Computational Inexpensive Two Step Auto White Balance Method

Sergio Goma, Milivoje Aleksic
ATI Technologies Inc., 75 Tiverton Court, Markham, ON, Canada, L4A4Y8

ABSTRACT

The chromaticity of an acquired image reconstructed from a Bayer pattern image sensor is heavily dependent on the scene illuminant and needs color corrections to match human visual perception. This paper presents a method to 'white balance' an image that is computationally inexpensive for hardware implementation, has reasonable accuracy without the need of storing the full image, and is aligned to the current technical development of the field. The proposed method introduces the use of a 2D chromaticity diagram of the image to extract information about the resultant scene reflectance. It assumes that the presence of low-saturated colors in the scene will increase the probability of retrieving accurate scene color information.

Keywords: auto white balance, iluminant chromaticity, illuminant estimation, chromatic adaptation, chromaticity chart, cell-phone camera, image processing;

INTRODUCTION

The chromaticity of an acquired image reconstructed from a Bayer pattern image sensor is heavily dependent on the scene illuminant and the Bayer pattern filters. Thus, when displayed, the image needs corrections to be applied in order to be perceived as the eye perceived the original scene. Some of those corrections are applied at the display level (and are related to the display performances), but some need to be applied in the sensor image-processing path to correct for image sensor specific parameters (i.e. color filters). Automatic white balancing is still an open research topic mainly because of the complexity of scene illumination, an example being the influence of the surrounding of the scene to the reflected chromaticity of the image[1]. This paper presents a method to 'white balance' an image, that is computationally inexpensive for hardware implementation, has reasonable accuracy without the need of storing the full image, and is aligned to the current technical development of the field. The proposed method makes use of a chromaticity diagram of the image to extract information about the resultant scene reflectance, and assumes that the presence of low-saturated colors in the scene would increase the probability of retrieving accurate scene spectral reflectance.

CMOS sensors used in cell-phone cameras have an SNR around 48dB. Because of this, accurate color reproduction is hard to achieve. As is pointed out by Barnhofer, Folwer, Olding and Wandell[2], the noise response of the sensor plays a big part in color reproduction accuracy and therefore a compromise solution forces the choice color rendering matrix to also trade off between mean deviation and reproduction variance. In this regard, some guidance is being offered by Xiao, Zhang and Fowler [3] as a quantitative estimate to the question: how good does the color reproduction need to be for cell-phone cameras[3]. Regarding Xiaos, Zhang and Fowler's results[3], and based on the fact that cameras analyzed in[3] are consumer grade DSC who's sensor's SNR are on the order of 65dB, the numbers deemed acceptable for color error are a challenging target for today's typical cell-phone camera. In this regard, the authors[3] have found that for cell-phone cameras, the numbers presented are a 'nice to have', though hard to get value, especially when used in automatic mode with combined white balance and color correction.

The 'white balance' approach presented in this paper targets chromatic adaptation (see Figure 1) rather than color constancy (see Forsyth[4]), because the main use case for cell-phone cameras is considered to be capturing day-to-day scenes vs. colorimetric measurements or machine vision applications. For a discussion on this subject, see Fairchild'[5].

Digital Photography II, edited by Nitin Sampat, Jeffrey M. DiCarlo, Russel A. Martin,
Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 6069, 60690D, © 2006 SPIE-IS&T · 0277-786X/06/$15

