

VLSI Architecture for Image Contrast Enhancement using Modified Adaptive Gamma Correction with Weighting Distribution

Y. Premson* and R. Sakthivel

VIT University, Vellore – 632014, Tamil Nadu, India;
ypremson@gmail.com, rsakthivel@vit.ac.in

Abstract

Background/Objectives: Due to the huge volume of data involved, it is very much challenging to design efficient contrast enhancement algorithms in real time applications. In this paper an efficient hardware is presented for image enhancement. **Methods/Statistical Analysis:** The computation algorithms are based on the calculations of image Probability Density Function (PDF) and Cumulative Distribution Function (CDF). For better results weighted PDF and smoothed CDF computations are performed. Then the adaptive gamma correction is used for enhancing the image contrast. A compensated CDF is used as the adaptive gamma parameter. To reduce hardware complexity, approximation techniques are employed. In the modified algorithm, the bi-histogram equalization is utilized. Xilinx system generator is used for hardware co-simulation. The hardware is implemented on an FPGA based 'Zed Board'. **Findings:** The hardware oriented method achieves similar quality image as the software approach and the results are qualitatively and quantitatively analyzed. The PDF and CDF based computations are faster than other image processing methods. So this algorithm is suitable for real time applications. The image is found to have a better quality in the modified AGCWD method. The PSNR value also is found to be better than the normal method. But the hardware utilization of the modified algorithms is found to be higher than the normal algorithm. The bi-histogram approach is suitable to preserve the mean brightness of the original image. **Applications/Improvements:** Future works may modify the proposed method for reducing the hardware requirements. Contrast enhancement is one of the crucial image processing techniques in high definition image and video applications. Image enhancement techniques find applications in LED and LCD display processing, medical image analysis etc.

Keywords: Adaptive Gamma Correction, Contrast Enhancement, Histogram Modification, Weighting Distribution, Zed Board

1. Introduction

In battery powered devices power as well as area optimization is a relevant topic of research for achieving low cost and low battery consumption. Contrast enhancement is a basic problem in many of the present-day display based gadgets. One of the basic issues with any image processing application is the hardware implementation complexity and contrast enhancement is not an exception. A poor contrast image is very much annoying for the human eye and can be a disaster in machine vision applications. Image enhancement helps a

human to have a better quality of information contained in an image. For computer vision it helps in better image feature processing and analysis.

Automated digital image contrast enhancement finds applications in many real world problems like, medical imaging, display devices, astronomy, aerial and ocean imaging, to name a few. There exists a variety of image enhancement techniques which are already implemented in hardware. An improved contrast enhancement algorithm is presented in this work which employs methods like bi-histogram equalization, gamma correction and weighting the probability density of the

* Author for correspondence

luminance pixels. Using this method, images of better quality can be obtained by improving the brightness of the dimmed images. Also some approximation techniques are employed for reducing hardware complexity.

Many kinds of Adaptive Gamma Correction (AGC) techniques based on Probability Density Function (PDF) and Cumulative Distribution Function (CDF) exist for image enhancement. Also the weighting distribution is incorporated in some of them. The different modules used in these methods are, 1) Image Statics Computation (ISC), 2) Weighted PDF (WPDF), 3) Smoothed CDF (SCDF), 4) AGC and 5) the Final Luminance Transformation. The ISC finds the image histogram and the functions of other modules are self-explanatory from their names. In the modified version of this method, (AGCWD) the equalization is applied after dividing the histogram into two parts. After equalization the mean value of CDF is used for applying Adaptive Gamma Correction. This work is implemented on an FPGA based 'Zed Board XC7Z020' using Xilinx system generator platform and it achieves a good image quality which is qualitatively and quantitatively analyzed.

Histogram is an excellent means of statistical representation of an image. It can also be considered to the probability distribution of some kind of data. From an image histogram the frequency of appearance of different gray levels can be estimated. If a histogram contains only a fraction of the total gray levels, it will be a poor contrast image. A good contrast image will have a good coverage of all possible gray levels in the image. In such cases the fine details in the image can be observed more clearly. In histogram equalization the intensity values are spread along the total range according to certain rules for achieving better contrast. Traditional methods often result in excessive enhancement and therefore the resulting images will have un-natural look. Many new methods are suggested in the literature to cop up with the situation.

