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Novel Image Contrast Enhancement for SoC of Small Mobile Display

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Abstract:Recently,the mobile phone has emerged as a leading icon of the convergence of consumer electronics. A wide variety of mobile phone applications such as DMB (digital multimedia broadcasting), digital photography, video telephony, and full internet browsing are now available to consumers. To meet the demands of these applications, image quality has become increasingly important. Furthermore, touch windowsare popular on mobile display panels,but they cause contrast loss because ofthe low transmittance of ITO film. This paper presents an image contrast enhancement algorithm to be embedded on aSoC.A clipped histogram stretching (CHS) method is proposed here to enable the algorithm to adapt to the input images, while an S-shaped curve algorithm and a gain/offset method are proposed for static applications. Finally, the performance of the proposed algorithm is evaluated using histograms, RGB pixel distributions, entropy values, and dynamic range values of the resulting images.

Keywords:Mobile display,Contrast Enhancement,Histogram Stretching, SoC, FPGA

I. Introduction

In recent years, numerous new applications such as DMB (Digital Multimedia Broadcasting), video telephony, and full Internet browsing have been playing very attractive roles in mobile phone services. For this reason, image enhancement of small mobile displayshas become a demanding issue for mobile users.

Theimage enhancement technologies which have been studied for large-screen TVs could also be useful for small mobile displays. Among these, image contrast enhancement is one of the most important methods.The resolution of a mobile display is considered high when it is greater than WVGA(800×480), but the resolution of source images is even less. That is why source images need to be upgraded. Image scaling also causes a blurring effect [1, 2],which degrades image contrast by pixel interpolation processing. Furthermore, touch-screen phonesare very popular, but the transmittance of ITO is relatively low (approximately 75–79%), and deposition of ITO (indium-tin oxide, In_2O_3/SnO_2) film on the touch-screen glass causes a loss of contrast ratio in the display. The most widely used method of image enhancement is intensity transformation to enhance the image contrast ratio. In this method,a linear, logarithmic, or power function is used to transform the input image intensity. Those functions are classified as gain/offset control and gamma correction methodsdepending on the display characteristics of each device. Recently,an adaptive histogram stretching method has been widely used. In this method, a histogram of the input image is analyzed and then transformed into the desired shape. Compared with all other methods, theresults reported here show that the proposed algorithm is the most effective for a variety of images.

This paper reports on the development of a novel CE (contrast enhancement) algorithm to be embedded in aSoC (system on chip) for mobile display which is implemented on anFPGA(flexible programmable gate array). The algorithms investigated are CHS (clipped histogram stretching), S-shape curve, and gain control.The performance of the FPGA with each proposed algorithm is evaluated and compared with others in the section on simulation results.This paper is organized as follows: Section I gives the introduction of image enhancement technologies. Section II describes the proposed contrast enhancement algorithm. Section III shows the experimental results to validate the proposed algorithm. The last section IV concludes the paper followed by the references

II. Proposed CE Algorithm

The block diagram of the display controller for the SoC under development is shown in Fig. 1.The capture block is used to transform the input image format and color matrix to replace RGB with YUV. The SoC has a frame memory (SDRAM, 16MB) which is used for prevention of tearing and for frame-rate conversion. Real-time input pixel data are stored into frame memory. The image enhancement block receives the pixel data from the scaling block. In this block, image enhancement is performed, and then a LUT (look-up table) is positioned to provide necessary functions for the image display. The user can upload the gammacorrection list arbitrarily using an I^2C(inter-integrated circuit) serial port. In the image enhancement block, CHS(clipped histogram stretching) can process RGB or YUV. This component prevents color distortion effectively by using only the Y-component. The image enhancement circuit is placed after the frame memory. A detailed image enhancement block diagram is shown in Fig. 2. CHS, the S-shaped curve, and gain control are used for contrast enhancement. Each block will be explained in detail in the next section.

