ENHANCING THE OUTPUT OF SPATIAL COLOR ALGORITHMS

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ABSTRACT

Development and implementation of spatial color algorithms has been an active field of research in image processing for the last few decades. A number of investigations have been carried out so far in mimicking the properties of the human visual system (HVS). Various algorithms and models have been developed, but they produce more or less neutral output. Some applications demand the preservation of appearance of the original image along with the enhancement performed by these models. It is our attempt in this paper to present a number of techniques that are designed to satisfy the requirements of those applications. Our techniques work in two general stages. In the first stage, properties of the original image are extracted and stored. In the second stage, the resulting images from the image enhancement models are processed with those properties. Most of these techniques perform quite well for different categories of images. We combine different approaches such as *gamma, scaling, linear, scaling* and *clipping* to preserve properties like color cast, maximum and minimum channel value etc. Our methods have been extended for Low-key and High-key images as well.

Index Terms— color correction, image enhancement, color cast, spatial color algorithms.

1. INTRODUCTION

Over the past few decades, researchers have been trying, through a range of physiological and psychological experiments, to understand the process of visual perception of the Human visual system (HVS). Now-a-days, it is already known that, the HVS constructs the final perception on the basis of meaningful information from the spatial relationships among various stimuli, as well as considering the stimuli that comes from every single point of a scene [1]. Our visual sensation, including some well-known visual effects, is originated as a direct consequence of this phenomenon and almost all the color sensations can be perceived with proper arrangement of the same stimulus in the space [2].

A number of works have been pursued trying to mimic some characteristics of the Human visual system (HVS) in the last few years. Researchers have been trying to imitate several features of our visual system like color constancy, lightness constancy, automatic color correction, high dynamic range image rendering etc. They tried to build up models that would perform like the visual sensation formation through spatial comparisons, which in turn allows realizing a number of robust adjustment mechanisms for dealing with various viewing conditions. The method for realizing the spatial comparisons is one of the focusing points that the researchers have always considered while forming this model. It is obligatory for a model to have both global and local approach to explore the information around each point [3].

Several models have been developed so far, among them Retinex works with locality of perception. This model, developed by Land and McCann [4], has been considered as base model for many researchers since its development. They implemented and analyzed different techniques [5], [6], [7] to enhance further improvement related to noise reduction and computational efficiency. ACE (Automatic color equalization), developed by Rizzi et al., is another technique to keep the local and global effect of digital images, accounting for chromatic/spatial adjustment and maximizing the image dynamic [8]. Another recent development in the field of image enhancement applications is STRESS (Spatio-Temporal Retinex-like Envelope with Stochastic Sampling) developed by Kolås et al [9].

These models aim to keep the local and global effect of images by implementing different techniques. But, the processed images, which are the output from these models, are always neutral. They loose, while processing the original image, several properties of the original image like maximum level of color value for each individual chromatic channel and also the minimum and mean value as well. Moreover, these techniques do not preserve the lightness and saturation information of the original image. As a result, they produce, more or less, neutral output, which is not always desired in some applications like keeping the color cast of an image inside a museum or maintaining the color cast of the sky and sea water in a bright sunny day and so on. We have proposed here several ways to keep the non-neutral properties of the original image so that it can be useful in a number of applications. Our techniques work in two different stages, firstly: extracting and storing the related properties of original image and secondly: processing the output from different models like ACE or STRESS, to give back some of the properties of the original image, to the ‘processed’ image. Throughout all the content

