AUTO GAIN CONTROL BASED ON LOOK UP TABLE FROM SCENE•LUMINANCE CURVE IN MOBILE PHONE CAMERA

Tae-Hyoung Lee, Wang-Jun Kyung*, Cheol-Hee Lee, Hee-Chan Park, and Yeong-Ho Ha,**

*School of Electrical Engineering and Computer Science, Kyungpook National Univ.,
1370 Sankyuk-dong, Buk-gu, Daegu 702-701, KOREA
phone: 82-53-940-8835, fax: 82-53-957-1194, email: yha@ee.knu.ac.kr
web: http://cilab.knu.ac.kr

ABSTRACT

Auto-exposure(AE) control automatically calculates and adjusts the exposure of the tone of the subject to the mid-tone of the photograph. In the case of real-time performance, this is usually controlled by the sensor gain for consecutive input images. However, unsuitable sensor gain control methods invariably cause oscillation of the average luminance values for continuous input images, resulting in flickering. Also, in mobile phone cameras, only simple information, such as the average luminance value, can be utilized to calculate the sensor gain, due to coarse performance and cost. Therefore, this paper presents a new real-time AE control method using a look up table(LUT) based on S(Scene)· L(Luminance) curves to avoid the generation of flickering. Prior to the AE control, a LUT is constructed using S·L curve information, which illustrates the characteristic of the output average luminance for input gray patches with corresponding sensor gains. The AE control is then performed by estimating a current scene as a gray patch using the proposed LUT as the first process. This estimation is feasible because the average luminance is the only factor that can be obtained from an input image in a mobile phone camera. That is, the spatial information of images or patches is meaningless. Therefore, a gray patch and scene with the same average luminance are considered the same in a mobile phone camera. A new sensor gain is then estimated using a transposed LUT with the previously estimated patch. The entire estimation process is performed using linear interpolation to achieve real-time execution. Based on experimental results, the proposed AE control method demonstrated real-time, flicker-free exposure estimation.

1. INTRODUCTION

The image signal processor (ISP) in a digital image acquisition system is responsible for the execution of a number of steps, including auto-exposure(AE), auto-focus, colour-interpolation, noise reduction, and auto white balance[1,2,3]. Among these steps, the role of AE is to control the gain in order to estimate the amount of light needed to obtain an image related to the mid-tone of the photograph. AE also preserves the average luminance for consecutive inputs of the same scene, thereby avoiding flickering.

In the case of a mobile phone camera, the exposure is controlled by two factors: shutter speed and sensor gain. In this study, the shutter speed is assumed to be fixed, as a variation of this value in mobile phone cameras can cause certain artifacts requiring post-processing[4,5]. When applying a high sensor gain to the input scene, the resultant images become brighter, whereas they become darker if a low sensor gain is applied to obtain mid-tone or target-tone images. If AE is not present, light scenes are usually over-saturated, while dark scenes are faded out.

Practical and simple AE control methods are usually included in patents applying to real mobile phone cameras. A simple and widely adopted method is ratio control between the input and target luminance, where the desired value is produced through iterative estimation. Corelogic[4] and Samsung[6] Electronics utilized this method by multiplying the ratio between the target luminance and the average luminance with the previous sensor gain. However, the simplicity and iterative nature of this method often produces flickering problems. Thus, to avoid iterative estimation, other parameters (such as the focus and quantization error) have also been introduced, or a LUT generated for immediate estimation using more common parameters. Samsung[7] and LG Electronics each introduced an AE control method using their own parameters or LUT. Nonetheless, such methods still have drawbacks. Algorithms using extra parameters are usually device-dependent, and some still require iterative estimation. Meanwhile, LUTs entail a long and difficult process of data acquisition, also have problems with device dependency, and usually require a complete retuning if the target luminance is changed.

