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Optimized Systolic Array Design for Median Filter in Image Filtration

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ABSTRACT: Systolic array structure are used in median filter for the calculation of median. A 3×3 sliding window architecture is used to calculate the median. In 3×3 there are 9 elements and from these 9 elements we have to find the median using systolic array. Median filter are used to remove the impulsive noise from the image. An optimized systolic array structure is proposed for the design of median filter. The optimized systolic array is designed and verified on Xilinx software using Spartan 3 low power kit.

Keywords: Systolic array, median filter, impulse noise, FPGA implementation

I. INTRODUCTION

There are numerous specific motivations for image processing but many fall into following two categories: (i) to remove unwanted signals that corrupt the image and (ii) to extract information by rendering it in more useful form. Image de-noising falls into first category and is very important for not only visual enhancement but also to facilitate automatic processing. Digital image enhancement is a field of engineering that studies methods to recover an original scene from degraded observations [1, 3]. Often, the captured image may not be of good quality because of factors such as noise, poor brightness, contrast, blur, or artifacts.

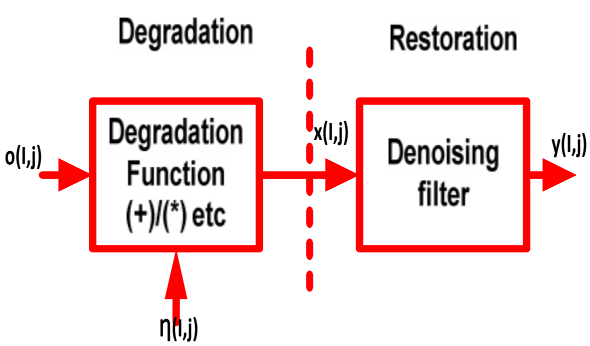

Fig. 1. Image degradation and restoration process due to noise only.

Figure 1 shows the block diagram for image degradation and restoration process in which degradation function is noise η (i , j) at the location (i, j), that operates upon image pixel o (i, j), to generate degraded pixel x(i, j). The degraded pixel is then processed by a de noising filter to provide an estimate y(i, j) of the original value. In general, the more we know about the degradation functions, the closer will be y(i, j) to o(i, j).In case of image processing, however, linear techniques are proved inadequate as they cannot cope with the nonlinearities of the image formation model and do not take into account of human visual system. These methods, therefore, often produce blurred images and are insensitive to impulse noise. Image signals are composed of flat regional parts and abruptly changing areas such as edges, which carry important information for visual perception. Thus, over the last 15 years, nonlinear approaches have been found to be more effective for this purpose. Nonlinear techniques are able to suppress non-Gaussian and signal dependent noise to preserve important signal elements such as edges and fine details and eliminate degradations occurring during signal formation or transmission through nonlinear channels [14]. If the image is degraded only by noise then the restoration can be done by using suitable de-noising algorithm a overall block diagram of image filtration is shown in figure 2.

For this purpose the nature of noise must be known. In an image processing system noise can be divided into three main categories: Gaussian noise (naturally occurring), sensor induced noise (photon counting, speckle etc.) & processing noise (quantization, transmission etc.). Accordingly, the following noise models are used in image processing literature.

(i) Additive, random and independent of image (Amplifier noise).

(ii) Additive, random and dependent on image (Speckle noise).

(iii) Random but not fitting into above two models (Salt & pepper, Random valued impulse noise [15]).

Median filters are non-linear filters that fit in the generic category of order-statistic filters. Median filters are widely used for reducing random defects, commonly characterized by impulse or "salt and pepper" noise in a single image. This non- linear technique has proven to be a good alternative to linear filtering as it can effectively suppress impulse noise while preserving edge information. This paper focuses on processing an image pixel by pixel and in modification of pixel neighborhoods and the transformation that can be applied to the whole image or only a partial region MATLAB and Simulink for Model-Based Design provide signal, image, and video processing applications with a development platform that spans design, modeling, simulation, code generation, and implementation. A Model-Based Design to target FPGA can design and simulate systems with MATLAB, Simulink and then generate bit-true, cycle-accurate, synthesizable VHDL code using HDL Coder.

Median filtering is considered a popular method to remove impulse noise from images. This non-linear technique is a good alternative to linear filtering as it can effectively suppress impulse noise while preserving edge information. The median filter operates for each pixel of the image and assures it fits with the pixels around it. It filters out samples that are not representative of their surroundings; in other words the impulses. Therefore, it is very useful in filtering out missing or damaged pixels of the image.

The complexity in implementation of median filter is due to the large amount of data involved in representing image information in digital format. General purpose processor as an implementation option is easier to implement on but not time-efficient due to additional constraints on memory, I/O bandwidth and other peripheral devices. Full custom hardware designs like Application Specific Integrated Circuits (ASICs) provide the highest speed to application but at the same time they have very less scope for flexibility.

