colour. In order to keep the consistence of region in dominant hue clustering, we first smoothed the painting using a mean-shift based smoothing algorithm [20]. Then k-means clustering with $k = 3$ was used to cluster the pixel values from the smoothed image in RYB. The clustering texture of each pixel was defined as $(H, S = 1)$ in a polar coordinate space (H, S). Then it was converted to the Cartesian coordinates (x, y) for clustering.

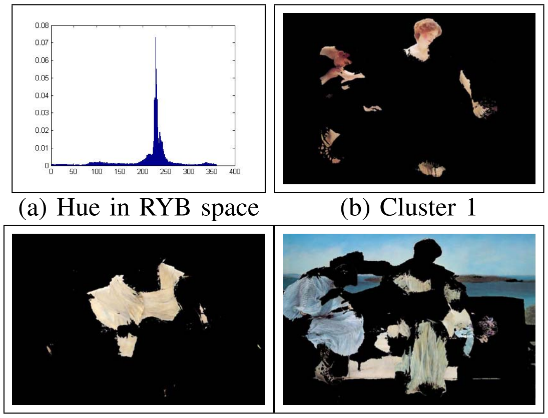
One problem in the clustering is when the image contains only complementary contrast with two colours. One cluster of the partitioned three clusters may have extremely few pixels. In this case this cluster was merged to the nearest cluster. The cluster centre is the mean of the hues in the cluster and it was used to represent the dominant hue. The hue extraction result of the painting in Fig. 1 is shown in Fig. 5.

After k-means clustering, the size of a cluster, $s(i)$, $i = 1, 2, 3$, is given by the number of pixels in the cluster i. A weight, $w(i)$, is assigned to each cluster i,

$$w(i) = \frac{s(i)}{max(s)}, i = 1, 2, 3 \quad (3)$$

where $s = \{s(i)\}$.

To show the relative size of each cluster in the RYB wheel, we defined a sector covering the range of hue spanned by the cluster. The radius (distance from the circumference) of the sector was determined by the weight of cluster calculated from (3). Then a nonlinear transform of the weight was performed to visualise a small cluster in the RYB colour



(a) Hue in RYB space (b) Cluster 1

(c) Cluster 2 (d) Cluster 3

Figure 5. Dominant hue extraction of the painting in Fig. 1(a).

wheel:

$$w(i) = \begin{cases} \sqrt{0.5} \times \sqrt{w(i)} & w(i) \leq 0.5 \\ w(i) & otherwise \end{cases} \quad (4)$$

The nonlinear transform amplified the weight less than 0.5. The arc of the sector shows the range of hue, i.e., the spread of hue, of each cluster. The visualisation of the dominant hue distribution in Fig. 5 is shown in Fig. 1(d). This is the characterisation of the colour scheme used in the painting.

3) Dominant Hue Alignment and Mapping : A photograph is a captured thing that is not subject to the same considered arrangement of hue that a painter gives to a painting. After extracting the dominant hues and finding the hue spread width and the mean value for each dominant hue region in the photographic image, they were compared to those extracted from the painting. The pairing of dominant hues between the painting and photograph was based on their relative position in the colour wheel after alignment.

The basic principle of the alignment is to minimise the total rotation angle of all the dominant hues in the colour wheel. m_{r1}, m_{r2}, m_{r3} denote the mean positions of dominant hues of reference painting. And m_{s1}, m_{s2}, m_{s3} denote the mean positions of dominant hues of the source photograph. The optimisation alignment rotated one of the dominant hues of the reference painting $m_{rp}(p = 1/2/3)$ to the position (mean value) of one dominant hue of the photograph $m_{sq}(q = 1/2/3)$ to minimise the total sum of rotation angles, i.e.,

$$arg \min_{\alpha,p,q} \sum_{M_{ij}} \alpha_{M_{ij}}, i, j = 1, 2, 3 \quad (5)$$

M_{ij} is the matched pair of the ith hue of the reference with the jth hue of the source which have the nearest distance after the dominant hues of the reference rotate a angle α. $\alpha_{M_{ij}}$ is the rotation angle of matched pair M_{ij} , which is $\alpha_{M_{ij}} = (m_{ri} + \alpha - m_{sj}) \mod 360$.