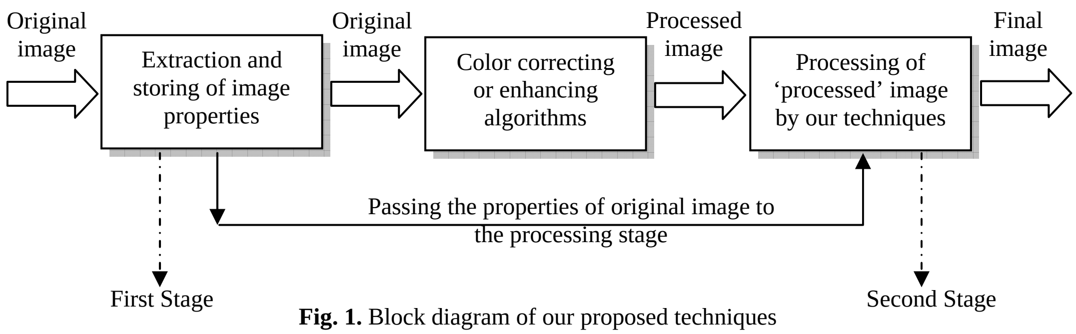

Fig. 1. Block diagram of our proposed techniques

of this paper, 'processed' image is referred to as the output image from the color correction or enhancement algorithms or models.

The rest part of the paper is arranged like following: Section 2 describes some existing spatial color algorithms, in Section 3 our proposed method has been described, Section 4 shows and describes the results associated with our ideas and finally, in Section 5 we have drawn our conclusion.

2. SPATIAL COLOR ALGORITHMS IN GENERAL

Retinex, one of the earliest models, developed by Land and McCann, deals with locality of perception by long paths scanning across images. A number of implementations and analysis have been carried out based on this first model. Further developments [10] of this model mainly differed in the technique of attaining locality. Random Spray Retinex (RSR) [11] is a recent implementation which investigates the effect of different spatial samplings.

ACE, developed by Rizzi et al., is a new algorithm for automatic enhancement of digital images, considering concurrent global and local effects [8]. This algorithm has been implemented by following two stages: first stage deals with color constancy and contrast tuning by accounting for chromatic/spatial adjustment, while the second stage maximizes the image dynamic by configuring the output range to implement an accurate tone mapping [8]. ACE showed potential results to mimic several characteristics of the HVS, like color and lightness constancy, controlling the contrast etc.

STRESS, another very recent development whose properties are in line with Spatial Color Algorithms [12], is implemented with an extremely small number of sample points, using two envelopes for characterizing the local visual context [9]. This algorithm shows promising result in mimicking properties, like local contrast stretching, automatic color correction, high dynamic range image rendering etc, of the HVS. STRESS has been successfully implemented for spatial gamut mapping and color to gray scale conversion as well.

All the algorithms mentioned here produce output that doesn't preserve some properties like color cast, low-key, high-key properties of original image after processing. Our motivation is to keep these properties of the original image which are associated with the *processed* image, to satisfy some requirements like preserving the mean chromatic channel value or mean lightness level etc, through a number of techniques that are analyzed in the following section.

3. PROPOSED METHODS

Very often, we expect the appearance of the *processed* image as close as to its original one or we expect it to be looking natural. But, the color correcting or enhancing algorithms produce output image which are comparatively neutral in properties. Hence, to achieve our expectation, we have proposed several techniques. These techniques work in two general stages, which are discussed below.

In the first stage, of the block diagram in Fig.1, some relevant properties, like the maximum, minimum and mean value for each chromatic channel, are extracted and stored before the processing starts. For extracting saturation and lightness values, a conversion from RGB color space to HSL color space is performed; then the necessary information are extracted and stored to use them in processing the *processed* images.

The second stage takes the *processed* image, from different models like ACE or STRESS, as input and performs one of the following techniques. In this stage, the resulting image, from enhancement model, is processed with the stored information from the first stage, so that the final image can have almost similar chromatic, lightness and saturation value as the original one. Here, in this paper, we have taken the *processed* image from the algorithm STRESS [9] and showed our methods on this model. STRESS makes the minimum and maximum channel value as 0 and 1 respectively, for any image. So, for our techniques, we have mapped our images in the range 0–1.

