COMBINATIONAL AE-AF SYSTEM WITH FUZZY CLIMBING SEARCH SERVO

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ABSTRACT

This paper presents a combinational system, which can perform the functionalities of Auto Focus (AF) and Auto Exposure (AE) at the same time in a very efficient manner. At the first step, this system uses a DOG (Difference of Gaussian) filter to measure image's contrast and sharpness simultaneously. Then, a fuzzy logic-based scheme is proposed for the adjustment of focus and exposure. This system can be easily implemented with low hardware complexity.

Keywords: Autofocus, Autoexposure, Fuzzy logic, mountain climbing servo, lens control

1. INTRODUCTION

AF (Auto-Focus) and AE (Auto-exposure) are two important functionalities in digital cameras. AF affects the clarity of images, while AE affects the brightness. Traditionally, AF and AE are treated as two separate operations in digital cameras [2]-[3]. To achieve AF, we usually adjust camera's focus based on the sharpness of image contents. Since a better focused image tends to have sharper boundaries in the image, a common way to achieve AF is to use a bandpass filter or a highpass filter to measure the amount of some high-frequency components in the image. As the amount of high-frequency components reaches its maximum value, the image is well focused [1]-[4]. On the other hand, the AE operation is usually achieved by adjusting the image lightness to a proper level. A properly exposed image usually has its intensity values well distributed over a wider range. Hence, an AE system can apply some kinds of measures over the image histogram to determine the degree of exposure [2]-[3].

Based on our observations, we found that AE actually shares some similar characteristics with AF. The degree of exposure not only affects image's lightness but also image's contrast. As compared with an over-exposed image or a under-exposed image, the edges in a properly exposed image tend to have large contrast values. As a result, if we can detect image sharpness and image contrast at the same time, it is feasible to combine AF and AE into a single module.

2. THE PROPOSED ALGORITHM

2.1. Estimation of Sharpness and Contrast

To simultaneously measure the sharpness and contrast values of edges, we estimate the Laplacian of the input image I(x,y). To calculate the Laplacian, we adopt the LOG (Laplacian Of Gaussian) filter, which has been widely used in image processing. The kernel of this operator is defined as

$$\nabla^2 g(x,y) = \frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2} \qquad (1)$$

where g(x,y) is a 2-D Gaussian function. Here, a larger value of σ_m corresponds to a larger kernel, which means heavier computations but better SNR performance. If computational complexity is of major concern, some other simpler 2nd-derivative operators can also be used.

Without loss of generality, an image edge can be modeled as a vertical edge, expressed as a blurred step function with contrast h. That is,

$$I(x,y) = h \cdot \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi\sigma_b^2}} e^{-\frac{u^2}{2\sigma_b^2}} du \, . \qquad (2)$$

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Here, σ_b corresponds to the sharpness of the edge. A smaller value of σ_b indicates a sharper edge. As we convolve I(x,y) with $\nabla^2 g(x,y)$, the convolved image becomes

$$\begin{aligned}\nabla^2 I(x,y) &= I(x,y) * \nabla^2 g(x,y) \\ &= \nabla^2[I(x,y) * g(x,y)] \\ &= \nabla^2[h \cdot \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi(\sigma_b^2+\sigma_m^2)}} e^{-\frac{u^2}{2(\sigma_b^2+\sigma_m^2)}} du] \qquad (3) \\ &= h \cdot \frac{1}{\sqrt{2\pi(\sigma_b^2+\sigma_m^2)}} (-\frac{x}{(\sigma_b^2+\sigma_m^2)}) e^{-\frac{x^2}{2(\sigma_b^2+\sigma_m^2)}}.\end{aligned}$$

It can be seen that a sharper edge (smaller σ_b) or a high-contrast edge (larger h) produces a larger value of ∇^2 I(x,y) around the edge. Hence, for an M×N image, we define

$$P = \sum_{y=1}^{N} [\max_x \left| V^2 I(x,y) \right|] \qquad (4)$$

and seek to find the settings of focus and exposure that produce the largest magnitude of P. Figure 1 illustrates how the value of P varies with respect to the settings of focus and exposure. As the image is well focused and properly exposed, the value of P reaches its maximum value. Hence, with the use of LOG filtering, AE and AF can be achieved in a combinational way. Figure 2 shows the value of P with respect to a few different settings of focus and exposure. It can be easily seen that P does reach its maximum value when the image is well focused and properly exposed.

