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HARDWARE IMPLEMENTATION OF IMAGE ENHANCEMENT TECHNIQUES IN SPATIAL DOMAIN

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Abstract-

Image Enhancement is the process of improving the quality and the information content of original image so that resultant image becomes more suitable for display or further analysis. The main objective of image enhancement is to make image appropriate for the certain applications. Image enhancement techniques have been widely used in many applications of image processing where the subjective quality of images is important for human interpretation. Spatial domain refers to the image plane itself and is based on direct manipulation of pixels in an image. In this paper, various point processing and spatial filtering techniques are discussed in spatial domain. These techniques are implemented using reconfigurable hardware platform of field programmable gate array (FPGA). System Generator is used in order to integrate Xilinx FPGA design process with MATLAB/Simulink. It provides a high-level description to easily realize the complex computations of a digital image.

Keywords—Image Enhancement, Point Processing Techniques, Spatial Filtering, Xilinx System Generator, Spartan-3E FPGA

INTRODUCTION

The field of image analysis research has undergone a rapid evolution over the past decade. Image processing nowadays has various applications in the fields of medical imaging, weather meteorology, machine learning, computer vision and even artificial intelligence. The main objective of image processing is to improve the quality of the image for human interpretation and analysis [1]. Image enhancement techniques serve as a preprocessing step in various image processing applications such as segmentation, object detection and recognition. These techniques change an image to make it perfect to human observer or to make it enhanced for an automatic computer algorithm. The main objective is to prominence certain features of interest in an image for advance analysis and image display. It is a method used to increase the visual quality of image due to non-ideal acquisition method. The processed images results are more suitable than the original image for a specific application [2].Spatial domain techniques directly deal with the image pixels. The pixel values are manipulated to achieve desired enhancement. The main advantage of spatial domain techniques is that they are conceptually simple to understand and their complexity is low which suits real-time implementations [3].The versatility of spatial filtering is more compared to transform domain as it can be used for both linear and nonlinear filtering. Spatial domain filtering deals with various practical applications like image sharpening, blurring and noise removal [4]. The need to process the image in real time is time consuming and leads to the only method of implementing the algorithm at hardware level. FPGAs are inherently parallel; this gives the speed to those real time applications while retaining the programmable flexibility of software at a relatively low cost [5]. Xilinx System Generator (XSG) allows common environment for MATLAB/Simulink and Integrated System Environment (ISE) Design Suit. XSG provides an efficient way of designing complex algorithms. It automatically generates required hardware description language along with test bench. Field Programmable Gate Array (FPGA) is used for prototyping purpose. Spartan-3E Starter Kit can be programmed by downloading generated bit stream file [6].

IMAGE ENHANCEMENT IN SPATIAL DOMAIN

Image enhancement techniques can be generally categorized as Spatial domain and transform or (frequency domain). Further, spatial domain techniques are divided into two processes. These are: Point processing techniques and Spatial Filtering. All the image enhancement techniques discussed here are implemented in spatial domain. Spatial domain is simply the plane containing the pixels of an image. The spatial domain processes is represented by the expression:

$$g(x,y) = T[f(x,y)]$$

where, f (x,y) is the input image,
g (x,y) is output image and
T is an operator defined over a neighborhood of point (x,y)

Point Processing Techniques:

These techniques are also called as Intensity transformation as it operates on single pixel value (intensity) of an image. The simplest spatial domain operations occur when the neighbourhood is simply the pixel itself. In this case, T is a grey level transformation function or a point processing operation. Point processing operations take the form s = T (r) where, 's' refers to the processed image pixel value and 'r' refers to the original image pixel value.

1. Image Negative: Negative images are useful for enhancing white or grey detail embedded in the dark region of an image, especially when black areas are dominant in size. Negative transform exchanges dark pixels with bright pixels and vice versa. The negative transform of an image is defined by:

$$s = (L-1) - r$$

where, (L-1) is maximum pixel value (which is 255 for grey image) and r is pixel value of an image.

