International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:7, No:8, 2013

Design of Auto Exposure Unit Based On 2-Way Histogram Equalization

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Abstract**—**Histogram equalization is often used in image enhancement, but it can be also used in auto exposure. However, conventional histogram equalization does not work well when many pixels are concentrated in a narrow luminance range. This paper proposes an auto exposure method based on 2-way histogram equalization. Two cumulative distribution functions are used, where one is from dark to bright and the other is from bright to dark. In this paper, the proposed auto exposure method is also designed and implemented for image signal processors with full-HD images.

Keywords**—**Histogram equalization, Auto exposure, Image signal processor, Low-cost, Full HD Video.

I. Introduction

AUTO exposure (AE) adaptively controls the brightness of the acquired images from the image sensor to get better visibility. Usually, AE calculates a brightness gain of the acquired image, where the average brightness of the image is similar to the target brightness. However, AE often fail to enhance the image visibility when the image is too dark or too bright.

Histogram equalization (HE) can be a solution for this problem. HE mainly performs contrast enhancement, but it also controls average brightness. In the hardware implementation, HE is more efficient than AE, since HE exploits more simple and regular computation than AE. So, HE is often used in the image signal processors for both brightness and contrast controls.

HE controls luminance values to have more uniform distribution based on the cumulative distribution function. However, it often suffers to enhance visibility when many pixels are concentrated in a narrow luminance range. To overcome these problems, many HE algorithms such as brightness preserving bi-histogram equalization (BBHE) [1], dualistic sub-image histogram equalization (DSIHE) [2], recursive mean-separate histogram (RMSHE) [3] are proposed. However, these algorithms exploit quite complex and irregular computations, which are not suitable for hardware implementation.

In this paper, a simple and efficient auto exposure method is proposed based on 2-way histogram equalization. Two cumulative distribution functions are used, where one is from dark to bright and the other is from bright to dark. The proposed algorithm is also designed and implemented for image signal processors with full-HD images.

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II. Auto Exposure and Histogram Equalization

A. Auto Exposure

AE automatically controls iris, shutter speed, and analog gain control by detecting the amount of light to be projected. In general, AE calculates gain to make average brightness of input image equal to a target value. Equations (1) and (2) are auto exposure gain and compensated output value, respectively.

$$Gain = \frac{Target\ luminance\ value}{Average\ value\ of\ luminances\ in\ a\ frame} \tag{1}$$

$$Pixel_{out} = Pixel_{in} \times Gain \tag{2}$$

However, AE controls only brightness of the image and it cannot enhance image contrast. Furthermore, in the hardware implementation, AE requires dividers in (1) and multipliers in (2), which significantly increase hardware complexity.

B. Histogram Equalization

HE generates a transformation function based on the histogram of input image. Equations (3), (4), (5), and (6) are cumulative distribution function, histogram function, transformation function, and compensated output value, respectively.

$$CDF(n) = \sum_{k=0}^{n} V(k) \tag{3}$$

$$V(n) = Number\ of\ pixels\ in\ a\ frame\ whose\ luminance\ is\ n \tag{4}$$

$$HE(n) = \frac{CDF\ (n)}{Number\ of\ pixels\ in\ a\ frame} \times 255 \tag{5}$$

$$Pixel_{out} = HE(Pixel_{in}) \tag{6}$$

HE enhances image contrast, and also controls average brightness. Note that (5) and (6) include division and multiplications, but they can be implemented by lookup tables. Therefore, HE does not require dividers or multipliers, which significantly reduces hardware complexity.

C. Comparison between AE and HE

Fig. 1 shows the results of AE and HE in Fig. 1, HE results show better brightness and contrast when compared with AE results.