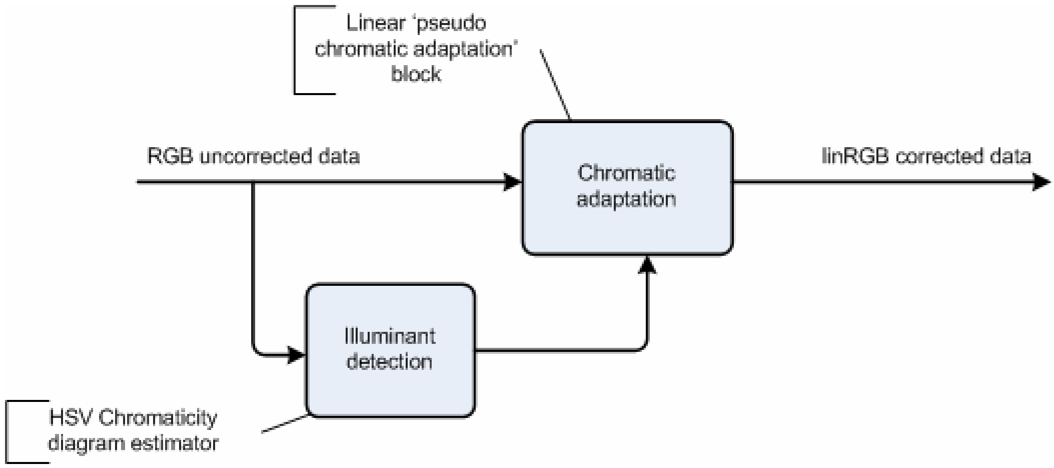

Figure 1 Chromatic adaptation

Following, the proposed 'white balance' algorithm is presented as a two step process:

(1) Pseudo 'white point' estimation or 'illuminant' color temperature estimation. Because the 'white point' notion doesn't make sense until it is displayed and seen by the eye, it is called pseudo. Also, color temperature of the illuminant refers to a simplified way of characterizing the spectral properties of a light source by the temperature of a black body that is metametric with the illuminant.

(2) Pseudo 'chromatic adaptation'. Because the 'chromatic adaptation' also doesn't make sense until the image is displayed on a device and perceived by the eye, this phase is called 'pseudo'. In this step, the chromaticity of the image is changed by means of a linear transformation using a 3x3 matrix such that it will be similar to one produced under a D65 type of illuminant.

Both steps make use of a generated 2D chromaticity chart of the acquired image and use the centre of weight of a predetermined area of the chart to determine a pseudo 'Chromatic Adaptation Transform Vector'. This is used to evaluate the transformation matrix. Also, if the centre of weight is located inside a pre-delimited area, fixed measured transformations can be used.

The steps of the algorithm that implement the proposed solution are:

1. White point estimation (iterative process):
1.a. in the chromaticity chart, calculate the intersection with a restriction area (i.e.. highly saturated color distribution of the image).
1.b. Calculate the centre of weight of the area determined at 1.a., which represents the 'Image Estimated Color Temperature'

Repeat 1.a. and 1.b. for a number of regions of interest and discriminate the regions that do not have enough color information.

If all estimated color temperatures for the considered regions are in one of the predefined areas, use the predefined values for step2), else use an average value for estimated color temperature.

2. Chromatic transformation. Here there are 2 cases: if the illuminant is one of the predefined illuminants, then a predefined chromatic adaptation transformation is used, else:
2.a Use a linear transformation in a cone response color space (here, a linearized Bradford transform is used)
2.b In the cone response space, apply a correction to transform the estimated color temperature to the reference D65 illuminant.
2.c Apply the inverse transformation of step 2.a.

METHODOLOGY

A polar-coordinate system of representing color can be used for color appearance diagrams to show adaptation from one illuminant to another. As such, it can be used to show the hue/saturation direction and magnitude of the required transformation[6]. The authors have found that an HSV system is a color polar-coordinate system which meets most of the requirements needed to implement the metric used to compute the 'white point' of the image. Beside reasonable accuracy in representation, it's benefits are simplicity of implementation and linear computation. HSV was chosen over HSL because it has a better representation of saturation compared to HSL. Saturation is one of the practical factors used to discriminate, using the chromaticity diagram, which parts of the image are used to compute the estimated 'white point'. Actually the main information extracted is the hue shift of the chromaticity diagram, but the magnitude of the computed vector is a direct result of the constrained area. A three dimensional representation of the HSV polar-coordinates color system is shown in Figure 2.

