Enhanced Image-Colour-Transfer

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An Enhanced Implementation of the Colour Transfer Method Proposed by E Reinhard et al.

This document is applicable to L*a*b processing. For L$\alpha\beta$ processing see separate document.

The Reinhard Colour Transfer Method

Reinhard et al [Ref 1] presented a method for matching the colour distribution of a target image to that of a source image by use of a linear transform in the lαβ perceptual colour space so as to match the mean values and standard deviations of the target image to those of the source image along each of the colour space axes. By resetting the parameters of the target image to match those of the source image, the colour information in the target image is modified to better resemble that of the source image.

The processing steps are as follows.

1. Convert the both the source and target images from RGB colour space to lαβ colour space
2. Compute the mean and standard deviation of each of the three l, α and β components for both images.
3. Standardise the three components of the target image by subtracting the respective mean values and dividing by the respective standard deviation values.
4. Reformulate new target values by applying the respective source standard deviations as scaling factors to the standardised components and adding in the source mean values.
5. Convert the resultant from lαβ colour space to obtain the output image in RGB colour space.

The third and fourth steps can be represented as follows.

$z_c = (x_c - \hat{\mu}_{tc})/\hat{\sigma}_{tc}$ $\quad X_c = z_c * \hat{\sigma}_{sc} + \hat{\mu}_{sc}$ for outputs $X_l,\ X_\alpha,\ X_\beta$, and inputs $x_l,\ x_\alpha,\ x_\beta$.

Effectively here, the x_l, x_α, and x_β values are reworked for every pixel in the target image so that collectively their mean values and their standard deviations are reset to match the values observed in the colour source.

Processing is performed in the lαβ colour space because the three components in this space have been observed to show low inter-dependency for certain classes of natural imagery and it can be more acceptable to process components independently in this colour space.

The Enhanced Colour Transfer Method

The basis of the enhanced colour transfer method is as follows.

Let s_1 and s_2 be two independent (zero correlation) variables with mean values equal to zero and standard deviations equal to one. It possible to construct variables a_1 and a_2 with mean values equal to zero and standard deviations equal to one but with mutual cross correlation 'R' by means of the following operations.

$$a_1 = \sqrt{\frac{1+R}{2}} \times s_1 + \sqrt{\frac{1-R}{2}} \times s_2 \quad \text{and} \quad a_2 = \sqrt{\frac{1+R}{2}} \times s_1 - \sqrt{\frac{1-R}{2}} \times s_2$$

Conversely, the inverse relations can be applied to derive independent variables s1 and s2 from correlated variables a1 and a2.

$$s_1 = \frac{a_1+a_2}{\sqrt{0.5\times(1+R)}} \quad \text{and} \quad s_2 = \frac{a_1-a_2}{\sqrt{0.5\times(1-R)}}$$

The enhanced colour transform method incorporates additional steps compared to the original method by which the correlation between the colour components 'α' and 'β' is modified so that it corresponds to the value observed in the colour source image rather than that in the target image.

This can be achieved by inserting additional steps into the previously described method as follows.

3.0 Standardise the three components of the target image by subtracting the respective mean values and dividing by the respective standard deviation values.
   3.1 Cross-multiply the corresponding values of the 'α' and 'β' components and hence determine the average cross product value for both the target and source images.
   3.2 Denote the two average cross products as the correlation values R_t and R_s respectively.
   3.3 Using the value R_t, which represents the correlation between the 'α' and 'β' channels in the target image, form new independent variables from the values z_α and z_β.
   3.4 Using the value R_s, which represents the correlation between the 'α' and 'β' channels in the sample image, form new standardised variables z'_α and z'_β with correlation value R_s.

4.0 Reformulate new target values by applying the respective source standard deviations as scaling factors to the (modified) standardised components and adding in the source mean values.

The new intermediate steps can be represented as follows.

