

whitebalPR – a New Method for Automatic White Balance

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Abstract

Unlike previous methods, whitebalPR determines the color of illumination by obtaining exact measurements from the photographic scene rather than by estimating it. The new method is based on polarization-difference imaging and discloses new opportunities to measure the color of illumination within digital cameras. It exploits the polarization of light that is specularly reflected at dielectric surfaces.

An embodiment is given to integrate whitebalPR into digital cameras.

The experimental results demonstrate a very high potential of accuracy and reliability by this approach.

Introduction

A correct white balance (WB) is a basic task for high image quality in digital photography. The result of a proper WB is the neutral reproduction of grey objects independent of the spectral energy distribution of the current illuminant.

Digital cameras offer various WB modes to compensate for the color of the illumination such as

- a manual adjustment using a grey card reference,
- fixed settings to a given color temperature or
- an automatic white balancing (AWB) procedure inside of the camera.

It's known from experience that the automatic WB of digital cameras depends on the image content and may lead to visually different image results for the same scene illuminant.

Due to its importance for image quality, numerous AWB strategies and methods have been developed [3]-[7]. All these methods are based on image processing algorithms being directly applied to the sensor's RGB image data.

The white balancing process consists of two steps:

1. Determination of an estimate for the chromaticity of the scene illuminant from the captured image data
2. Adaptation of the image data to that chromaticity

The first step in particular is responsible for the accuracy and quality of the total WB process and therefore is focused on in this article. In literature the algorithms performing step one are referred to as color constancy algorithms and can be divided into physics-based and statistics-based methods:

The physics-based algorithms (e.g. maximum RGB, dichromatic reflection model) are based on the characteristics of object reflectances and utilize the fact that illuminating light reflected at the surfaces of dielectric objects maintains the color of the incident light. However, specular highlights often can't be successfully evaluated in consequence of saturated image regions. The approach of the so-called dichromatic reflection model needs segmentation into object surfaces and only is effective under well-defined illumination conditions [6]. Newer techniques analyze highlight areas to obviate the segmentation process [8].

The statistics-based algorithms (e.g. Color by Correlation, grey world etc.) rely on the probability of the distribution of the

observed colors dependant on the color of illumination. These methods often fail if only few or dominant colors occur in the scene [6].

For scene analysis (e.g. 3D shape recovery) in computer vision, different approaches have been investigated to separate the surface reflection (the so-called *specular* component) from the body reflection (the so-called *diffuse* component) [9-15]. The surface reflections produce image highlights as a complex function of the illumination and viewing geometry and the surface orientation and roughness. Hence, one strategy is to dispose of the highlight component before analysis by simple models [10]. The methods to separate the specular and diffuse components are generally based on the dichromatic reflection model.

Besides the purely computational methods, the specular components can be effectively separated by using a polarization filter in front of the camera [11-15]. A sequence of images is taken by rotating the filter and processed to reconstruct the specular and diffuse reflections.

A similar application for using a polarization filter is the so-called polarization-difference imaging (PDI). Its aim is descattering by subtracting two differently polarized images [16, 17].

The proposed new method for automatic white balance is based on the physical measurement procedure according to PDI but adapted to the task to measure the color of illumination.

Color Constancy by whitebalPR

Basic Principle

Unlike the previous color constancy methods, this new proposal is based upon the degree of polarization that arises by reflections at dielectric surfaces.

This physical phenomenon is described by Fresnel's law [2] according to equations (1) – (3):

$$\alpha_2 = \sin^{-1} \left(\frac{n_1}{n_2} \cdot \sin(\alpha_1) \right) \quad (1)$$

$$\rho_s = \left(\frac{\sin(\alpha_1 - \alpha_2)}{\sin(\alpha_1 + \alpha_2)} \right)^2 \quad (2)$$

$$\rho_p = \left(\frac{\tan(\alpha_1 - \alpha_2)}{\tan(\alpha_1 + \alpha_2)} \right)^2 \quad (3)$$

It determines the specular reflectance for a dielectric glossy surface specified by its refraction index n_2 . The specular reflectance ρ depends on the angle of incidence α_1 and is different for the two electric field components perpendicular (index "s") and parallel (index "p") to the plane of incidence (see Figure 1 and Figure 2).