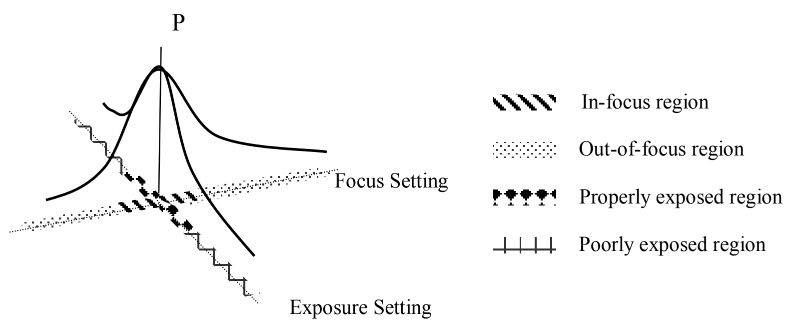

Fig. 1 Combinational AE/AF measurement

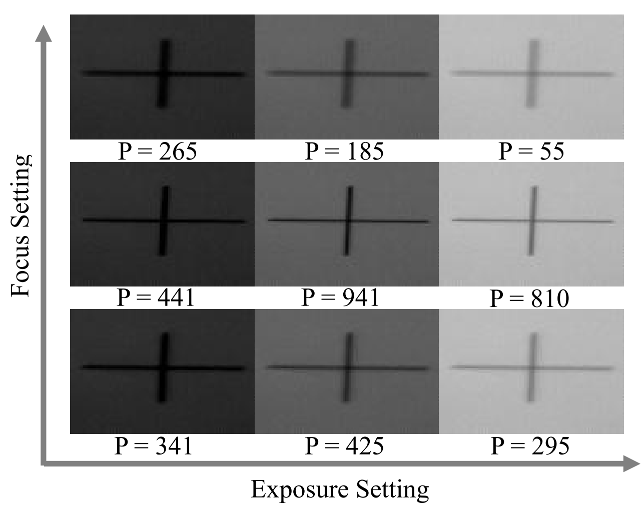

Fig. 2 The value of P with respect to different settings of focus and exposure.

Furthermore, to reduce the computational complexity of LOG filtering, we use a DOG (Difference of Gaussian) filter instead. The DOG filter is defined as the difference of two Gaussian filters with different standard deviations. It has been indicated in [5] that, as the two Gaussian functions have standard deviations in the ratio 1:1.6, the DOG operator can well approximate the LOG operator, but with a greatly reduced computational complexity when σ_m is large.

The block diagram of our proposed combinational AE/AF system is shown in

Fig. *3*. The optical system comprises focal lens and iris, which are controlled by the focus settings and exposure settings. The P-value Estimator is the proposed detector, which can estimate the contrast and sharpness of input images based on Equation (4). The detail block diagram of P-value estimator is shown in

Fig. *4*. The input image is fed into the estimator to calculate the Laplacian of the image. Then, the maximum magnitude of the Laplacian values along each row is calculated. These maximum magnitudes are accumulated to calculate the P-value. Based on the calculated P-value, the exposure controller and the focus controller adjust the exposure settings and focus settings of the optical system, as shown in

Fig. *3*.

