A VIDEO CAMERA SYSTEM WITH ENHANCED ZOOM TRACKING AND AUTO WHITE BALANCE

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Abstract—**This paper presents an advanced video camera system with robust automatic focus (AF), automatic white-balance (AWB), and enhanced zoom tracking. The proposed system can achieve accurate zoom tracking with significantly reduced system memory. It can also find accurate in-focus state even when the camera shoots at a CRT monitor or a light source. The proposed AWB technique compensates the luminance intensity of color components without degrading the image.**

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

I. Introduction

It is well known that 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 analog technology. In addition, the performance of the automatic adjustments including AF, AWB, auto exposure (AE) and zoom tracking has been improved, which are important features for high image quality, under various shot conditions [1]- [6].

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 the 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 [7]- [8]. Popular auto focusing techniques accomplish the in-focus state using the hill-climbing control.

The zoom tracking is the continuous adjustment of a camera's focal length, to keep in-focus state of camera image during zoom operation [2]. Without zoom tracking operation, a camera system cannot maintain in-focus state during zooming. Some conventional zoom tracking techniques were implemented using curve trace stored in a look-up table [3]. The simple look-up table method, however, requires a large system memory. Moreover, it is difficult to select a proper curve when the zoom lens moves toward the tele-angle.

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 the light source so that a white object appears as white under any light source. For AWB, the averaged value of the color difference signal in the image is used as the color temperature. 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 the light source and the ones by chromatic object, various AWB algorithm have been proposed [11]- [13].

This paper presents an advanced camera system which performs robust AF, AWB, and enhanced zoom tracking under various scene situations. The proposed AF technique prevents the camera from de-focusing when shooting at a computer monitor or a scene with a strong light source. The proposed zoom tracking algorithm maintains the in-focus status during the zoom operation and significantly reduces the system memory. In addition, the AWB algorithm compensates the color difference by deciding whether the color distortion of the scene is caused by a light source or a chromatic object.

The paper is organized as follows. In Section II, the proposed camera system is briefly introduced and the proposed automatic adjustment methods 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 opti-

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cal 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 then 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 for AF, integrated luminance value for AE, and integrated RGB data for AWB. The microcontroller transmits a motor control signal to a motor driver so that the focusing lens is moved in a direction that increases focusing value. The read only memory (ROM) in the micro controller stores the look-up table which has zoom trace data for various object distances.

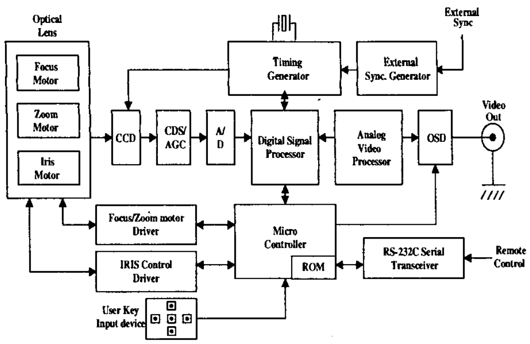


Fig. 1. Functional block diagram.

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, while *Window 2* is a half size of the image frame.

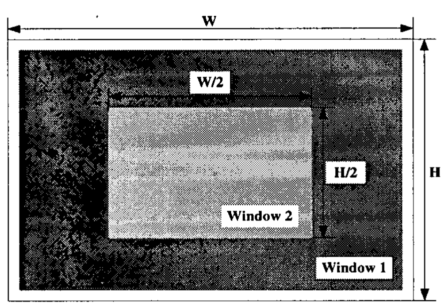


Fig. 2. The focusing control window.

The AF method uses two high pass filters with different cut-off frequencies for each window. Fig. 3 shows the focus values associated with f_{iL} and f_{iH}, when f_{iL} and f_{iH} are the low and high cut-off frequencies from window i (i=1, 2), respectively. The f_{iL} is used to determine 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. This is called the $Hill-Climbing$ algorithm.