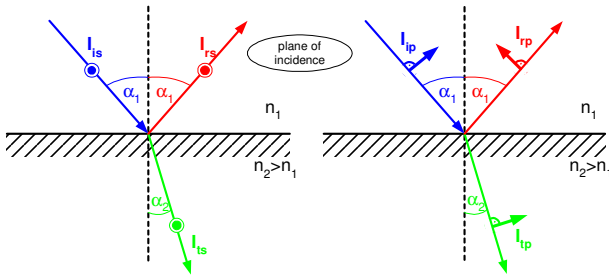


Figure 1. Definitions for Fresnel's law with the electric field component perpendicular (left) and parallel (right) to the plane of incidence.

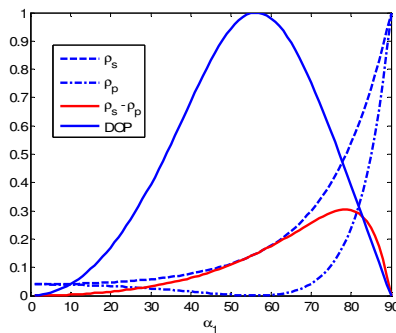


Figure 2. Typical specular reflectances ρ_s and ρ_p for a dielectric surface with a ratio of refraction indices $n_2/n_1=1.5$. Additionally, the curves for the degree of polarization (DOP) and the difference reflectance ($\rho_s - \rho_p$) are given for that case.

For non-polarized incident light, its electric field has no preferred orientation resulting in the arithmetic mean of ρ_s and ρ_p for the overall reflectance $\rho = (\rho_s + \rho_p) / 2$.

The reflected light gets at least partially polarized as the reflectances ρ_s and ρ_p differ for angles α_i except $\alpha_i = 0^\circ$ or $\alpha_i = 90^\circ$. To offer a measure the degree of polarization (DOP) is reasonably defined as

$$DOP = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = \frac{\rho_s - \rho_p}{\rho_s + \rho_p}. \quad (4)$$

A value $DOP = 1$ indicates completely polarized light. Figure 2 exhibits this behaviour for an angle of incidence of about $\alpha_i = 56^\circ$, the so-called Brewster angle. In this case, the parallel electric field component disappears and causes the complete polarization of the reflected light.

The most significant statement of the dichromatic reflection model for the application of polarized reflections to color constancy is the thesis that specular reflectances of dielectric surfaces are approximately independent of the wavelength [18]. Therefore, the specularly reflected light of arbitrary surfaces is spectrally composed like the illumination and looks neutral by definition [1]. For deriving the color of illumination, the task is to measure the specular reflection and to evaluate its color.

Figure 3 shows three different types of reflection phenomena of dielectric materials:

1. specular reflections at matt surfaces,
2. specular reflections at glossy surfaces and
3. diffuse reflections from the object body.

In contrast to the specular types, the diffuse reflection type (often referred to as remission) is the carrier of the object's color information. Moreover, the diffuse reflected light is non-polarized by multiple scattering effects within the body. This characteristic is the second key characteristic of reflected light needed to separate the colored diffuse part from the neutral specular part.

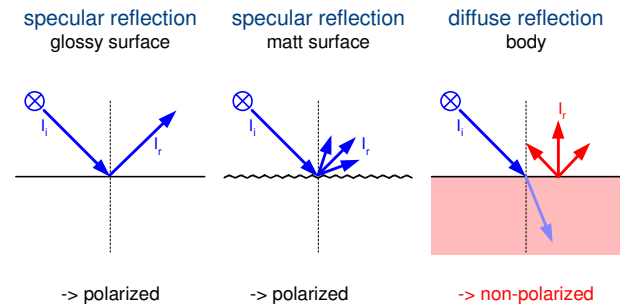


Figure 3. Different types of reflections at surfaces of dielectric objects

Polarization-Difference Imaging and Color

In consequence, the specular reflection can be evaluated by at least two images which are taken under different polarization directions (Figure 4).