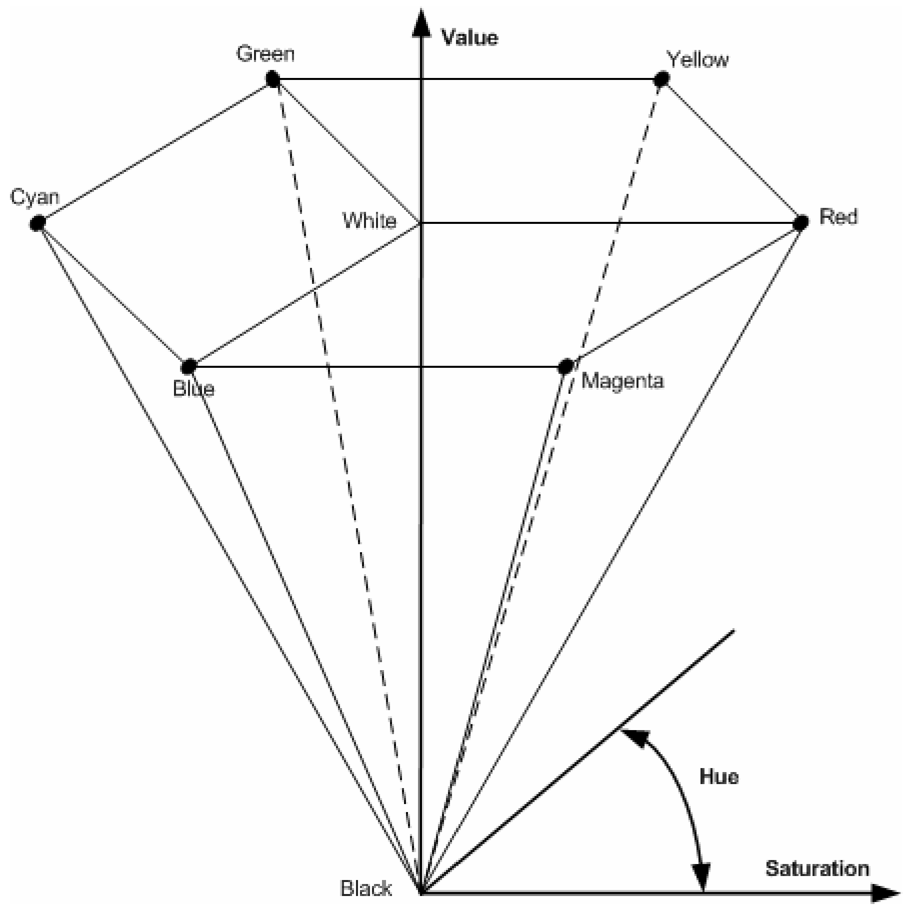

Figure 2 HSV polar-coordinate color representation system

The 'white point' estimation is based on a predetermined subset of the chromaticity diagram in HSV. The constraints used are based on luminance and saturation. The pixels with luminance too high or too low are discriminated, as are those pixels which either have the color information compromised because of pixel saturation, or are too dark and the color information is buried in noise, as pointed out in other similar approaches[8]. The volume in HSV space used to discriminate pixels used for 'white point' estimation is both luminance and saturation constrained, reflecting the assumption that the presence of low-saturated colors in the captured image can be used to retrieve the dominant color information.

To further simplify the problem, the authors have found that a plane projection of the HSV polar-coordinates system can be used to represent and classify the chromaticity of an image with enough accuracy to meet the target color reproduction. The plane projection is accomplished using the following formulae:

$$X = R - \frac{B+G}{2}$$

$$Y = 0.866 \cdot (G - B)$$

Where:

$$Sat = \sqrt{X^2 + Y^2}$$

$$Hue = \frac{atg\left(\frac{X}{Y}\right)}{2 \cdot \pi}$$

$$Value = \left(\frac{R+G+B}{3}\right)$$

1. 'White point' estimation

A practical implementation of the proposed 'white point' estimation method relies on the plane projection of the HSV chromaticity diagram, as shown in Figure 3.

