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Short Paper

Calibration-Based Auto White Balance Method for Digital Still Camera*

LI-CHENG CHIU AND CHIOU-SHANN FUH
Department of Computer Science and Information Engineering
National Taiwan University
Taipei, 106 Taiwan

This paper introduces a calibration-based auto white balance method for digital still camera. The main idea is to detect white-points in an image accurately. White-Point Color Temperature Curve (WPCTC) is constructed from sensor calibration and is utilized to estimate white-point locations in a scene. Minimum Color Temperature Distance (*MCTD*) with a luminance threshold is defined to further locate white-points of an image exactly. Our proposed method is performed in *RGB* color space so it is suitable for digital still camera pipeline design. In our experiments, our approach is compared with other white balance methods and performs better in color consistency.

Keywords: white balance, white-point, white-point color temperature curve, sensor calibration, minimum color temperature distance

1. INTRODUCTION

The demand of Digital Still Cameras (DSCs) grows dramatically in the past years worldwide. Auto white balance is one of key technologies in digital cameras. DSCs usually adopt Charge-Coupled Device (CCD) or Complementary Metal Oxide Semiconductor (CMOS) as photoreceptor elements. Due to the limitation of current sensor manufacture technology; there still exist differences of response curves between human eyes and photoreceptor elements. Besides, each sensor has individual spectrum response curve even under the same light source. This phenomenon makes image colors captured by a sensor different from colors observed by human eyes. Auto white balance mainly compensates such differences and makes captured colors consistent with colors observed by human eyes. In high-end digital still camera market, an additional sensor is used to detect spectrum or illumination of environments and image colors are reproduced accurately by environment information. To reduce cost, a secondary spectrum sensor is often unavailable in most consumer digital cameras so various auto white balance methods based on image information rather than environment illumination are proposed to compensate the differences of response curves between sensors and human eyes.

This research proposes a sensor calibration-based white balance method using WPCTC and *MCTD* to estimate white-point locations in *G/R-G/B* color space. Image

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colors are further reproduced through the balances of *RGB* channels with accumulation of white-points. This paper is organized as follows. Section 2 describes previous related researches on auto white balance. Our proposed method and white-point characteristics are described in section 3. We verify the performance of our method and compare with other white balance methods in section 4 and followed by the conclusions and future works in section 5.

2. PREVIOUS RELATED WORKS

Gray World Assumption (GWA) [1-4] states that average of scene reflection is achromatic and can be defined as

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} \frac{K}{R_{acc}} & 0 & 0 \\ 0 & \frac{K}{G_{acc}} & 0 \\ 0 & 0 & \frac{K}{B_{acc}} \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$
$$K = (R_{acc} + G_{acc} + B_{acc})/3 \tag{1}$$

where (R', G', B'), (R, G, B) and (R_{acc}, G_{acc}, B_{acc}) are processed, original and accumulated pixel values for *RGB* channels. GWA assumes that accumulated pixel values of *RGB* channels are consistent in any scene so the diagonal matrix in Eq. (1) demonstrates the compensation gain of each channel. GWA is a popular method because a great deal of reflective surfaces usually exists in most scenes. This method will fail when major colors of a scene are dominated by few colors. Then, color compensation in Eq. (1) will result in excessive color correction.

Perfect Reflector Assumption (PRA) [1-4] describes that the brightest area in a scene corresponding to the points on a specular surface which transmits a great deal of information about the illumination of a scene. It means that the brightest area in a scene discloses white-point locations under various light sources. PRA adjusts color consistency based on the balance of the brightest white-points.

Fuzzy Rule Method (FZM) [5] analyzes images in $Cr - Cb$ color space and detects white-points when Cr/Cb is located within -1.5 to 0.5. Weng [6] examines a pixel as a white-point using proposed dynamic chromaticity threshold in $Cr - Cb$ domain and adjusts color based on pixels passing through the examination. Varsha [7] proposed a histogram equalization preprocessing on image to enhance contrast first; then obtain white-points by predefined threshold examination. This method works well on most complicated scenes but will fail when few white-points exist in a scene.

From above discussion, we can find that most researches propose methods in various color spaces to extract white areas of an image and then adjust colors based on detected white areas. *YCrCb* domain is often-used color space because the chromaticity of *YCrCb* color space represents color information. Unfortunately only *RGB* raw data format can be output from current image sensors. Our research is inspirited by the problem and we find an effective white-point detection method in *RGB* domain. The details of our method are described in the following section.

