# AN ADVANCED VIDEO CAMERA SYSTEM WITH ROBUST AF, AE, AND AWB CONTROL

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*Abstract*—**This paper presents an advanced video camera system which has robust automatic focus (AF), automatic exposure (AE), and automatic white-balance (AWB) control. The proposed AF algorithm decides the correct moving direction of lens and detects the accurate in-focus state even though the scene is interfered with the high light intensity. Experimental results demonstrate that the proposed system can be an effective alternative to conventional systems using the hill-climbing method.**

*Keywords*— **automatic focus, automatic exposure, automatic white balance.**

## I. Introduction

IT is well known that the digital signal processing technology has been adopted in consumer video cameras. The digitalization of consumer video cameras has brought in a variety of new digital features, such as an image stabilizer and an electronic zoom, that were difficult to achieve with the analog technology. In addition, the performance of the automatic adjustments including AF, AE, and AWB has been improved which are the important features for high image quality under various shot conditions [1]- [3].

The AF technique for video cameras maximizes the high frequency components of an image by adjusting the focusing lens. In general, focused images have higher frequency components than de-focused images of a scene. One of measures for finding the best focusing position in the focus range is an accumulated high frequency component of a video signal in a frame/field. This measure is called the focus value. The best focusing position of the focus lens is obtained at the maximum position of the focus value [4]- [5]. Popular auto focusing techniques accomplish the in-focus state using the hill-climbing control. However, this simple method fails when unusual scene as an object having high contrast appears.

The camera exposure can be controlled using the total luminance of the image. However, when the luminance difference between the main object and the background is high, over- or under-exposure of the main object occurs. In this case, a bright area is saturated or a dark area is masked because of the narrow dynamic range. In order to overcome this problem, some AE algorithms give more weight to appropriate areas of the image [6]- [7].

When an white object is illuminated with a low color temperature light, the color of the object appears reddish, while with a high color temperature light, the color appears bluish. Therefore, it is necessary to compensate the color difference caused by light source so that a white object appears as white under any light source. For AWB, the averaged value of color difference signal in the image is used as the color temperature data. However, when an uniform colored object occupies a large part of the image, the color compensation may cause the loss of integrity of the color. In order to discriminate between the color difference signals produced by light source and the ones by chromatic object, various AWB algorithm have been proposed [8]- [9].

This paper presents an advanced camera system which performs AF, AE, and AWB under various scene situations. The AF technique prevents the AF operation from de-focusing of the scene interfered with the high luminance object using the integrated luminance value. The AE method compensates the luminance of the main object using the proposed backlight detection. The AWB algorithm compensates the color difference by deciding whether the color distortion of scene is caused by light source or chromatic object.

The paper is organized as follows. In Section II, the proposed camera system is briefly introduced and the proposed automatic adjustments are presented. Section III presents the experimental results and conclusions.

## II. Proposed Camera System

Fig. 1 shows the functional block diagram of the proposed camera system. As shown in Fig. 1, an image is focused onto a color CCD sensor through an optical lens. The output signals of the CCD sensor are adjusted to maintain the output level via auto gain control (AGC)/correlated double sampling (CDS) and

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digitized via an A/D converter. The proposed camera system utilizes a SONY digital signal processor (DSP) to process the digitized image. The DSP produces a focusing signal, integrated luminance value, integrated RGB data for AF, AE, and AWB respectively. The micro controller transmits a motor control signal to a motor driver so that the focusing lens is moved in a direction which the level of the focusing signal is increasing. Then, the focusing lens is moved to a location at which the level of the focusing signal has a peak value.

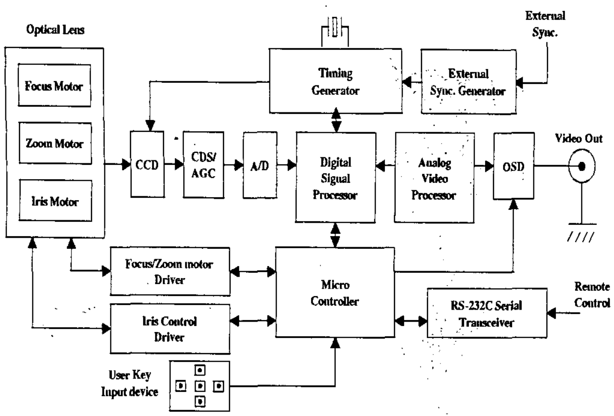


Fig. 1. Functional block diagram of the proposed camera system.

## A. AF Algorithm

The focusing signals are generated from the two windows, *Window 1* and *Window 2* as shown in Fig. 2. *Window 1* almost covers the image frame and *Window 2* is a half size of the image frame.