Y. T. Kim has proposed a brightness preserving Bi-Histogram Equalization (BBHE) method¹. The BBHE is not altogether new but is an extension of the existing Histogram Equalization (HE) in which HE is applied on two images obtained by decomposing the original image based on the mean. So in BBHE the mean brightness will be preserved while enhancing the contrast. V. Nandhini et al. have proposed an extension of this method based on the mean median². This algorithm is found wide applications in consumer electronics like camera, camcorder, TV etc.

the main drawback of this method is the requirement of more hardware compared to the normal HE. By using quantized probability density functions the required hardware can be reduced.

'Equal Area Dualistic Sub-Image Histogram Equalization' (EA-DSHE) helps to effectively enhance images³. It keeps the input luminance within limits also. So this technique can be directly used in video systems. In this method the image decomposition is done by keeping the areas same based on its original probability density function. And the images will be combined at the end.

K. S. Sim et al. have proposed the Recursive Sub-Image Histogram Equalization (RSIHE)⁴. Compared to conventional HE better image compensation is obtained in RSIHE. Energy preservation, better contrast and PSNR are the features of RSIHE. When the pixels are proximate they exhibit strong dependency. The information conveyed by this dependency is preserved in the RSIHE method.

Recursively Separated and Weighted Histogram Equalization (RSWHE)⁵ enhances image contrast and preserves image brightness. In RSWHE the input histogram is recursively sub-divided and is modified by a power law based weighting function. The equalization is done independently on the sub-images. Results of experiments show that the image brightness is better preserved in this method compared to existing methods.

A method based on pixel probability distribution and gamma correction is proposed⁶. The flow chart of this method is given in Figure 1. In this method also better quality images were produced compared to state of the art techniques.

For image and video enhancement, a method based on adaptive gamma correction using weighted distribution is proposed⁷. The algorithm is similar to that demonstrated by Chiu⁶. Temporal information derived from the difference between successive frames was used to reduce the processing complexity of video signals. For systems with limited resources, this method was found very much suitable as observed from the timing analysis of the results.

The hardware corresponding to the algorithm described⁷ is implemented^{8,9}. The hardware improvement is achieved by using a parameter controlled re-configurable architecture. The performance is demonstrated by using the architecture to process video frames at 48.23 fps at high definition resolution 1920 X 1080. Timing analysis shows that the architecture is suitable for real time applications.

The architecture described⁹ is an approximate solution to the software based algorithm⁷.

The contrast enhancement methods can be classified into two basic groups, namely 1) Direct and 2) Indirect methods. In the direct method contrast specific terms are directly used for the enhancement. In the indirect method probability density function based approach is followed. Also the histogram modification or gamma correction techniques are combined along with probability density function.

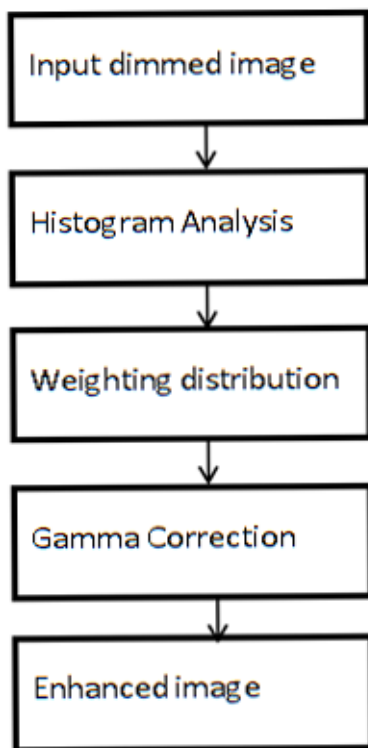


Figure 1. Flow chart of the contrast enhancement method⁶.

3.1 Histogram Modification (HM) Techniques

From the histogram of an image, the frequency of appearance of the intensity values can be analyzed. In a good histogram there will be a good coverage of all possible intensity values. For those types of images, the details in the image can be more clearly observed.

Consider the image, represented as $X = X(i, j)$ with the L discrete intensity values denoted from X_0 to X_{L-1} . $X(i, j)$ represents the intensity of the image at position (i, j) in the image coordinate system.

If n_k denotes the number of pixels whose grey level is

X_k , the histogram of the image can be denoted as, $H(X) = (n_0 \text{ to } n_{L-1})$.