The hue distribution of each dominant hue of the source was scaled by the hue spread of the corresponding dominant hue in the reference painting and rotated to the mean position of the aligned corresponding dominant hue. The mapping function is

$$H(i) = \left\{ [sH(i) - smean] \times \frac{wdr}{wds} + rmean + \alpha \right\} \quad (6)$$

where $sH(i)$ is the ith dominant hue distribution of the source image with mean value $smean$. $rmean$ is the mean value of the aligned corresponding dominant hue of the reference. wdr and wds are the spread widths of the reference dominant hue and source dominant hue, respectively. The final mapped hue value will be $H(i) \mod 360$.

When there were 2 clusters in the reference and 3 clusters in the source, two source dominant hues were paired with the same dominant hue of the reference. In this case, the two source dominant hues were rotated to the coverage range of the paired reference dominant hue, instead of rotating to the mean value.

B. Saturation and Lightness Mapping

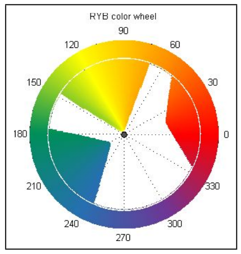
The histogram distributions of lightness and saturation reflected the global saturation and lightness contrast of the images. So the overall saturation and lightness distribution was extracted. The image was converted from RGB to HSV space and the histograms in S and V were used to represent the overall distribution of saturation and lightness respectively. Histogram matching technique was used to map the saturation and lightness values in the photographic image to those from a painting. By doing so, the distributions of saturation and lightness was closer to those of the painting. This accomplishes the transfer of saturation and lightness attributes of the style.

IV. Experiments and Discussion

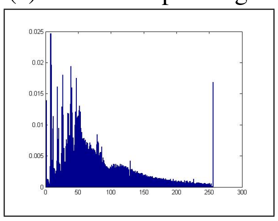
Paintings from two well-known artists were used as reference in our experiment to test the proposed algorithm. The saturation and lightness distributions of these paintings was extracted in HSV colour space and the dominant hues were extracted in the RYB colour space. For a given photographic image, similar attributes were computed. Histogram matching was performed on the lightness and saturation attributes first. Then the hue mapping was performed using the method in section III.A.3 on the saturation and lightness modified image.

Fig. 6-9 show four paintings (reference painting 1-4) and their hue, saturation and lightness distributions. The first two paintings in Fig. 6 and 7 are by Sir Lawrence Alma-Tadema (English 1836-1912), one of the most renowned painters of the late nineteenth-century. In them, we see large regions of low saturation and high lightness, where there is no perceptually presented hue. In the centre regions, there is a broad hue spread. For reference painting 1, it is from red,

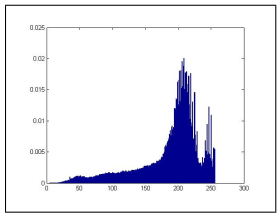
(a) Reference painting 1



(b) Hue distribution



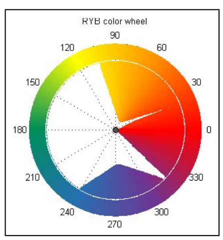
(c) Saturation distribution



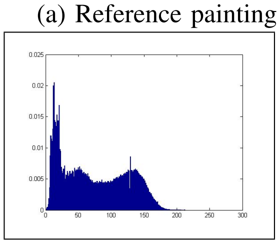
(d) Lightness distribution

Figure 6. Reference painting 1: Sir Lawrence Alma-Tadema (1836-1912). "A Coign of Vantage", 1895. Big lightness contrast with a big high lightness region, high saturation contrast with a large low saturation region. The colour scheme is red-green complementary with a broad orange to green spread.