2. Image Thresholding: Thresholding often provides an easy and convenient way to perform this segmentation on the basis of the different intensities or colors in the foreground and background regions of an image. In the simplest implementation, the output is a binary image representing the segmentation. Black pixels correspond to background and white pixels correspond to foreground (or vice versa). Each pixel in the image is compared with this threshold. If the pixel's intensity is higher than the threshold, the pixel is set to white (pixel intensity value equals to 255) in the output. If it is less than the threshold, it is set to black (pixel intensity value equals to 0).

3. Brightness Enhancement: It is nothing but shifting of intensity values to higher level. Both darker and lighter pixels get their intensity values shifted by some constant value.

Spatial Filtering:

Spatial filtering is an image processing technique for changing the intensities of a pixel according to the intensities of the neighboring pixels. Fig. 1 shows the mechanics of spatial filtering using 3×3 filter mask (neighborhood) [1]. A filter consists of neighborhood and predefined operation that is performed on image pixels encompassed by the neighborhood. Filtering creates a new pixel with coordinates equal to the coordinates of the center of neighborhood and its value is the result of filtering operation. At any point (x,y) in the image, the response g(x,y) of filter is sum of products of filter coefficients and the image pixels encompassed by the filter mask. It is expressed in mathematical form as:

$$g(x,y) = w(-1,-1)f(x-1,y-1) + w(-1,0)f(x-1,y) + \ldots\ldots + w(1,1)f(x+1,y+1)$$