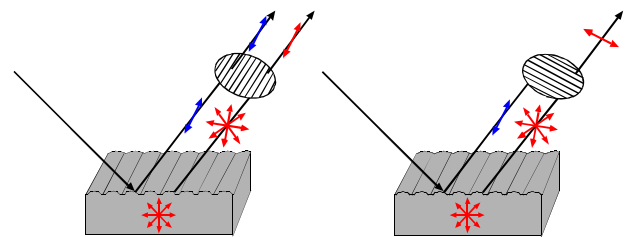


Figure 4. Effect of different polarizer orientations on surface reflections (polarized, blue) and body reflections (non-polarized, red).

The subtraction of the polarized images (analogue to polarized-difference imaging PDI) detects the polarization of the neutrally reflected light parts and eliminates the non-polarized colored parts. The result is the color of illumination within the scene and how the sensor receives it (see Figure 5 and Figure 6).

Both the reflected light intensity and its degree of polarization considerably depend on the orientation of the object surface to the light source and of the camera and also on the roughness of its surface, but not at all on the remitted color. In the case of three-dimensional objects a locally variable signal level of the difference image results accordingly (see Figure 6 bottom).

The ratios of the difference color values are the exact information needed for an accurate white balance of an image captured under these conditions of illumination (Figure 7).

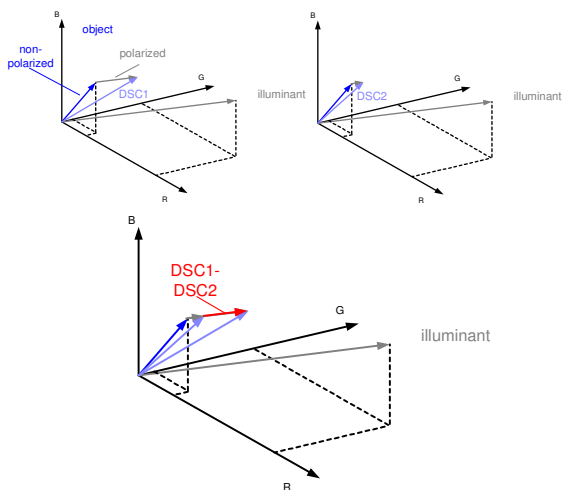


Figure 5. Illustration of polarization-difference imaging in the DSC color space. Only the polarized part is being varied by the polarizer in front of the camera between the two captures (top left and right). The difference vector (DSC1-DSC2) instantaneously offers the requested color of illumination (bottom).

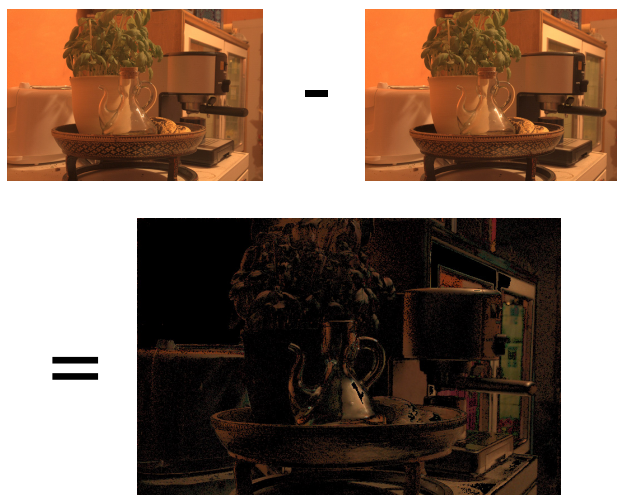


Figure 6. Subtraction of two differently polarized images to determine the difference image. All images are displayed over an appropriate gamma curve with $\gamma=2.2$. The difference image shows saturated pixels as black pixels being faded out for the evaluation of the color of illumination.

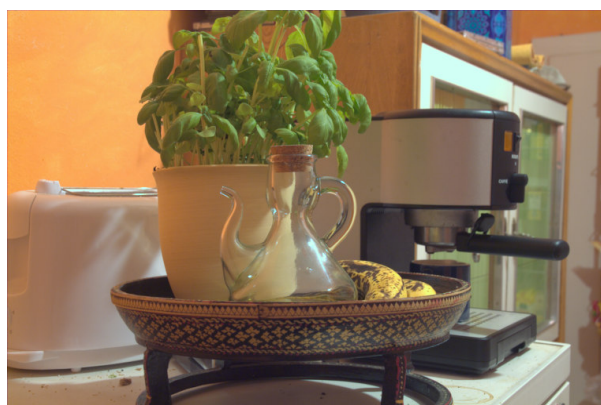


Figure 7. Result of the new WB method.