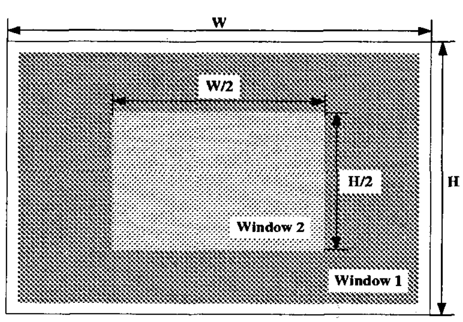


Fig. 2. The focusing control window.

Fig. 3 shows two types of focus value curves associated with the cut-off frequency of the high pass filter, where $f_{iL}$ and $f_{iH}$ are focus values obtained using the low and high cut-off frequencies from $Window\ i$, respectively. The $f_{iL}$ is used for the moving direction of the lens since the skirt area of the curve has a steeper slope. On the other hand, the $f_{iH}$ is utilized for finding the peak since it has a steeper slope in the in-focus range of the curve.

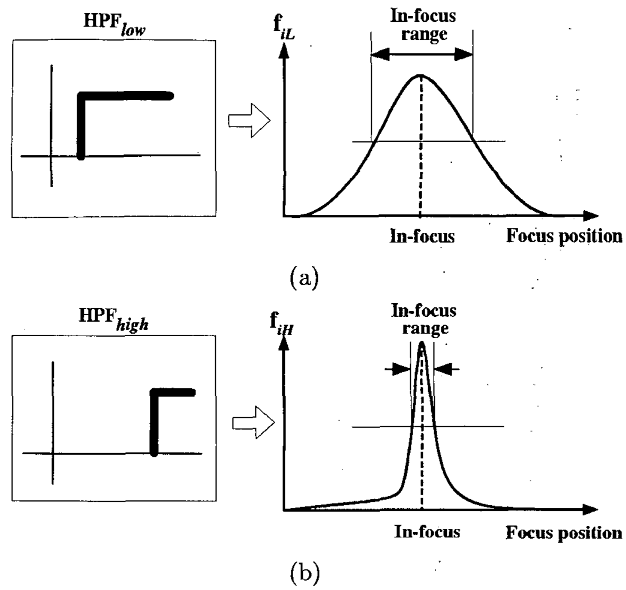


Fig. 3. (a) The HPF with a low cut-off frequency and its focus value curve, (b) The HPF with a high cut-off frequency and its focus value curve.

In the hill-climbing algorithm, if a high contrast object exists in the focusing window, there is a possibility that uncorrect focusing results occur. Fig. 4(a) and (b) show in-focused and de-focused images containing the light source, respectively. In Fig. 4(c), the increasing focus value of $f_{1L}(m)$ suddenly decreases after a spurious or false peak (local maximum) is reached. In the conventional hill-climbing method, the focusing lens moves reversly in this situation since the slope is descending. As a result, the focusing signal has a peak at the blurred state.

In order to solve this problem, the proposed AF algorithm uses *the integrated luminance value* as well as the focus value for the moving direction of the lens. Fig. 5 shows the characteristic of the integrated luminance value versus the focal lens position. It is seen that the integrated luminance value curve monotonously decreases without producing the false peak as it goes to the global minimum point. This scheme is named *the valley-descending method.*

In Fig. 6, the proposed AF algorithm has two operational modes: 1) the search mode and 2) the watch mode. The AF algorithm starts with the search mode

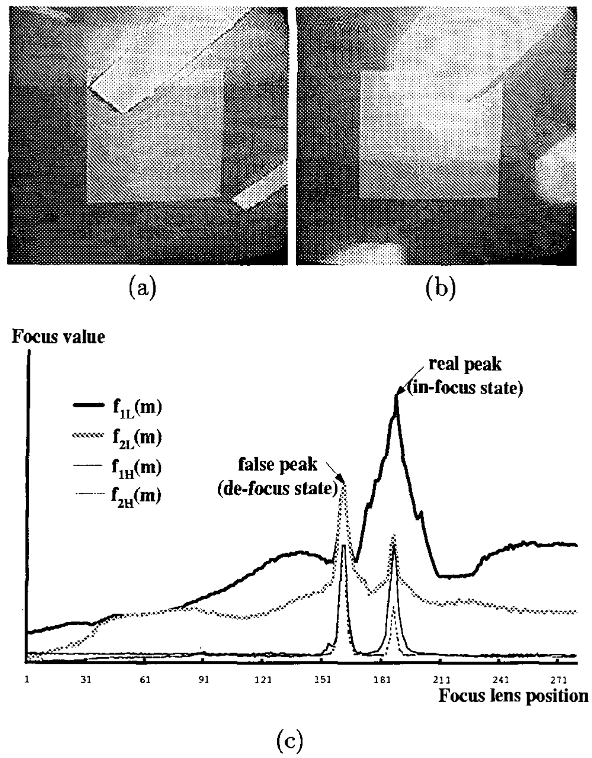


Fig. 4. (a) In-focused light, (b) De-focused light, and (c) The focus curve.