Accordingly, this paper proposes a new AE control algorithm to eliminate the flicker effect. It is also essential that the algorithm can run in real-time using the resource-bound platforms available in mobile camera systems. The proposed AE control method uses a LUT based on S(Scene)· L(Luminance) curves that reflect the relationship between input scenes and the output luminance according to the sensor gain. On the AE process, it is assumed that a gray patch and a scene with the same average luminance value are the same. In addition, due to the limited image information capacity of mobile phone cameras, the only image information parameter used is the average luminance values. Taking this assumption as verified, a LUT is built describing the relationship between all the gray patches in the Gretag Macbeth Colour Chart and the corresponding average luminance with a set of sensor gains. This data was acquired by capturing the gray patches using a mobile phone camera. As regards the performance of the AE control, the gray patch corresponding to the current input image is first estimated, given the current average input luminance, sensor gain, and the LUT. A transposed version of the LUT is then computed for a better estimate of the future value. Finally, the new sensor gain is computed by linear interpolation of the transposed LUT values using the estimated patch and the desired target luminance. As it is LUT-based, the proposed work directly estimates the new sensor gain (without need of iteration), yet differs from other LUT approaches, as the table is easier to compute and device independent, plus the target luminance can be changed without any need to re-compute the LUT itself.

2. PROPOSED AE CONTROL METHOD

2.1 Prior assumption

The LUT used in this paper reflects the relationship between input images and the output luminance according to a set of sensor gains. However, since there are an infinite number of input images for a real scene, the LUT can not contain all of the input images information. Therefore, the proposed method assumes that a gray patch and a scene with the same average luminance are the same, which is made possible by using just the average luminance throughout the AE process. In this paper, the AE algorithm is performed using the average luminance of a Bayer image. When the sensor gain is applied to every pixel of a CMOS sensor, this is proven by Eqs. (1) and (2), representing a simplified form of the pixel value for a Bayer image and the calculation of the average luminance for an input scene, respectively.

$$Bayer(x,y) = SG \times q\left(\sum_{\lambda} R(\lambda) \times I(\lambda) \times F_{R,G,or\,B}(\lambda)\right) \quad (1)$$

$$Y_{ave} = \frac{1}{N \times M}\sum_{x=1}^{N}\sum_{y=1}^{M} Bayer(x,y) \quad (2)$$

where *R* is the reflectance, *I* is the illuminant, *F* is the camera sensitivity, *q* is the function acquiring digital RGB value, and *SG* is the sensor gain. Plus, the Bayer image is the input scene with a $N \times M$ size, and Y_{ave} is the average luminance which is the only information from the input image. In this case, Y_{ave} should be calculated using all the pixel values for the Bayer image, meaning that individual pixel values are useless to recognize the input scene. Also, the influence of the sensor gain on the input gray patch is equal to the case of the real scene if the gray patch and real scene have the same average luminance, as the same sensor gain (*SG*) is applied to every pixel linearly. An example of this is shown in figure 1, which demonstrates that when a gray patch and scene have the same average luminance, the increase in the average luminance is the same as the increase in the sensor gain for both images, as the sensor gain is applied to the Bayer image linearly for each pixel. Thus, for any input image, if the average is the same, the input images are treated as gray patches in the AE process.

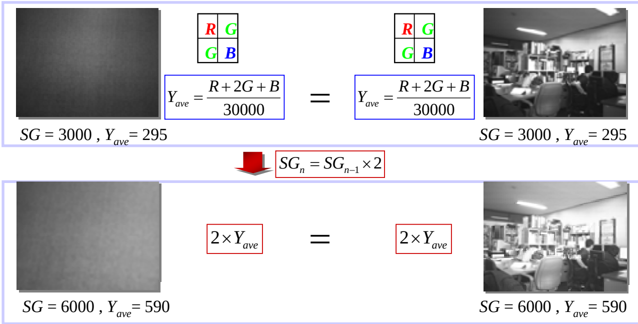

Figure 1.

2.2 Construction of LUT

The proposed LUT represents the relationship between the input gray patches and the output average luminance for a set of sensor gains. This is constructed based on measuring gray patches using a mobile phone camera. The experimental environment is described in figure 2 and includes Macbeth chart gray patches, a Gretag Macbeth Judge IIs viewing booth, and mobile camera module. In this case, the type of illuminant does not have any influence on the LUT construction, as the calculation of the average luminance is not influenced by the type of illuminant. D65 was selected for this experiment.