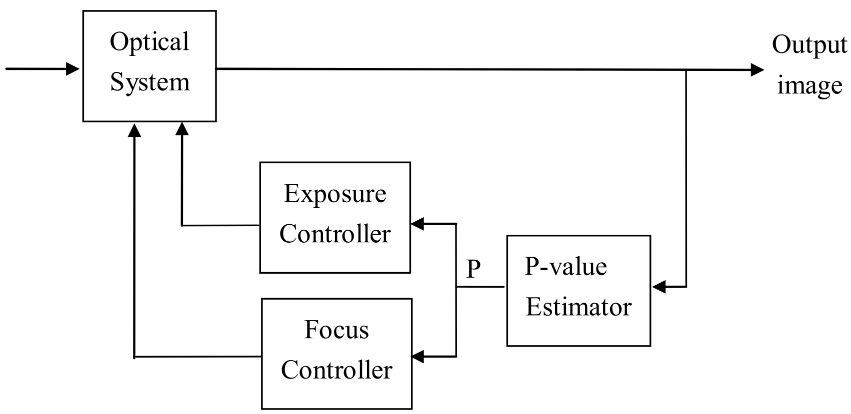

Fig. 3 Block diagram of Combinational AE/AF system

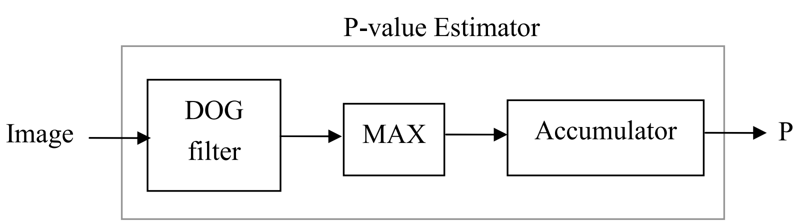

Fig. 4 Block diagram of P-value Estimator

2.2. Fuzzy rule-based mountain climbing

To achieve AF and AE, we can start from an initial setting of focus and exposure. Then, we adjust the settings of lens and aperture step by step to increase the value of P, as illustrated in Fig. 5. As the maximum value of P is reached, both AE and AF are achieved. During this mountain-climbing process, the number of times on the adjustment of lens and aperture is a key factor that affects the efficiency of the AE/AF system. To reduce the number of adjustments, we adopt a fuzzy rule-based approach for the climbing search. This approach is performed by alternately adjusting lens and aperture step by step. To simplify the explanation, we take the adjustment of lens as an example. The adjustment of aperture is achieved in a similar way.

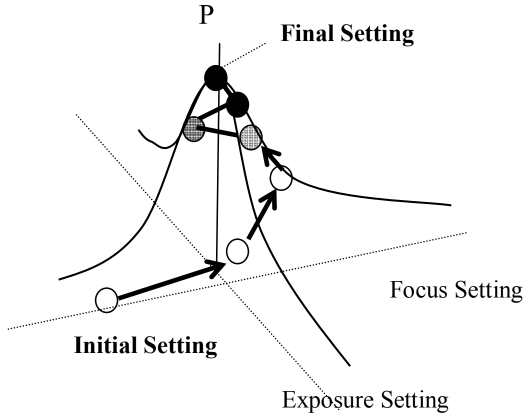

Fig. 5 Illustration of Climbing Search

Table 1

Case	(p3-p2)/(p2-p1)	Next
Out-of-focus	Positive, Large	Large
Nearly-focused	Positive,	Median
In-focus	Positive, Samll	Samll
Over-focused	Negative	Negative

To adjust lens, we consider three successive settings of lens position. The situations of three successive settings are classified into four different categories: out-of-focus, nearly-focused, in-focus, and over-focused, as illustrated in Fig. 6 The out-of-focus case means the lens position is still away from the correct focus region. The nearly-focused case means the lens position begins to step into the correct focus region. The in-focus case means the lens position is hovering inside the correct focus region. The over-focus case means the lens position has steped outside the correct focus region and becomes less focused. Table.1 shows the difference between these four situations. Here, we use the ratio (p3-p2)/(p2-p1) to distinguish these four different cases and to determine the step size of the next movement. Here, p1, p2, and p3 represent the P-values at the 1st, 2^{nd}, and 3^{rd} steps, respectively. Note that different images may have different P-curves. Since this ratio depends on relative differences, but not the absolute value of P, the detection result is less sensitive to the variation of P-curves.

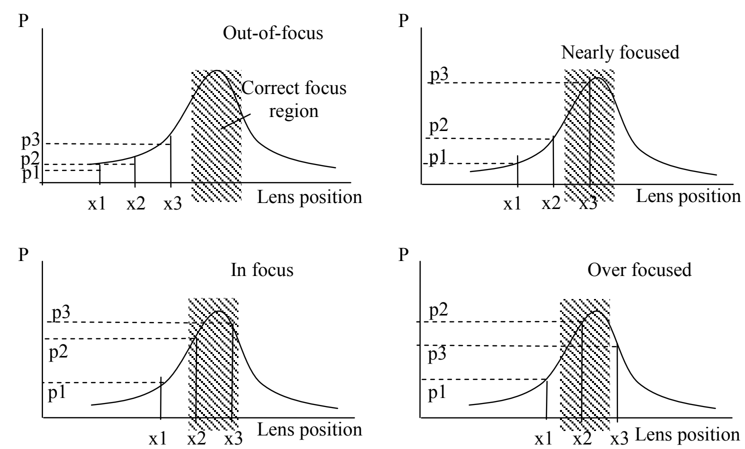

Fig. 6 Four different cases during focus adjustment: out-of-focus, nearly-focused, in-focus, and over-focused.