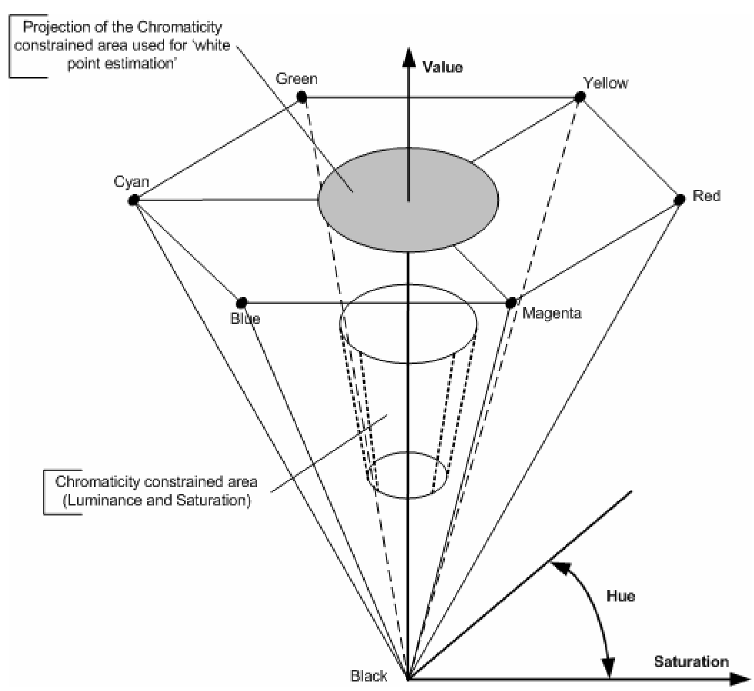

Figure 3 Chromaticity constrained area used for 'white point' estimation

The area used to compute the 'white point' is discriminated in luminance and in saturation, as is indicated in Figure 3 with 'Chromaticity constrained area'.

In
Figure 4(a), an example is offered of a chromaticity diagram generated from a MacBeth chart reference image. The resulting chromaticity diagram represents the colors of a synthetic MacBeth chart that was blurred using a classic blur operator to make it easier to discern (the perfect synthetic colors would be represented by mere dots).

Figure 4(b) depicts a graphic illustration of the proposed method of 'white point' estimation. It's easy to relate Figure 4(a) and (b) to identify the primaries as they can be found in the 2D projection of the HSV color system.

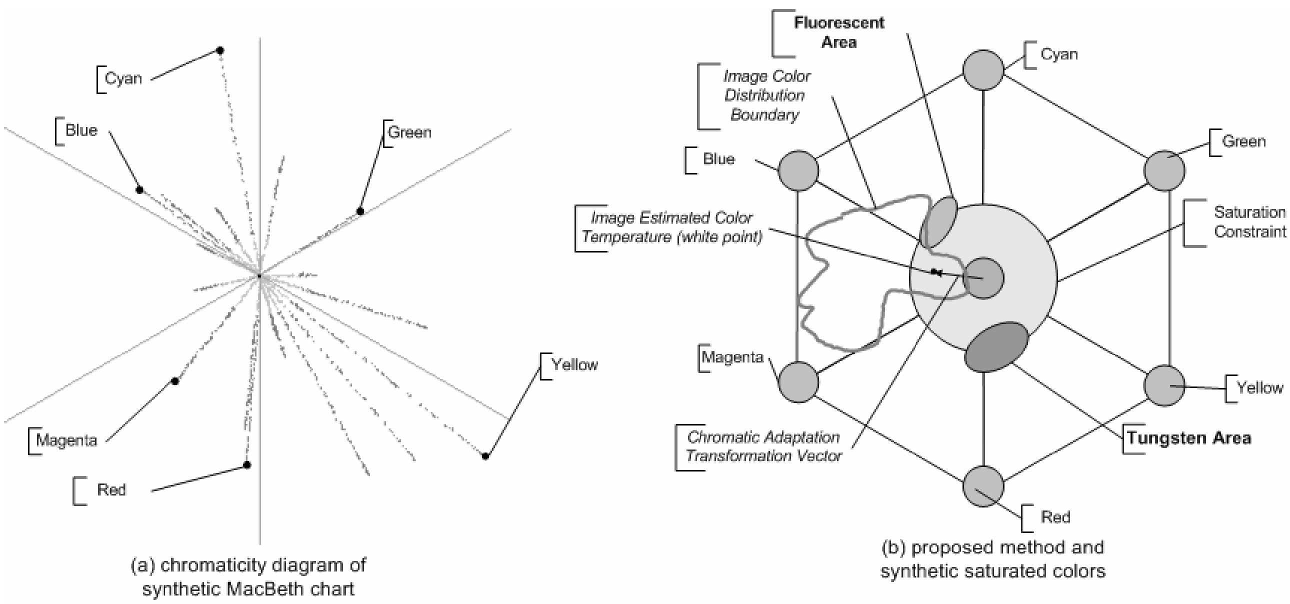

Figure 4 (a) Synthetic reference: MacBeth chart chromaticity diagram in proposed methodology (b) 'white point' estimation methodology using a plane projection of the HSV chromaticity diagram