6 Macbeth chart gray patches should be numbered. As mentioned above, an input scene is represented by scalar values as the average luminance. Therefore, the gray patches were numbered on 6 levels according to the luminance ordering. In this paper, the black patch was defined as 0, while the white patch was defined as 255, and the other gray patches were then numbered based on equal intervals of 51. Also, the D65 used was 306 which was the highest value, as this represents the brightest objects in an input scene that the mobile phone camera can recognize.

Next, the set of sensor gains was decided. In this case, since the output luminance values for the Macbeth chart gray patches with a specific sensor gain were not linear, sensor values with an almost uniform output were selected due to the linear interpolation in the next AE process. Thus, 11 sensor gain levels were defined and used as the column index for the LUT in this study. The number of gray patches and sensor gains can be changed depending on the user's purpose. With a higher number of patches and sensor gains, the memory consumption is higher and the performance time longer, however, the results are more accurate.

In the experiments, the mobile phone camera took pictures of each gray patches and the D65 illuminant, respectively, as Bayer images with the set of sensor gains. Using G

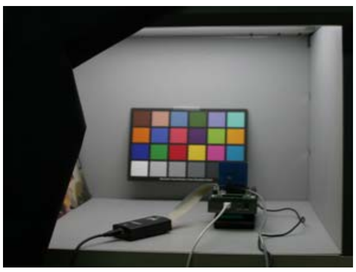

Figure 2. Experimental environment.

pixel values from the Bayer images, the output average luminance values were then calculated using Eq. (2), as the G values of an image represent the luminance of a pixel. The method of calculating the average luminance can be changed depending on the purpose. The final results are shown in figure 3 as a graph, while the measurement results, i.e. the LUT, are presented in figure 3 as (+) symbols, where the lines show the variation of the output average luminance for the input with the same sensor gain by just connecting the (+) symbols.

At a result, the LUT represents the relationship between the input gray patches (scenes) and the output average luminance values for each corresponding sensor gain. In addition, a transposed form of the LUT represents the relationship between all the sensor gains and the output average luminance for each corresponding patch. The following equations applied to the AE process are the proposed LUT(*LUT*), transposed LUT(LUT^T), gray patches(*P*), and sensor gains(*SG*), respectively.

2.3 AE control using LUT

The proposed method is performed using only the constructed LUT information, average luminance, and target luminance with sensor gain. The whole procedure is illustrated figure 8 with the proposed LUT graph. First, the average luminance of the input scene is obtained using the current sensor gain. This average luminance is then compared with the target luminance, which is the optimal luminance for consecutive input images. If the difference is lower than a certain threshold, the previous sensor gain is used(①), otherwise, the proposed method is performed(②). The proposed method involves two steps: estimation of the gray patch corresponding to the current input scene using the proposed LUT with the current sensor gain and average luminance(③), followed by estimation of a new sensor gain using the transposed LUT with the prior estimated patch and target luminance(④,⑤). These two steps are explained in detail in the next sections.

2.3.1 Estimation of gray patch as input scene

The difference between the average and target luminance is first checked before executing the AE process. If Y_{tar} is the target luminance and $Y_{threshold}$ is the difference threshold, $|Y_{tar} - Y_{ave}| > Y_{threshold}$ is the necessary condition for execution. Therefore, if the change in the luminance of the input scene is larger than the threshold, the proposed method is performed.

A gray patch corresponding to the input scene is then estimated using the LUT providing information on the relationship between the gray patches and the output luminance, the current sensor gain, and current average luminance. The result (scalar value of gray patch) is calculated using a linear function between the input and output luminance for the current sensor gain. That is, if the current sensor gain and average luminance are known, a gray patch with the same luminance as the input scene can be estimated. Figure 4 shows an example of the gray patch estimation. In this figure, if the current sensor gain is SG_9 and the input average luminance