3. OUR PROPOSED CALIBRATION-BASED AUTO WHITE BALANCE

Fig. 1 is a typical image processing pipeline of digital still camera. It is observed that white balance in image pipeline is processed in *RGB* domain so color space transformation is unavailable in the white balance stage. It is also clear that most color processing steps in pipeline are carried out in *YUV* color space. Raw data in Fig. 1 represent the digitalized image pixel without further digital image processing and have single signal for each pixel (*R*, *G*, or *B*) shown in Fig. 2 rather than three signals for each pixel (*R*, *G*, and *B*), like JPEG format.

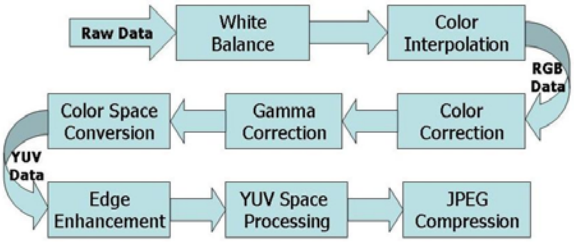


Fig. 1. A typical image processing pipeline.

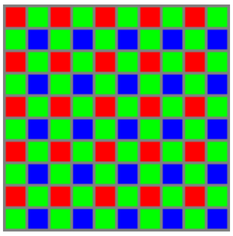


Fig. 2. Raw data format.

Fig. 3. GretagMacbeth ColorChecker.

Auto white balance aims that colors in a scene captured by an image sensor should be reproduced similar to colors observed by human eyes. Under various light sources, *RGB* values of white colors are always consistent so white color is usually regarded as an indexed color in a scene. In order to address white areas of an image correctly and meet the limitation of sensor output, our method models white-point detection in $G/R - G/B$ color space. The $G/R - G/B$ coordinate demonstrates the color temperature behavior of light sources. When color temperature of light source is higher, blue component is more and red component is less. On the contrary, blue component is less and red component is more when color temperature of light source is lower. Raw data with a GretagMacbeth ColorChecker in Fig. 3 under various light sources are gathered and G/R and G/B ratios of all blocks in GretagMacbeth ColorChecker are analyzed in Fig. 4. It is observed that

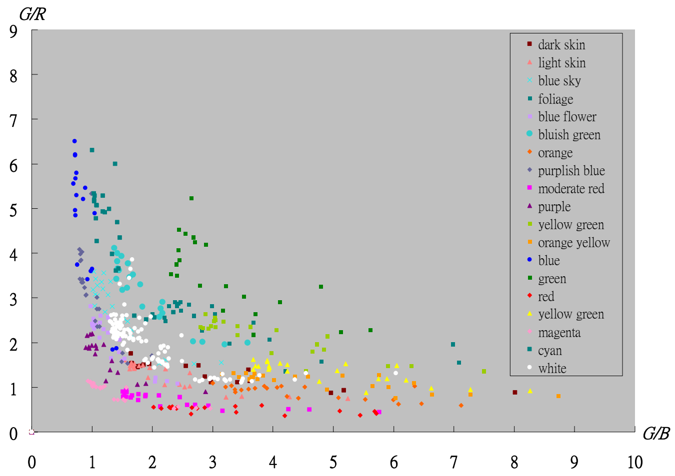


Fig. 4. Color block locations of GretagMacbeth ColorChecker in $G/R - G/B$ coordinate.

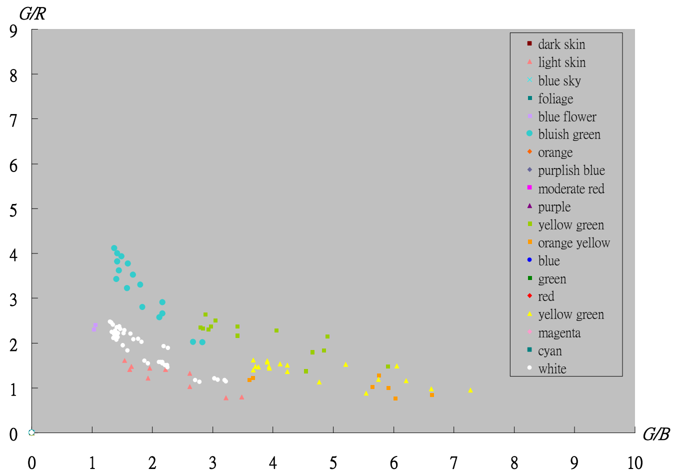


Fig. 5. Color block locations of GretagMacbeth ColorChecker in $G/R - G/B$ coordinate with a luminance threshold, 70.