As illustrated in Figure 4(b) the methodology of the proposed algorithm includes two steps: First, the 'chromatic adaptation transform vector' is determined using an average of the chromaticity diagram within the aforementioned constraints (luminance and saturation). The chromatic adaptation vector is defined as connecting the 'white point' (which defines the estimated illuminant in the captured image) and the centre of chromaticity diagram (which \defines 'white point' for the D65 illuminant). Second, a chromatic adaptation is computed or, if available, selected from a set of predefined ones.

2. Chromatic adaptation

After the 'white point' has been estimated, the second step of the proposed method is the chromatic transformation from the estimated illuminant to the D65 reference illuminant. As shown in the literature[9,10], a 'white point' transformation using only a diagonal matrix offers low performance and a computed linear transformation can perform significantly better. Our approach in this step uses pre-computed transformation matrixes for known illuminants (see Fig.4 (b)). In this step, if the 'chromatic adaptation vector' points to an area associated with a predetermined illuminant, the pre-computed transformation from that illuminant to D65 is used. If this is not the case, a transformation matrix is computed from the estimated 'white point' to the D65 illuminant. For this step, the linearized Bradford transform is used in the manner suggested in[11]. Even though there is evidence that spectral sharpening might perform better than the linearized Bradford transform[12], the linearized Bradford transform was used for practical reasons - the resultant coefficients for the spectral sharpening transformation requires a higher SNR from the sensor than what a typical cell-phone camera sensor offers today.

RESULTS

To have an estimation of the performance of the proposed methodology, the following characterization was done: Using a cell-phone camera CMOS sensor and four illuminants, several pictures were taken and the algorithm was applied step by step, measuring for each step the performances as a color error in La*b* space. The illuminants used were: D75 at around 7500K, F at around 4100, A at 2865K and a second tungsten illuminant at around 2300K denoted HOR. For all 4 illuminants, pictures of MacBeth chart were taken. To characterize the color reproduction accuracy, the metrics used were: mean square error (MSE) and root mean square error (RMS) in a*b* plane of CIELAB color space, measured with camera colors corrected for saturation as well as uncorrected. The RMS error gives more weight to large errors. To do the measurements, ImaTest measurement software was used[13].

For each illuminant 2 other images were computed from the image taken: one with only a simple white point correction according to the first step of the algorithm and a second image that included a chromatic adaptation transform to the white point found in step 1.

The following table summarizes the results:

	illuminant	**D75 (7500K)**			**F (4100K)**			**A (2865K)**			**HOR (2300K)**		
		orig	Awb	ca	orig	awb	ca	orig	awb	ca	orig	awb	ca
Saturation corrected	MSEa	32	15.3	**10.5**	16.8	9.49	**10.9**	17.7	12	**12.3**	24.8	16.9	**12.1**
	RMSa	34.6	16.8	**12.3**	18.8	11.7	**13.8**	20.3	15.6	**16.5**	27.9	19.6	**14.9**
Saturation uncorrected	MSEb	28.6	19.6	**10.5**	18.3	14.3	**10.9**	18.8	16.9	**12.3**	23.4	20.5	**12.4**
	RMSSb	32.2	23.7	**12.3**	22	18.8	**13.7**	22.2	21.9	**16.5**	26.6	25.3	**15.1**

Figure 5 Table: 'orig' -original uncorrected sensor response, 'awb'-using proposed white point correction (awb step 1), -'ca' using chromatic adaptation in sensor space (awb step 2)