3.1. Keep White Point (KW)

This technique deals with preserving the maximum value for each chromatic channel by scanning through each channel individually and then, these values are passed to the second stage in Fig.1 to process the *processed* image. The diagram in Fig.2 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from

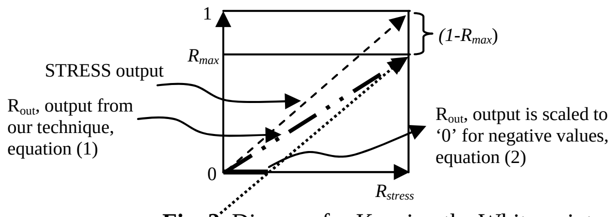

Fig. 2. Diagram for Keeping the White point

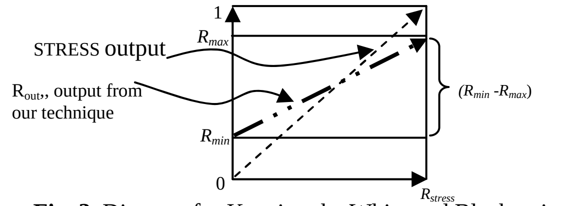

Fig. 3. Diagram for Keeping the White and Black point.

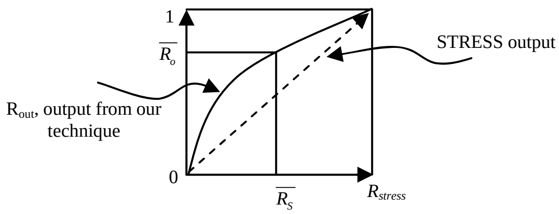

Fig. 4. Diagram for keeping the mean by gamma

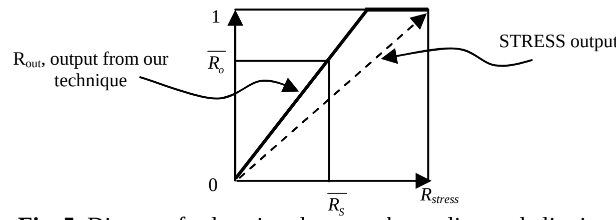

Fig. 5. Diagram for keeping the mean by scaling and clipping

STRESS algorithm. Let's consider in Fig.2, R_{max}, the maximum red channel value of original image, is 0.7; the final value, R_{out}, is calculated by the following equations:

$$R_{out} = R_{stress}\ R_{max} \tag{1}$$

$$R_{out} = R_{stress} - (1 - R_{max}) \tag{2}$$

The same procedure is followed for green and blue channel as well. A thorough scanning is performed afterward, for each pixel of each channel of the output image from STRESS model and those pixels are mapped to R_{out}, G_{out} and B_{out} respectively. If, for any pixel, the above equation gives negative value, then that value is scaled to 0. Thus, the final image retains the maximum chromatic channel value of the original image.

3.2. Keep White and Black point (KWB)

This technique deals with preserving the maximum and minimum value for each chromatic channel. The diagram in Fig.3 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from STRESS algorithm. Let's consider in Fig.3, R_{max} and R_{min}, the maximum and minimum red channel value of original image, is 0.9 and 0.2 respectively; the final value, R_{out}, is calculated by the following equation:

$$R_{out} = R_{\min} + R_{stress}\ \left(R_{\max} - R_{\min}\right) \tag{3}$$

The final image, which retains the maximum and minimum chromatic channel value of the original image, is produced in the same way as described in the first three lines of the second paragraph of Section 3.1.

3.3. Keep Mean (KM)

This technique deals with preserving the mean value for each chromatic channel by scanning through each channel individually. We propose following three different techniques to maintain the mean value of the channels of original image in the final image.

3.3.1. By gamma correction (KMG)

The diagram in Fig.4 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from STRESS algorithm. R_{out} can be obtained by the following equation:

$$R_{out} = R_{stress}^{\gamma^R} \tag{4}$$

$$\gamma^R = \frac{\ln \overline{R_o}}{\ln \overline{R_s}} \tag{5}$$

3.3.2. By scaling and clipping (KMSC)

The diagram in Fig.5 shows the final value, R_{out}, for red channel, which is derived in the following way:

$$R_{out} = \begin{cases} 1 & if\ R_{out} > 1 \\ R_{stress}\ \dfrac{\overline{R_o}}{\overline{R_s}} & otherwise \end{cases} \tag{6}$$

In Fig.4 and Fig.5, $\overline{R_o}$ and $\overline{R_S}$ indicate the mean values for red channel of the original image and the *processed* image respectively.

