An Implementation of Pitie's Image Colour Transfer Method, based upon a Linear Monge-Kantorovich Solution.

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Introduction

This is a C++/OpenCV implementation of the processing that was first presented as a Matlab implementation here:- https://github.com/frcs/colour-transfer . (See *'colour_transfer_MKL*.m'.) The basis of the implementation is described in [Ref 1].

Comparison to the Xiao Method

The method described here has similarities to the so-called 'Xiao method' although it is not identical. The Xiao method is described in [Ref 2]. The latter method has received greater attention because it was highlighted in a survey of colour transfer methods by Faridul et al [Ref 3].

It has recently been established that the original Xiao method is not robust and can sometimes give spurious results. An augmented version of the original method has been developed which is more resilient [Ref 4], [Ref 5].

The following shows a comparison of processed images for the linear Monge-Kantorovitch (LMK) method and the robust form of the Xiao method.

It can be seen that there is very little to choose between the two processed images. The LMK processing gives an image which is probably more ascetically pleasing by a small margin. The plant stalks appear to have a more natural yellow colour than in the Xiao processed image. It does not necessarily follow, however, that LMK processing is better here. It could be that the orange tinge which the Xiao processing attributes to the stalks is a more faithful reflection of the palette source.

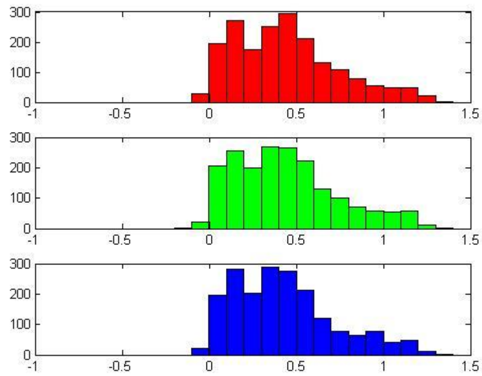
It has been found that there are only small differences when images are processed by the two methods. It would take an extensive study to determine which gives the better outcome on average. For the present it can be observed that the original Xiao method was not sufficiently reliable and that the subsequent modification to make the method more robust is somewhat empirical and its breath of applicability is uncertain. For this reason, it is recommended that the LKM method should be used in preference.

Limitations of the LKM Method

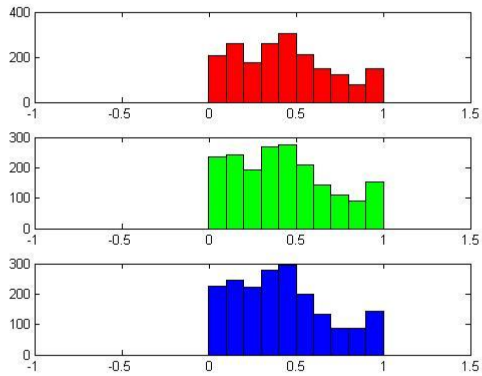
The LKM method often provides good colour transfer, but it can have potential limitations. Pitie identifies that the LKM method has certain optimal properties [Ref 1] in that it minimises the amount of colour change and has a good monotonicity property which preserves the relative position of colours. Unfortunately the advantages of the LMK method can only be fully realised if the final image can be displayed without any modification, but this is often not the case.

The figures below show the distribution of the red, green and blue channels for the processed image as shown previously for the LMK method. The left hand charts show the distributions for the image prior to display. The right hand charts show the distributions for the image as displayed. (In practice the latter distribution was derived by saving the image in jpeg format and then analysing the image once it had been read back.) The histograms were computed from images that had been generated by Pitie's implementation in Matlab.

RGB Distribution for Computed Image



RGB Distribution for Displayed Image



It can be seen that the distributions for the displayed image are significantly different from those in the ideal image as it was computed. This is because values that lie outside the range 0 to 1 in the ideal image are clipped at those limits when displayed.

The computed image has been derived by applying a linear transformation process which has certain optimal properties. However, any subsequent clipping introduces a non-linear step and also compromises the image characteristics. This latter outcome can be most clearly understood in relation to the Xiao method. The objective for that method is to match the cross colour covariance matrix of the target image to that of the source image. The effect of any subsequent clipping is to modify the covariance values of the final image so that they no longer match those of the source image.

In so far as the clipping process is an ad hoc non-linear operation, then it is permissible to apply an alternative ad hoc non-linear processing scheme if that reduces the adverse effects of hard limiting overall. In common parlance, there may be some benefit in applying 'soft limiting' in preference to 'hard limiting'. Such an approach has previously been implemented for a colour transfer scheme known as 'Enhanced Image Colour Transfer' method [Ref 6]. One of the variants of that method incorporates an option for rescaling of the colour channels.

One possibility for addressing non-linear image conditioning is to apply 'saturation value weighting'. A pixel with a saturation value '0' is black, grey or white and so has no colour. It could be expected that these pixels should not acquire a colour tinge from processing. A pixel with saturation value '1' is pure red, blue or green. A clipping operation applied to such pixel does not modify its colour balance. With 'saturation value weighting', images can be determined as a weighed sum of the initial image and the processed target image such that the weight given to the processed image is equal to the saturation value of the initial image. This possibility could the subject of a future investigation.