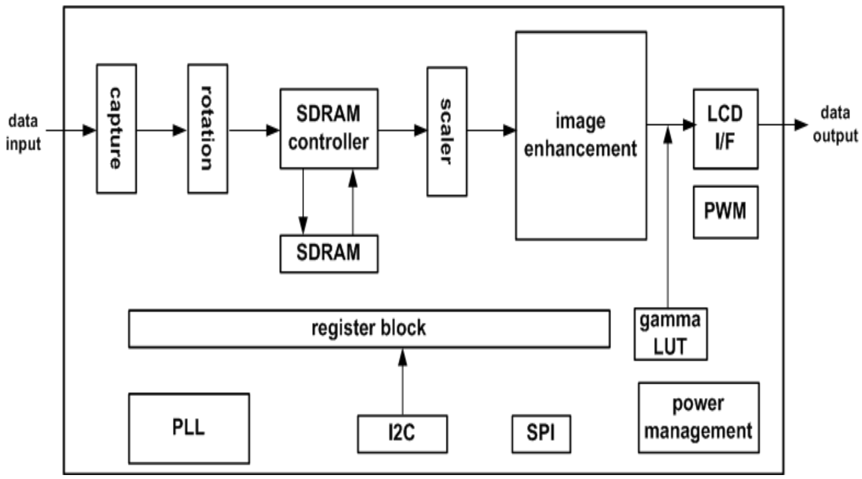

Fig. 1 System architecture of the image enhancement SoC

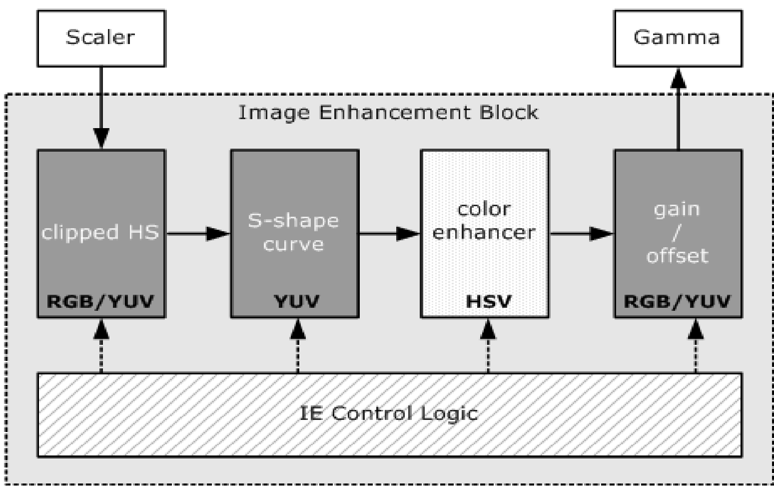

Fig. 2Functional block diagram of the image enhancement system

A. CHS

CHS is an adaptive contrast-enhancement technique which can extend the histogram of moving input images dynamically [3]. Figure 3 shows a demonstration result from the CHS method. New minimum (I'_{min}) and maximum (I'_{max}) intensity values are provided from the input images. When equations (1) and (2) are satisfied, $I'_{min}$and $I'_{max}$are obtained. Next, the histogram is stretched according to equation (3). The CHS block requiresamemory device togenerate histogram information. For this purpose,a 15.36-KB SRAM is allocated (because each pixel can have only one intensity value). This means that the available resolution is VGA and that the system can process R, G, and B separately. Figure 4 shows the H/W (hardware) structure of the CHS.

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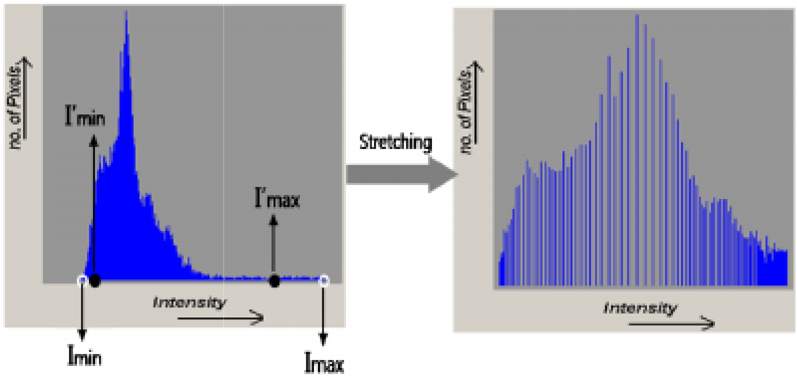