3.3.3. By scaling (KMS)

The diagram in Fig.6 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from STRESS algorithm. R_{out} is derived in the following way:

$$\begin{gathered} R_{out} = R_{stress}\ \frac{\overline{R_o}}{\overline{R_s}}\ S \\ where,\ S = \left(\max\left\{\frac{\overline{R_o}}{\overline{R_s}}, \frac{\overline{G_o}}{\overline{G_s}}, \frac{\overline{B_o}}{\overline{B_s}}\right\}\right)^{-1} \end{gathered} \tag{7}$$

3.3.4. By linear method (KML)

The diagram in Fig.7 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from STRESS algorithm.

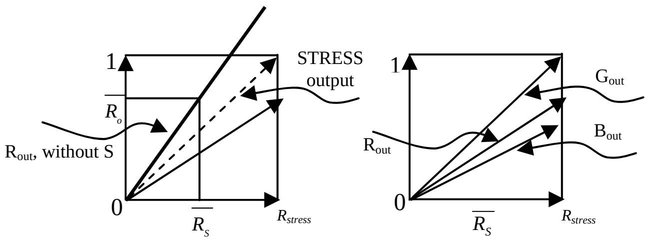

Fig. 6. Diagram for keeping the mean for red channel by scaling (left). Final values from RGB channel (right).

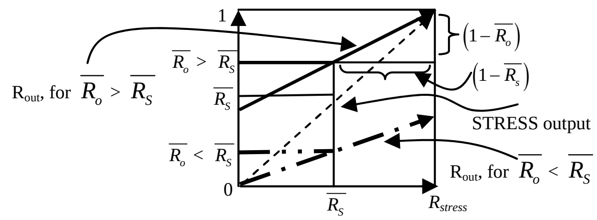

Fig. 7. Diagram for keeping the mean by linear method.

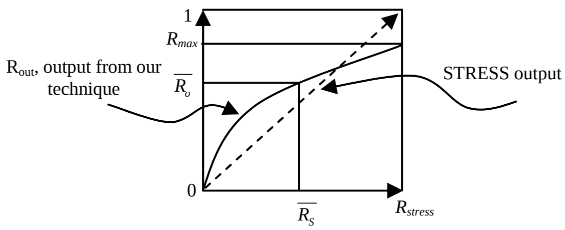

Fig. 8. Diagram for keeping the white point and mean.

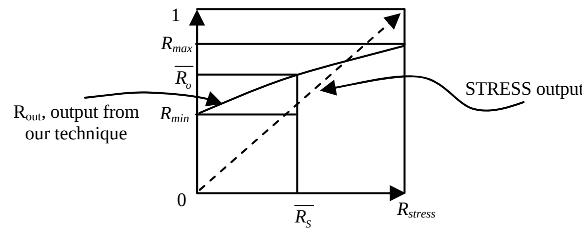

Fig. 9. Diagram for keeping the white point, black point and mean.

In Fig.7, $\overline{R_o}$ and $\overline{R_s}$ indicates the same meaning as in 3.3.2. The final value for red channel, R_{out}, is derived in the following way:

$$R_{out} = \begin{cases} R_{stress} \dfrac{\overline{R_o}}{\overline{R_s}} & if\ \overline{R_o} < \overline{R_s} \\ \dfrac{1-\overline{R_o}}{1-\overline{R_s}}\left(R_{stress} - \overline{R_s}\right) + \overline{R_o} & otherwise \end{cases} \tag{8}$$

3.4. Keep the White point and Mean value (KMWG)

This technique deals with preserving the maximum and mean value at the same time for each chromatic channel. The diagram in Fig. 8 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from STRESS algorithm. Rout, is calculated by the following equation:

$$\begin{aligned} R_{out} &= R_{\max}\ R_{stress}^{\gamma^R} \\ where\ \gamma^R &= \frac{\log\left(\overline{R_o} / R_{\max}\right)}{\log \overline{R_s}} \end{aligned} \tag{9}$$

The final image, which retains the maximum and mean chromatic channel value of the original image, is produced in the similar way as described in the first three lines of the second paragraph of Section 3.1.