The correlation values are computed as follows.

$$\hat{R}_t = \frac{1}{n}\sum Z_{t\alpha}(i) * Z_{t\beta}(i) \quad \text{and} \quad \hat{R}_s = \frac{1}{m}\sum Z_{s\alpha}(i) * Z_{s\beta}(i)$$

The standardised colour components are modified as follows.

$$s_\alpha = \frac{z_{t\alpha}+z_{t\beta}}{\sqrt{0.5\times(1+\hat{R}_t)}} \quad \text{and} \quad s_\beta = \frac{z_{t\alpha}-z_{t\beta}}{\sqrt{0.5\times(1-\hat{R}_t)}}$$

$$z_\alpha = \sqrt{\frac{1+\hat{R}_s}{2}} \times s_\alpha + \sqrt{\frac{1-\hat{R}_s}{2}} \times s_\beta \quad \text{and} \quad z_\beta = \sqrt{\frac{1+R_s}{2}} \times s_1 - \sqrt{\frac{1-\hat{R}_s}{2}} \times s_2$$

In the former relationships the 'n' and 'm' values denote the number of pixels in the respective images. In the latter relationships, the transforms are applied to each pixel within the target image. Note that the computation of correlation values normally requires the subtraction of mean values and division by standard deviation values, but this is not necessary here because the correlation is computed directly from standardised values which have already been pre-processed.

In practice, library packages such as OpenCV offer functions which convert image data to the Cielab L*a*b colour space rather than the lαβ colour space. Reinhard and Pouli [Ref 2] found that L*a*b mostly outperforms lαβ for colour transform processing. For these reasons, the L*a*b colour space is utilised for the enhanced colour transfer method in preference to lαβ.

Alternative Formulation

The intermediate steps 3.1 to 3.4, as described previously, can be represented as follows.

$$z_\alpha = W_1 z_{t\alpha} + W_2 z_{t\beta} \quad = \frac{1}{2}\left[\sqrt{\frac{1+\hat{R}_s}{1+\hat{R}_t}} + \sqrt{\frac{1-\hat{R}_s}{1-\hat{R}_t}}\right] z_{t\alpha} + \frac{1}{2}\left[\sqrt{\frac{1+\hat{R}_s}{1+\hat{R}_t}} - \sqrt{\frac{1-\hat{R}_s}{1-\hat{R}_t}}\right] z_{t\beta}$$

$$z_\beta = W_1 z_{t\beta} + W_2 z_{t\alpha} \quad = \frac{1}{2}\left[\sqrt{\frac{1+\hat{R}_s}{1+\hat{R}_t}} + \sqrt{\frac{1-\hat{R}_s}{1-\hat{R}_t}}\right] z_{t\beta} + \frac{1}{2}\left[\sqrt{\frac{1+\hat{R}_s}{1+\hat{R}_t}} - \sqrt{\frac{1-\hat{R}_s}{1-\hat{R}_t}}\right] z_{t\alpha}$$

The output standardised variables are computed as weighted sums of the input standardised variables. Each output channel is derived as a scaled contribution from the corresponding primary input colour channel plus a contribution from the other secondary channel. If the contribution from the secondary channel is zero then the original Reinhard method is implemented with no additional enhancement processing. If the contribution from the secondary channel is similar in size to that from the first channel then the colour transfer can sometimes be too intense and the colouring can appear somewhat artificial. To address this, the enhanced implementation of colour transfer incorporates an option to limit the size of the secondary channel contribution relative to that of the primary channel. Even when limiting is applied some level of additional colour enhancement will be implemented over and above that of the standard processing method.

Data Rescaling

A feature of both the simple and the enhanced Reinhard algorithm is that the data is shifted and scaled within the adopted colour space (which for simplicity will be assumed to be L*a*b). These operations can cause some of the data values within the modified image to lie outside of their permitted range. Where necessary, the L*a*b values must be bought back within range before the image can converted back to RGB format. Typically this can be achieved by saturating the values at their upper and lower bounds prior to conversion.

As an alternative to the saturation of extreme data values, the data could be scaled back to ensure that no values lie outside the permitted range. This may seem counterintuitive. An additional rescaling operation would partly countermand some of the processing operations previously applied to the data. In practice, of course the data must by necessity either be rescaled or saturated and either of these operations will alter the distribution of the data causing it to deviate from the characteristics that had originally been intended. The advantage of rescaling is that it represents a moderation of the data rather than a dislocation.

The enhanced implementation of colour transfer offers scaling as an option to clipping (saturating) the data. Scaling is applied to each L*a*b component of the image to bring the data closer to the centre of the permitted range so that no value lies outside the permitted limits. The ‘L’ component is scaled alone, but the ‘a’ and ‘b’ components are jointly scaled by the same factor to ensure consistent colour definition.