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t)\, f(x+s,y+t)$$

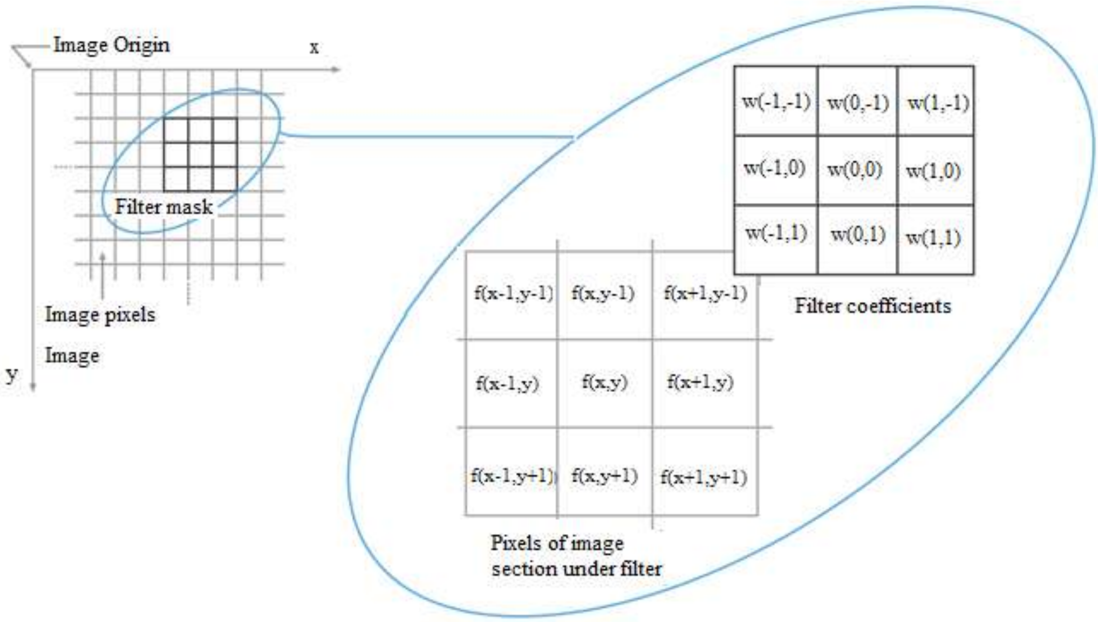


Figure 1 : Mechanics of Spatial Filtering using 3×3 filter mask

1. Smoothing Spatial Filters: Smoothing filters are used for blurring and for noise reduction. Blurring is used in pre-processing steps, such as removal of small details from an image prior to object extraction, and bridging of small gaps in lines or curves. Noise reduction can be accomplished by blurring. The output (response) of a smoothing filter is simply the average of pixels contained in the neighbourhood of filter mask. The pixel value in an image is replaced by the average of intensity levels in the neighbourhood defined by filter masks. This process results in an image with reduced sharp transitions in the intensities, Since, random noise typically consists of sharp transitions in intensity levels, the most obvious application of smoothing filters is noise reduction. There are linear and non-linear filters available in the spatial domain. In this paper, only linear filters have been discussed and implemented.

2. Sharpening Spatial Filters: The principle objective of sharpening is to highlight fine detail in an image or to enhance detail that has been blurred, either in error or as a natural effect of a particular method of image acquisition. Sharpening is accomplished by spatial differentiation. Thus, image differentiation enhances edges and other discontinuities and deemphasizes areas with slowly varying intensities. Different operators provide various gradient masks which are used to locate the change in intensity transitions. Different classical operators such as Robert, Prewitt and Sobel are used to find out horizontal and vertical gradients of an image which after applying suitable threshold block gives edge detected image [7].

SYSTEM DEVELOPMENT & DESIGN

The Xilinx System Generator [10] is a plug-in to MATLAB/Simulink that enables designer to develop high-performance DSP systems for Xilinx FPGAs. It provides a common environment for MATLAB/Simulink and ISE Design Suit. System generator is invoked by configuring MATLAB R2013b with ISE Design Suit 14.7. Figure 2 (a) shows flow of system generator. Any image processing application can be implemented in Xilinx system generator using three basic steps. These are image pre-processing, system generator blocks and image post processing. Gateway In and Gateway Out act as a connector between Simulink blocks and System Generator blocks. Various types of compilation can be achieved using system generator token as shown in figure 2 (b). Hardware co-simulation compilation utilizes JTAG model which is used to observe Software and Hardware output images simultaneously [8].

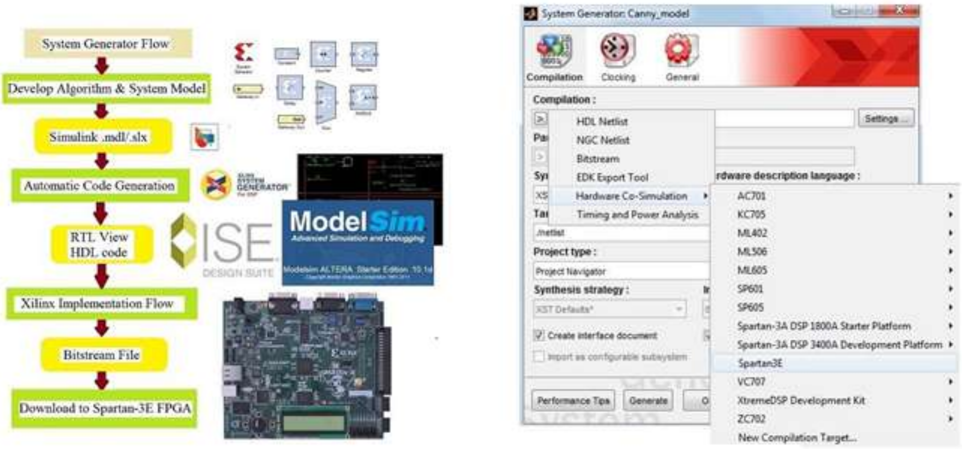
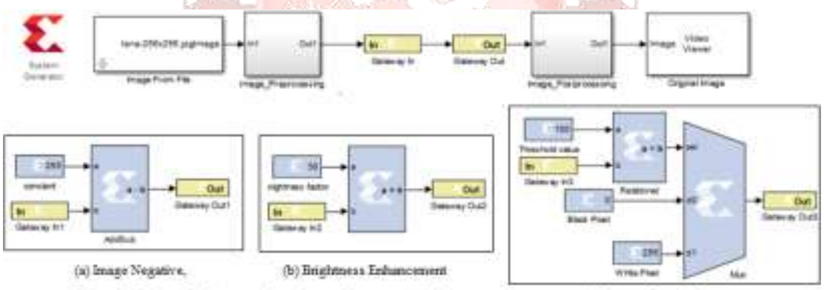


