Review on Image Enhancement Techniques: FPGA Implementation perspective

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Abstract— Extensive research has been done on image enhancement and hence it has become essential to categorize the research outcomes and provide an overview of the available enhancement techniques. In this paper different image enhancement techniques with their conceptual details are reviewed. The broad categorization of the reviewed algorithms is brought out with the emphasis on the state of art research in each category. The paper emphasizes on the review of Field Programmable Gate Array (FPGA) implementation of the image enhancement techniques.

Keywords- FPGA; Image Enhancement; Spatial and Frequency Domain, ASG.

I. INTRODUCTION

Digital Image Processing (DIP) is one of the Digital Signal Processing application having a wide range of applications such as space exploration, Image transmission and storage for business applications, medical processing, radar, sonar and acoustic image processing, robotics and automated industrial inspection[1]. The areas of DIP being quite heterogeneous, to gain a basic knowledge of these areas it is essential to classify images according to their sources like electromagnetic energy spectrum, acoustic, ultrasonic and electronic or synthetic images generated by computer [2]. All these applications involve different processes and they require images with good visual perception. Developing images with good perceptual quality by highlighting the obscured details or certain features of interest in an image is the basic idea behind image enhancement.

Image enhancement involves techniques to accentuate or sharpen the image features such as edges, boundaries or contrast to make a graphic display more useful for display and analysis. Such images with good contrast and visual quality are required for all important areas of image processing. The inherent information content is not increased by applying Enhancement techniques but there is an increase in the dynamic range of chosen factors [1]. With the growing research in the field of Image enhancement it has made it very essential to categorize the image enhancement methodologies. Section II discusses the development of various enhancement techniques. Section III presents the review based on the FPGA implementations of the enhancement algorithms and some of the pioneer development related to reconfiguration technology in the spatial and frequency domain of the image enhancement techniques.

II. IMAGE ENHANCEMENT TECHNIQUES

Image enhancing techniques can be broadly classified into spatial and frequency domain methods.

A. Spatial Domain Methods

Methods in this domain refer to image plane itself and the image processing methods are based on direct manipulation of pixels in an image. Two principal categories of spatial processing are available such as, intensity transformation and spatial filtering.

1) Intensity Transformations:

This transformation processing technique is based on a single pixel of an image. This transformation consists of brightness control; contrast stretching, thresholding, histogram equalization, gamma correction and histogram modification.

![Intensity Transformation](image1)

Figure 1. Intensity Transformation
Histogram equalization (HE) is one of the image enhancement techniques in spatial domain which is considered to be most popular because of its simplicity and comparatively better performance on all types of images [3]. Histogram equalization is a transformation that stretches the contrast by redistributing the gray level values uniformly.

2) Histogram Equalization Algorithm:
Let’s suppose that \( X=\{X(i, j)\} \) denotes a digital image, where \( X(i, j) \) denotes the gray level of the pixel at \((i, j)\) place. The total number of the image pixels is \( N \), and the image intensity is digitized into \( L \) levels that are \( \{X_0, X_1, ... , X_{L-1}\} \). So it is obvious that \( X(i, j) \in \{X_0, X_1, ... , X_{L-1}\} \) suppose \( n_k \) denotes the total number of pixels with gray level of \( X_k \) in the image, then the probability density of \( X_k \) will be

\[
p(X_k) = \frac{n_k}{N}, \quad k=0, 1, ... , L-1
\]

The relationship between \( p(X_k) \) and \( X_k \) is defined as the probability density function (PDF), and the graphical appearance of PDF is known as the histogram. Based on the image’s PDF, its cumulative distribution function (CDF) is defined as

\[
c(X_k) = \sum_{i=0}^{k} p(X_i)
\]

Where \( k=0, 1, ... , L-1 \), and it is obvious that \( c(X_{L-1})=1 \). Thus the transform function of histogram equalization can be defined as

\[
f(X_k) = X_0 + (X_{L-1}-X_0)c(X_k), \quad k=0,1,.....,L-1
\]

Suppose \( Y=\{Y(i,j)\} \) is defined as the equalized image then \( Y=f(X)=\{f(X(i,j))\} \ X(i,j) \ X \)

Conventional histogram equalization however results in images that have unnatural look due to excessive contrast enhancement. Researchers have focused on improvement of the HE based contrast enhancement and new forms of histograms for contrast enhancement have been developed.