Based on the histogram $H(X)$ of the image X , the Probability Density Function (PDF) of the image is defined as:

$$P(u_k) = \frac{n_k}{n} = \frac{n_k}{n_0 + n_1 + \dots + n_{L-1}} \text{ for } k = 0, 1, \dots, L-1 \quad (1)$$

Where u_k represents the k th gray level in the image.

In a histogram if most of the pixels are close to the origin the image will appear as dark or if they are to the right end, the image will appear as bright. The histogram equalization spreads out the intensity along the total range of pixels. Dynamic range of pixel intensities is a major factor that determines the contrast of images. Dynamic range is the ratio between highest and lowest intensities. Keep on reducing the difference between u_k and u_{k-1} , histograms become a continuous function, very much similar to the Probability Density Function (PDF). Consider u as a random variable, then;

$$p_u(u) \rightarrow pdf \quad (2)$$

Apply the transformation to obtain a uniform distribution function from a continuous function:

$$v = f(u) = \int p_u(w), 0 \leq u \leq 1 \quad (3)$$

This transform is similar to the Cumulative Distribution Function (CDF). From the PDF, the CDF is defined as:

$$cdf(k) = \sum P(k) \quad (4)$$

The histogram equalization maps an input X_k into an output gray level $f(k)$, through a level transformation function, defined as:

$$f(k) = X_0 + (X_{L-1} - X_0) cdf(k) \quad (5)$$

Thus, the input is remapped into the entire dynamic range of the image.

1.2 Gamma Correction Techniques

In gamma correction, an adaptive parameter, γ is varied to obtain a class of HM techniques. The Transform based Gamma Correction (TGC) is defined as:

$$T(l) = l^{\gamma}_{\max(l/l_{\max})} \quad (6)$$

Where $l_{\max}$ represents the maximum intensity of the processing image. Each pixel intensity is transformed according to Equation (6).

If a fixed parameter (γ) is kept for the transformation, the intensity change over different images will also remain the same. The theory of probability can be applied to solve this problem. The Probability Density Function (PDF) and Cumulative Distribution Function (CDF) for the image intensity levels can be calculated for this:

$$pdf(l) = \frac{n_l}{MN} \quad (7)$$

Where n_l represents the number of pixels with intensity l and MN is the total number of pixels in the image. The CDF is a function of PDF and is defined as:

$$cdf(l) = \sum_{k=0}^l pdf(k) \quad (8)$$

The final transformation for equalization uses the CDF and is defined as:

$$T(l) = cdf(l) l_{\max} \quad (9)$$

Some modifications can be brought to the CDF function for better results. A normalized as well as Adaptive Gamma Function can significantly improve the results. The normalization will help to retain the available histogram statistics. Considering Equations (6) and (9), it can be observed that a smaller gamma value generates a more significant adjustment. So a compensated CDF is used as the adaptive parameter. This results in modifying the intensity to a function of the CDF. This is called the Adaptive Gamma Correction (AGC) method.

$$T(l) = l^{\gamma}_{\max(l/l_{\max})} = l^{(1-cdf(l))}_{\max(l/l_{\max})} \quad (10)$$

Using the AGC method a good balance between low and high intensity enhancement could be achieved.

1.3 Adaptive Gamma Correction with Weighting Distribution (AGCWD) Method

Equation 10 can be further modified by using a Weighting Distribution (WD) function to the AGC. The corresponding equation is given as:

$$pdf_w(l) = pdf^{\alpha}_{\max\left(\left[\frac{pdf(l)-pdf_{\min}}{pdf_{\max}-pdf_{\min}}\right]\right)} \quad (11)$$

Where α is an adjusted parameter, $pdf_{\max}$ and $pdf_{\min}$ are the maximum and minimum PDF, respectively. The modified CDF is given as:

$$cdf_w(l) = \sum_{k=0}^l \frac{pdf_w(k)}{\sum pdf_w} \quad (12)$$

Where the sum of pdf_w is calculated as:

$$\sum pdf_w = \sum_{l=0}^{l_{\max}} pdf_w(l) \quad (13)$$

Finally, the gamma parameter is modified as follows:

$$\gamma(l) = 1 - cdf(l) \quad (14)$$

The block diagram of the AGCWD method is shown in Figure 2. The ISC block calculates the image histogram. From this the weighted PDF is calculated. Then the smoothed CDF is computed and the parameters for applying the Adaptive Gamma Correction are computed. And finally the luminance transformation is applied to obtain the output image. AGCWD method can be used effectively for enhancing color images.