3.5. Keep White and Black point and Mean (KMWBG)

This technique deals with preserving the minimum, maximum and mean value at the same time for each chromatic channel. The diagram in Fig. 9 shows the final value, R_{out}, for red channel, after processing the red channel value, R_{stress}, from STRESS algorithm. R_{out}, is calculated by the following equation:

$$\begin{aligned} R_{out} &= \left(R_{\max} - R_{\min}\right)\ R_{stress}^{\gamma^R} + R_{\min} \\ where\ \gamma^R &= \frac{\log\left(\left(\overline{R_o} - R_{\min}\right)/\left(R_{\max} - R_{\min}\right)\right)}{\log \overline{R_s}} \end{aligned} \tag{10}$$

The final image, which retains the minimum, maximum and mean chromatic channel value of the original image, is produced in the same way as described in the first three lines of the second paragraph of Section 3.1. R_{min}, R_{max} and $\overline{R_o}$, in Fig.8 and Fig.9, indicate the minimum, maximum and mean red channel value of original image respectively.

3.6. Keep Lightness and Saturation

This technique deals with preserving the mean lightness and saturation values of the original image. This method works similar to the method described in Section 3.3. But, for extracting the related information about lightness and saturation, the color space should be transformed to HSL from RGB. After extracting, the color space is again transformed to RGB from HSL. Then, the rest of the procedure is followed as described in Section 3.3. Before processing the processed image, RGBtoHSL conversion is performed again; then necessary operation is done and finally HSLtoRGB conversion takes place. Here, in case of operation on color spaces, only the lightness and saturation properties are considered; hue is not considered in any conversion.

4. RESULTS AND DISCUSSION

The environment in which our techniques are implemented includes GCC, MinGW and CImg library. Each of our techniques is built to be performed well for specific category of images. Of course, the technique which works

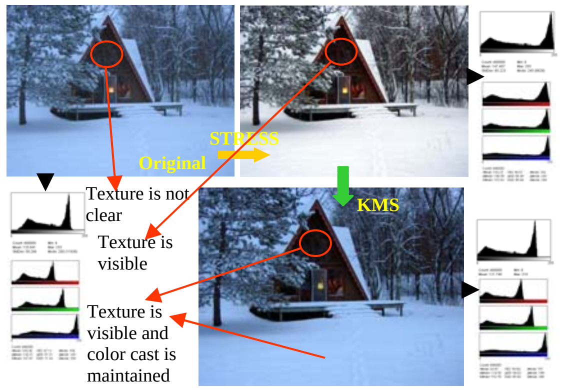

Fig. 10. Keeping the color cast while maintaining the image enhancement by KMS.

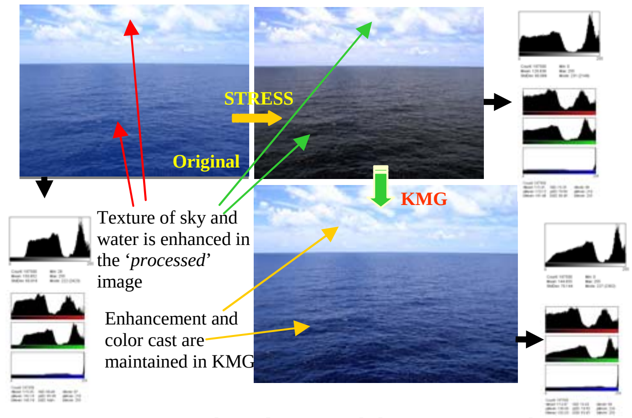

Fig. 12. Keeping the color cast while maintaining the image enhancement by KMG.

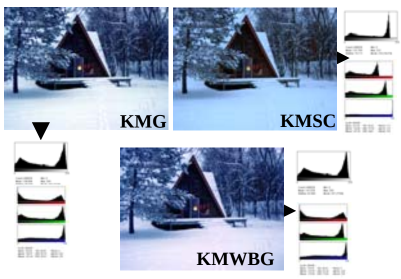

Fig. 11. Keeping the color cast while maintaining the image enhancement by KMG, KMSC and KMWBG.