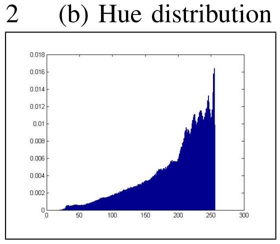
(a) Reference painting 2



(b) Hue distribution



(c) Saturation distribution



(d) Lightness distribution

Figure 7. Reference painting 2: Sir Lawrence Alma-Tadema (1836-1912), "The Finding of Moses", 1904.

yellow to green. For reference painting 2, it is from blue-purple, red to orange. The two paintings have high saturation contrast and high lightness contrast among the clothes and skin. The consistent saturation and lightness style is clearly discernible within the relative histogram distributions of these paintings shown in Fig. 6 and 7(c)(d).

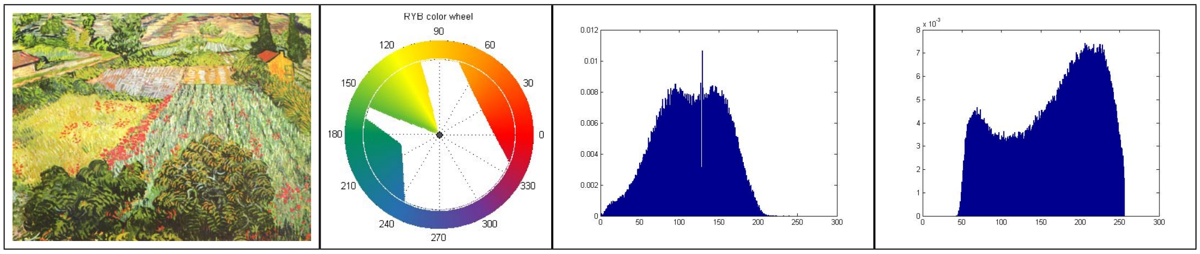
The last two paintings in Fig. 8 and 9 are from Vincent Van Gogh (Dutch, 1853-1890), whose paintings had a far-reaching influence on 20th century art for their saturated colours and emotional impact. Vivid red, yellow and green can be clearly seen in the painting "The Poppy Field" (Fig. 8), and vivid blue and yellow in the painting "Starry Night Over the Rhone" (Fig. 9). Compared with the first two paintings, the saturation and lightness distribution is even and therefore of low contrast.

The experiment shown in Fig. 10 used the reference painting 1 in Fig. 6 and painting 3 in Fig. 8. The two reference paintings have similar colour scheme with different spread width and different relative position of dominant hues, and different saturation/lightness contrast distributions. Comparing the results in Fig. 10(b) with (c), and Fig. 10(e) with (f), which are from the same source photograph using different references, we can see the obvious difference in the colour appearance. The saturation and lightness distributions before and after style transfer of the source image 1 in Fig. 10 are compared with the distribution of the reference, as shown in Fig. 12(a)-(d). It can be seen that the saturation and lightness distributions of the style-transferred images are similar to the corresponding reference paintings, even the hue mapping in RYB space has some influence on the saturation and lightness distributions. In order to show the influence of hue mapping, the lightness and saturation matching results before hue mapping of the source photograph 1 using reference 1 and 3 are illustrated in Fig. 12(e)(f). Comparing with the results after hue mapping in Fig. 10(b)(c), the colour difference can be clearly seen in the green grass in Fig. 10(b) and in the sky in Fig. 10(c). However, the adjusted colour is not unnatural for having only a small rotation to the neighbouring colour to adjust the global contrast. However, when hue mapping was performed in the hue wheel from RGB space, the results are strange as the hue arrangement in RGB is less perception coherent (see the results in Fig. 12(g)(h)).

The experiment in Fig. 11 used the reference painting 2 in Fig. 7 and painting 4 in Fig. 9. The two reference paintings have distinct differences in hue distribution, painting 2 has a wide spread of hue from purple, red, orange, yellow. In contrast, painting 4 has a narrow blue and yellow-green. From the result in Fig. 11(b), we can see that the resultant image using reference 1 has a wide colour spread around the dominant colour, through orange, yellow, green and blue. In appearance, the result from reference 4 "Starry Night Over the Rhone" has a narrow colour spread, green and blue (Fig. 11(c)).