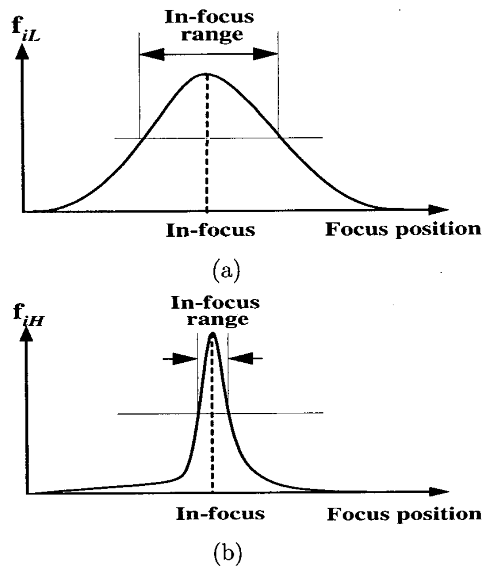


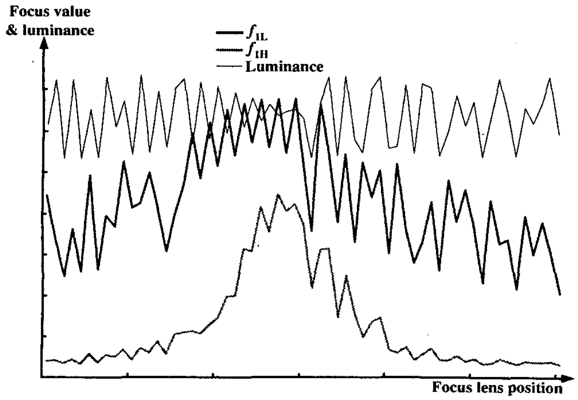
Fig. 3. (a) The focus value curve obtained by an HPF with a low cut-off frequency, (b) The focus value curve obtained by an HPF with a higher cut-off frequency.

In the hill-climbing algorithm, if a CRT monitor or a light source exists in the focusing window, there is a possibility of uncorrect focusing due to luminance fluctuations which in turn produce unstable focus values. Fig. 4(a) shows the focus and the luminance values of 75Hz CRT monitor. The data fluctuation makes it difficult to find a maximum value in the hill-climbing method.

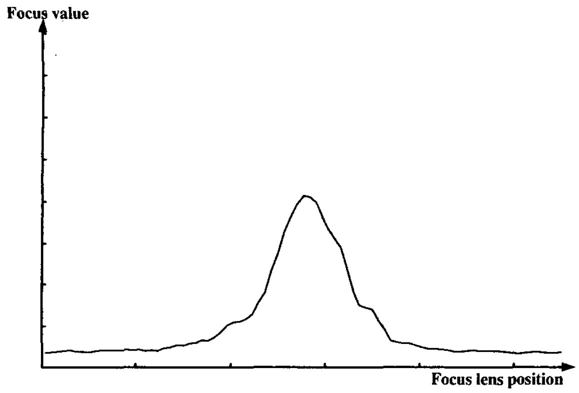
To solve this problem, the focus and luminance values are used. For the scene with the CRT monitor image, a nonlinear (median followed by average) filter is used to smooth the f_{1H} data, and the in-focus lens position with the maximum focus value is found by the hill-climbing method from the smoothed f_{1H}. Fig. 4(b) shows the filtering result of f_{1H}. It is seen that the in-focus state can now be obtained at the position of the maximum focus value.

B. Adaptive Zoom Tracking Algorithm

In some conventional look-up table zoom tracking methods, the control circuit comprises of a microprocessor equipped with read only memory (ROM) that



(a)



(c)

Fig. 4. (a) Focus and luminance values of a 75Hz monitor image, (b) f_{1H} after application of a non-linear filtering.

stores trace data curves for various focal distances. When the zoom lens is shifted for executing a zooming operation, the focusing lens is correspondingly shifted along the proper trace curve. Since the ROM can not store the trace data for many distances due to limitations of its memory size, the traces between the stored traces are estimated using the following equation:

$$d_c = D_c \frac{d_s}{D_s}, \tag{1}$$

where D_s is the difference between the focus positions of the upper and the lower traces, and d_s is the difference between the focus positions of the estimated and the lower trace at the zoom start point of Fig. 5. D_c is the difference between the focus positions of the upper and the lower traces, and d_c is the difference between the focus positions of the estimated and the lower trace at the current zoom point. As the zoom lens is shifted, the focusing lens tracks the trace stored or estimated.