Brightness Preserving Bi-Histogram Equalization (BBHE) separates the input image histogram into two parts based on input mean and then each part is equalized independently[4]. This method tries to overcome the brightness preservation problem. Dualistic Sub Image Histogram Equalization (DSIHE) [5] method divides the original image into two equal area sub images based on gray level probability density function. Then the two sub images are equalized separately and later composed into one image. Minimum Mean Brightness Error Bi Histogram Equalization (MMBEBHE) [6] is the extension of BBHE. But the main difference is that this method searches for a threshold level that decomposes the image into two sub images such that the minimum brightness difference between input and output image is achieved whereas the former considers only input image to perform decomposition. The BBHE, DSIHE, MMBEBHE are grouped under bisection mean brightness preserving histogram equalization (MBPHE) in which the methods separate the input histogram into two sections and equalizes them separately. Under multi section MBPHE we have Recursive Mean-Separate Histogram Equalization (RMSHE) [7]. RMSHE proposes to perform image decomposition recursively up to the scale \( r \), generating \( 2^r \) images instead of decomposing the image only once as in case of BBHE or DSIHE. Though there are improvements with respect to brightness preservation there are side effects observed. Another technique Dynamic Histogram Equalization (DHE) [8] employs a partitioning operation over the input histogram to divide it into some sub histograms so that they have no dominating component in them. Each sub histogram then goes through HE and is allowed to occupy a specified gray level range in enhanced output image. This method has an advantage over other approaches is the contrast enhancement does not produce severe side effects such as washed out appearance, checker board effect or undesirable artifacts. The Brightness Preserving Dynamic Histogram Equalization (BPDHE) [9] produces output image with mean intensity almost equal to mean intensity of input image thus satisfying the requirement of maintaining the mean brightness of the image. Multilevel Component Based Histogram Equalization (MCBHE) [10] combines the global histogram equalization, BPDHE, multilevel gray level thresholding and connected component analysis to produce an image with improved global and local contrast and minimal distortion.

Intensity transformations are considered zero memory operations but, they are not able to differentiate between several regions of the image that need different levels of enhancement because these methods treat the image globally.

3) Spatial Filtering:
It is deals with performing operations by working in a neighborhood of each pixel in an image. These are mask processing operations since they can take into account neighboring pixel intensities in the original image for computing the intensity value in the resulting image. Spatial filtering performs operations such as image sharpening, Noise reduction, edge enhancement. These filters can be linear or nonlinear. If the operation performed on the pixels is linear then the filter is called a linear filter otherwise it is a nonlinear filter.

Linear filters are smoothing or low pass filter, sharpening filter, Laplacian filter, Un-sharp masking, High boost filter. Nonlinear filters are order statistic filters like Median filter, Max & Min filter.

Figure 2. Examples of spatial filtering
contrast areas much more than area that do not exhibit high image dynamics. Hence output image suffers from unpleasant overshoot artifacts. Adaptive Unsharp Masking [11] employs an adaptive filter that controls the contribution of sharpening in such a way that contrast enhancement occurs in high detail areas and little or no image sharpening occurs in smooth areas. This algorithm performs well when compared with several approaches available in literature like linear unsharp masking filter, Type 1B algorithm [12]-[13], cubic unsharp masking [13] [14], the order suitable unsharp masking technique [15] and adaptive algorithm [16]. A new approach to local contrast enhancement [17] using rank order filters with spatially adaptive neighborhood is presented. The approach is based on difference type operations between details to be enhanced and their surrounding background. Piece Wise Linear (PWL) model based enhancement found in [18] is a novel technique for sharpening of noisy images. The proposed enhancement system adopts a simple PWL function in order to sharpen the image edges and to reduce the noise.

Spatial operations are performed in the local neighborhood of input pixels which helps to enhance the image at different levels. But limitations of these methods are they may enhance the noise in excess along with image or smoothen the image in areas that need accurate details.

B. Frequency Domain Methods

For processing in frequency domain, operations are performed on Fourier transform of an image rather than on the image itself. The techniques that fall under this category include Low pass filtering, High pass filtering, Homomorphic filtering, Linear and root filtering.

Homomorphic filtering is applied on low contrast images and the High pass filter is used as a surround function. The principle idea of Homomorphic filtering is to remove the illumination in the image. But this technique destroys some part of the image which does not require enhancement and that part is recovered using a threshold after applying Homomorphic technique [19]. Wavelet analysis has proven to be a powerful image processing tool in recent years. When images are to be viewed or processed at multiple resolutions the wavelet transform is the tool of choice [20].

Frequency domain methods introduce certain artifacts and cannot simultaneously enhance all parts of the image very well and it is difficult to automate the image enhancement procedure.