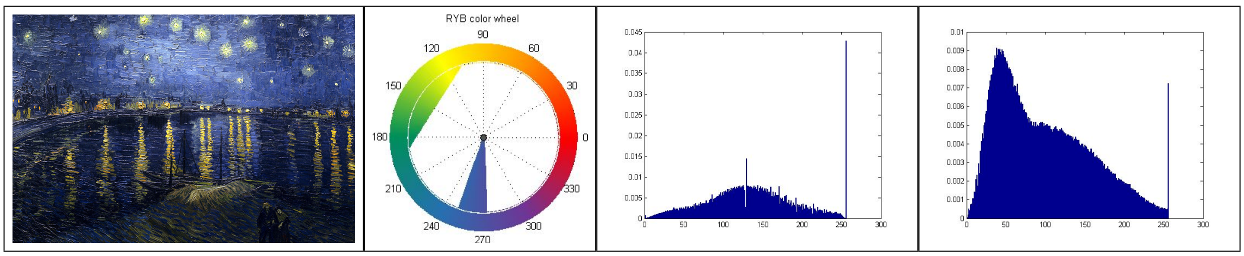
The experiment results confirm the difference between our proposed research with existing research, e.g. harmonisation and recolor. The operation of hue mapping in our research is similar with harmonisation, however it is based on example instead of template, and the hue is measured in artist colour space to express the colour contrast as perceived and practiced by an artist. Compared with results derived from a simple recolor, our results do not transfer the colours of the reference painting to the source photograph. They match the global contrast, which expresses the relative position distribution in the wheel, as opposed to its absolute value.

However, the proposed algorithm has some limitations.



(a) Reference painting 3 (b) Hue distribution (c) Saturation distribution (d) Lightness distribution

Figure 8. Reference painting 3, Vincent Van Gogh (1853-1890), "The Poppy Field" 1888. Small lightness/saturation contrast with an even lightness/saturation distribution. The colour scheme is similar with reference painting 1 in Fig. 6, but has different spread widths and relative positions of dominant hues.



(a) Reference painting 4 (b) Hue distribution (c) Saturation distribution (d) Lightness distribution

Figure 9. Reference painting 4, Vincent Van Gogh (1853 - 1890), "Starry Night Over the Rhone", 1888.

First, there is not a uniform colour space to express the hue, saturation and lightness values by which an artist operates. We maped the hues in RYB space and the saturation and lightness in HSV space converted from RGB. The three attributes are handled separately. In some cases, it produced artefacts in the results. In the future we will consider a hue depended lightness and saturation mapping in a uniform artist colour space. Second, the paper can only transfer the global style of the painting through attention of the global contrast without the consideration of the content. In the next research, local contrast will be considered as a factor in the style of painting.

V. Conclusion

The paper presents a method of transferring the style of a painting to a photographic image. The style of a painting is considered to consist of the contrast in three aspects, namely the hue, saturation, and lightness. The transfer of saturation and lightness attributes is by histogram matching technique using the histograms obtained from the HSV space converted from RGB. The last step of the transfer is hue mapping. We studied the painters RYB colour wheel and extended the bilateral conversion between RGB and RYB. The dominant hues are extracted from discernable hues using k-means clustering to constitute the colour schemes driven by colour contrast. Dominant hue pairing is determined by optimisation alignment and the hue spread width defines the scaling of hue range. Experiments on a number of photographic images with paintings from two well-known artists demonstrate the feasibility and performance of our proposed style transfer method. Currently our work considers painting style as being defined as the global contrast of the three attributes hue, saturation and lightness. Our current results are encouraging and future work will further develop upon what we have achieved and will also explore other constituent aspects of a painter's style.

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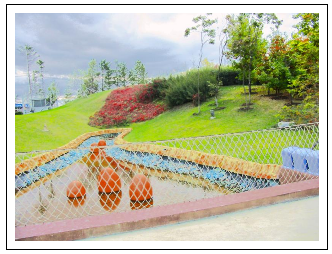
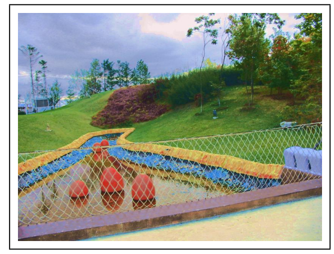
(a) Source photograph 1



