2009 Ninth International Conference on Intelligent Systems Design and Applications

Image Constrast Control based on Łukasiewicz's Operators and Fuzzy Logic

N.M. Hussein Hassan, A. Barriga
Instituto de Microelectrónica de Sevilla (CNM-CSIC)/Universiy of Seville
c/ Americo Vespucio s/n. 41092-Sevilla, Spain
e-mail: nashaat@imse.cnm.es, barriga@imse.cnm.es

***Abstract*—This paper describes a technique to control the contrast in images based on the application of Łukasiewicz algebra operators. In particular, the technique is based on the bounded-sum and the bounded-product. An interesting feature when applying these operators is that it allows low cost hardware realizations (in terms of resources) and high processing speed. The selection of the control parameters is perform by a fuzzy systems**

Keywords-image contrast control; fuzzy logic;

I. INTRODUCTION

The sensory human systems are organized to respond rapidly to the temporary and spatial changes of the energy stimulus. When there is a temporary change in the energy applied to the sensor there is initially a strong response. Then the senses adapt rapidly (they respond less) to the constant and continued use of the energy. The visual system shows two types of behaviors: firstly to have the aptitude to answer (to see) both with weak lightings and with very brilliant lightings, and secondly to have the aptitude to discriminate between two objects that reflect very nearby intensities between them. To be able to adopt these types of behavior the visual system has two mechanisms: the mechanism of rapid adjustment and the mechanism of local adjustment. Into the first case the retina changes its operative range (range of light intensity) approximately three tenths of second after the change taking place in the light intensity level. In case of the mechanism of local adjustment different parts of the retina adapt to different levels from lighting.

The luminance describes the energy of the stimulus and does not describe the changes of the energy. For this reason the contrast is defined in order to describe the changes of the energy. There are many proposals for the contrast measurement. Basically the contrast can be defined as the change of the relative luminance of the elements of an image. Therefore it corresponds to the difference of luminance that exists between two points of an image. The histogram of the image turns out to be a useful tool to determine the contrast in the image [1].

In this paper we are going to present a contrast control technique that allows low cost hardware realizations and high processing speed.

The paper is organized as follows. In the next section we will describe images contrast control techniques. Then we will present the effect of Łukasiewicz algebra operators in the contrast of an image. Finally we will consider fuzzy logic inference systems for the control of contrast.

II. TECHNIQUES OF CONTROL OF CONTRAST

A definition of contrast is the contrast of Weber and it is commonly used in the context of the lighting. It consists of the difference between two luminance divided by the lowest luminance.

$$C = \frac{L_{\max} - L_{\min}}{L_{\min}}$$

Another definition frequently used in photography is that of simple contrast. It is the difference between the brilliant and dark parts of the picture. This definition is not useful for luminance of the real world due to its wide dynamic range and the logarithmic characteristics of the response of the human eye.

$$C = \frac{L_{\max}}{L_{\min}}$$

The peak-to-peak contrast or Michelson's contrast measures the relation between spread and the sum of two luminances. This definition is used in signal processing theory for determining the quality of a signal regarding to its noise level.

$$C_M = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}}$$

A further type of contrast measure is the variance. It is given by the following expression:

$$\sigma^2 = \frac{1}{MN} \sum_{k=1}^{L} (k - \bar{k})^2 n_k$$

where M and N are the dimension of the image, k is he value of the luminance in the range $[1,L]$, n_k is the frequency of the k luminance level , and $\bar{k}$ is the mean value of the luminance distribution,

$$\bar{k} = \frac{1}{MN} \sum_{k=1}^{L} k n_k$$

When all the pixels have the same gray level its variance is zero, and when the difference between all the possible pairs of pixels is larger the variance is greater.

On the other hand the values $\{p_k = n_k/MN;\ k=1,2,\dots,L\}$ constitute a probability distribution on the set of the luminance values as $\sum_{k=1}^{L} p_k = 1$. It is possible to use the entropy as a contrast measure [2]:

978-0-7695-3872-3/09 $26.00 © 2009 IEEE
DOI 10.1109/ISDA.2009.174

$$H = -\sum_{k=1}^{L} p_k \ln p_k$$

When the distribution of luminance tones of the pixels is uniform ($p_k = 1/L$) then the entropy reaches its maximum value (which is $ln(L)$) which corresponds to an image with maximum contrast. This suggests that a standard measure in the interval [0,1] of the contrast of an image is $H/ln(L)$.