Based on the aforementioned four different cases, we establish the membership functions as shown in Fig. 7. Fig. 7(a) shows the membership functions for out-of-focus, nearly-focused, and in-focus, where the states a_1 and a_2 correspond to the in-focus case, the states a_3 and a_4 correspond to the nearly-focused case, and the states a_5 and a_6 correspond to the out-of-focus case. On the other hand, for the case of over-focused, we design another set of membership functions, as shown in Fig. 7(c). Depending on different states, the lens position will be moved to different positions, as shown in Fig. 7(b) and (d). Moreover, since the P-curve is usually approximately symmetry with respect to the peak, we can roughly predict the peak according to the value of (v3-v2)/(v2-v1). If the value is close to 1, as the state a2 shown in Fig. 7(c), the peak position will be estimated to be close to x2, as shown in Fig. 7(d). The states a1 and a3 are the fine tuning states and the corresponding lens positions are shown in Fig. 7(d). This fuzzy rule-based scheme provides a faster way for climbing search and can reduce the number of lens adjustments.

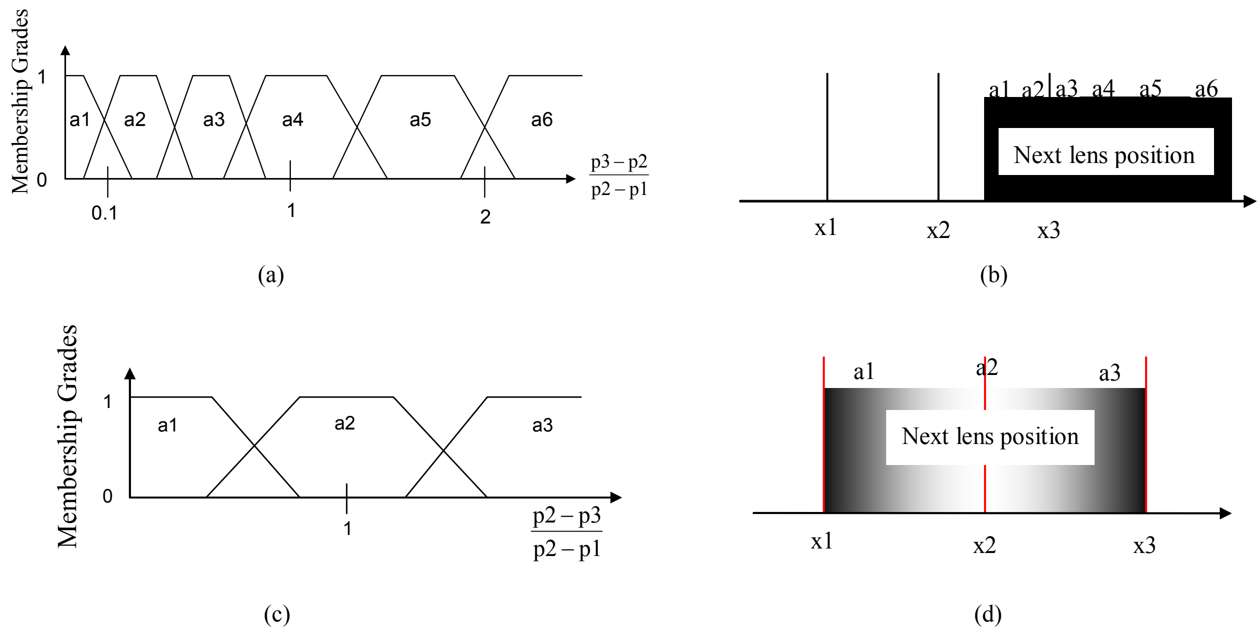

Fig. 7 (a) Membership functions for the cases of ***Out-of-focus****,* ***Nearly-focused,*** *and* ***In-focus.*** *(b) Adjustment for the cases of* ***Out-of-focus, Nearly-focused,*** *and* ***In-focus.*** *(c) Membership function for****Over-focused****. (d) Adjustment for****Over-focused.***