(b) Result of source 1-reference 1



(c) Result of source 1- reference 3

(d) Source photograph 2

(e) Result of source 2-reference 1

(f) Result of source 2- reference 3

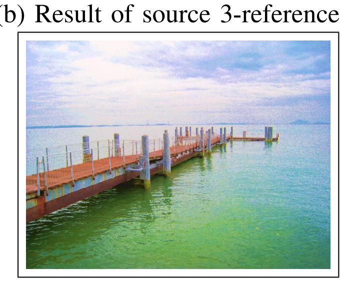
Figure 10. Painting style transfer results of two reference paintings which have distinct difference of saturation and lightness contrast (Reference 1 is painting1 "A Coign of Vantage", 1895 in Fig. 6, reference 3 is painting 3 "The Poppy Field" 1888 in Fig. 8). The top row is the style transferred result on photograph 1. The second row is the style transferred result on photograph 2.

(a) Source photograph 3

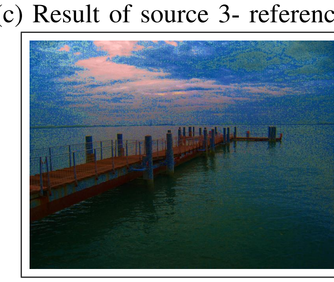
(b) Result of source 3-reference 2

(c) Result of source 3- reference 4

(d) Source photograph 4



(e) Result of source 4-reference 2



(f) Result of source 4- reference 4

Figure 11. Results of style transfer. Reference 2 is painting 2"The Finding of Moses", 1904 in Fig. 7. Reference 4 is painting 4 "Starry Night Over the Rhone", 1888, in Fig. 9. The two paintings have distinct difference on colour spread. The top row is the style transferred result on photograph 3. The second row is the style transferred result on photograph 4.

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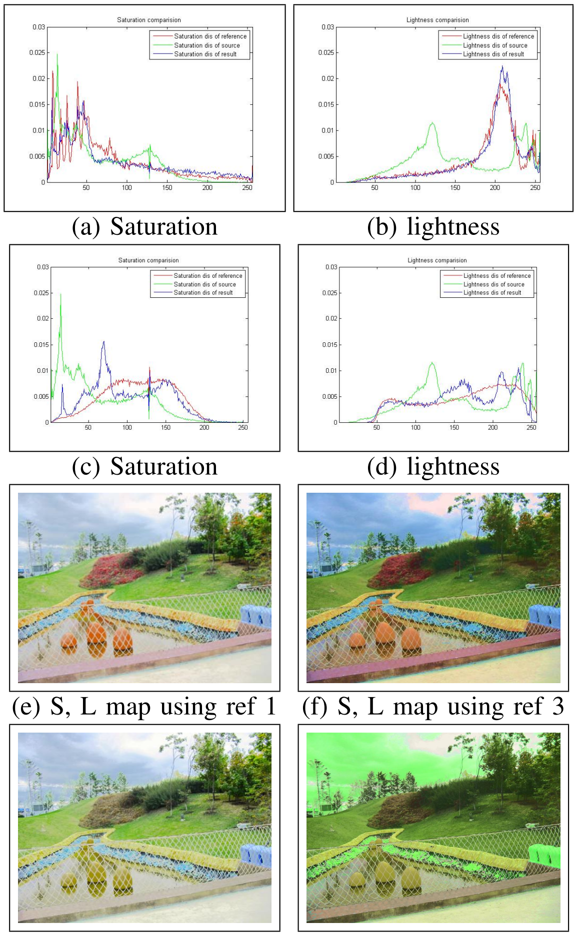

(a) Saturation (b) lightness

(c) Saturation (d) lightness

(e) S, L map using ref 1 (f) S, L map using ref 3

(g) H map using ref 1 (h) H map using ref 3

Figure 12. (a)-(d) are the comparisons of saturation and lightness distributions before and after style transfer of source photograph 1 using reference paintings 1 and 3. The top row is using reference1, the second row is using reference 3. The third row is saturation and lightness mapping results of source photograph 1. The bottom row shows the hue mapping results in RGB space of source photograph 1 using reference paintings 1 and 3.

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