Note that entropy is a measure of uncertainty. When it goes zero corresponds to minimum contrast and for an image with uniform distribution, which corresponds to the maximum contrast, the uncertainty or lack of information is maximum.

Due to the process of digitalization of images the pixels are codified by a limited number of bits. For example, in the case of 8-bit monochrome images supposed to distinguish 256 levels of gray. If the range of variation in the brightness of the image is much smaller than the dynamic range of the camera then the true range of numbers will be much smaller than the full range from 0 to 255. That is, the image obtained at the output of the sensors of the camera does not have to cover the full range. In many situations the recorded image will have a much smaller range of brightness values. These values can be found in the mid-range (intermediate gray values) or to bright or dark ends of the range.

The visibility of the elements that form an image can be improved by stretching the contrast in order to reassign the values of pixels to fill the entire available range. This means that the pixels are interpolated between the extreme values of the dynamic range.

A usual mechanism of contrast enhancement is to perform a linear interpolation [1], [3], [4], [5]. This technique of linear expansion of the contrast allows to increase the visual discrimination and is useful when the image has luminance variations that allow to distinguish between the elements that comprise it.

There are hardware implementations circuits that perform the contrast control. Thus in [4] describes a circuit implemented in a 0.25μm CMOS technology. The method described in [3] applies in video images and is based on the piecewise linear functions approximation of the cumulative density function (CDF).

Other techniques are based on local transformations of the pixels and are called point operations. The point operations, or point to point functions, require in each step to know the value intensity of a single pixel, to which the desired transformation is applied. After processing the pixel is not needed, therefore this type of operation are called zero memory

Point operations are performed more efficiently with lookup tables (LUTs). The LUTs are simple vector that use the value of the current pixel as an index of the vector. The new value is the vector element stored at that position. The new image is constructed by repeating the process for each pixel. Using LUTs avoid repeated and unnecessary computations. When working with images of, for example, 8 bits only need to calculate 256 values. In this case the size of the image is irrelevant since the value of each pixel of the image is a number between 0 and 255 and the result of lookup table produces another number between 0 and 255. These algorithms can be implemented without using any intermediate memory since the output image can be stored in the same memory space that the input.

One of the non-linear transformations most widely used is the Gaussian transformation that is given by:

$$g(i.j) = \frac{\phi\left(\dfrac{f(i,j)-0.5}{\sigma\sqrt{2}}\right) + \left[\dfrac{0.5}{\sigma\sqrt{2}}\right]}{\phi\left(\dfrac{0.5}{\sigma\sqrt{2}}\right)}$$

where the brackets in the expression $[x]$ represent the floor function of x, and

$$\phi(x) = \frac{2}{\sqrt{\pi}} \int_{0}^{x} e^{-y^2}\, dy$$

This transformation increases the contrast of the image making the dark parts darker and the bright part clearer.

III. CONTRAST CONTROL BY MEANS OF ŁUKASIEWICZ OPERATORS

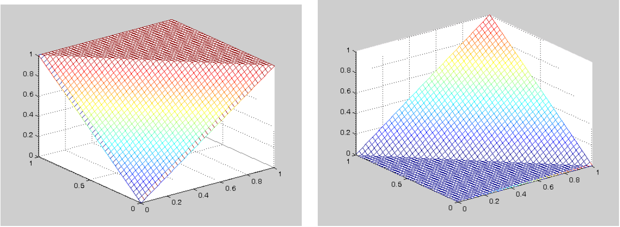
The development of the theoretical concepts of the multi-valued logics began in the decade of the 20s by Jan Łukasiewicz, who established the generalization of the classic logic to the multi-valued logic. Later, at the end of the 50s, C.C. Chang formalized the multi-valued algebra based on Łukasiewicz logic. The basic operator's definitions are:

bounded-sum: $x \oplus y = \min(1, x + y)$
bounded-product: $x \otimes y = \max(0, x + y - 1)$

In order to visualize the meaning of the operators, figure 1 shows the graphical representation of the bounded-sum and the bounded-product.

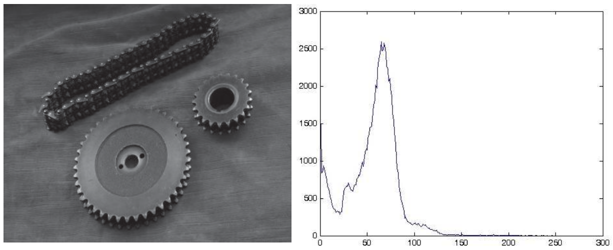
The application of the operators of Łukasiewicz in an image gives place to a transformation of the distribution of the levels of the pixels. This transformation produces a shift from low levels to high or from high levels to low, ie the application of Lukasiewicz operators most of the gray levels of the image undergo a shift in the histogram.