the same block under various light sources are neighboring locations in $G/R - G/B$ coordinate and will be concentrated into a curve band, named as color temperature band. The concentration will be clearer when a luminance threshold, 70, is used to remove lower luminance pixel coordinates. Pixel luminance is a significant factor in the $G/R - G/B$ coordinate. Image sensor current noise is a zero-mean vibration and will be added into *RGB* channels when raw image is output. Therefore pixel luminance is higher, noise effect is lower; pixel luminance is lower, and noise effect is relatively higher. In Fig. 5, a luminance threshold is used to exclude low luminance pixels from the same raw data. It is obvious that white colors under various light sources are also concentrated into a band, named as White-Point Color Temperature Band (WPCTB). This band implies that white areas in various scenarios can be included in the WPCTB. It is concluded that white-

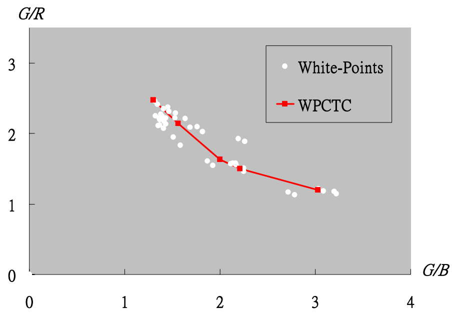


Fig. 6. Five-node piecewise color temperature curve represents WPCTC.

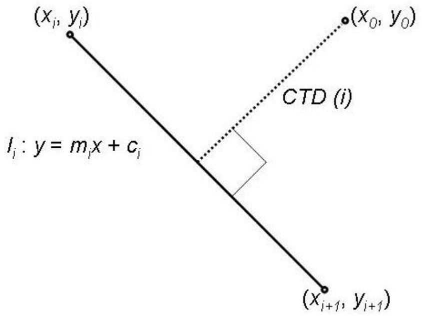


Fig. 7. $CTD(i)$ from (x_0, y_0) to the line between (x_i, y_i) and pixel (x_{i+1}, y_{i+1}).

points in a scene will be located into a band in the *luminance* – *G*/*R* – *G*/*B* three-dimensional color temperature coordinate.

The calibration of our proposed white balance is to capture a white chart by image sensor under five specific light sources. In our experiments, the color temperatures of these five light sources are 7,500K, 6,500K, 5,000K, 4,100K, and 3,100K. The five locations in *G*/*R* – *G*/*B* coordinate are demonstrated in Fig. 6 and this five-point curve is called as White Point Color Temperature Curve (WPCTC). Let these five color temperature coordinates be (x_1, y_1), …, (x_i, y_i), …, (x_5, y_5) and define color temperature distance and a Minimum Color Temperature Distance (*MCTD*) of a arbitrary pixel (x_0, y_0) as

$$CTD(x_0, y_0, i) = \frac{|m_i(x_0 - x_i) - (y_0 - y_i)|}{\sqrt{m_i^2 + 1}} \qquad i = 1, \ldots, 4 \tag{2}$$

and

$$MCTD(x_0, y_0) = \begin{cases} \sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2} & \text{if } x_0 < x_1 \,\&\, y_0 > y_1 \\ \sqrt{(x_0 - x_5)^2 + (y_0 - y_5)^2} & \text{if } x_0 > x_5 \,\&\, y_0 < y_5, \\ \text{Minmum}(CTD(i)) & \text{otherwise} \end{cases} \tag{3}$$

where m_i represents the slope between pixel (x_i, y_i) and pixel (x_{i+1}, y_{i+1}). Functions $CTD(x_0, y_0, i)$ and $MCTD(x_0, y_0)$ denote the four projection distances and shortest projection distance from arbitrary pixel to each line of WPCTC. Eq. (2) is the formula of projection distance from arbitrary pixel to one line with known slope in Fig. 7. It is clear that four *CTDs* and one *MCTD* must exist for each pixel. When *MCTD* is calculated, white-point detection mechanism can be expressed as

$$White\ Point = \begin{cases} \text{Yes} & \text{if } MCTD \le distance\ threshold \;\&\&\; L \ge luminance\ threshold \\ \text{No} & \text{otherwise} \end{cases}. \tag{4}$$

It means that an image pixel is regarded as a white-point when pixel luminance (L) exceeds the luminance threshold and *MCTD* is under the distance threshold. The luminance threshold is current noise cut-off threshold. It will affect the amount of white points but have few influences on final result when this threshold is large enough. Both two thresholds are image sensors characteristics and can be easily obtained by empirical analysis. Experiments show satisfactory results in most scenarios and sensors when the luminance and distance thresholds, 70 and 0.25, are used.