Algorithms to Determine the Chromaticities of the Illuminant

The further analysis of the differently polarized images is carried out on a PC based upon intensity-linear color signals (R, G, B). They are generated from the raw data file by means of the dcrw raw converter software.

For calculating the chromaticity of the illuminant from a suitable pair of images $(R, G, B)_1$ and $(R, G, B)_2$ the following steps are performed:

1. Calculation of the difference image:

$$\begin{aligned} R^\Delta(x, y) &= R_1(x, y) - R_2(x, y) \\ G^\Delta(x, y) &= G_1(x, y) - G_2(x, y) \\ B^\Delta(x, y) &= B_1(x, y) - B_2(x, y) \end{aligned} \quad (7)$$

The difference image $(R, G, B)^\Delta$ generally is signed.

2. Transformation to the red and green chromaticity values:

$$\begin{aligned} r(x, y) &= \frac{R^\Delta(x, y)}{R^\Delta(x, y) + G^\Delta(x, y) + B^\Delta(x, y)} \\ g(x, y) &= \frac{G^\Delta(x, y)}{R^\Delta(x, y) + G^\Delta(x, y) + B^\Delta(x, y)} \end{aligned} \quad (8)$$

3. Evaluation of the histogram distribution $h(r, g)$ with an accuracy of $\Delta r = \Delta g = 0.01$

For the histogram computation only pixels are considered which are not clipped in any color.

4. Determination of the mean chromaticity (\bar{r}, \bar{g}) of the scene illuminant by averaging the chromaticities weighted with the histogram values $h(r_i, g_i)$:

$$\begin{pmatrix} \bar{r} \\ \bar{g} \end{pmatrix} = \frac{\sum_N \begin{pmatrix} r_i \\ g_i \end{pmatrix} \cdot h(r_i, g_i)}{\sum_N h(r_i, g_i)} \quad (9)$$

For reducing the impact of noise on the histogram evaluation only chromaticities are considered, whose relative histogram values are more than 10% of the maximum: $h(r_i, g_i) > \text{Max}(h(r, g))/10$

5. The blue chromaticity value \bar{b} can be identified by

$$\bar{b} = 1 - \bar{r} - \bar{g} \quad (10)$$

For the maximization of the level of the difference signal it is recommended to subtract pairs of images with polarization directions being perpendicular to each other.

The evaluation of several polarization directions takes into account different positions of light sources within the scene. Usually 2 pairs of images (e.g. $0^\circ/90^\circ$ and $45^\circ/135^\circ$) are adequate to control the procedure sufficiently robust (see above).

Integration into Digital Cameras

The application is shown schematically in Figure 8. A scene is optically projected and multi-captured under different orientations of the polarizer. The image sequence is computationally processed to the color of illumination.

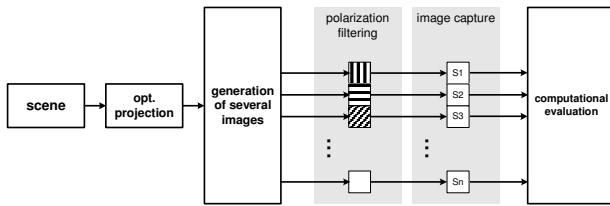


Figure 8. Schematic of the new method to analyze the color of illumination.

Different approaches to realize PDI in digital cameras are specified in [19]. In order to provide for a local white balance, it appears particularly interesting to combine the color filter array (CFA) with a polarization filter array on the HiRes image sensor (Figure 9). Since the lighting conditions rather slowly change within a scene, the polarization filter array can be spread on the sensor's surface in order to disturb the image information as few as possible by the polarization areas.