Iteration

It has been seen that the colour transfer operation may be distorted by additional scaling or saturation operations. Further distortion may occur because certain combinations of ‘L’, ‘a’ and ‘b’ values can convert to RGB values which are out of range, even when the components themselves are individually within range. Because range distortions can occur in the colour transfer process, repeated processing may offer an improvement for the colour transfer quality. Initially colours from the source image can be applied to the target image to produce a resultant image. Subsequently, the colours from the source image can be reapplied to the resultant image to produce a new resultant image. This latter operation may be repeated for a number of iterations. Iteration processing has been found to deepen the colour of the resultant image in some cases, particularly when used in combination with rescaling. It is normally sufficient to perform just one further iteration in additional to the initial processing.

The enhanced implementation of colour transfer allows a number of iterations to be performed with the default number set to two iterations.

Shading

Although the Reinhard method is called a colour transfer method, shading (lightness and darkness) is also transferred from the source to the target image. This is appropriate for an application such as image stitching because it is desirable that the constituent images be comparable in both colour and shading to ensure an invisible join. It is also appropriate in a situation, say, where colour transfer is applied to modify a daytime image to a night time scene. Strictly, however, the phrase ‘colour transfer’ implies the transfer of colour only and there are situations where this is desirable.

In the context of the Reinhard colour transfer method, the transfer of colour but not shading is a simple matter. In the standard approach, the lightness component of the target image is modified to match the lightness component of the source image using similar processing to that applied to the two colour components. In ‘pure colour’ processing the colour components are processed but the lightness component is left unmodified.

The enhanced implementation of colour transfer allows an option for retaining the shading of the target image, independent of the source image shading.

Observations

The enhanced colour transfer method achieves a potential advantage over the standard method by talking account of the correlation between the colour components in the L*a*b colour space. In some image pairs it could be that the correlation is similar in both the target and the source image (perhaps even near to zero in both). Under such circumstances, enhanced processing will provide no benefit over standard processing although it should not give rise to any noticeable disadvantage.

For the processing described here it can be expected that improved colour fidelity will be achieved with increasing iteration. In cases where the source image colours are particularly vivid it may be that the muted colours of a single iteration are more ascetically pleasing. Generally though, it would better to select a source image whose colour content is appropriate and to iterate sufficiently to achieve full colour transfer. An example overleaf shows an image subject to a single iteration and the same image subject to two iterations.

A novel application for colour transfer is that of indirect colour shading. Here the colour source image is a modified version of the target image. As an example, consider a situation where it is required to adjust the sky colour in an image. Commercial software applications offer various tools to address this requirement, but an alternative and sometimes simpler approach would be to use indirect colour shading. Here, a duplicate of the original image would be taken and a block within the sky would be set to a different colour perhaps directly or perhaps by pasting from another image. The colour of the original target image would then be modified by the colour transfer from the customised source image. In the examples overleaf the 'ocean scene' is an example of indirect colour shading.

The enhanced method of colour transfer only addresses the cross correlation between the colour components. It does not address any cross correlation between either of the colour channels and the lightness/darkness channel. It is not clear whether it would be useful to modify the target image to incorporate any relationship between colour and brightness as observed in the source image, let alone any dependency of brightness on colour. A brief and approximate investigation has been undertaken and this suggests that, in some circumstances, the transfer of colour brightness dependencies could create anomalous effects in the final image.

Published reviews of colour transfer methods often distinguish between photorealism and painterly effects. The latter addresses the process of generating images that mimic the colour palette and style of a particular artist such as Van Gogh or Seurat. The style of some artists is more susceptible to this process than others. Magritte and Dali, for example, are two artists whose style would be difficult to replicate by colour transfer methods since surrealist art depends more on image content than image rendition. Colour transfer does however, offer the interesting possibility of photo-surrealism, where colour transfer can be used to generate ascetically pleasing images that look realistic but whose colours are clearly unreal.

Commercial photo processing applications offer options such as 'Solarize', 'Gradient Map' and 'Posterize' which can be used to transform images to achieve multi-colour or psychedelic outcomes. Colour transfer can also offer the possibility of colourful imagery but with the possibility of greater subtlety and control. The 'brick wall' imagery overleaf illustrates this.