to decide the initial direction of the lens movement. This mode makes a decision of whether the high luminance object exists in the focusing control window or not. If the focusing control window contains a high luminance object, the valley-descending algorithm is used for the direction of the lens movement. Otherwise, the hill-climbing method is utilized. At the best focus position, the watch mode starts.

The watch mode decides whether the search operation will resume or not. To do so, the absolute difference is first computed as

$$d = |\overline{f}(t) - f_p(0)|, \tag{1}$$

where $f_p(0)$ is the focus value at the time that the search mode is converted to the watch mode, and $\overline{f}(t)$ is the time averaged focus value given by

$$\overline{f}(t) = \frac{\sum_{t=0}^{l-1} f_p(t)}{l}, \tag{2}$$

where $l$ is the duration of the watch mode and $f_p(t)$ represents the focus value at time $t$. The search mode

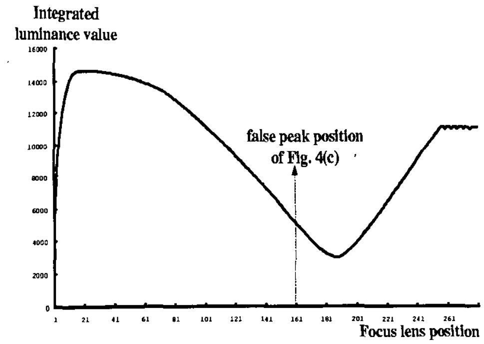


Fig. 5. The integrated luminance curve.

resumes if

$$\begin{cases} d > \frac{3}{4} f_p(0), & \text{for light intensity,} \\ d > \frac{1}{2} f_p(0), & \text{for normal intensity,} \\ d > \frac{1}{4} f_p(0), & \text{for dark intensity.} \end{cases} \tag{3}$$

### *B. AE Algorithm*

In the backlighting condition, the exposure control based on the average luminance of the whole image causes the under-exposure of the main object. This is because the luminance difference between the main object and the background is large and the average luminance is dominated by the luminance of the background. Therefore, it is necessary to emphasize the luminance of the main object according to the degree of backlighting.

The proposed AE method divides a scene into five regions as shown in Fig. 7. In most cases, the background region is located in the upper part of the scene, and the main object is in the center of the scene. The accumulated luminance data in each region is weighted differently according to the degree of backlighting, i.e. the luminance difference between the background and the main object region. The luminance difference $D_b$ for backlighting detection is given by

$$D_b = [R_0 + max(R_2, R_3)] - (R_1 + R_4) \tag{4}$$

where $R_i$ denotes the average luminance of *Region i*, and $max(R_2,R_3)$ is used to decide if the light source is in the right side or left side of the scene. In order to transform the degree of backlighting into the normalized interval [0,1], we use a transfer function as shown in Fig. 8.

The luminance of the main object regions, Regions 1 and 4, is more weighted using the normalized degree of backlighting, $N_b$, than that of the background regions. The total luminance is obtained by adding the weighted luminances of each region.

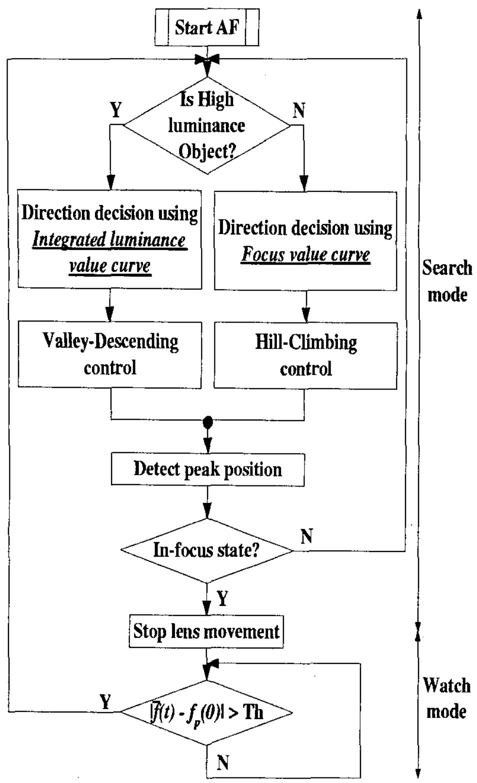


Fig. 6. The flow of the proposed algorithm.