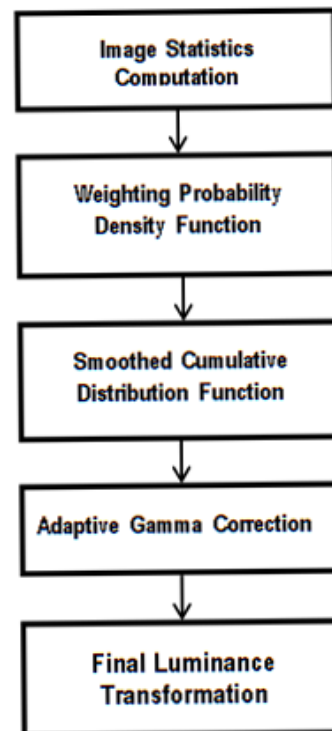


Figure 2. Block diagram of AGCWD.

1.4 Hardware Oriented AGCWD Algorithm

The computations performed in the different units of the AGCWD method of Figure 2 are as follows:

1.4.1 Image Statistics Computation (ISC)

The Equation is slightly modified to reduce hardware complexity due to division operation. So Equation (7) is re-written as:

$$pdf'(l) = n_l \quad (15)$$

Where $pdf'(l) = pdf(l)XMN$; $l = lmin, tolmax$, and n_l is the frequency of appearance of level l in the image.

1.4.2 Weighting Probability Density Function (WPDF)

$$pdf'_w(l) = \max(pdf) \times \left(\frac{pdf'_w(l) - \min(pdf')}{\max(pdf') - \min(pdf')} \right)^\alpha \quad (16)$$

Where α is an adaptive parameter set to 0.5. The Equation (16) can be rewritten as:

$$pdf'_w(l) = \max(pdf') \times 2^\beta \quad (17)$$

Where $\beta = \alpha [\log_2(pdf'(l) - \min(pdf')) - \log_2(\max(pdf') - \min(pdf'))]$

1.4.3 Smoothed Cumulative Distribution Function (SCDF)

Equation (12) can be re-written as:

$$cdf'_s(l) = \frac{\sum_{k=lmin}^l pdf'_w(k)}{\sum_{k=lmin}^L pdf'_w(k)} \quad (18)$$

Where $cdf'_s(l)$ is the smoothed CDF.

Equation (18) can be written in the hardware computation form as:

$$[cdf'_s(l)] = {}^2(([\log_2(\sum_{k=lmin}^l (pdf'_w(k)) - [\log_2(\sum_{k=lmin}^L (pdf'_w(k))]) \quad (19)$$

1.4.4 Adaptive Gamma Correction (AGC)

$$T(l) = (l_{min}) \times 2^{\gamma(\log_2 l - \log_2 (l_{max} - l_{min}))} \quad (20)$$

Where $T(l)$ represents the transformation function and $\gamma = 1 - cdf'_s(l)$

1.4.5 Final Luminance Transformation (FLT)

A representative relationship, after simplification through the above steps may be given for the final image as:

$$Y(i,j) = \{T(X(i,j)) \text{ for all } X(i,j) \in X\} \quad (21)$$

The logarithm and power of 2 are found out using approximation techniques as follows:

$$\log_2 h = [(0.1519h - 1.02123)h + 3]h - 2.13, h \in [0, 1] \quad (22)$$

$$2^h = [(0.079h + 0.2242)h + 0.6967]h + 0.999, h \in [0, 1] \quad (23)$$

2. The Proposed Modified AGCWD Method

The AGCWD algorithm is modified in this work. A bi-histogram based implementation mentioned in¹ is incorporated for better enhancement. It is a mean brightness preserving algorithm. Figure 3 shows the essence of this method. The initial histogram is subdivided based on the mean brightness level. One of them consists of the samples less than the mean level and the other, more than the mean level. The separation intensity level XT in the diagram represents the mean brightness value of the input image. Then the sub histograms are equalized separately and the mean brightness can be preserved in this way.