Concluded by above discussion, our proposed auto white balance method can be divided into three parts: white-point color temperature curve construction, white-point detection mechanism, and white balance adjustment. The detailed algorithm flow of our method is demonstrated in Fig. 8. First of all, white-point coordinates under five light sources are calibrated for a sensor and WPCTC of this sensor is composed of these five $G/R - G/B$ coordinates. WPCTC is the characteristic curve of a sensor and will not be changed during whole white balance procedure after sensor calibration. The second step is the white-point detection mechanism. An image pixel is regarded as a white-point when it pass through the examination of Eq. (4); then, corresponding *RGB* pixel values of this white-point are recorded and accumulated separately. If a pixel fails the examination of Eq. (4), do nothing and examine next pixel. The procedure is repeated until all pixels are examined. In the last step, the compensation white balance gains for red and blue channel are calculated by

$$\begin{aligned} R_{gain} &= G_{qual.acc}/R_{qual.acc} \\ B_{gain} &= G_{qual.acc}/B_{qual.acc} \end{aligned} \tag{5}$$

where (R_{gain}, B_{gain}) are the compensation white balance gains for red and blue channels and ($R_{qual.acc}$, $G_{qual.acc}$, $B_{qual.acc}$) denotes the accumulated *RGB* pixel values of qualified white points in an image.

4. EXPERIMENTS

In order to verify the performance of our proposed method, we prepare an image processing pipeline simulator including all functions in Fig. 1. Our simulator accepts raw data from sensor output. We implement three white balance methods in *RGB* color space, GWA, PRA, and our method and final results are compared by objective and subjective evaluations. Besides white balance function, all other functions and parameters are the same and the luminance and distance thresholds, 70 and 0.25, are used in our simulator.

GretagMacbeth ColorChecker images under seven light sources (3,000K, 4,500K, 5,000K, 5,800K, 6,500K, 7,000K, and 7,500K) are used to evaluate the capability of color reproduction between various white balance methods. We use average chromaticity [6, 7] in Eq. (6) as objective evaluation and comparison results of 20th block in GretagMacbeth ColorChecker are listed in Table 1.

$$\text{Average chromacity} = \sqrt{C_r^2 + C_b^2} \tag{6}$$

When perfect white balance is obtained, the three channels of 20th block will be consis-