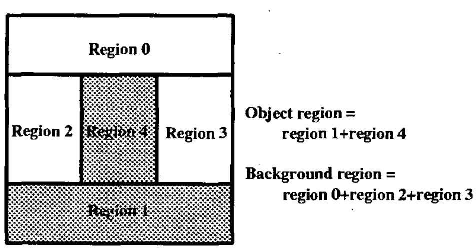


Fig. 7. The window for AE detection.

## C. AWB Algorithm

For AWB control, the integrated color difference values, R-G and B-G, over one image frame are averaged. The R and B gains are adjusted so that the integrated color difference values are close to white color. However, when a chromatic object occupies a large part of the image, the color compensation may cause the loss of integrity of the color. In order to overcome this problem, we use a predefined shaded region as shown

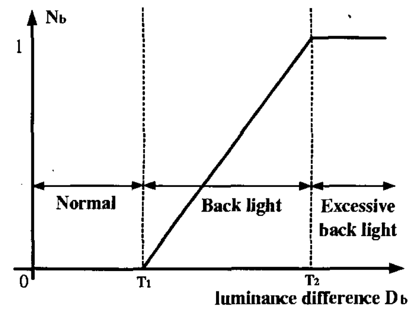


Fig. 8. The transfer function $D_b$.

in Fig. 9. The predefined region can be expressed as

$$\begin{aligned} &-a < B - G < a, \\ &-b < R - G < b, \\ &-c < (R - G) + (B - G) < c, \end{aligned} \tag{5}$$

where $a$, $b$, and $c$ are parameters read from the EEPROM when the system starts. For color compensation, the values of R and B gains are converted into values within the predefined shaded region.

When the camera is shifted to the telescope mode, the scene is mostly covered by an object. If the object has a monotone color, the integrated color difference value will be abruptly changed, although the color temperature of the light source is not changed. In the telescope mode, the domain of R and B gains as shown in Fig. 10 are utilized for color compensation. For AWB, the values of R and B gains are converted into appropriate values within the narrow shaded region defined by

$$\begin{aligned} R_{min} &\le R \le R_{max}, \\ B_{min} &\le B \le B_{max}, \\ T_1 &\le R + 3B \le T_2. \end{aligned} \tag{6}$$

## III. Simulation Results and Conclusions

Fig. 11 illustrates the result of the proposed AF algorithm when the scene contains the light source. The proposed AF algorithm uses the integrated luminance value curve to decide the moving direction of the lens. Since the integrated luminance value curve $L(m)$ is decreasing at the focus lens position $P$ in Fig. 11(b), the spurious peaks, $f_L(P)$ and $f_H(P)$, are ignored. After the global minimum point in the curve $L(m)$ is reached, the curve $f_H(m)$, which is obtained by the HPF with the low cut-off frequency using *Window 1*, is exploited to find the in-focus position. Fig. 11(a) is the in-focused scene where $f_H(m)$ has the global maximum. For comparison, the conventional hill-climbing algorithm is applied to the same scene, and the result is shown in Fig. 12(a). In Fig 12(b), the hill-climbing

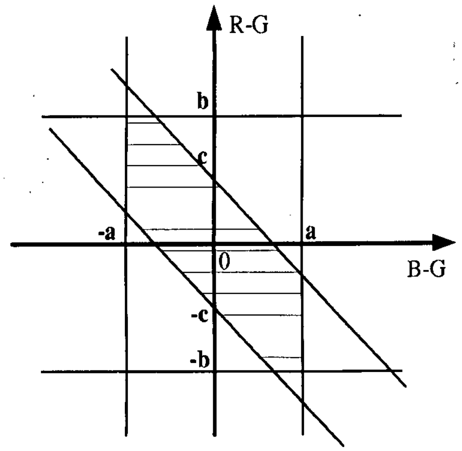


Fig. 9. The predefined region of color difference values.

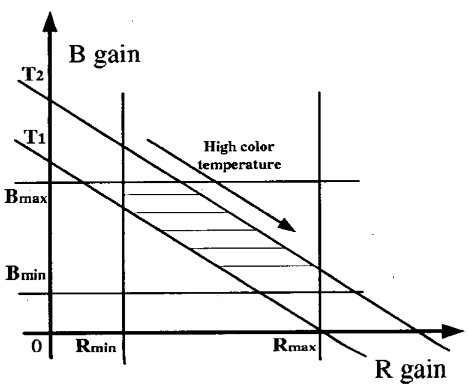


Fig. 10. The control region of R and B gain.