For proper operation it is sufficient to apply two polarization directions twisted by 45° , e.g. 0° and 45° . For orthogonally polarized light components (e.g. 0° and 90°) we have

$$I_{\text{non-polarized}} = I_{0^\circ} + I_{90^\circ} \quad (5)$$

and in consequence for the corresponding difference image

$$I_{0^\circ} - I_{90^\circ} = I_{0^\circ} - (I_{\text{non-polarized}} - I_{0^\circ}) = 2I_{0^\circ} - I_{\text{non-polarized}} \quad (6)$$

Thus, all directions in steps of 45° can be evaluated by charging the polarized pixels against its non-polarized neighborhood.

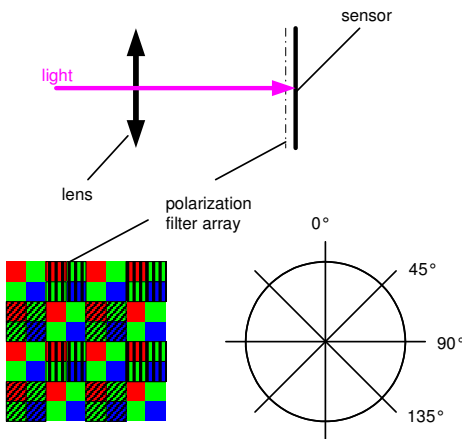


Figure 9. Sensor module with color and polarization filter array.

The advantages of the integration into the camera sensor are as follows:

- Simultaneous capturing of different polarization directions
- Congruence of the exposures
- Possibility to analyze and balance the color of the illuminant locally

Experimental Setup

For this investigation the images are taken with Fuji's DSLR S3 Pro, whose optics is combined with a manually adjustable polarization filter. The scene is captured at least three times using the raw data format by means of a tripod. From exposure to exposure, the transmission axis of the polarization filter is rotated manually to receive different polarization directions (e.g. 0° , 45° , 90° , 135°). The exposure settings have to be left identically within one cycle.

It is very important that static conditions exist between the exposures of one cycle. Therefore, the images have to be congruent with each other and of the same exposure level. Every deviation of these requirements (e.g. by moving objects or intensity variations of the illumination especially for outdoor photography) causes measuring errors within the difference image.

Depending on the characteristics of the scene and the objective of the investigation it can be appropriate to use different exposure levels for image acquisition and analysis. Thus, shadows (due to noise) and highlights (due to clipping) of the scene might be utilized yet which otherwise couldn't be reasonably examined.

Results and Discussion

In order to convey a first impression of the functionality and the performance of whitebalPR, the image example from above is processed and opposed to the results of another approach of color constancy methods, the grey world algorithm.

We simply realized grey world by the total mean over the (r,g,b)-chromaticities of the original image (or exactly $((R,G,B)_1 + (R,G,B)_2)/2$). Only non-saturated pixels are taken into account for this averaging.

Figure 10 demonstrates the functionality of whitebalPR against grey world very clearly. Discounting the object colors by the PDI method obviously works fine. Thus, the color of illumination dominates the chromaticity histogram of the polarization-difference image of whitebalPR. In consequence, the analyzed white point (WP) lies very close to the real measured grey chromaticity (Grey).

On the other hand, the original chromaticity histogram (left center Figure 10) is strongly biased by the orange colored wall and the green plant leaves. The WP estimated by greyworld departs from grey and causes a bluish color appearance compared to the neutral result by whitebalPR.

Figure 11 exhibits the impact of specular reflections at glossy dielectric surfaces on PDI by whitebalPR. The scene is set up by an artificial test chart and a pane of glass. The different objects of the testchart are mirrored by the directional reflection at the glossy surface of the glass.

Two effects can be observed:

1. Discounting the object colors within the mirror image fails (Figure 11 top left and right).
The specular reflections at the pane of glass polarize the colored non-polarized light parts of the objects. That way, the object colors become "visible" for PDI.
2. The polarization-difference image indicates a signal level by the mirror image being higher than the signal level by the objects themselves.

The signal level of the PD image primarily depends on two variables:

1. The angle of incidence (cf. α_i , Figure 1 and Figure 2). It is represented by the half of the angle spanned by the camera and the light source with respect to the object point. The PD signal level is directly proportional to the difference of the orthogonal reflectances ($\rho_s(\alpha_i) - \rho_p(\alpha_i)$) and strongly prefers high angles of incidence around 70° - 80° (see Figure 2).
2. The roughness of the object surface. Glossy reflections are proportional to the luminance of the mirrored object and always brighter than matt reflections. Matt reflections tend to be proportional to the illuminance at the surface point.