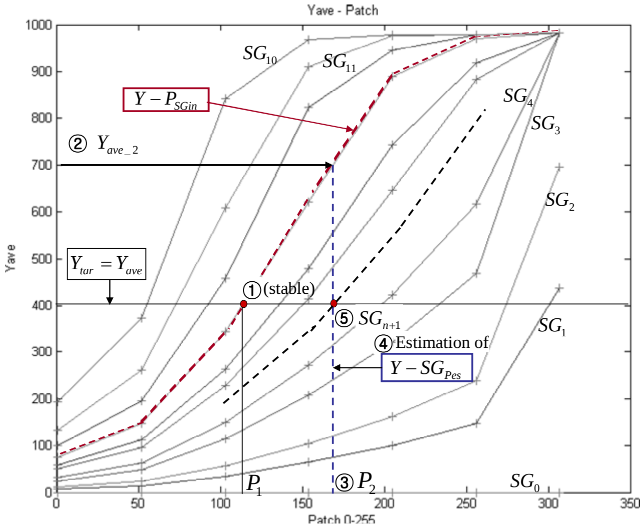

Figure 3. LUT and AE process

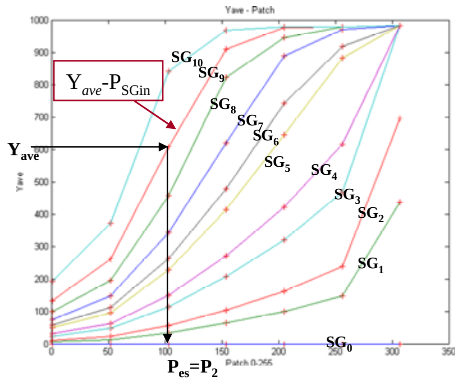

Figure 4. Estimation of the patch for current input image.

is Y_{ave}, the Y-P_{SGin} curve corresponding to the current sensor gain (SG_{in}) can be driven using the LUT. Thereafter, the gray patch P_2 can be estimated as the corresponding current input. In the case the current sensor gain exists in *SG*, Y-P_{SGin} can be found as shown in figure 4. However, if the current sensor gain exists between SG_i and SG_{i+1}, the Y-P_{SGin} curve can still be driven using a linear interpolation between the two nearest sensor gains as follows:

$$Y - P_{SGin} = \frac{SG_{in} - SG_i}{SG_{i+1} - SG_i} \times (LUT(i+1, j) - LUT(i, j)) + LUT(i, j) \quad (3)$$

where *LUT* is an *N*x*M* matrix of the average luminance for all patches *P* and all sensor gains *SG*, *N* is the index of the patches, *M* is the index of the sensor gains used in the measurement, *i* and *i*+1 represent the order of the two nearest sensor gains for the current gain, and *j* is the order for the luminance of the *i* index. The gray patch (P_{es}) corresponding to the input scene is then estimated using Y-P_{SGin} from Eq. (4) with the input average luminance as follows:

$$P_{es} = \frac{Y_{ave} - (Y - P_{SG}(j))}{(Y - P_{SG}(j+1)) - (Y - P_{SG}(j))} \times (P(j+1) - P(j)) + P(j) \quad (4)$$

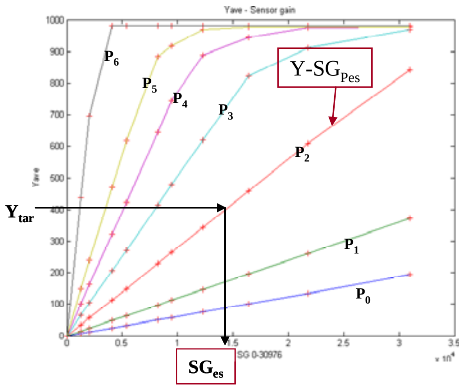

Figure 5. Estimation of final sensor gain.

2.3.2 Estimation of new sensor gain

The next procedure involves estimating the new sensor gain to enable the luminance of the next frame image to be close to the target luminance. This procedure requires information from a transposed LUT that represents the relationship between all the sensor gains and the output average luminance for all the patches. Therefore, similar to the gray patch estimation, if the estimated gray patch and target luminance are known, the new sensor gain can be estimated using a transposed LUT. Figure 5 shows this procedure in connection with the example given in figure 4. Using the estimated P_{es} ($=P_2$), the $Y\text{-}SG_{Pes}$ curve can be driven as follows.

$$Y-SG_{Pes}=\frac{P_{es}-P_i}{P_{i+1}-P_i}\times(LUT^T(j,i+1)-LUT^T(j,i))+LUT^T(j,i) \quad (5)$$

where i and i+1 are the nearest orders for P_{es}, and j is the order for the luminance of i index. As a result, $Y\text{-}SG_{Pes}$ is found for P_2, as shown in figure 10.