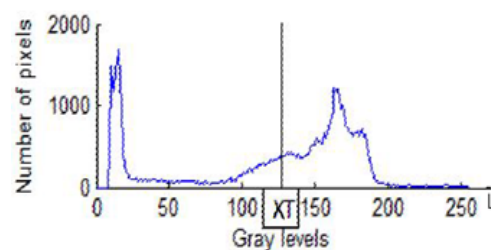


Figure 3. Bi-histogram equalization.

From Figure 3 it is clear that the first histogram has values from 0 to XT and the second, $XT+1$ to $L-1$. Then the WPDF and SCDF are calculated for both the histograms. The mean of these SCDF is the final SCDF. Then the AGC and FLT are applied. The simulation block diagram using Xilinx System Generator (XSG) is shown in Figure 4. Image pre-processing and post-processing units are common for all the image processing applications which are designed using Simulink block-sets. The units

in between the gateway-in unit and the gateway-out unit are the equivalent of the hardware implemented inside the FPGA.

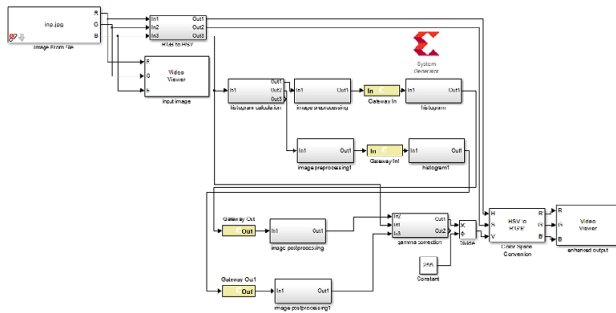


Figure 4. XSG simulation block of modified AGCWD method.

3. Results and Discussion

This section presents the results of hardware oriented AGCWD algorithm and the modified AGCWD algorithm. Both logarithms are realized using Xilinx System Generator and are implemented in Zed Board XC7Z020. The experimental setup is shown in Figure 5. Image quality of results of both of the algorithms is compared. Compared to the traditional AGCWD method modified AGCWD algorithm gives a better quality image. The main drawback is that the modified AGCWD algorithm will have almost double the hardware components than the normal algorithm. The simulated and hardware used output images are shown along with the input image for the AGCWD and modified AGCWD methods in Figures 6 and 7, respectively. The visual quality of the results due to the modified AGCWD algorithm is higher than that of the traditional AGCWD algorithm. The respective FPGA floor-plans are shown in Figure 8(a) and (b).

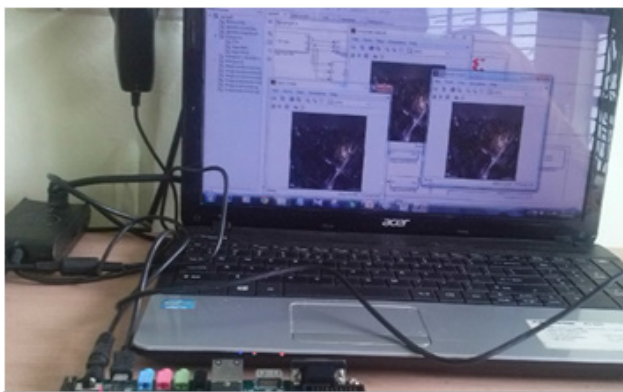


Figure 5.