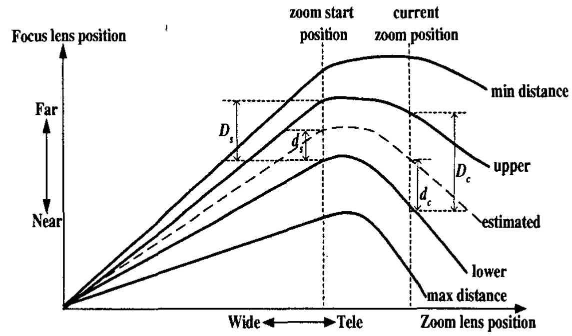


Fig. 5. The conventional zoom tracking algorithm.

However, if the lens position sensors do not have sufficient resolution then accurate estimation curve traces are not acquired. This results in bad focusing. The de-focusing gradually increases as the zoom lens moves toward the tele-end. For better estimation more acquired data is needed thus increasing ROM size.

The proposed adaptive zoom tracking algorithm requires less trace data stored in ROM as shown in Fig. 6. To the right of the reference point α all trace curve data is stored in ROM as in the look-up table method. However, to the left of the α only few points of the trace curve data are stored. Each curve is divided into the linear and nonlinear regions. In the linear region, the left and right end points are stored in the memory and the rest are calculated from the two points using the linear interpolation method. In the nonlinear region, the focus position at each zoom position is estimated using the trace data stored in the ROM.

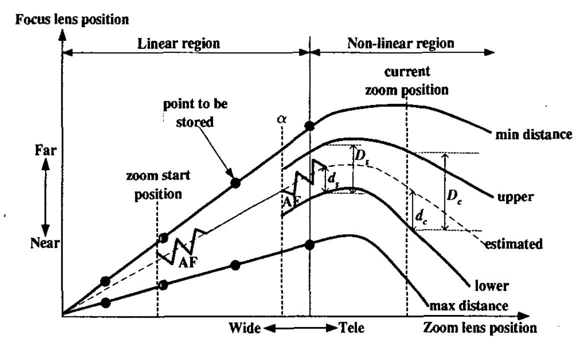


Fig. 6. The proposed adaptive zoom tracking algorithm.

Fig. 6 and 7 illustrate the proposed algorithm. First, when the zoom key is pushed, the position of the zoom

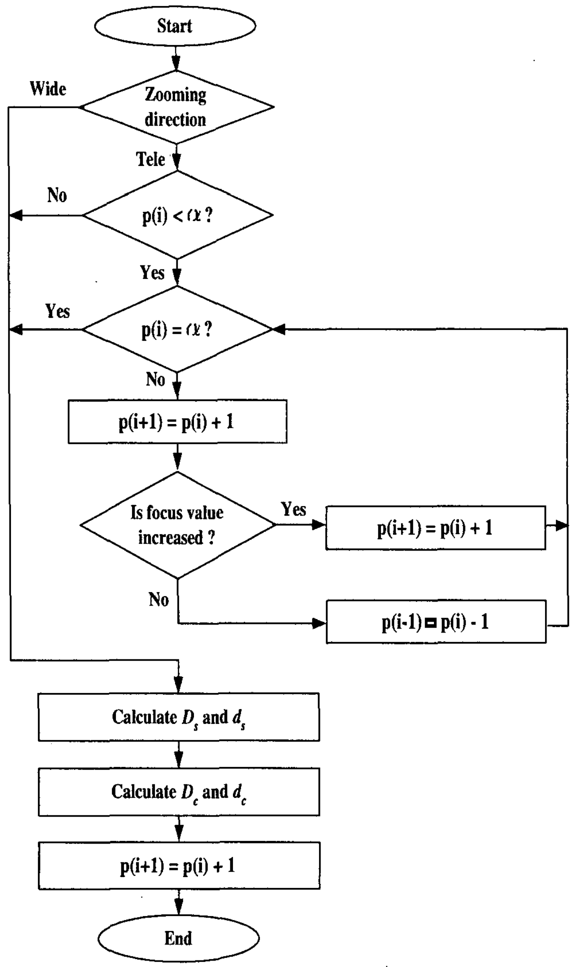


Fig. 7. The flowchart of proposed adaptive zoom tracking algorithm.

lens, namely, the zoom start point is examined. Let $p(i)$ be the current position of the zoom lens. A determination is made whether the zoom lens is moved towards the tele-end or the wide-end as follows: If the zoom lens is shifted toward the wide-end, D_s, d_s, D_c, and d_c are calculated. Then the zoom and focus lens are shifted along the estimated trace toward the wide-end. If the zoom lens is shifted toward the tele-end, the current zoom position is examined with respect to α. If $p(i) > \alpha$, D_s, d_s, D_c, and d_c are calculated to estimate the zoom trace. The zoom and focus lens are shifted using the estimated trace towards the tele-end.