Fig.3Clippedhistogram stretching

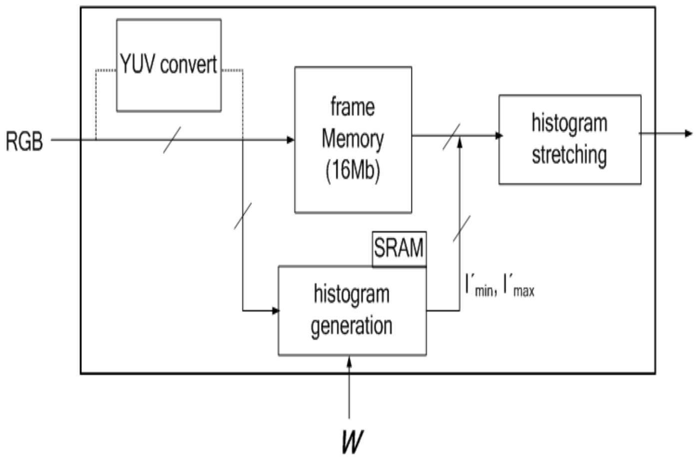

Fig. 4Hardware block diagram of the CHS scheme

Histogram generation is performed before the histogram stretching block to generate the new intensity values I'_{min} and I'_{max}. These new minimum and maximum intensity values are chosen using*w*values (weighting factors) from the input image pixel data which are stored sequentially in SRAM. Next, histogram stretching is performed while reading the pixel data from frame memory. As shown in Fig. 4, the histogram generation block is located in parallel with the frame memory. This is why the histogram stretching block receives the new intensity values and the frame data of the same frame simultaneously. The following equations are used to search for new minimum and maximum intensity values:

$$I'_{min} = k_1,\ where \sum_{i=0}^{k_1} n_i \leq H \times V \times w \quad (1)$$

$$I'_{max} = k_2,\ where \sum_{i=0}^{k_2} n_i \leq H \times V \times w \quad (2)$$

whereH and V are the horizontal and vertical resolution, respectively of the input image, and *w*is a selectable weighting factor that represents the clipping ratio of the whole histogram energy from 0.1% to 0.9%. In equations (1) and (2), n_i is the number of pixels at intensity value *I*in the input image, and $k_1$and k_2 are pixel intensity values ranging from 0 to 255. The histogram is stretched according to equation (3).

$$I_o = \begin{cases} 0, I_i < I'_{min} \\ \frac{I_i - I'_{min}}{I'_{max} - I'_{min}} \times 255\ ,\ I'_{min} \leq I_i \leq I'_{max} \\ 255, I_i > I'_{max} \end{cases} \quad (3)$$

B. S-shapedCurve

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The S-shaped curve method is a static contrast enhancement technique which can be used for still images. This method is indifferent to the histogram of the input image, but simply transforms input pixelsinto output pixelsby means ofan arbitrary mapping process. Unlike CHS, it does not require any memory.In this research, only the luminance component(Y) was considered. Figure 5 shows a block diagram of the S-shaped curve generation algorithm.

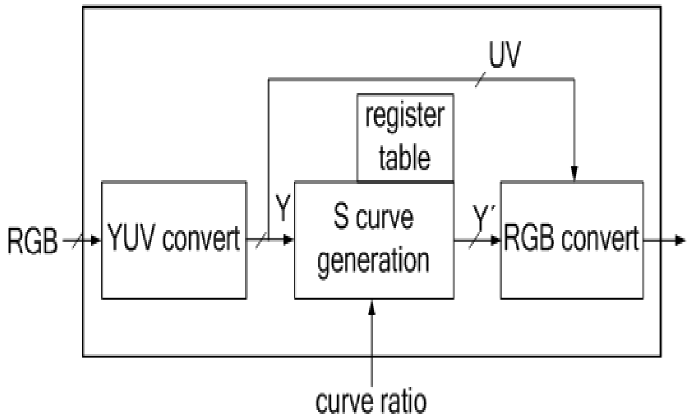

Fig.5H/W blocks of the S-shaped curve generation algorithm

The following equation is used to generate the S-shape curve:

$$Y'_i = Y_i \times (1 \pm CR) \square T_i \times CR + 0.5 \qquad (4)$$

where$Y_i$is the luminance component of the input image, Y_i' is the new luminance component generated byequation (4),CR isthe ratio of curvature, and T_i is a constant value which is embedded in the register table block. The T_i register table block is implemented using power pads and ground pads forsimplicity and compact block size. A plot of T_i versus Y_i is shown in Fig. 6.