III. IMAGE ENHANCEMENT USING FPGA

Most of the image enhancement implementations found in literature are based on MATLAB and C/C++. MATLAB is a high performance language for technical computing and excellent tool for algorithm development and data analysis. Reconfigurable hardware in the form of FPGA is considered as a practical way of obtaining high performance for computationally intensive image processing algorithms. FPGAs have been traditionally configured using Hardware Description Languages (HDL) Verilog and Very High Speed Integrated Circuits (VHSC) HDL (VHDL). C-based HDLs have also been used [21]. Another area where research is ongoing is to develop and employ high level design tools which will bring down the development time required for deploying signal processing solutions using FPGA. Xilinx System Generator (XSG) is one such tool that enables the use of Mathworks model based design environment Simulink for FPGA design. [22]

Image processing application developers are trying to exploit the performance capability of a direct hardware solution, while programming in an application oriented model. Z. Salcic et.al [23] have devised a technique which improves the image contrast enhancement. Low cost FPGA hardware is used and the images used are X-ray images. The enhancement uses filtering via High Boost Filter (HBF) followed by Histogram Equalization (HE). Efficient hardware implementation of enhancement procedures and hardware/software co-design for achieving high performance low cost solution is possible with the proposed Image Enhancement Co-processor (IMECO). Chandrashekar et.al have used thermographic images to carry out image enhancement and the implementation is on FPGA [24]. The image enhancement capabilities and properties of Successive Mean Quantization Transform (SMQT) are analyzed during their studies. They have shown that the transform is capable to perform both a nonlinear and shape preserving stretch of image histogram.

For computing Histogram statistics and equalization in parallel, nonconventional schemes for real time histogram equalization have been explored by Abdullah M Alsuwailen et al [25]. The proposed system is using Stratix II family FPGA. The maximum clock frequency used is 250 MHz and the total time required to perform histogram equalization on an image of size 256X256 is 0.256ms.

S. Sowmya, Roy Paily [26] have investigated the implementation of brightness control, contrast stretching and histogram equalization algorithm on FPGA that have become a competitive alternative for high performance DSP applications. The minimum time period in case of all the implementations is 5ns for a test image of 100X100.

Tarek M Bitibbsi et.al[27] address the hardware implementation of five image enhancement algorithms in spatial domain using FPGA. The algorithms chosen are median filter, contrast stretching, histogram equalization, negate image transformation and power law transformation. The computational speed improvement was achieved by implementing the different techniques of enhancement on FPGA.

Nitin Sachdeva and Tarun Sachdeva [28] have considered FPGA implementation of a new system for real time Histogram equalization for improving the perception quality of image. The system developed is for simultaneous computation of histogram statistics and HE and it is based on counters used in conjunction with specially designed decoder. They found that the computation speed improved and the time required for HE of an image of size 256X256 is 0.263ms.

A high speed nonlinear Adaptive median filter is considered for implementation by D Dhanasekaran and K Boopathy Bagan [29]. Dual purpose served by the implemented filter is to remove the impulse noise and reduce the distortion in the image. Filtering of an image corrupted with impulse noise of probability greater than 0.2is successfully achieved.
Reconfigurable hardware implementation of median filter with various window sizes is presented by Tripti Jain et al [30]. A median filter for impulse noise removal during image enhancement, morphological and other operations was designed and implemented on Spartan XC3S500E FPGA.

Median filter and edge detection tasks which form the essential steps during image processing are implemented using double parallel architecture on FPGA by Ye Li et al [31]. Image level parallel and an operation level parallel is included in the scheme. The image level parallel divides one image into different parts and processes them concurrently. The operation level parallel, which is embedded in every image level parallel, fully explores every parallel part inside the algorithms. A dramatic speed improvement is observed even when the scheme is deployed on low cost FPGA platform with low frequency and limited resources.

Francis Fons et al [32] have proposed implementation of an automatic fingerprint recognition system using efficient hardware-software architecture. The outcome reveals that a middle range reconfigurable FPGA faces both real time and parallel compute intensive demands of the fingerprint image enhancement process.

S Allin Christie et al [33] have presented an efficient architecture for various image filtering algorithms and tumor characterization using Xilinx System Generator. An alternative architecture is offered through a graphical user interface that combines MATLAB, Simulink and XSG and explores important aspects concerned to hardware implementation.

A hardware design for enhancement of color and grey scale images is implemented by Abhishek Acharya et al [34] on an FPGA. XSG was used to program the model and test in FPGA using the hardware co-simulation feature of the tool. In the nutshell the reconfiguration hardware such as FPGA is a powerful tool to implement complex enhancement algorithms of image processing.

IV. CONCLUSION

A comprehensive review of image enhancement techniques and its migration towards FPGA domain was considered. It is seen that image enhancement encompasses a collection of techniques which improve the perception of an image or convert it to a form suitable for analysis by human or automated image processing technique. These techniques offer a wide variety of approaches and the choice depends on the specific task, image content, and observer characteristic and viewing conditions.

Despite the effectiveness of spatial domain techniques when applied separately, in practice a combination of such methods can be used to achieve more effective image enhancement. Secondly, spatial and frequency domain methods have their merits and shortcomings but researchers are developing new methods which have the best properties from both spatial and frequency domain. Moreover with the FGPA’s finer flexibility and powerful computing capability, the implementation of these algorithms in FPGA paradigm is an open area of investigation.

REFERENCES