The flowchart of the fuzzy rule-based mountain climbing process is shown in Fig. 8. In the proposed process, the adjustments of focus and exposure are performed in an alternative manner. After initialization, three successive settings of focus (or exposure) are made and the corresponding P-values are estimated. Based on these three P-values, p1, p2, and p3, we evaluate the membership grades based on the fuzzy rules mentioned above. Then the focus (or exposure) adjustment is performed based on the membership grades. If the adjustment step decided from the fuzzy system is less than the predetermined threshold T1, the searching is completed. Otherwise, the system will estimate the new P-value and use this new P-value, together with the previously estimated p2 and p3, to evaluate the next membership grades. The iterative adjustments continue until both focus and exposure are well adjusted.

3. SIMULATION RESULTS

To demonstrate that the P-value with respect to exposure and focus settings is indeed as we have predicted in Fig. 1, we did an experiment that takes pictures in different settings of exposure and focus. Some sample images of this experiment are shown in Fig. 9, where the horizontal axis corresponds to different exposure settings while the vertical axis corresponds to different focus settings. In this experiment we took 14 different exposure settings and 21 focus settings. Fig. 9 shows the pictures at exposure setting No.2, 4, 8, 11, 14 and focus setting No.1, 5, 9, 13, 21. After estimating the P-value of each picture, we have a set of P-value with respect to different settings of exposure and focus. The estimation results of P-value are plotted in *Fig. 10*, where the image with the maximum P-value is at F9E11 (No. 9 at focus setting and No. 11 at exposure setting). The corresponding picture is shown in *Fig. 9*.

In Fig. 12, we show how the P-value varies with respect to different focus settings. For each curve in Fig. 12, the exposure setting is fixed. It can be seen that these two curves do resemble what we have expected. Then, we apply the fuzzy rules mentioned above over each curve to examine the number of adjustments and the prediction results. Here, we tried different initial focus settings and record the number of adjustments and the final focus settings. In Table2, we list some experimental results. It can be seen that the final focus settings for Curve 1 and Curve 2 are around 28 and 25, respectively. The number of adjustments is about 4 to 7.