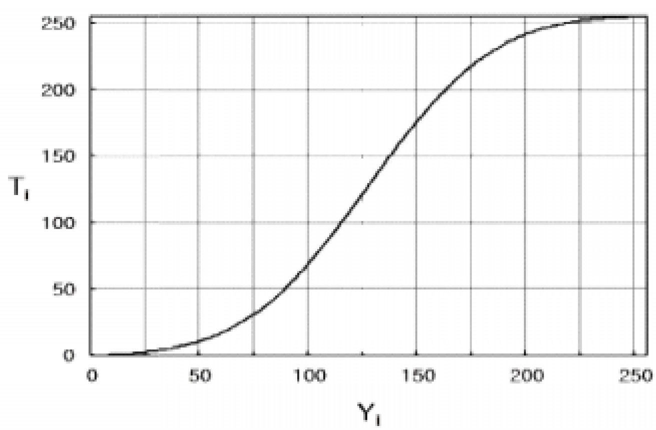

Fig.6PlotofT_i versus $Y_i$usedfor S-shaped curvegeneration

T_i is determined byY_i and has 171 constant values at 256 gray levels.Figure 7 shows the relation between the luminance value of the input image (Y_i) and the new luminance value (Y_i'). The shape of the S-curve is determined by whether the CR is positive or negative.

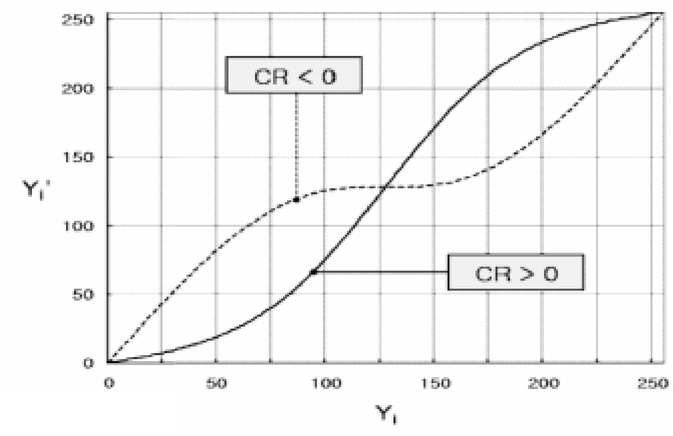

Fig.7Plot ofY_i' versus $Y_i$for the S-shaped curve

C. *Gain/Offset Control*

The offset control method increases the brightness of an image by simply adding an arbitrary value to the input pixel value. Similarly, the gain control method enhancesthe contrast of an image by multiplying each input pixel value by an arbitrary value. This method is depicted in Fig. 8:

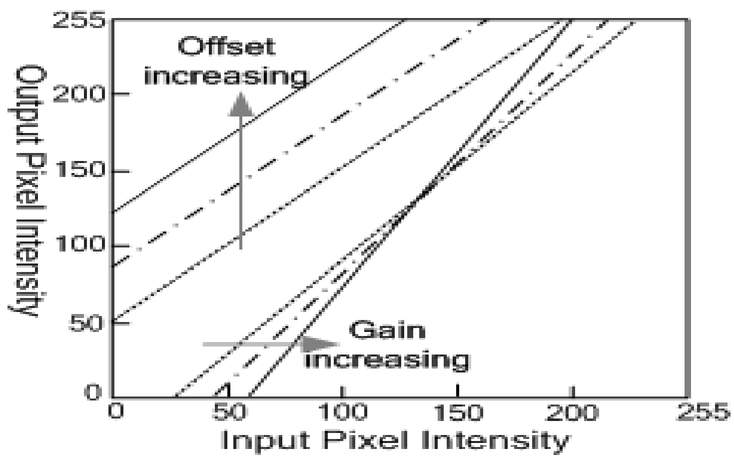

Fig. 8Gain andoffset curve

III. Experimental Results

The results of the simulationsperformed in this researchare shown inFig. 9. The source image has 640×480 resolution and is in 24-bit RGB format. Figure 9(a) showsthe source image;in Fig. 9(b),the CHS method has beenused to obtain the luminance Y. Figure 9(c) shows the source image as processed by the S-shaped curve algorithm, and the output of the gain control method is shown in Fig. 9(d). It can be seen that Figs.9(b) to 9(d) have clearer contrast than Fig. 9(a) in the areasrepresenting sky with clouds, the roof of the lighthouse, the pole of the lighthouse, and the grass in front of the fence.