Thus, for each illuminant, one image was captured and two were generated from the captured one. For each of these, the chromatic diagram projection was calculated and the diagrams were compared side by side (see below). Each row of chromatic diagrams represents results for one illuminant. The first chromatic diagram is titled 'orig' and represents the chromatic diagram of the original uncorrected picture, the light area showing the constrained area used to calculate the chromatic adaptation vector, which is represented magnified in the same picture. The second chromatic diagram, titled 'awb' represents a chromatic diagram of a diagonal transformation of the uncorrected picture to the 'white point' in RGB space. As it can be seen, the 'white point' correction is accurate for white, but the resultant picture suffers from hue and saturation errors, thus the chromatic adaptation step becomes necessary in order to achieve the targeted color reproduction error. The third picture titled 'ca' represents a chromaticity diagram of the uncorrected picture after a chromatic adaptation transformation described by the chromatic adaptation vector identified by the 'white point'. The chromatic adaptation result presented is optimized in sensor space for the predetermined type of illuminant identified by the chromatic adaptation vector.

In the following figures, the axis definitions are omitted for clarity, but for reference Figure 4 should be used. Also, the source images have not been included and the chromaticity diagram was used to convey the result since the method is considered objective. Also, for each illuminant, (c) shows the position of the primaries in the reference MacBeth chart as small squares. Note the noise increase in (c) due to applied processing (the SNR of the original is critical in this step).

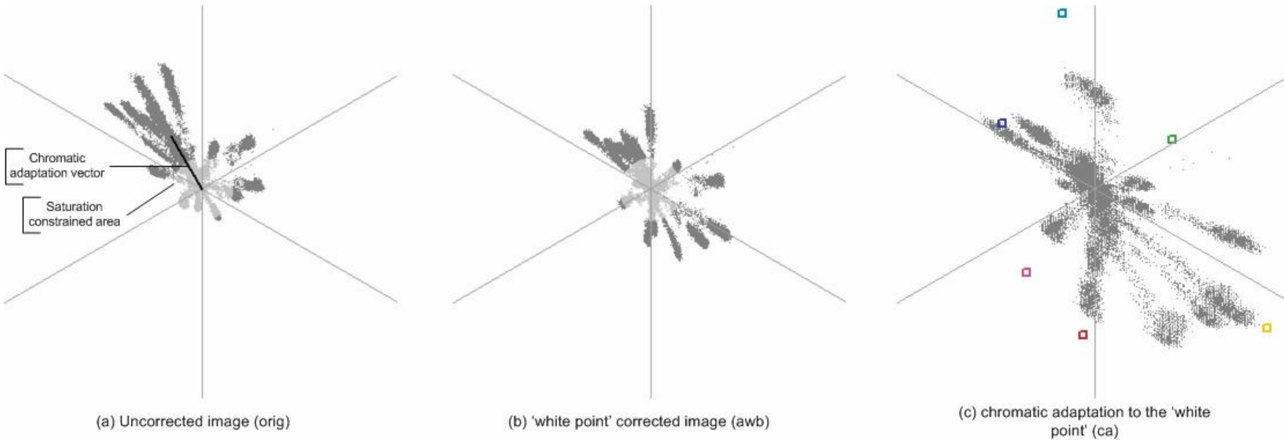

Figure 6 Illuminant D75(7500K) chromatic diagrams: uncorrected, 'white point' correction and chromatic adaptation