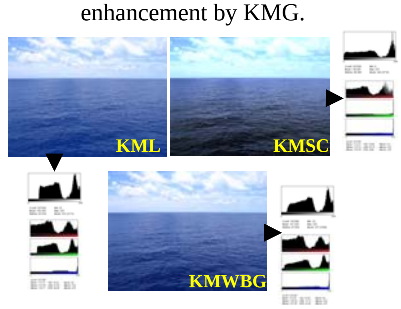

Fig. 13. Keeping the color cast while maintaining the image enhancement by KML, KMSC and KMWBG.

well for high key image might not be suitable for processing color cast images and so on.

For instance, some of the techniques performed quite well to keep the color cast whenever needed. The top-left image in Fig.10 shows a photo of a normal snowy day. Here, in the *'processed'* image, though the image is enhanced i.e. the textures in the dark portion of the glass area are seen better, the color cast is completely removed and the photo seems neutral or unnatural. Here come our techniques to keep the color cast while maintaining the enhancement as well.

In Fig.10, we can see that in the *'processed'* image (top-right), the histogram is stretched to cover the full dynamic range and some sort of histogram equalization and smoothing is performed. In the Keep mean by scaling (KMS) technique, the ratio among all channels of the original image and the KMS image is maintained, thus the enhancement of 'processed' image is kept and the color cast is maintained as well. Effects of some other techniques like KMG, KMSC and KMWBG are illustrated in Fig.11.

In Fig.11, all the techniques are aimed to maintain the enhancement of the *'processed'* image and the color cast of the original image as well. Some of the techniques perform better than the others which are obvious according to their corresponding processing criteria. In Fig.12, there is another example of maintaining color cast in a photo of ocean and sky in a bright day.

In Fig.12, the *'processed'* image (top-right) improved the representation of sky and water but looses the desired color cast of water completely i.e. became neutral. The histogram of blue channel of the *'processed'* image clearly shows this effect by keeping most of the tones in the lower part of the histogram. So, KMG, according to its working criteria, maintains the enhancement and give back the color cast to some level. Effect of some other techniques like KML, KMWBG and KMSC are illustrated in Fig.13.

In Fig.13, all the techniques are aimed at maintaining the enhancement of the *'processed'* image and the color cast of the original image as well. Some of the techniques perform better than the others, but KMSC produces some sort of distortion of color in the sky which is also visible in the histogram of the green channel in Fig.14 (left). Here, clipping has taken place which is undesired. Moreover, some sort of unwanted color cast was found in the dark area of the image which is the outcome of KML technique. In Fig.14 (right), the KML technique introduces blue color cast in the front side of the house due to elevation of the black point, which is not desired. But, there is always the option of choosing other techniques, if some sort of problem is found with one technique.

Our techniques are applied to high-key and low-key images as well. Fig.15 and Fig.16 show some illustrations of our techniques on the images of both types.

From the figures, Fig.15 and Fig. 16, it is evident that some of our techniques perform quite well in maintaining the vividness of the original image while maintaining the enhancement of the *'processed'* image. Moreover, it is apparent that KWB is mainly applicable to high-key and

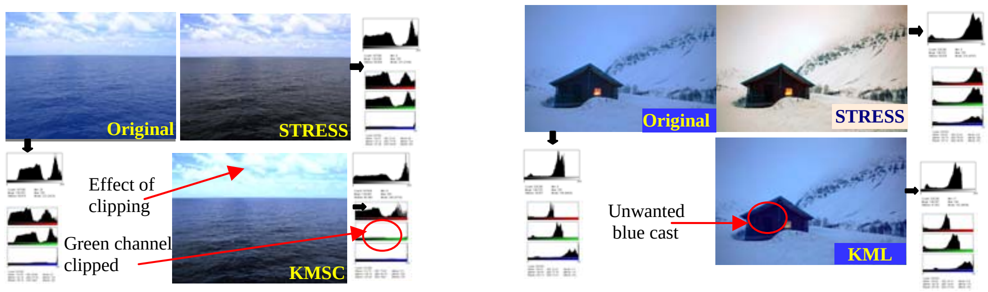

Fig. 14. Clipping effect of KMSC (left). Linear effect of KML (right).