The bounded-sum operator acts as a low-pass filter and performs a shift of the pixels to high levels. This way a clearer image is obtained. Figure 2 shows the effect of applying the bounded-sum to consecutive pixels of the original image. It is possible to observe the displacement of the pixels towards the white by giving a brightness image.

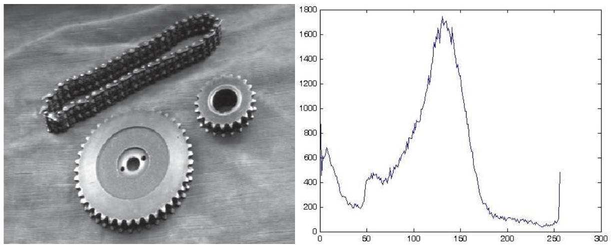


a) b)

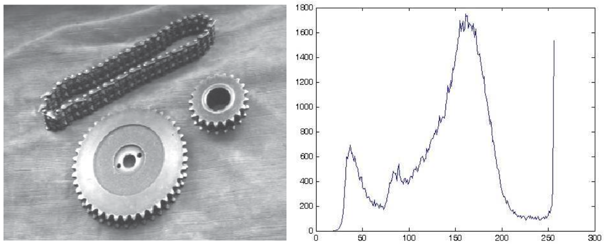
Figure 1. Surfaces corresponding to the operators
(a) bounded-sum and (b) bounded-product.



Original image

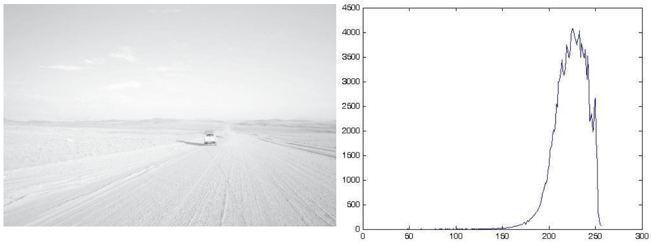


$x \oplus y$

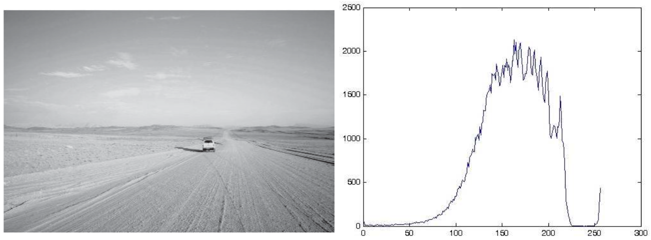


$x \oplus y \oplus 30$

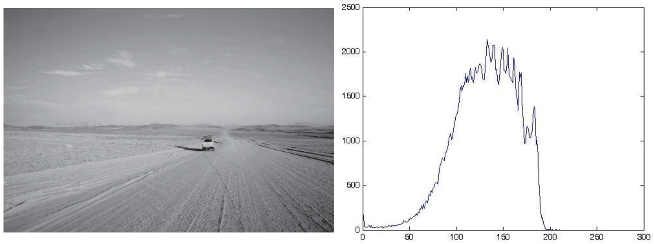
Figure 2. Control of contrast using the bounded-sum and the histogram of the images



Original image



$x \otimes y \otimes (-30)$



$x \otimes y \otimes (-60)$

Figure 3. Control of contrast using the bounded-product and the histogram of the images

The contrast control using the bounded-sum can be done by introducing an additional parameter that allows to regulate the displacement of the frequency:

$$x \oplus y \oplus C$$

where *C* is the parameter of control of the contrast. The range of values that can take *C* (encoded with 8 bits) is in the interval [-128,127]. Figure 2 shows the effect of the bounded-sum with different values of the control parameter (*C*=0 and *C*=30).

The complementary operation to the bounded-sum corresponds to the bounded-product. This operator gives place to a displacement of the histogram towards the black. This effect is observed in figure 3 that shows the result of applying the bounded-product and its histogram.