If $p(i) < \alpha$, the following process is executed: The zoom lens is moved towards the tele-end and the current focus value is compared with the previous focus value. If the current focus value is greater than the previous focus value, the focus lens is moved in the same direction as in the previous step. Otherwise, the focus lens is moved in the reverse direction. When the zoom lens reaches α, i.e., $p(i) = \alpha$, the AF operation is resumed.

C. AWB Algorithm

For AWB control, the integrated color difference values, R-G and B-G, over one image frame are used. Any uniform color can be represented with a point on the R-G, B-G coordinate system as shown in Fig. 8. The proposed AWB method adjusts the gain of color signals such that the color difference moves to the origin represented by the white color. Each color component is given by

$$X = I_X \cdot A_X, \tag{2}$$

where X is one of the R, G, B color components, I_X is the integrated value of X generated from DSP, and A_X is the control gain of each color component. The proposed AWB method assumes that the integrated values of the R, G, B color components are equal. This assumption leads to the target gains for the white color given by

$$\begin{aligned} A_R &= (I_G/I_R) \cdot A_G, \\ A_B &= (I_G/I_B) \cdot A_G, \end{aligned} \tag{3}$$

where I_R, I_G, and I_B are the integrated value of each color component, A_G is a given control gain of Green, and A_R and A_B are the target gains of Red and Blue, respectively. The A_R and A_B are adjusted so that the integrated color difference value moves towards the white color.

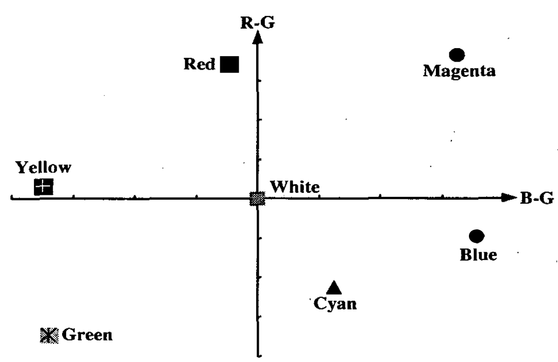


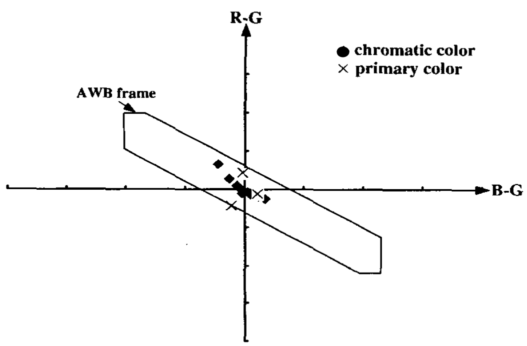
Fig. 8. The color coordinate system.

To discriminate a scene with a singe primary color from that with chromatic color, we use a predefined region, named as *the AWB frame* (Fig. 9(a)). The scene whose color difference value is outside of the frame has a single primary color and as a consequence the AWB control is not needed. However, when the luminance intensity is low, the color difference is within the frame even though the scene has a single primary color (Fig. 9(a)). The AE control should solve this problem, but the image degradation can be caused by excessive AGC (Auto Gain Control).

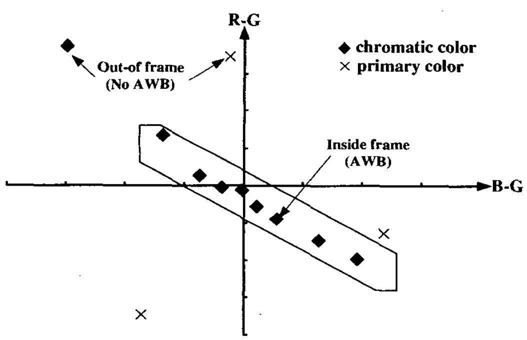
The proposed algorithm uses *the normalized color difference* to compensate the luminance intensity without image degradation. The normalized color difference is obtained by

$$D_N(X,G) = D(X,G) \cdot T_G/I_G, \qquad (4)$$

where X is one of the R and B components, $D(X,G)$ is the color difference which is equal to either $|R-G|$ or $|B-G|$, $D_N(X,G)$ is the normalized color difference, T_G is the target value of Green, and I_G is the integrated value of Green. Fig. 9(b) shows how the normalized color difference of the primary color is extended to the outside of the frame.