(a) (b)

(c) (d)

(e) (f)

Fig. 1 Comparison of AE and HE results (a), (b) Original image (c), (d) AE results (target brightness=127) (e), (f) HE results

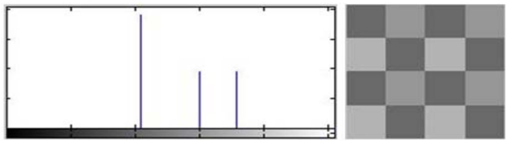
III. Proposed Histogram Equalization

A. Problem of Conventional Histogram Equalization

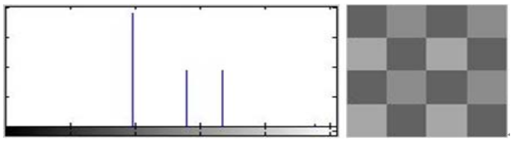
In general, HE shows better results than AE, but HE often faces serious problems when many pixels are concentrated in a narrow luminance range. Fig. 2 shows an example. AE does not sufficiently enhance the visibility, but it seems quite natural. On the contrary, HE sufficiently enhances the visibility, but it seems quite unnatural. To solve these problems, many algorithms [1]-[3] are proposed, but most of these algorithms require quite complicated and irregular histogram modifications [4]. Therefore, these algorithms are not suitable for hardware implementation.

B. 2-Way Histogram Equalization

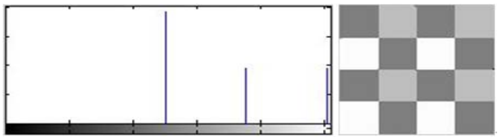
Basic histogram equalization in (3) - (6) is quite simple and it is suitable for hardware implementation. However, it suffers from above problems. Basically, these problems come from the fact that the cumulative distribution function in (3) is unidirectional from dark to bright. Therefore, in this paper, 2-way histogram equalization is proposed. Two cumulative distribution functions are used, where forward cumulative distribution function is calculated from dark to bright and backward cumulative distribution function is calculated from bright to dark.



(a)



(b)



(c)

Fig. 2 Problems of HE when many pixels are concentrated in a narrow luminance range (a) Original image and histogram (b) AE results (target brightness=127) (c) HE results

$$CDF_{forward}(n) = \sum_{k=0}^{n} V(k) \quad (7)$$

$$CDF_{backward}(n) = \sum_{k=n}^{255} V(k) \quad (8)$$

$$HE_{forward}(n) = \frac{CDF_{forward}(n)}{Number\ of\ pixels\ in\ a\ frame} \times 255 \quad (9)$$

$$HE_{backward}(n) = \left(1 - \frac{CDF_{backward}(n)}{Number\ of\ pixels\ in\ a\ frame}\right) \times 255 \quad (10)$$

$$Pixel_{out} = \frac{HE_{forward}(Pixel_{in}) + HE_{backward}(Pixel_{in})}{2} \quad (11)$$

From (3)-(11), the proposed 2-way HE is simplified into (12) and (13). Note that computational overhead of the proposed 2-way HE is quite small, since only *V(n)* is added to the conventional HE.

$$HE_{2-way}(n) = \frac{CDF\ (n) - \frac{V(n)}{2}}{Number\ of\ pixels\ in\ a\ frame} \times 255 \quad (12)$$

$$Pixel_{out} = HE_{2-way}(Pixel_{in}) \quad (13)$$

Fig. 3 shows the results of the proposed 2-way HE. Comparing Figs. 2 and 3, it is clear that the proposed 2-way HE shows better results when many pixels are concentrated in a narrow luminance range.