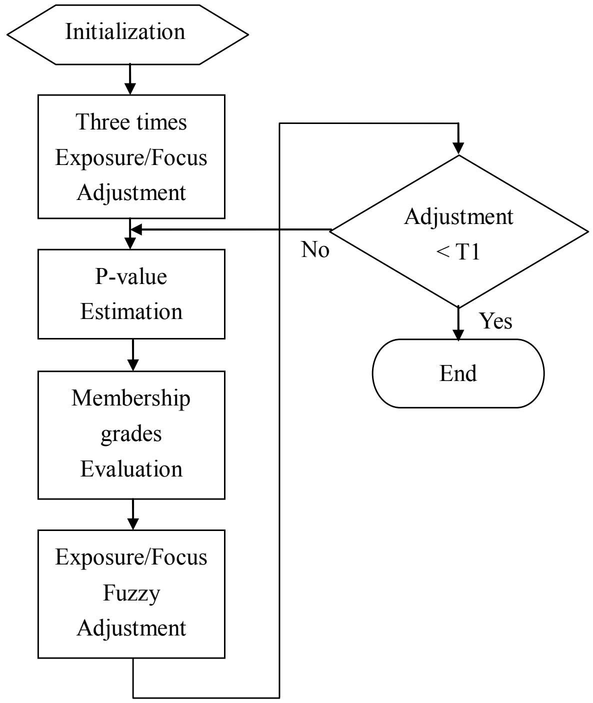

Fig. 8 The flowchart of Fuzzy rule-based mountain climbing apparatus

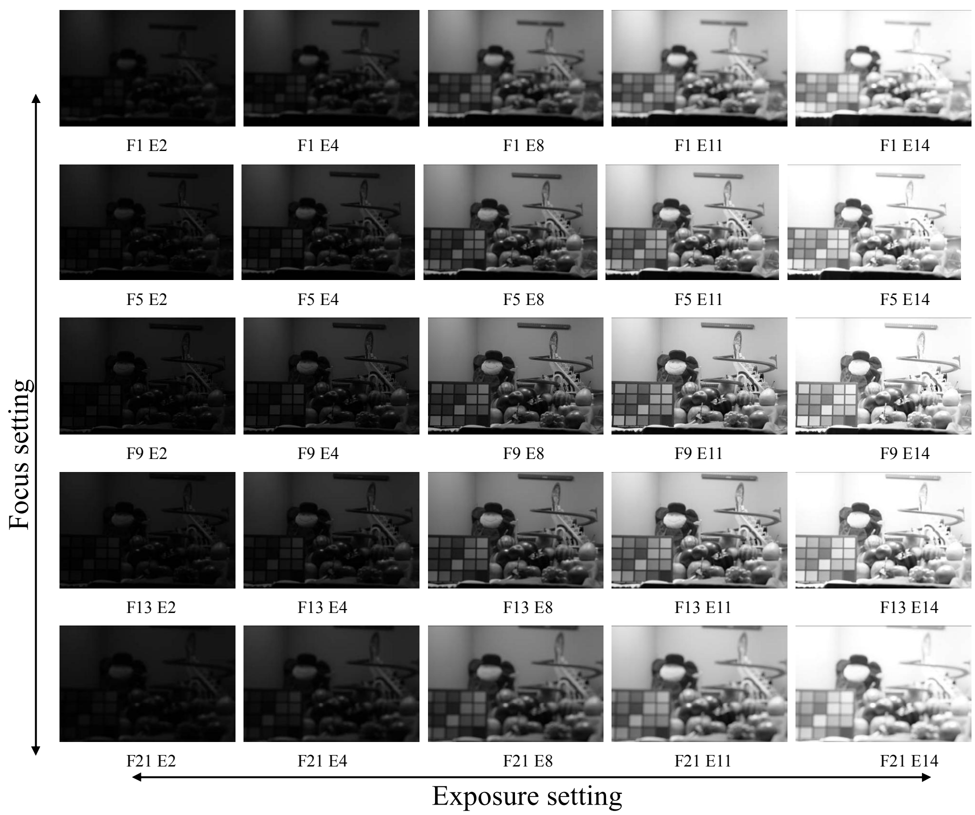

Fig. 9 Samples of experimental pictures

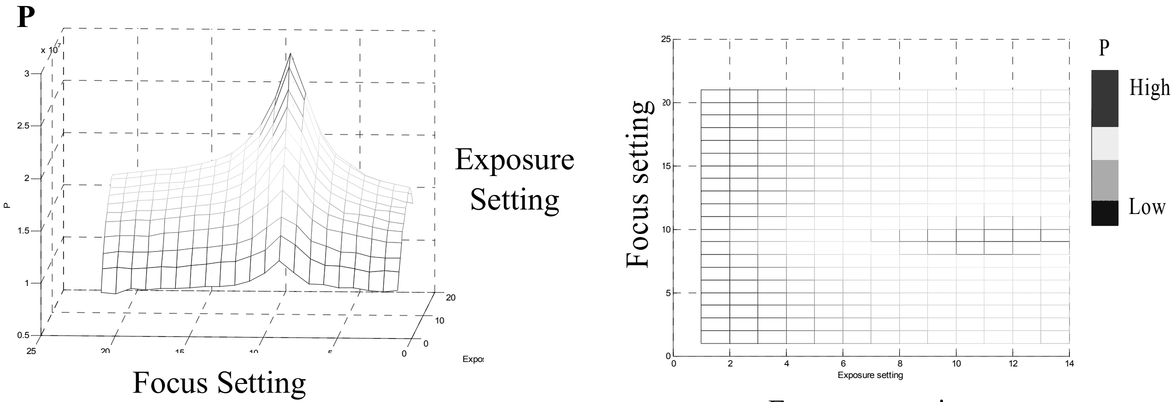

Fig. 10 (a) P-values with respect to different settings of focus and exposure.
(b) Top view of Fig. 11(a)