The LMK processing method can be schematically described as follows. The mean values of the red, green and blue channels within the target image are subtracted from each pixel. This gives rise to 'colour deviation data' centred upon an origin with co-ordinates (0, 0, 0). The colour deviation data undergoes a transform which implements a rotation and scaling of the data. The mean values of the red, green and blue and channels as computed from the source image are then added back onto the transformed 'colour deviation data'. This processing may give satisfactory images but it is slightly inconsistent as will be described.

Consider a pixel in the original target image and consider the content of its red channel. The mean red value is subtracted from this channel. Effectively 'pure red luminosity' is subtracted from the channel to give the (red) colour deviation value. A transformation is applied to the colour deviation values within each pixel. This scales the existing red deviation within the red channel but also (typically) adds into the red channel weighted contributions from the green and blue channel deviations within that pixel. The resultant is then increased by an amount equal to the average value within the source image. Again 'pure red luminosity' is added back into the red channel.

So there is a process where pure red is subtracted from the red channel, the remaining red content is scaled and combined with contributions from the green and blue channels and then pure red is added back. This may produce satisfactory results but it is slightly inconsistent given that 'colour intermixing' is only applied to the colour deviation components of each pixel and not to the mean value content.

The LKM processing itself is concerned with scaling and rotating the data around a point in RGB colour space but it is by no means clear why that particular point should be chosen for the origin. There is scope for further investigation here. (For example, one could subtract the individual mean RGB value from each pixel, apply a transform to the deviation data and then add back scaled mean values where the scaling ratios are determined by comparing the overall mean levels in the target and source images.)

Some General Observations on Image Colour Transfer Methods

At first sight, it might be thought that any colour transfer processing method should aim to match the colours in the target image to those in the source image as closely as possible. In practice this can be problematic. Pitie et al [Ref 7] explain this as follows. *"Consider a pair of landscape pictures where the sky in one picture covers a larger area than in the other. When transferring from one picture to the other, the excess of sky colour may be used in parts of the scenery on the ground in the other."* Furthermore, Faridul et al [3] report that for close correspondence colour mapping *"the resulting image may be too harsh as the transfer can amplify artefacts that were previously invisible,* *indicating that higher-order properties of the image may need to be matched or preserved to achieve a successful result"*.

It follows that the objectives for a successful colour transfer method are not clearly defined and that it may therefore be difficult to identify an optimum method. It could be that the best criterion is that a method should mostly achieve an acceptable colour match but subject to the constraint that it should achieve the best minimum quality for the most difficult image combinations (i.e . apply a maximin decision criterion).

There has been a recent trend to evaluate different colour transfer methods by observer comparison trials. In many cases great care has been taken to randomise the presentation of the images to the observers, but this procedure is somewhat compromised by the fact that the actual choice of image pairs for a trial can greatly influence the outcome. A truly objective trial would require the images themselves to be selected at random from the population of images that might in future be utilised for processing. This criterion is ill-defined and cannot therefore be properly addressed.

It may be that given these limitations, one should settle for a relatively simple processing method. But it may be that by developing a greater understanding of, for example, clipping artefact then methods can be developed that can be deemed to be preferable.

A recent trend in colour transfer processing has been to use neural network transfer methods. Such an approach can produce interesting results though it is sometimes difficult to judge the extent to which a network has been specifically tuned to particular image classes. At present, the neural methods are considered distinct from algorithm processing methods, but this need not necessarily be the case. It may be that there could be potential benefits from applying neural network methods to images that have been pre-processed by algorithmic methods. If an algorithmic method is assigned to do the 'heavy lifting' first then there could be greater potential for a neural method to provide a fine rebalancing of the image as a second stage.

Discussion

It has been found that the linear Monge-Kantorovitch method gives similar processing outcomes to the (ruggedised) Xiao method. There is no definitive reason to prefer either method but LMK processing is recommended since it appears to have the more robust formulation.

The display of LMK processed images can often involve data clipping which is a non-linear operation that compromises the intended image characteristics. The processing scheme for LMK has stages which are not entirely self consistent. Given this, there may be scope to develop new processing variants of the basic LMK method.

References

[1] https://github.com/frcs/colour-transfer/blob/master/publications/pitie07cvmp.pdf

[2] Xiao Xuezhong, and Lizhuang Ma. "Color transfer in correlated color space." In Proceedings of the 2006 ACM international conference on Virtual reality continuum and its applications, pp. 305-309. ACM, 2006.

[3] Faridul H S, Pouli T, Chamaret C, Stauder J, Tremeau A, Reinhard E. “A Survey of Color Mapping and its Applications. Conference: Eurographics 2014 - State of the Art Reports, 2014

[4] https://github.com/TJCoding/Ruggedised-Image-Colour-Transfer

[5] https://github.com/hangong/Xiao06_color_transfer

[6] https://github.com/TJCoding/Enhanced-Image-Colour-Transfer

[7] https://github.com/frcs/colour-transfer/blob/master/publications/pitie08bookchapter.pdf