The control of the contrast applying the bounded-product it is realized by means of parameter *C* in the following expression:

$$x \otimes y \otimes C$$

Figure 3 shows the application of the bounded-product with different values of the control parameter *C*.

IV. FUZZY LOGIC CONTROL

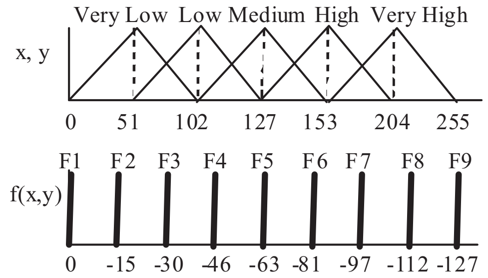
The technique of contrast control that has been presented is based on making a transformation of the histogram of the image by applying the operators bounded product and bounded sum. These operators give place to a shift and expansion of the values of the histogram. The control for this effect is achieved by a parameter *C* that allows to regulate the intensity of the transformation. The variation of contrast in an image need not be uniform. So there may be regions where the contrast is lower than in other parts of the image. Therefore, the parameter *C* should adapt to each region of the image in order to improve the quality of the transformation. Thus the expression that regulates the contrast by means of the bounded sum is given by the following expression:

$$x \oplus y \oplus f(x,y)$$

where *x* and *y* are pixels of the image and the parameter of control is the function *f(x,y)*.

The contrast control function *f(x,y)* depends on the characteristics of each image and allows to adapt the control operation locally. In our case we have applied a heuristic based in a fuzzy logic inference mechanism. Thus the system of decision-making is based on criteria of proximity, that is, if the values of the pixels are very close (low contrast) the function *f(x,y)* must be high whereas if the pixels are far the function should be low.

Figure 4 shows the specifications of the fuzzy system for the control of contrast. The membership functions correspond to five equally spaced triangular functions with



y \ x	Very Low	Low	Medium	High	Very High
Very Low	F1	F2	F3	F4	F5
Low	F2	F3	F4	F5	F6
Medium	F3	F4	F5	F6	F7
High	F4	F5	F6	F7	F8
Very High	F5	F6	F7	F8	F9

Figure 4. Fuzzy system with 5 membership functions for antecedents, 9 for consequent and 25 rules

overlapping degree of two. The output of the system is composed by 9 singleton functions. The rule base details the heuristic described previously. Figure 5 shows the surface corresponding to the function of control of contrast.

If x is Very Low and y is Very Low then f(x,y) is Very Low (F1)
If x is Very Low and y is Low then f(x,y) is Low (F2)
If x is Very Low and y is Medium then f(x,y) is Near Medium (F3)
. . .

Figure 6 shows an example of application of contrast control. The case of Figure 6b corresponds to the bounded sum, figure 6c corresponds to fuzzy control system. It can be observed in figure 6 that in the zone corresponding to the column can be appreciated the effects of the control of contrast. It is noted that when control is not established the values of the column are saturated (they take the white value) so that contrast is reduced. Nevertheless when a local control is applied (case c) the contrast is improved in the zone of the column.

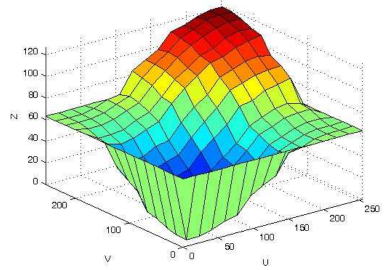
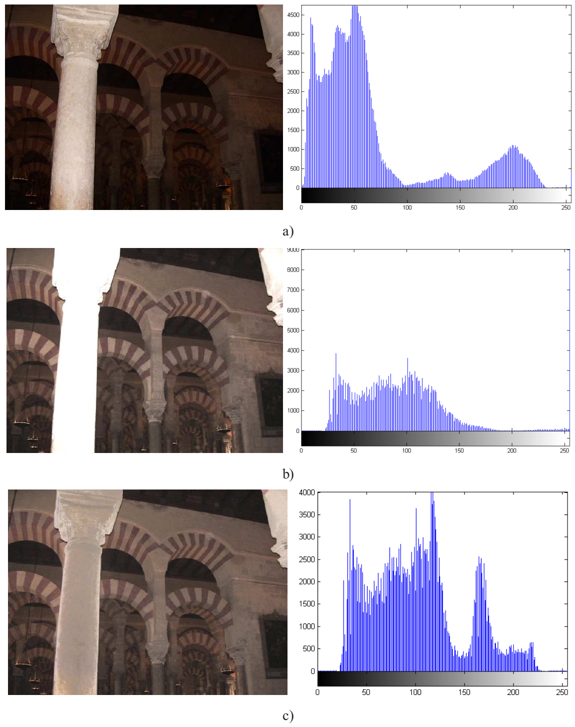


Figure 5. Surface corresponding to the function of control of contrast.



a)

b)

c)

Figure 6. a) Original image, b) $x \oplus y$, c) $x \oplus y \oplus f(x,y)$.