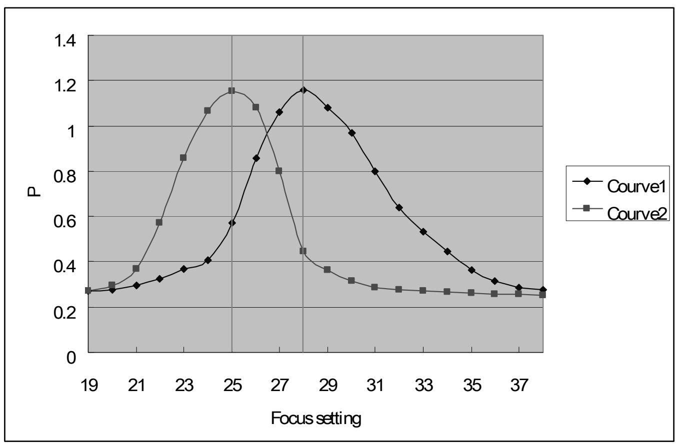

Fig. 12 P-values with respect to different focus settings

Table2

Courve1 Best Position: 28				
Initial position			Final position	Step count
x1	x2	x3		
19	21	23	27.9	7
19	21	24	28.1	7
19	22	25	28.0	6
19	22	26	28.7	5
19	22	27	27.4	5
19	22	28	28.0	7
19	23	27	27.4	6
19	23	28	28.4	6
19	23	29	28.5	6
19	23	30	28.5	5
19	23	31	27.4	6
23	25	27	28.2	5
23	25	28	28.0	6
23	25	29	28.2	5
23	25	30	28.1	6

Courve2 Best Position: 25				
Initial position			Final position	Step count
x1	x2	x3		
19	21	23	25.2	6
19	21	24	24.4	5
19	21	25	24.9	6
19	21	26	25.6	6
19	21	27	24.4	6
19	22	25	25.0	6
19	22	26	25.2	5
19	23	27	24.4	5
22	24	26	25.2	4
22	24	27	24.4	4
23	26	29	24.5	6
23	26	30	24.5	6
23	27	31	24.6	4
23	27	32	24.8	4
23	27	33	24.8	4

We also apply the fuzzy rule-based mountain climbing to perform combinational adjustment of focus and exposure. In Fig. 12(a) and (b), we plot over Fig. 13(b) each step of the adjustments for two different initial settings. It can be seen that both focus and exposure settings are efficiently adjusted within 6 steps.

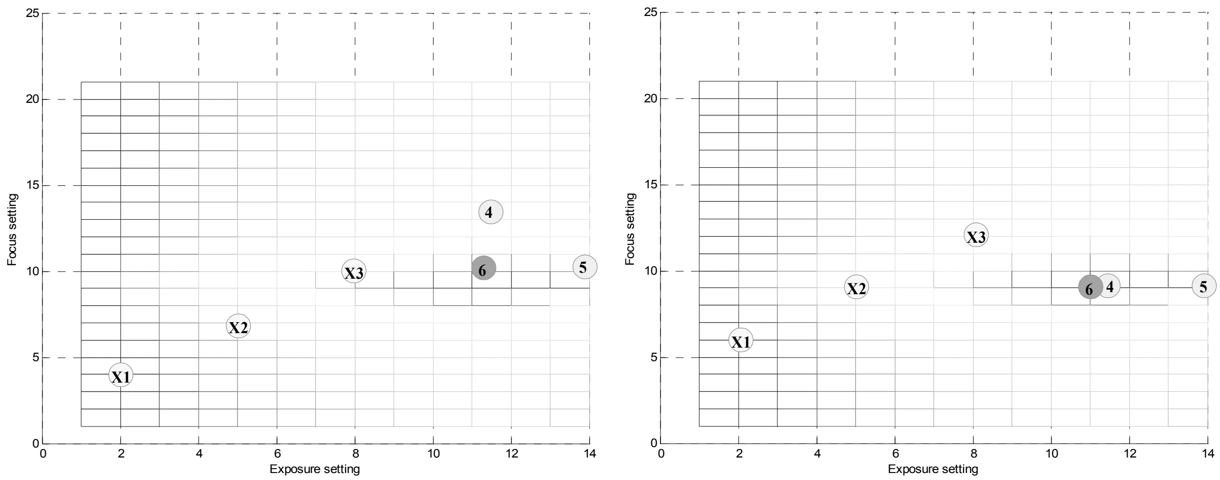

Fig. 14 *(a)(b)Illustration of two-dimensional adjustment with different initial settings*

4. CONCLUSION

In this paper, we provide a new approach to achieve combinational AF and AE. This system can be easily implemented with low hardware complexity. A fuzzy logic-based scheme is also proposed to improve the efficiency of adjustments. Experimental results have demonstrated the efficiency and feasibility of this approach.

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