Finally, the new sensor gain(SG_{es}) can be estimated using the target luminance Y_{tar} as follows:

$$SG_{es}=\frac{Y_{tar}-(Y_{es}-SG_{Pes}(i))}{(Y_{es}-SG_{Pes}(i+1))-(Y_{es}-SG_{Pes}(i))} \quad (6)$$
$$\times(SG(j+1)-SG(j))+SG(j)$$

As a result, applying the estimated sensor gain to the CMOS sensor allows the luminance of the next input to be close to the target luminance.

The whole procedure is performed using linear calculations, as the coarse capability of a mobile phone camera does not calculate minus, float, exponent, and log numbers including function operation. Thus, some errors are unavoidable.

2.4 Application

2.4.1 Real-time performance

The proposed method was applied to a Samsung mobile phone camera. The proposed procedure was coded using fixed point coding and only real numbers, plus the procedures were simplified, as shown in Figure 11. First, the 4 nearest points (4 magenta circles) to the current sensor gain and input average luminance were found, and the $Y\text{-}P_{SGin}$ curve was then driven based on a linear interpolation and used to estimate the gray patch(P_{es}) according to the current sensor gain(SG_{in}). After finding P_{es}, the 4 nearest points (4 cyan circles) to P_{es} and the target luminance(Y_{tar}) were found, and the $Y\text{-}SG_{Pes}$ curve then driven and used to estimate the new sensor gain(SG_{es}) according to Y_{tar}. As a result, the proposed procedure eliminated more than 10 multiplications.

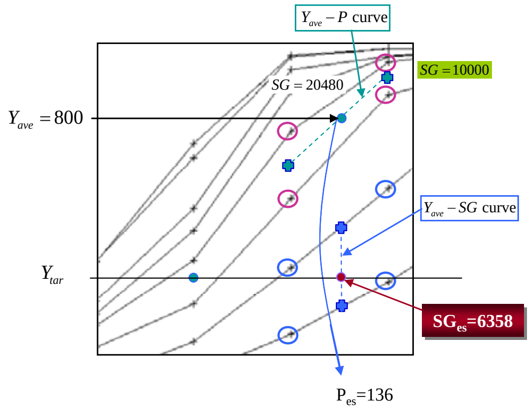

Figure 6. Real time execution of the proposed method.

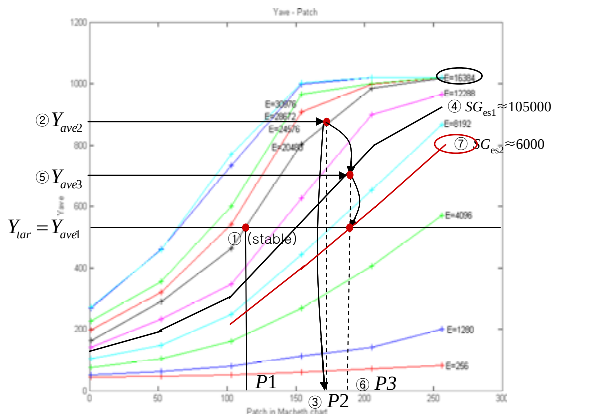

Figure 7. Performance of the proposed AE on saturated area.

2.4.2 Performance in saturated area

Usually, the output of the average luminance including saturated areas, such as a fluorescent lamp or the sun, does not follow the response for the sensor gains. This then causes continuous flickers or lots of iterations with a simple AE control algorithm. With the proposed algorithm, the estimation of a new sensor gain will not work for the first procedure with the input image including only half of the saturated areas. However, this problem can be solved using an iteration process of the proposed method. Figure 7 introduces the solution based on performing the proposed method two times. Almost all cases need no more than two iterations, and there are no flickers during the iteration process

3. EXPERIMENTAL RESULTS

One of the advantages of the proposed algorithm is that the target luminance can be chosen freely without any limitation. The proposed method can also be applied to any type of camera, that is, it is device independent, as only the input and output luminance relationship is used for the sensor gains.