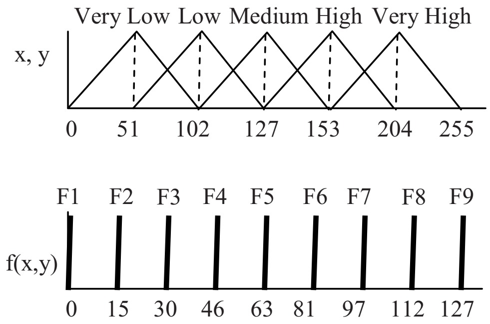
In the case of applying the bounded product the contrast is governed by the following expression:

$$x \otimes y \otimes f(x,y)$$

In the same way as in the case of the bounded sum the calculation of the function of the contrast control is based on a fuzzy inference engine using the knowledge base shown in figure 7.

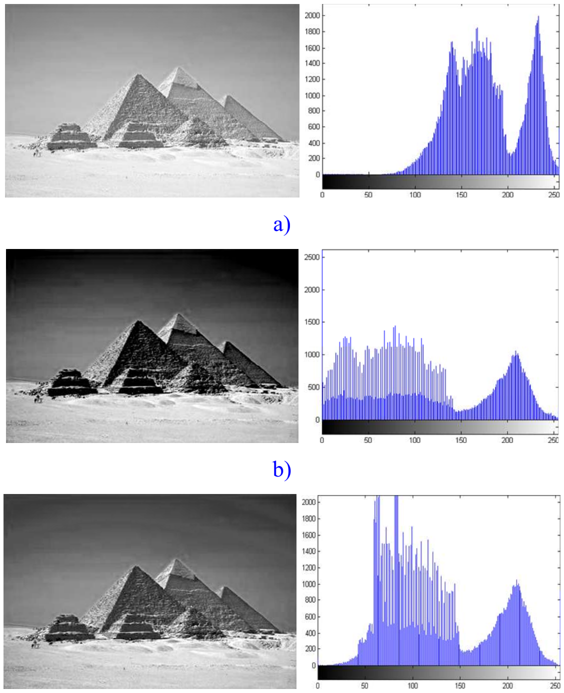
The results obtained from the bounded product application are shown in Figure 8. Figure 8b shows the results of the bounded product without adaptation while figure 8c corresponds to the control using the fuzzy system.

In the technique that we propose to control the contrast applies each of the two operators (bounded sum and bounded product) depending on the characteristics of the image. This way the bounded sum is used in the case of dark images while the bounded product should be applied in clear images. However, in general, the images may have zones with different characteristics. This means that dark zones and clear zones can coexist in the same image. For that reason it is necessary to adapt the control mechanism to the local characteristics of the image. For it a decision-making system is required in order to determine the type of operator to be applied at each case (bounded sum in the dark area of the image and the bounded product in the area clear).



x y	Very Low	Low	Medium	High	Very High
Very Low	F9	F8	F7	F6	F5
Low	F8	F7	F6	F5	F4
Medium	F7	F6	F5	F4	F3
High	F6	F5	F4	F3	F2
Very High	F5	F4	F3	F2	F1

Figure 7. Fuzzy system for the control of contrast using the bounded product.


a)

b)

c)

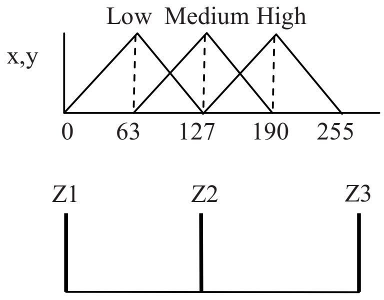
Figure 8. a) Original image, b) $x \otimes y$, c) $x \otimes y \otimes f\ (x, y)$.