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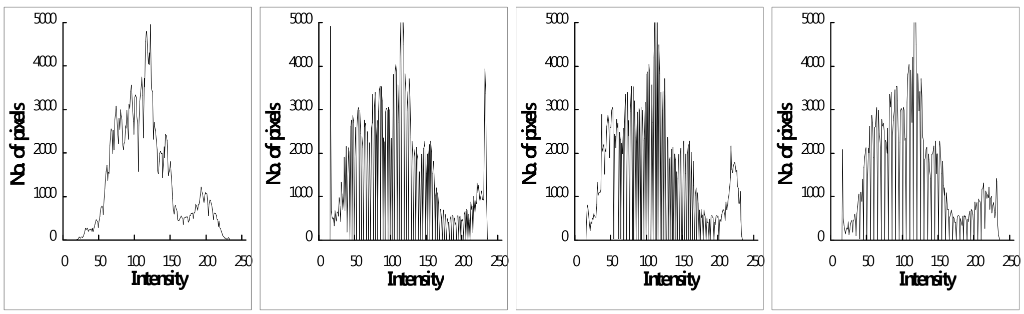
(a) (b) (c) (d)

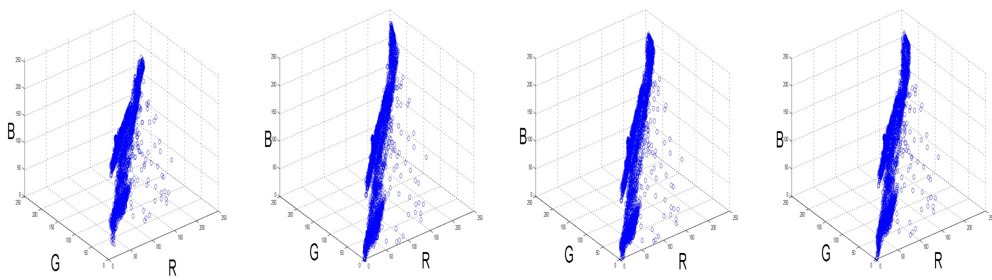
Fig. 9Simulated images: (a) source image, (b) CHS (w=9), (c) S-shaped curve (CR=9),(d) gain control method (gain = 25)

Figure 10 shows histograms of theoutput images. It is clear that the histograms of the output imageshave a wider extent than that of the source image. Even thoughthe dynamic range is extended to the maximum level, there are still discontinuities in the histograms of each image.Figure 11 shows the distributions of the RGB pixel values of the output images after contrast enhancement.



(a) (b) (c) (d)

Fig.10Histograms of output images: (a) source image, (b) CHS (w=9), (c) S-shaped curve (CR=9),(d) gain control method (gain = 25)



(a) (b) (c) (d)

Fig.11Distribution of RGB pixel values of output images after contrast enhancement: (a) source image, (b) CHS (w=9), (c) S-shaped curve (CR=9), (d) gain control method (gain=25)

Compared to the source image,Figs. 11(b) to 11(d) exhibit a greater range of RGB pixel values.In particular, the blue pixel valuesexhibit a broader range than the other R and G pixel values,which may make the simulated imagefeel colder than the source image. Contrast enhancement was investigated quantitatively using the entropy and Hsu et al. methods [4]. Entropy provides randomness that can be used to measure the degree of uniformity of the distribution of probability variables. In image processing, a pixel value is equivalent to a probability variable, and higher entropy means higher contrast ratio [5]. Hsu et al. proposed a simple method fordetermining by how much contrast has been enhanced [4]. Using the cumulative distribution function (CDF) of the histogramsof the source and processed images, an intensity value ratio between 25% and 75% was determined.Figure 12showsthe plotobtained usingthe Hsu et al. method, and Table 1 shows a summary of the results.

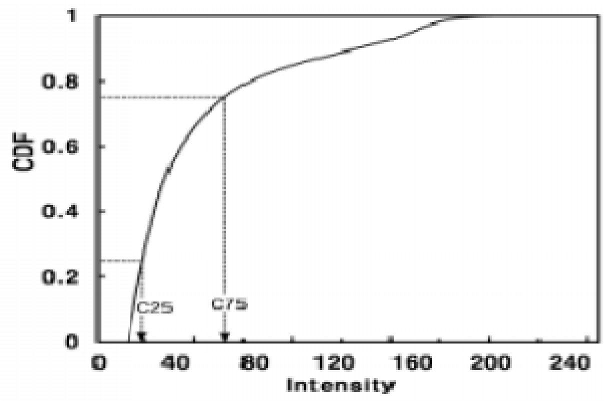


Fig. 12Contrast enhancement ratio measurement using CDF

TABLE I. CONTRAST ENHANCEMENT RATIO OF OUTPUT IMAGES

Method	Entropy	Hsu et al. method [4]		
		C25	C75	CE ratio(%)
Source	7.5366	86	136	0
CHS	7.6092	69	141	30
S-curve	7.7479	64	144	42
Gain	7.6704	76	139	20