Accordingly, the target luminance can be selected depending on the characteristic of the given device. In this paper, the given mobile camera had an average luminance range from 0 to 1024, and the target luminance was chosen as 200 considering the following additional algorithms, such as colour-interpolation and auto white balance. Also, the threshold value ($Y_{threshold}$) was determined as 20, which is the smallest variation for the smallest sensor gain adjustment.

Figure 8 shows the Bayer image with the average luminance before and after applying the proposed AE control method. The results show the image obtained when using the new sensor gain obtained after one performance of the proposed method, and the average luminance value from the resultant image was very close to the target luminance of 200. In addition, the proposed method was compared with the ratio control method, as most other methods are patented, thereby preventing simulation, due to specific parameter values and devices. The ratio control method uses the ratio between the target luminance and the current average luminance with the previous sensor gain[4]. The final result is then computed as follows:

$$SG_{es} = SG_{in} \times Y_{tar} / Y_{ave} \tag{7}$$

For a further comparison, different equations were used to determine the luminance difference according to a threshold value[8], represented by

$$SG_{es} = (SG_m - SG_{in})(Y_{ave} - Y_{ref}) / Y_{ave} + S_c \tag{8}$$

$$SG_{es} = SG_m - Y_{ref} \times (SG_m - S_c) / Y_{ave} \tag{9}$$

Figure 14 shows the experimental results, where (a) presents the performance accuracy based on comparing the target luminance with the average luminance from the new sensor gain, while (b) presents the number of iterations required for the next frame image to achieve an average luminance close to the target luminance. The results confirmed the ability of the proposed method to find the new sensor gain instantly and with accurate luminance values.

4. CONCLUTION

This paper proposed a method for AE control using a LUT based on S•L curves. First, it is assumed that gray patches and scenes that have the same average luminance can be equally exposed. A LUT is then constructed using a set of gray patches from a Gretag Macbeth chart and set of sensor gain values. In the AE algorithm, the current input is matched to one of the gray patches using the LUT and linear interpolation, and the estimated patch then used to obtain the new sensor gain using a transposed LUT and the target luminance.

The proposed method is able to compute new sensor gains in real-time, in contrast to other reported methods. Plus, the proposed LUT is constructed using easy measurements and is not camera-specific. Furthermore, the target luminance value can be adjusted without the need to compute the LUT again. When compared to other methods, the proposed algorithm produced a better performance in terms of accuracy an-

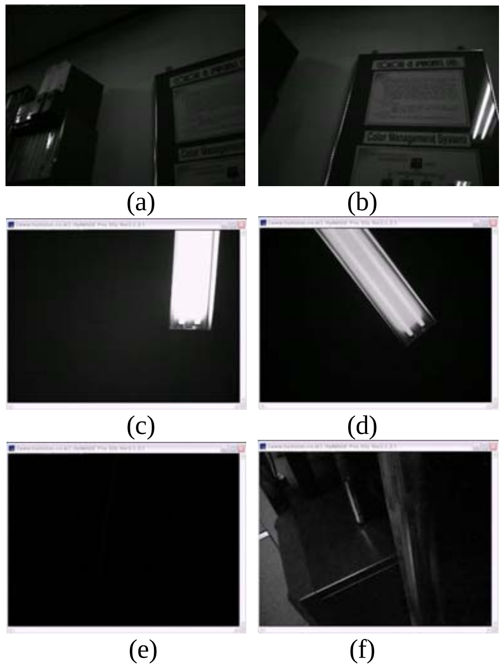

Figure 8. Result images; left without AE control and right with the proposed AE control

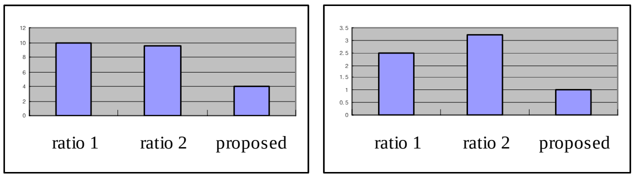

Figure 9. Comparison with other methods.

d execution speed.

5. ACKNOWLEDGEMENT

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