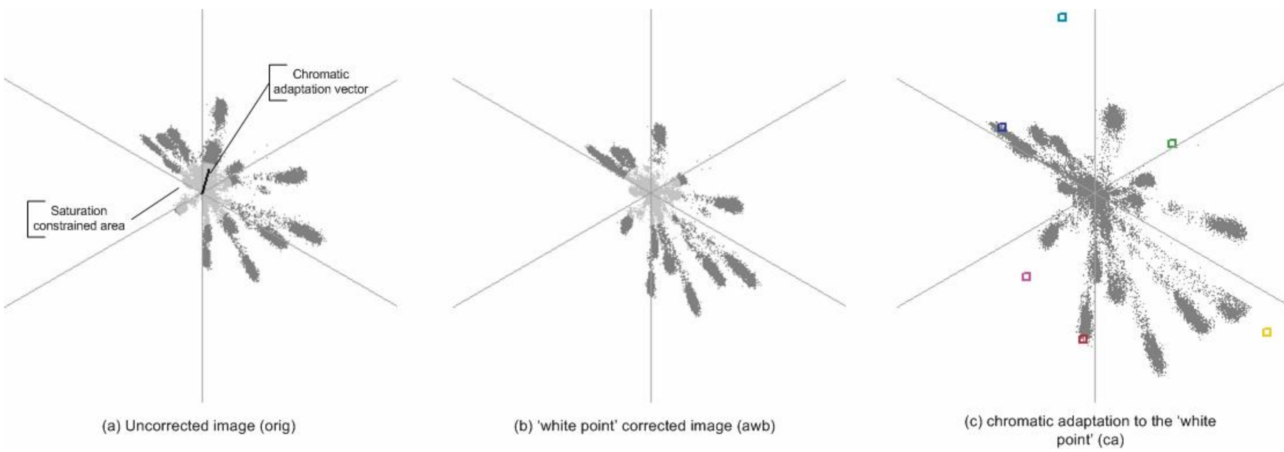

Figure 7 Illuminant F(4100K) chromatic diagrams: uncorrected, 'white point' correction and chromatic adaptation

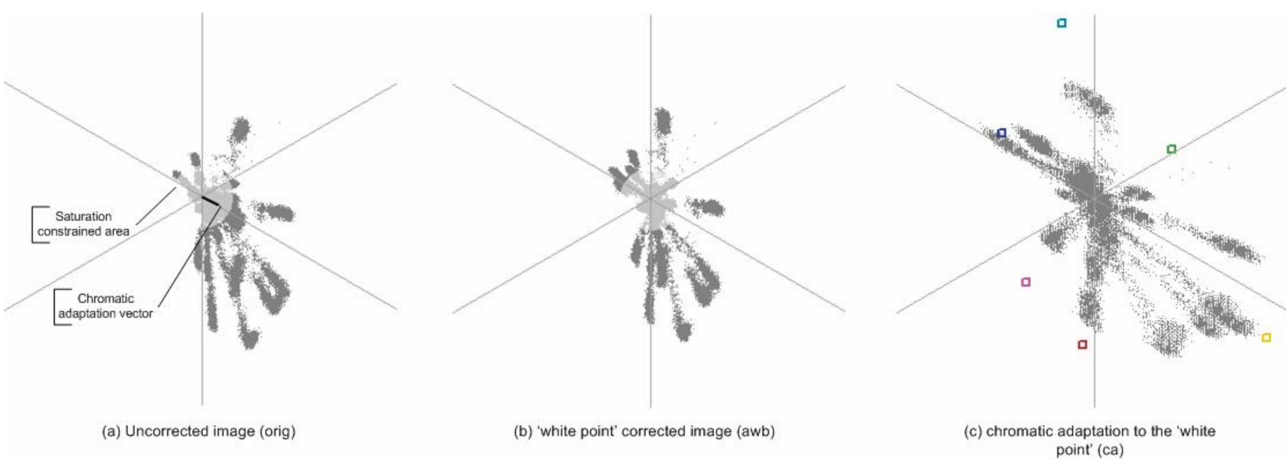

Figure 8 Illuminant A(2865K) chromatic diagrams: uncorrected, 'white point' correction and chromatic adaptation