(a)

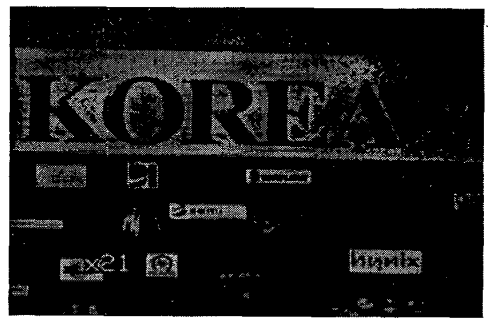


(b)

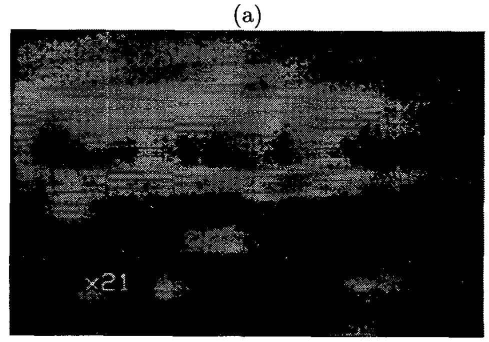
Fig. 9. The color difference normalization, (a) low luminance intensity, (b) normalized color difference.

III. Simulation Results and Conclusions

Fig. 10 illustrates the result of the proposed zoom tracking algorithm when the zoom tracking is finished. Fig. 10(a) and (b) show the results associated with the proposed algorithm and the simple look-up table method, respectively. As shown in Fig. 10, the proposed zoom tracking produces the in-focus image during the zoom operation, while the look-up table method does not. Fig. 11(a) presents another in-focused monitor scene processed by the proposed AF algorithm. For comparison purposes, the conventional AF algorithm is applied to the same scene, and the result is shown in Fig. 11(b). It is seen from these two pictures that the proposed algorithm better than the conventional method.



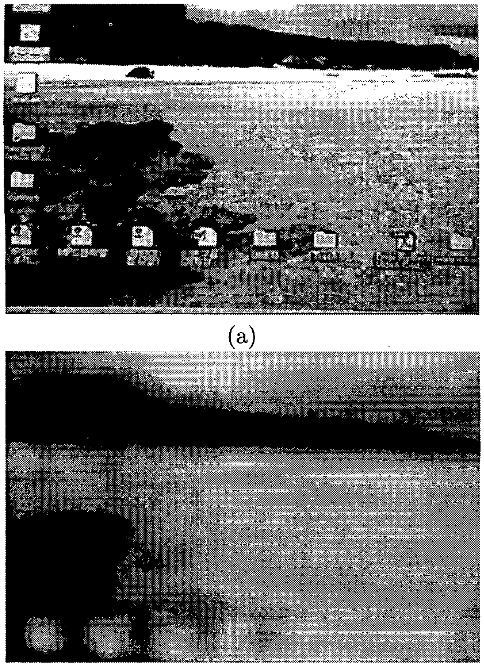
(a)



(b)

Fig. 10. (a) In-focused scene obtained by the proposed zoom tracking, (b) De-focused scene obtained by the simple table look-up method.

The proposed zoom tracking algorithm can reduce the data stored in memory, and prevent bad focusing caused by position detection error. Moreover the proposed AF algorithm finds the accurate in-focus state even when the camera shoots the CRT monitor or light source. The proposed AWB technique compensates the luminance intensity of color components using *the normalized color difference* without image degradation.



(a)

(b)

Fig. 11. (a) In-focused monitor scene obtained by the proposed AF algorithm, (b) De-focused monitor scene obtained by the conventional algorithm.

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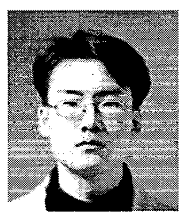

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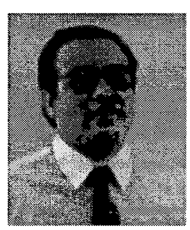

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