The decision-making system is based on an inference mechanism based on fuzzy logic. The specification of the fuzzy system is shown in Figure 9. The membership functions are three triangular functions equally distributed in the universe of discourse and with overlapping degree of two. On the other hand the membership functions of the consequent are 3 singleton (*Z1, Z2* and *Z3*) that correspond to each of the three mechanisms to generate the output. Thus *Z1* corresponds to perform the bounded sum while *Z3* supposes to apply the bounded product. *Z2* means that there is no change in contrast and therefore the output value corresponds to the input.

The rule base consists in 9 rules. When the contrast is low the bounded sum or the bounded product whereas if the contrast is high the output does not change with respect to the input.

In agreement with our strategy to control the contrast the system that we propose is based in applying a mask that moves through the image. Depending on the local contrast the system decides to apply the best operator. This decision is made using the fuzzy system discussed previously and shown in figure 9. The global system is composed by 3 fuzzy inference engine as shown in figure 10. The FIM1 and FIM2 fuzzy inference modules generate the functions of control of contrast associated with the bounded sum and the bounded product respectively. The FIM3 module corresponds to the decision-making system that selects the best operator. Finally it is possible to add an additional control parameter *C* that allows the user to perform a specific control. In this way the functionality of the system is given by the following expression:

$$x' = \begin{cases} x \oplus y \oplus f(x,y) \oplus C & if \quad z = Z1 \\ x & if \quad z = Z2 \\ x \otimes y \otimes f(x,y) \otimes C & if \quad z = Z3 \end{cases}$$



x y	Low	Medium	High
Low	Z1	Z1	Z2
Medium	Z1	Z2	Z3
High	Z2	Z3	Z3

Figure 9. Decision-making fuzzy system.

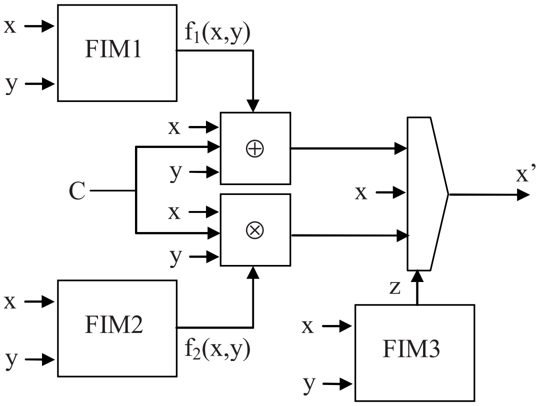


Figure 10. Schematic of the system for control of contrast.

CONCLUSION

In this paper a technique of control of contrast has been described based on the bounded-sum and bounded-product operators. These operators produce a shift and expansion in the histogram of the image. The control operation is performed by two fuzzy modules in order to select the values of the control parameters. Finally a decision-making fuzzy inference system selects the proper operator.

ACKNOWLEDGMENT

This work was supported in part by the Spanish Education and Research Council under grant no. TEC2008-04920/MICINN, and by the Andalusia Regional Government under grant no. P08-TIC-03674.

REFERENCES

[1] Z.Y. Chen, B.R. Abidi, D.L. Page, M.A. Abidi, "Gray-Level Grouping (GLG): An Automatic Method for Optimized Image Contrast Enhancement—Part I: The Basic Method", IEEE Transactions on Image Processing, vol. 15, no. 8, pp. 2290-2302, Aug. 2006.

[2] Amar Khellaf, Azeddine Beghdadi, and Henri Dupoisot, "Entropic Contrast Enhancement", IEEE Transactions On Medical Imaging, vol. 10, no. 4, pp- 589-592, Dec. 1991.

[3] S.Y. Kim, D. Han, S.J. Choi and J.S. Park, "Image Contrast Enhancement Based on the Piecewise-Linear Approximation of CDF ", IEEE Transactions on Consumer Electronics, Vol. 45, No. 3, pp. 828-834, Aug. 1999.

[4] H.C Kim, B.H. Kwon, M.R. Choi "An Image Interpolator with Image Improvement for LCD Controller", IEEE Transactions on Consumer Electronics, vol. 47, no. 2, pp. 263-271, May 2001.

[5] H.H. Cho, C.H. Choi, B.H. Kwon and M.R. Choi: "A Design of Contrast Controller for Image Improvement of Multi-Gray Scale Image ", 2nd IEEE Asia Pacific Conference on ASICs, pp. 131-133, Aug 2000.

[6] N.M. Hussein, A. Barriga: " Image Constrast Control based on Łukasiewicz's Operators", IEEE International Symposium on Intelligent Signal Processing (WISP'2009), Sept. 2009.