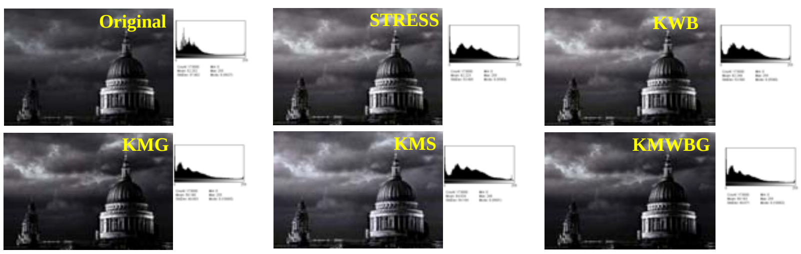

Fig. 15. Effect of our techniques on Low-key images.

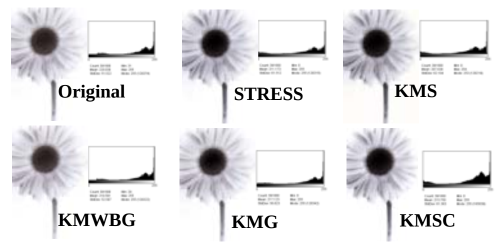

Fig. 16. Effect of our techniques on High-key images.

low-key images.

Though all the illustrations and explanations of each of the techniques could not be shown here because of space constraint, it is apparent that most of our techniques perform quite well; in case of color cast – specifically KMG, KML, KMWBG and KMS; and in case of Low-key and High-key images – specially KMG, KMS, KWB and KMWBG.

5. CONCLUSION

We have proposed here several techniques which aim at keeping the non-neutral properties of the original image and associate those with the *'processed'* image, to satisfy some requirements of specific applications like preserving the color cast while maintaining the enhancement of the original image and so on. Our techniques are simple and easy to implement and perform quite well for different category of images and the running time of these techniques is very low as well. Some sort of distortion might be introduced by some of the techniques, but there are always a number of choices of other techniques to avoid those artifacts. In the future, a psychophysical test should be performed for evaluating the subjective quality of the resulting images.

6. REFERENCES

[1]. T. Cornsweet., *Visual Perception*. Academic Press, New York, 1970.

[2]. J.J. McCann and K. L. Houston, "Calculating colour sensation from arrays of physical stimuli," *IEEE Transaction on SMC*, SMC-13, 5:1000–1007, 1983.

[3]. J.J. McCann, "Local/global mechanisms for color constancy," *Die Farbe*, 34:275–283, 1987.

[4]. E. Land and J. McCann, "Lightness and retinex theory," *Journal of Optical Society of America*, 61:1–11, 1971.

[5]. K. Barnard and B. Funt, "Investigations into multi-scale retinex," In Proc. of *Colour Imaging in Multimedia* '98, Derby (UK), 1998.

[6]. J.D. Cowan and P.C. Bressloff, "Visual cortex and the retinex algorithm," In Proc. *SPIE Human Vision and Electronic Imaging* VII, vol. 4662, S. Jose, California (USA), 2002.

[7]. T.J. Cooper and F. A. Baqai, "Analysis and extensions of the frankle-mccann retinex algorithm," *Journal of Electronic Imaging*, 13 (1):85–92, 2004.

[8]. Alessandro Rizzi, Carlo Gatta, and Daniele Marini, "A new algorithm for unsupervised global and local color correction," *Pattern Recognition Letters*, 24:1663-1677, 2003.

[9]. Øyvind Kolås, Ivar Farup and Alessandro Rizzi, "STRESS: A new human visual system inspired image processing method,"(submitted).

[10]. B. Funt, F. Ciurea, and J.J. McCann, "Retinex in matlab," *Journal of Electronic Imaging*, 13(1):48–57, 2004.

[11]. E. Provenzi, M. Fierro, A. Rizzi, L. De Carli, D. Gadia, and D. Marini, "Random spray retinex: a new retinex implementation to investigate the local properties of the model," *IEEE Transactions on Image Processing*, 16 (1):162–171, January 2007.

[12]. A. Rizzi and J.J. McCann, "On the behavior of spatial models of color," In Proc. of *Electronic Imaging* 2007, S. Jose, California (USA), 2007. (invited paper).