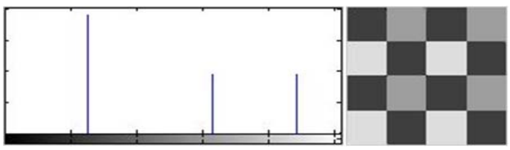


Fig. 3 Results of the proposed 2-way HE

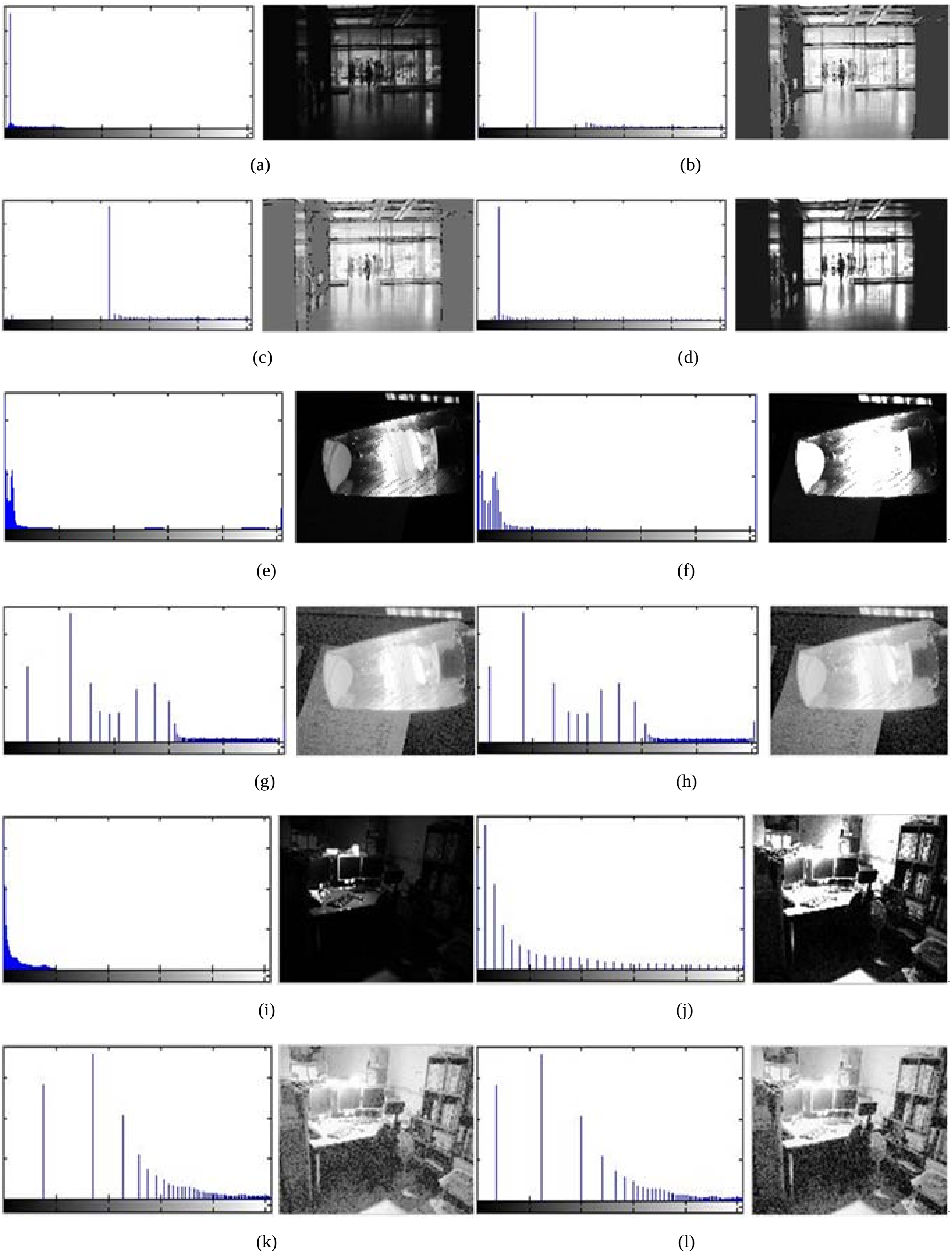


Fig. 4 Results of AE, HE, and the proposed 2-way HE (a), (e), (i) Original image and histogram(b), (f), (j) AE results (target brightness=127) (c), (g), (k) HE results (d), (h), (l) Proposed 2-way HE results

Fig. 4 shows the results of AE, conventional HE, and proposed 2-way HE in various images with overall dark and narrow histogram distribution. AE results (Fig. 4 (b), (f) and (j)) on dark area are forcibly converted to average brightness. So bright area is saturated and smearing appears. Dark area is not sufficiently equalized, so contrast is low. Conventional HE results (Fig. 4 (c), (g) and (k)) seem better than AE results, but dark area is shifted to high brightness range. On the contrary, in the proposed 2-way HE results, dark area is less shifted to high brightness range, so its contrast is much enhanced.