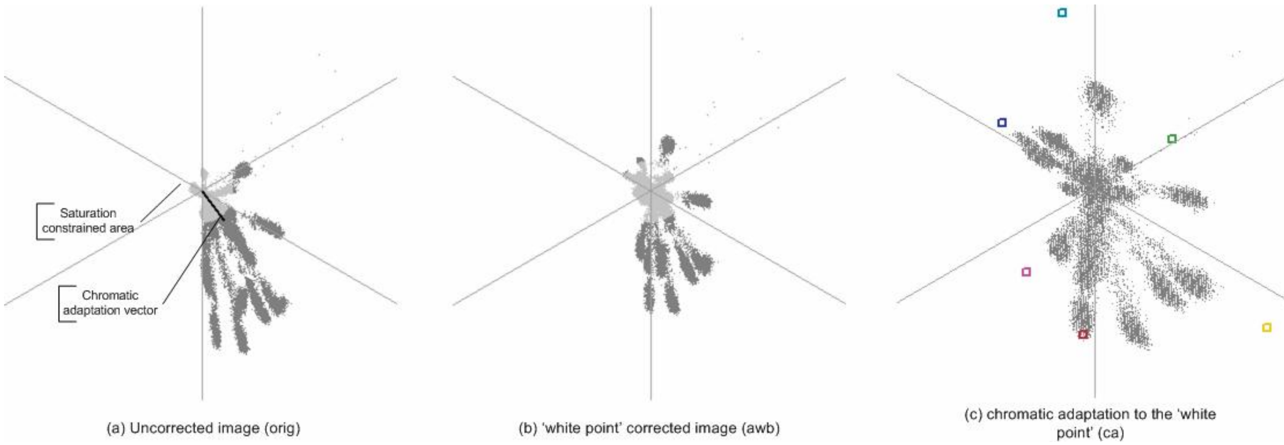

Figure 9 Illuminant HOR(2300K) chromatic diagrams: uncorrected, 'white point' correction and chromatic adaptation

As the chromaticity diagrams shows, the method provides reasonable accuracy in illuminant estimation, provided that scene colorimetric information is reasonable, but also that only a white point correction, although enough to 'white balance' the achromatic colors in the image, does not offer enough color accuracy in adapting for the scene illuminant.

CONCLUSIONS

A solution was proposed to address the 'white balance' problem for cell-phone cameras that is inexpensive to implement and can offer reasonable color performances in most situations. The solution is described as a two-step process: a 'white point' detection or illuminant estimation followed by a chromatic adaptation to a standard D65 illuminant. The paper introduces a projection of a polar-coordinates color space as a tool to generate a chromaticity diagram of the captured image. It is shown that such chromaticity diagrams offer enough information for the 'white point' detection with reasonable accuracy.

ACKNOWLEDGMENTS

The authors would like to thank to Greg VanSickle for the help and support in preparing this paper.

REFERENCES

1. David C. Day , *Evaluation of Optical Flare and Its Effects On Spectral Estimation Accuracy*, Technical Report, www.Art-si.org, (2003)
2. U. Barnhofer, J. DiCarlo, Ben Olding and B. Wandell, *Color Estimation Error Trade-offs*, *Proc. SPIE* Vol. 5017, Santa Clara, CA, (2003)
3. F. Xiao, X.Zhang, B.Fowler, Color Processing in camera phones: how good does it need to be?, Proceedings of SPIE-IS&T Electronic Imaging, Vol.5678 (2005), pp96-104
4. D.A.Forsyth, A Novel Algorithm for color Constancy, International Journal of Computer Vision, 5:1, 5-36 (1990) pp5-24
5. M.D.Fairchild, *Color Appearance Models*, 2nd ed, Wiley-IS&T Series in Imaging Science, pp132-133.
6. Wyszecki, G., & Stiles, WS (1982). *Color science: Concepts and methods, quantitative data and formulae*. 2nd ed Wiley Classics Library Edition (2000) pp443-451
7. R.S. Berns, Billmeyer and Saltzman's *Principles of Color Technology*, 3rd ed., John Wiley & Sons, 2000
8. K.Wnukowicz, W.Skarbek, *Color temperature estimation algorithm for digital images-properties and convergence*, Contributed paper at Opto-electronics Review 11(3) (2003) pp193-196

9. J.A.S.Viggiano*, Comparison of the accuracy of different white balancing options as quantified by their color constancy*, Sensors and Camera Systems for Scientific, Industrial, and Digital Photography Applications, San Jose, California;June 7, 2004; pp323-333;
10. F. Xiao, J. Farrell, J. DiCarlo and B. Wandell*, Preferred Color Spaces for White Balancing*, Proceedings of the SPIE Electronic Imaging '2003 Conference, Vol. 5017, Santa Clara, CA, (2003)
11. S. Süsstrunk, J. Holm, G. D. Finlayson, *Chromatic Adaptation Performance of Different RGB Sensors* , IS&T/SPIE Electronic Imaging, SPIE Vol. 4300, (2001)
12. G. D. Finlayson, S. Süsstrunk, *Spectral Sharpening and the Bradford Transform,* Proc. International Conference on Information Systems (2000), p. 236-243
13. Software package for camera performance measurements, http://www.imatest.com/
14. Lee, Hsien-Che, *Estimating the illuminant color from the shading of a smooth surface*, A.I. Memo 1098, MIT A.I Lab(1998)