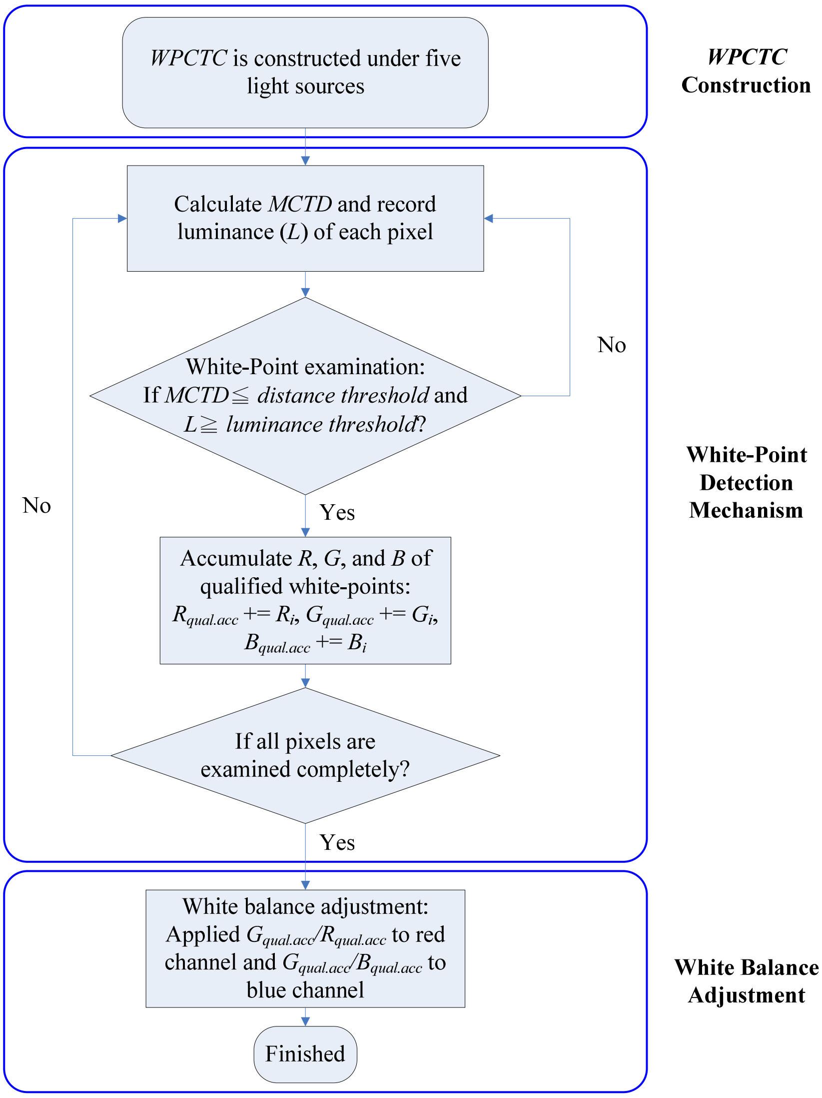


Fig. 8. Our proposed method flow.

Table 1. Chromaticity objective evaluation.

GWA has more stable results than PRA but our method performs the best in three methods.

Color Temperature	GWA	PRA	Our Method
3000K	3.064	4.255	0.991
4500K	2.941	5.978	2.109
5000K	4.145	2.511	1.522
5800K	3.534	1.426	0.968
6500K	3.448	5.290	0.887
7000K	3.285	4.929	0.476
7500K	3.510	2.749	0.829

tent and the average chromaticity will be zero. Experimental results show that GWA has more stable results than PRA but our method performs the best in color reproduction of three methods.

Besides objective evaluation, we examine real scenarios under various light sources by subjective observation. Fig. 9 shows a table under combination of two light sources, outdoor day light and indoor fluorescent lamp. In this case, GWA is a little too bluish, PRA performs too greenish, and our method obtains more accurate color consistency. Brush scene in Fig. 10 shows single dominant green color in a scene. GWA performs too purplish, PRA image is a little too greenish, and the image of our method has best color reproduction observed from upper floor. Fig. 11 represents a complex scene under cloudy weather and the scene color is dominated by the color of building, sky, and the asphalt road. Our proposed method also performs the best in this case, too. Fig. 12 shows a plant in a darker environment. Our proposed method can reproduce green and dark red leaves correctly.

Purple areas in Figs. 13 to 16 demonstrate the white-point detection results in Fig. 9 to 12 by PRA and our method. From the detection results, it is observed that PRA detects more over-exposure areas in the sky and green leaves than our method. More incorrect white-point detections will cause worse color reproduction and it is the reason why our method performs better than PRA.

From objective evaluation and observation of real scenarios, our method shows satisfactory and stable results. No matter complex light sources or only few dominant colors in a scene, our method is not misled by environment illumination and can reproduce color correctly. Experiments verify that our proposed method is feasible and performs well.

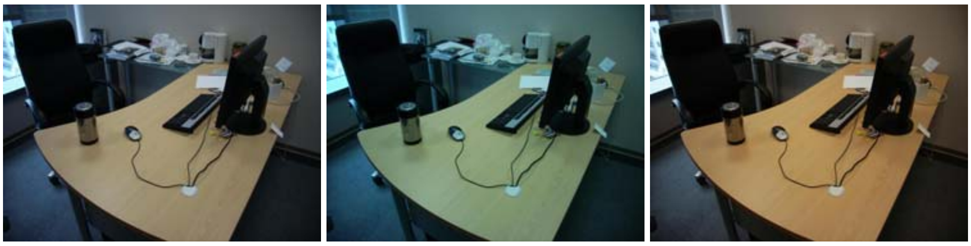

(a) (b) (c)

Fig. 9. Table scene under combined light sources with (a) GWA, a little too bluish; (b) PRA, too greenish; (c) Our proposed method.