Figure2 : (a) Xilinx System Generator Flow (b) Hardware Co-Simulation Window

Design of Point Processing Techniques:

Image preprocessing and image post processing blocks along with gateway blocks are necessary to propagate image through the Xilinx system generator blocks. Xilinx blocks required for the design is then connected in between gateway in and gateway out blocks. Point processing techniques such as image negative, brightness enhancement and image thresholding etc. are designed as shown in the figure 3(a), 3(b) and 3(c) respectively. Any input can be given using image from file block and processed (or output) image can be displayed using video viewer block. These blocks are present in the simulink library of MATLAB. The System Generator token in the model is the block which generates the HDL code. In addition to that it helps in cramming a large number of pixels to smaller spaces.



(a) Image Negative, (b) Brightness Enhancement (c) Image Thresholding

Figure 3: Design of point processing image enhancement techniques

Design of Spatial Filters:

Spatial filters are designed on the system generator platform using inbuilt 5×5 filter block. This block along with Virtex 2×5 Line Buffer provides various image processing applications such as smoothing, sharpening, edge detection etc. along with Xilinx reference block sets library [9]. Virtex 2×5 line buffer along with 5×5 filter is connected as shown in figure 4.

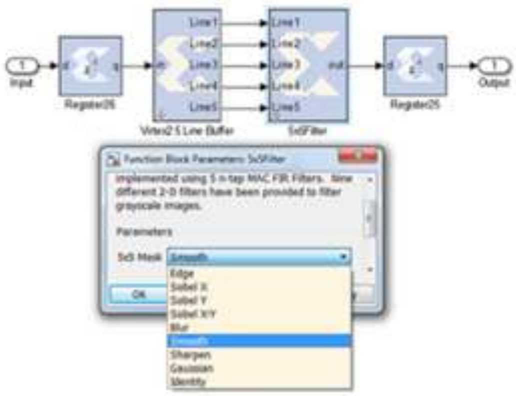


Figure 4: Design of Spatial Filters [Smoothing and Sharpening] using Xilinx Blocksets

RESULT ANALYSIS

All designed image enhancement techniques are implemented on the Spartan-3E starter kit [11]. The input image used for all the techniques is standard 256×256 lena grey image. Corresponding processed images are obtained at the output. In case of point processing techniques, resultant images for image negative, brightness enhancement and thresholding are shown in the figure 5(a), 5(b) and 5(c) respectively. Similarly, results for various spatial filtering techniques such as average smoothing filter, Gaussian smoothing filter and sharpening filter are shown in figure 6(a), 6(b) and 6(c). It is observed that Gaussian filter provides more smoothing as compared to averaging filter.

Figure 5: Original Image (a) Image Negative (b) Brightened Image (c) Image Thresholding

Figure 6: Original Image, Results for (a) Smoothing filter, (b) Gaussian smoothing filter, (c) Sharpening filter

CONCLUSIONS

The main objective of this paper was to implement spatial domain image enhancement techniques on the reconfigurable hardware platform. Point processing techniques are simple in design and have very less computational complexity. Thus, it can be used in real time image and video processing algorithms. Spatial filters are designed using xilinx reference block sets provided in the imaging library of system generator. Smoothing filter reduces the noise and sharpening filter enhances the details in an image. System generator enables hardware co-simulation making it possible to incorporate a design running on Spartan-3E starter kit directly without writing any hardware description language code. All the output images obtained after performing corresponding operations are observed. These results are verified with the software simulations as well.

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