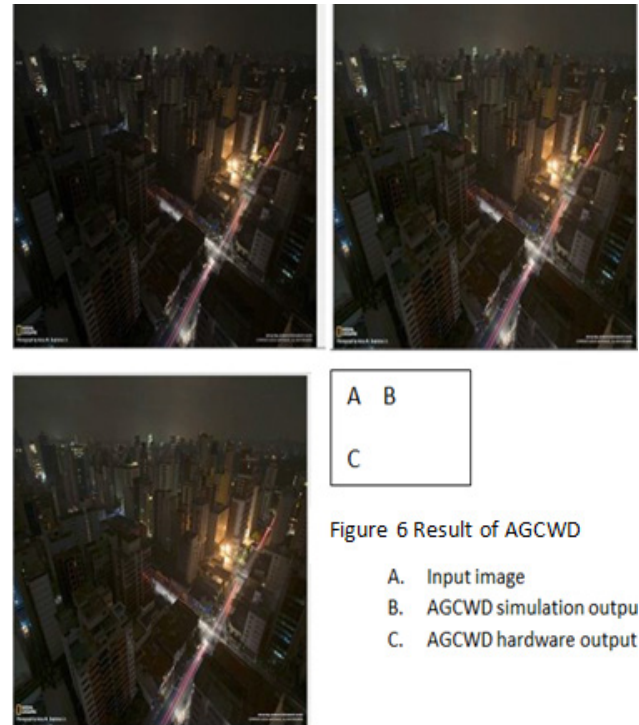


Figure 6. Result of AGCWD algorithm.

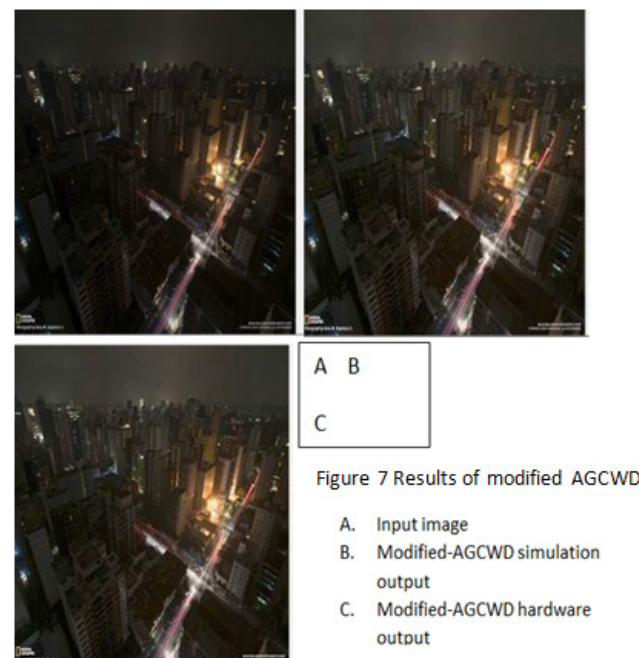


Figure 7. Results of modified AGCWD algorithm.

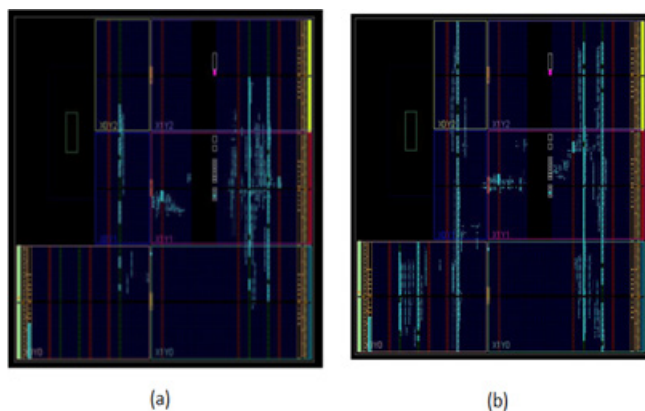


Figure 8. FPGA floor-plans generated on Vivado 2014.4 for (a) AGCWD and (b) modified.

The normal and the modified AGCWD methods are analyzed by finding the Peak Signal to Noise Ratio (PSNR) of each. These values are listed in Table 1. From Table 1, it can be observed that the quality of image for the modified algorithm is higher than that of the normal one.

Table 1. The image PSNR measurement

Test image	PSNR
AGCWD	17.9535
Modified-AGCWD	20.5561

4. Conclusion

A hardware oriented contrast enhancement algorithm is presented in this paper. It is a novel hardware architecture. The bi-histogram equalization method is combined with the existing AGCWD method to further enhance the image. The mean brightness of the image can be preserved in this method. The results are qualitatively and quantitatively analyzed and the results show that the proposed method performs well compared to the existing algorithms. For analysis purpose, a 275 X 258 resolution image is enhanced using this algorithm. The quantitative results are measured in terms of the image PSNR. The modified algorithm has high PSNR value, indicating

higher image quality. One drawback observed with the algorithm is higher hardware utilization. Modification of the algorithm to reduce hardware utilization can be a future research topic of interest. Parallel processing and re-configurable architecture can be employed to further improve this architecture.

5. References

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