References

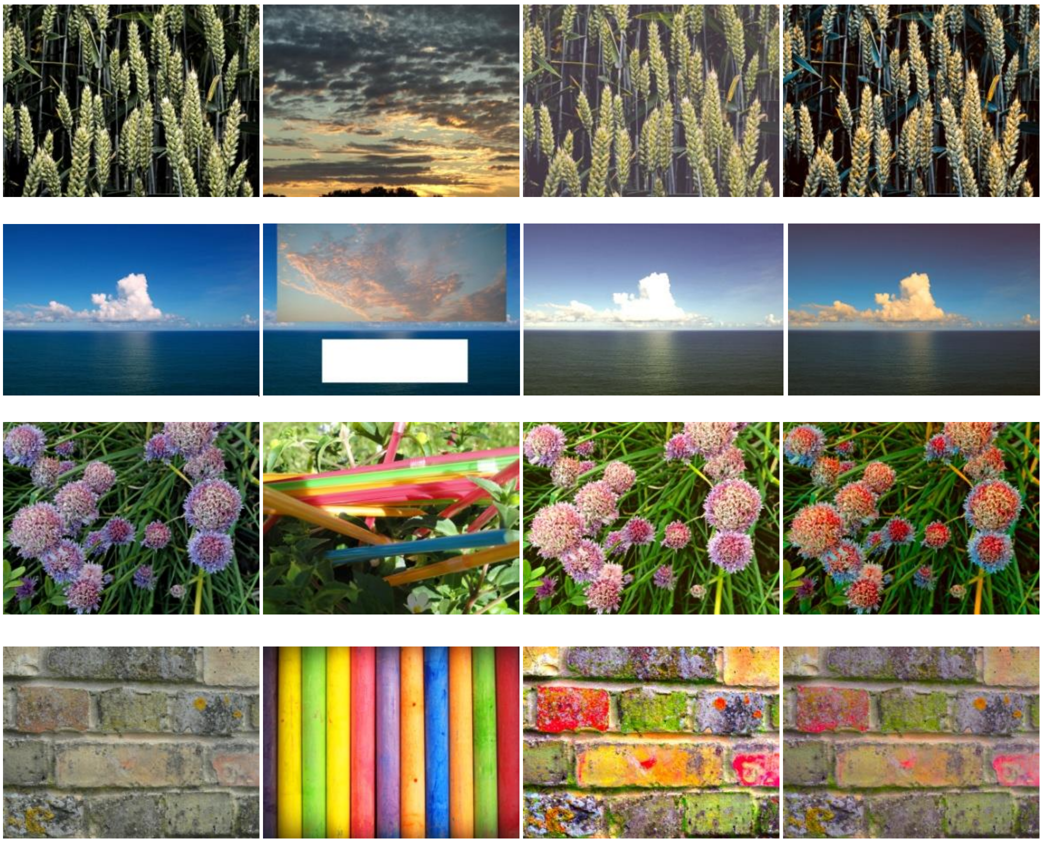
Ref1 https://www.cs.tau.ac.il/~turkel/imagepapers/ColorTransfer.pdf

Ref2 https://link.springer.com/content/pdf/10.1007%2F978-3-642-20404-3_1.pdf

1. **Processing Examples**:

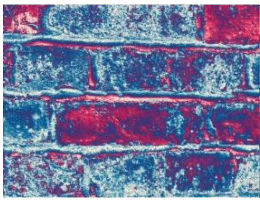
In the examples below, ‘Basic Processing’ corresponds to a single iteration with data clipping, no cross correlation processing and source-image-derived shading, whereas ‘Enhanced Processing’ corresponds to two iterations, with data scaling, cross correlation processing and target-image-derived shading.

Target Image Source Image Basic Processing Enhanced Processing



continued...

2. Processing Comparisons:

Enhanced Processing	Gradient Processing	Posterize Processing	Solarize Processing
			

3. Iteration Comparison:

Target Image	Source Image	Enhanced Processing One Iteration	Enhanced Processing Two Iterations
			

Here the second iteration intensifies the colour but in this case the more muted colour of the single iteration is probably preferable.

4. **An Example of Photo-surrealism**

The image below was generated using 'Adaptive Re-colouring' a new processing method which is proprietary to T E Johnson. As with the preceding flower images, this image looks photorealistic in monochrome but the colouration is surreal.