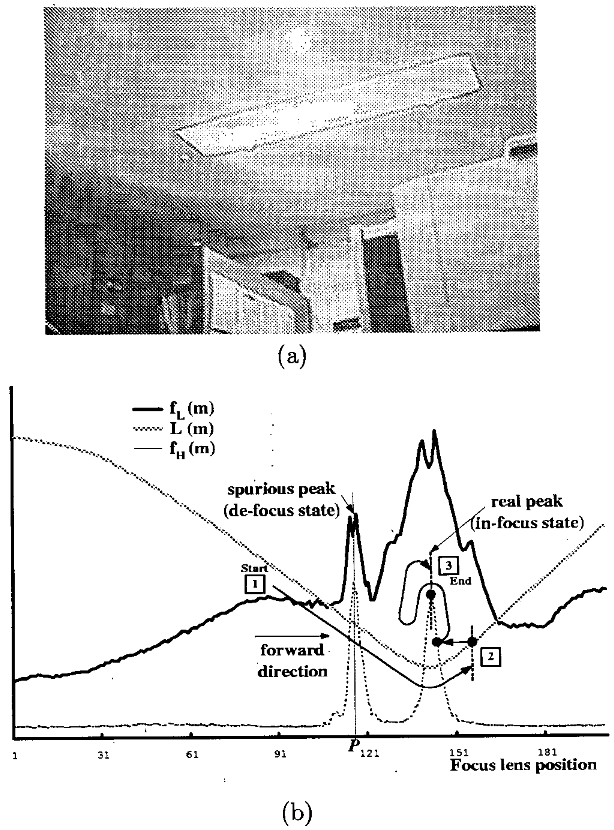


Fig. 11. The proposed AF method, (a) in-focused scene, (b) proposed peak detection procedure

algorithm uses the focus value curve $f_H(m)$ to decide the moving direction of the lens. As a result, the false peak, which is the de-focus state as shown in Fig. 12(a), is obtained at the focus lens position $P$.

Experimental results showed that the proposed AF algorithm decides the correct moving direction of lens and detects the accurate in-focus state even though the scene is interfered with the high light intensity. It is expected that the proposed camera system can be an effective alternative to conventional systems using the hill-climbing method.

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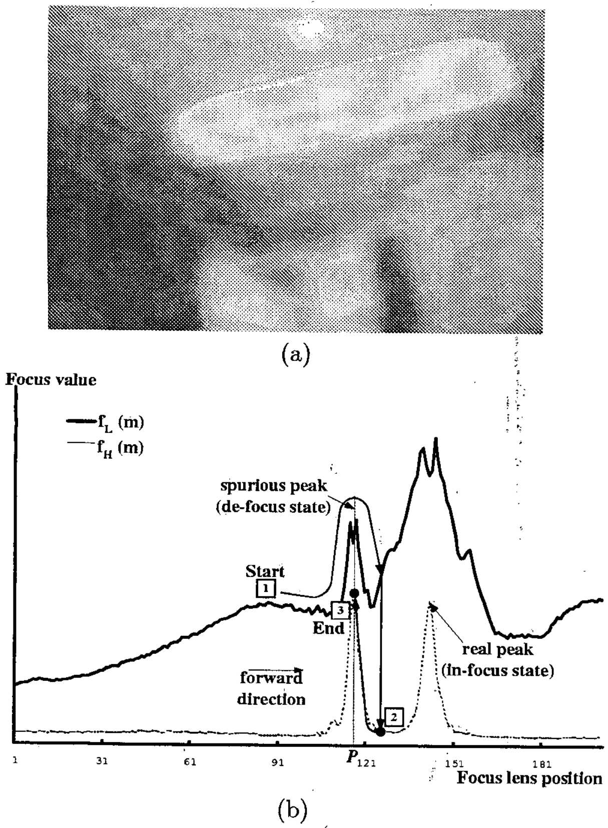
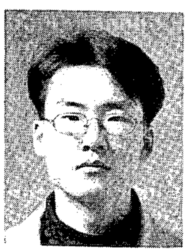



Fig. 12. The hill climbing algorithm, (a) de-focused scene, (b) hill-climbing search procedure

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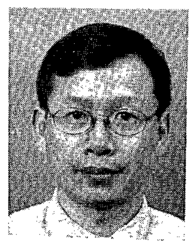

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