(a) (b) (c)

Fig. 10. Brush scene under cloudy light source with (a) GWA, too purplish; (b) PRA, too greenish; (c) Our proposed method.


(a) (b) (c)

Fig. 11. Street scene under cloudy light source with (a) GWA, too greenish; (b) PRA, too reddish; (c) Our proposed method.


(a) (b) (c)

Fig. 12. Plant scene under day light with (a) GWA, too purplish; (b) PRA, too greenish; (c) Our proposed method.

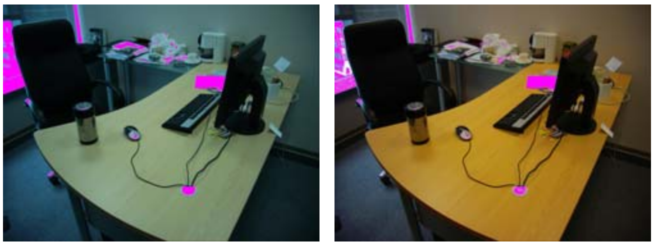
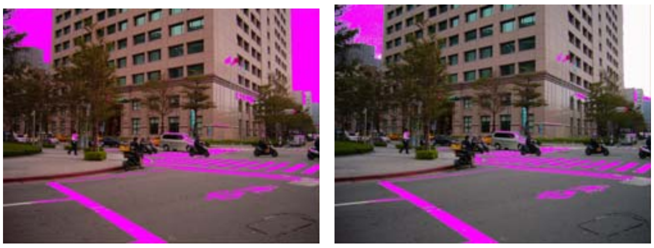

(a) (b)

Fig. 13. White-point detection results of Fig. 9 with (a) PRA; (b) Our proposed method.


(a) (b)

Fig. 14. White-point detection results of Fig. 10 with (a) PRA; (b) Our proposed method.



(a) (b)

Fig. 15. White-point detection results of Fig. 11 with (a) PRA; (b) Our proposed method.

(a) (b)

Fig. 16. White-point detection results of Fig. 12 with (a) PRA; (c) Our proposed method.

5. CONCLUSIONS AND FUTURE WORKS

This paper introduces a calibration-based auto white balance method for digital still camera design. Through calibrating the characteristic curve of a sensor, our method can accurately estimate white-point locations of an image. Besides *RGB* domain, raw data format makes white balance in other color spaces impossible. WPCTC with *MCTD* is used to model the WPCTB of a sensor. This model with distance and luminance thresholds provides an accurate white-point detection mechanism. From objective evaluation and subjective observation, our proposed method performs better than GWA and PRA methods and is easily implemented in digital still camera design.

Although our proposed method obtains excellent results in most scenarios, unsatisfactory results still exist in some extreme cases. Incorrect colors will appear when the color temperatures of calibration light sources are not chosen appropriately or the color temperatures of environment illumination are far from the WPCTC. These limitations should be further discussed and researched in the future.

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Li-Cheng Chiu (邱立誠) was born in Miaoli, Taiwan, on October 5, 1978. He received the B.S. degree in Mechanical Engineering from National Taiwan University, Taipei, Taiwan, in 2000. He also received the M.S. degree in Mechanical Engineering from National Taiwan University, Taipei, Taiwan, in 2002. Now he is a Ph.D. student in Computer Science and Information Engineering of National Taiwan University and a technical supervisor in industry. He focuses on digital camera system design and algorithm development.

Chiou-Shann Fuh (傅楸善) received the B.S. degree in Computer Science and Information Engineering from National Taiwan University, Taipei, Taiwan, in 1983, the M.S. degree in Computer Science from the Pennsylvania State University, University Park, PA, in 1987, and the Ph.D. degree in Computer Science from Harvard University, Cambridge, MA, in 1992. He was with AT&T Bell Laboratories and engaged in performance monitoring of switching networks from 1992 to 1993. He was an Associate Professor in Department of Computer Science and Information Engineering, National Taiwan University, Taipei, Taiwan from 1993 to 2000 and then promoted to a Full Professor. His current research interests include digital image processing, computer vision, pattern recognition, mathematical morphology, and their applications to defect inspection, industrial automation, digital still camera, digital video camcorder, and camera module such as color interpolation, auto exposure, auto focus, auto white balance, color calibration, and color management.