From table 1, we can seethe results of the entropy and Hsu et al. methods. In particular, the S-curve control method provides the highest contrast enhancement compared tothe other methods.The algorithms proposed in this paper, CHS, S-curve control, and gain control,were embedded on an FPGA(Field Programmable Gate Array) board to evaluate their performance. TheXC4VLX200-F1513CFPGA, one of the Vertex series manufactured by Xilinx with 200,000 gates, was used in this experiment.The system clock rate was 125MHz.The display panel wasa TFT-LCD made by LG Philips (LB070WV1)with a resolution of800×480. Figure 13 shows a photograph of the FPGA evaluation board.

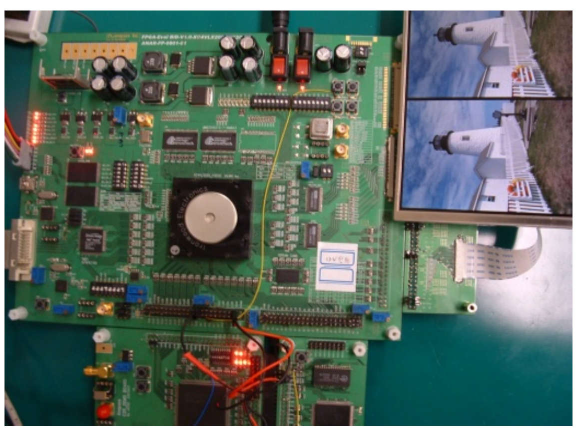


Fig. 13FPGA evaluation board

In Figure 14, the leftportionshows the source image, while the right portion shows the enhanced image on a real LCD panel. The same CHS algorithm was used to generateFigs. 14(a) and 14(b), but Fig.14(a) was processed using onlythe luminance component, whileFig. 14(b) wasprocessed using the RGB components. The result using the RGB componentsshows a more highly enhanced color effect than the image produced using luminance only. When choosing RGB or luminance components, the gamma characteristics of the display panel must be considered. In Fig. 14(c), S-curve controlwas used, andit is apparent thatthe white color is too highly saturated in the cloudsof the sky and the pole of the lighthouse.

(a) (b) (c)

Fig. 14.LCD display images using the FPGA board: (a) CHS(Y), (b) CHS (RGB), (c) S-shaped curve.

IV. Conclusion

This paper has reported on the development ofa novel method of contrast enhancement for anSoCof a small mobile display. The contrast enhancement algorithmsdeveloped are CHS(clipped histogram stretching), S-shaped curve, and gain control. To evaluate the performance of these algorithms, hardware blocks were embedded on an FPGA board. According to the simulation results, the S-shaped curve and CHS gave much higher enhancement ratios than gain control. However,one side effect was apparentin the transformation of the “feel” of the image because the distribution of RGB pixel valueswas distorted. The experimental resultsreported here have proven that a user-friendly image enhancement algorithm for SoChas beensuccessfully developed. Moreover, this algorithm can be simply embeddedto implement ahardware systemand has potential for application to real-time image contrast enhancement.

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BIOGRAPHY

Jin-Young Chung received B.S. and M.S. degrees in 1994 and 1996, respectively from the dept. of material engineering, Ajou University, Korea. From 2000 to 2005, he worked as a senior researcher in Pantec&Quritel co., Korea. He obtained a Ph.D. degree in 2010 from the dept. of electronics engineering,Kookmin University, Seoul, Korea. He is now working as a senior manager in Technical Sales and Marketing Division, Anapass Inc., Korea. His current research interest includesSoC of image processing for mobile display.

Ki-Doo Kim received B.S. degree in Electronics Engineering in 1980 from Sogang University, Seoul, Korea. He worked as a research engineer at the Agency for Defense Development in Korea from 1980 to 1985. He got the M.S. and Ph.D. degree in 1988 and 1990 from the Pennsylvania State University, USA. He joined Kookmin University asaAssistant Professor in 1991. He also served as a visiting scholar in the EE department, UCSD, USA from 1997 to 1998. He is now working as a Professor in the School of Electrical Engineering of Kookmin University, Seoul, Korea. His current research interest includes digital communication and digital signalprocessing , etc.