These observations let us draw the following conclusions:

- In the case of glossy surfaces (mirror images) only reflections of (dominant) light sources or neutral objects can be reasonably analyzed for the color of illumination. Colored objects cause measurement errors.
- Matt surfaces are appropriate to measure the color of illumination by whitebalPR.

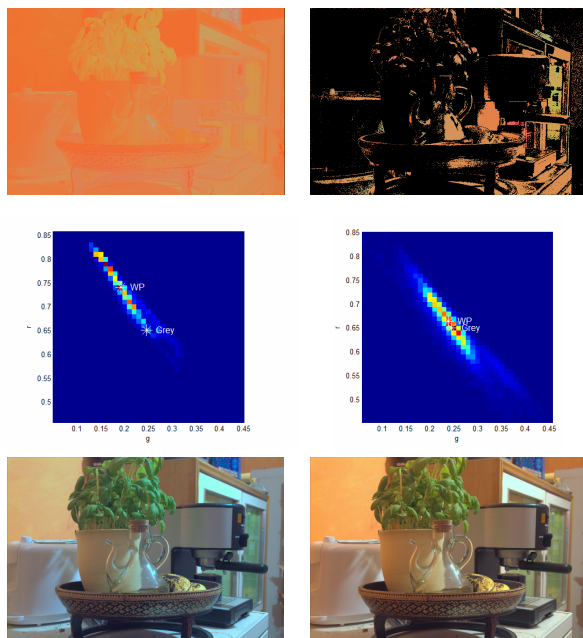


Figure 10. Comparison of the results of grey world (left column) and whitebalPR (right column). Top: chromaticity images of the original (left) and the polarization-difference image (right). Center and bottom: corresponding chromaticity histograms and final results after white balance to the detected white point (WP).

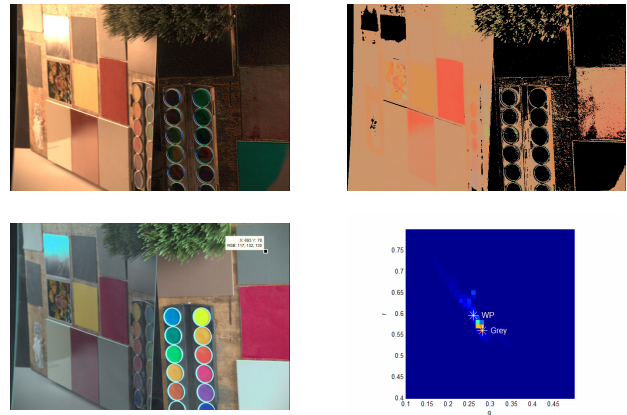


Figure 11. Impact of glossy surfaces and mirror images on whitebalPR. Mirrored colored objects appear in the PD image (top left: PD image, top right: PD chromaticity image) and move the white point away from grey (bottom right: chromaticity histogram). The balanced image (bottom left) is slightly color casted.

Conclusions

WhitebalPR is based on polarization-difference imaging and discloses new opportunities to measure the color of illumination within digital cameras. This is in contrast to previous methods estimating the color of illumination from the image data.

Further advantages of whitebalPR comprise:

- Potential of a high accuracy
- Potential of a local white balance
- No constraints or a priori information on illuminants
- No constraints on the colors of the scene
- Simple image processing algorithms
- No image segmentation required

The next steps for further investigations will be:

- Optimizing the data analysis concerning its measuring accuracy with noisy difference images
- Recognition of bad mirror images
- Exploring complex real scenes with multiple primary and secondary light sources

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Author Biography

Gregor Fischer received his diploma in electrical engineering (1990) and PhD in engineering sciences (1997) from the Aachen University. Following he worked in the basic research department for Agfa lab equipment in Munich/Germany. In 2004, Gregor Fischer has been appointed to the phototechnology professorship at the Institute of Media and Imaging Technology of the Cologne University of Applied Sciences. Since 2006 he is a member of the DIN working group for still photography.

His research focuses in image systems design, digital photography and different methods of digital image quality assessment and enhancement.