IV. Hardware Implementation

Fig. 5 shows the architecture of the proposed 2-way histogram equalization. Dual-port SRAM of 17×256 bytes is used to create histogram of input image. Input pixel value is the address of dual-port SRAM and the stored value of given address increases by 1. When all input pixels are processed, the stored data is transferred into single-port SRAM to form lookup table.

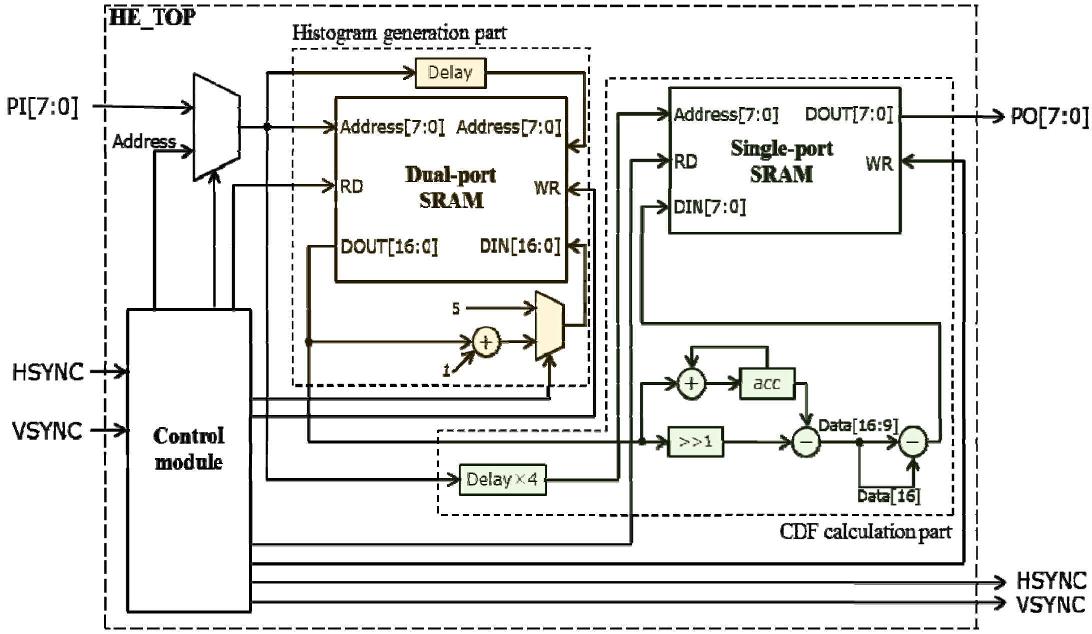


Fig. 5 Hardware architecture of the proposed 2-way HE results

V. Conclusions

In this paper, a simple and efficient auto exposure method is proposed based on 2-way histogram equalization. Two cumulative distribution functions are used, where one is from dark to bright and the other is from bright to dark. The proposed algorithm is also designed and implemented for image signal processors with full-HD images.

Acknowledgment

This research was supported by the MSIP (Ministry of Science, ICT&Future Planning), Korea, under University ITRC support program (NIPA-2013-H0301-12-2006) supervised by the NIPA (National IT Industry Promotion Agency).

This research was also supported by ETRI SW-SoC R&BD Center, Human Resource Development Project, funded by the MOTIE (Ministry of Trade, Industry, & Energy), Korea (10039239).

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