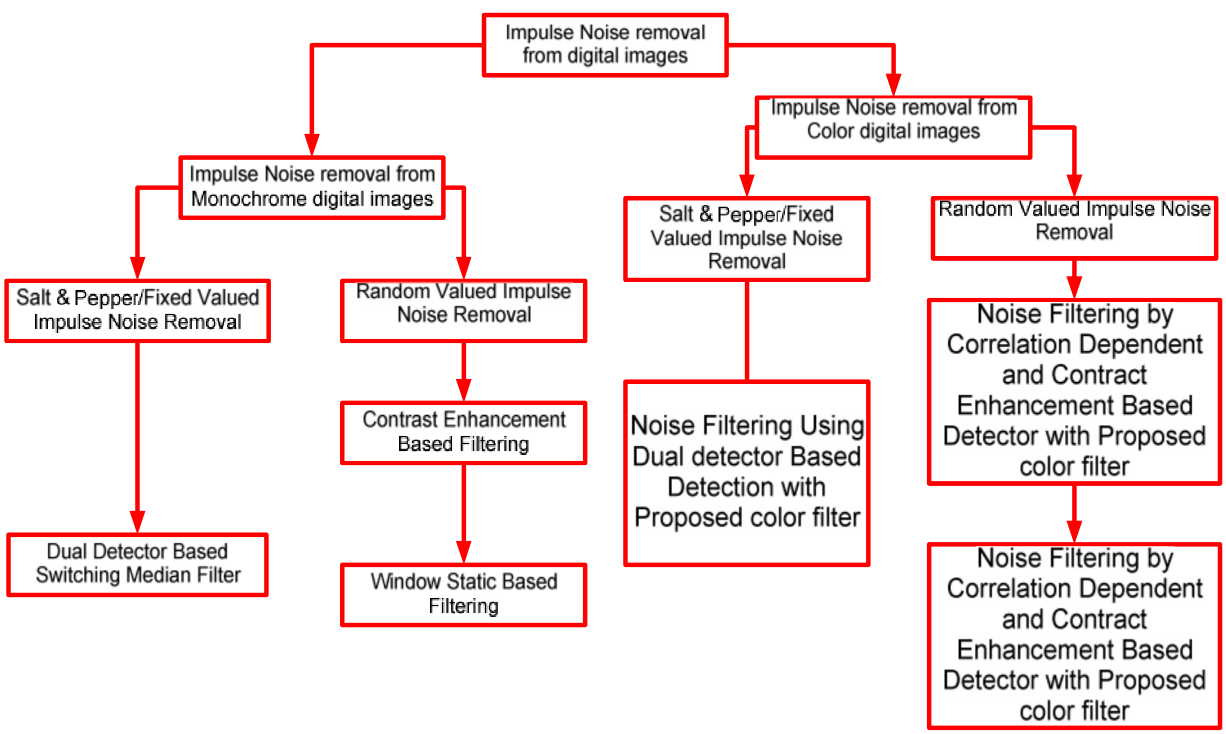

Fig. 2. Block Diagram of overall study.

Digital Signal Processors (DSPs) and Field Programmable Gate arrays (FPGAs) are two choices under the category of semi custom hardware devices. These devices give a balanced solution for performance, flexibility and design complexity. DSPs are best suited to computationally intensive applications. FPGA has been chosen for our application because of its various properties. FPGAs are reconfigurable devices, which enables rapid prototyping, simplifies debugging and verification. Its parallel processing characteristic increases the speed of implementation [1].

II. CLASSIFICATION OF NOISE

In literature, various mathematical models are proposed to describe the behavior of different types of noise. These models can be classified as follows.

(i) According to statistics: noise with Gaussian, Rayleigh or Poisson probability density functions.

(ii) According to mixing with signal: additive, multiplicative and other more complex mixing models where noise is random but does not fit into first two types, (thermal noise, photon counting noise, impulse noise).

(iii) According to dependence on the signal: statistically, noise may be independent of the signal or it can be signal dependent [10].

In image processing systems, the noise generated due to various sources is characterized by using some known probability distribution functions (PDF). For example, Gaussian function is used for thermal noise and under some reasonable conditions, it is the limiting behaviour of other noises e.g. photon counting noise and film grain noise. The Radian density function is helpful in characterizing range imaging (MRI), Exponential and Gamma density functions find applications in Laser imaging. Most image acquisition devices are photon counters and Poisson distribution is well suited for such type of noise. Rayleigh density function is used in ultrasound imaging [11].

In many applications it is assumed that noise is additive and statistically independent of the signal, Thermal noise is a good example of this model. Mathematically, it is described as

$$x(i,j) = y(i,j) + \eta(i,j)$$

Often, the noise added at the source and destination is signal dependent, it can be modelled by a multiplicative model as

$$x(i,j) = y(i,j) \times \eta(i,j)$$

The photon counting noise is an example of this case.

Because additive noise models are more convenient to tackle, we try to convert this type of problems to additive noise models, for example, Speckle noise is caused by backscatter signals from multiple distributed targets in synthetic aperture radar [12].

It is multiplicative in nature. The Lee filter converts the multiplicative model into an additive one, thereby reducing the problem of dealing with speckle noise to a known tractable case [13].

Impulse noise follows the bipolar density function and is statistically independent of the signal. It is neither additive nor multiplicative in nature. This type of noise replaces the pixel value by an impulse.

$$x(i,j) = y(i,j) \text{ or } \eta(i,j)$$

Impulse noise can be further divided into two categories: (i) uniform impulse noise and (ii) salt and pepper noise.

III. DENOISING OF IMAGES

Denoising of image means, suppressing the effect of noise to the extent that the resultant image becomes acceptable. The spatial domain or transform (frequency) domain filtering can be used for this purpose. There is one to one correspondence between linear spatial filters and filters in the frequency domain. However, spatial filters offer considerably more versatility because they can also be used for nonlinear filtering, something we cannot do in the frequency domain [14].

Recently wavelet transform is also being used to remove the impulse noise from noisy images [15] Historically, in early days filters were used uniformly on the entire image without discriminating between the noisy and noise-free pixels. Mean filters such as arithmetic mean filters, geometric mean filters, contraharmonic mean filters, alpha trimmed mean filters, rank-ordered mean filter, etc. were used to remove the impulse noise from the images [15].

In fact, these filters were useful for Gaussian noise and not for impulse noise. When these filters were applied to remove impulse noise from the images, it was found that besides removal of the noise, the recovered images were severely blurred. Hence the emphasis shifted to non-linear filtering in case of impulse noise. Classification of image denoising techniques for impulse noise is shown in Figure 3.

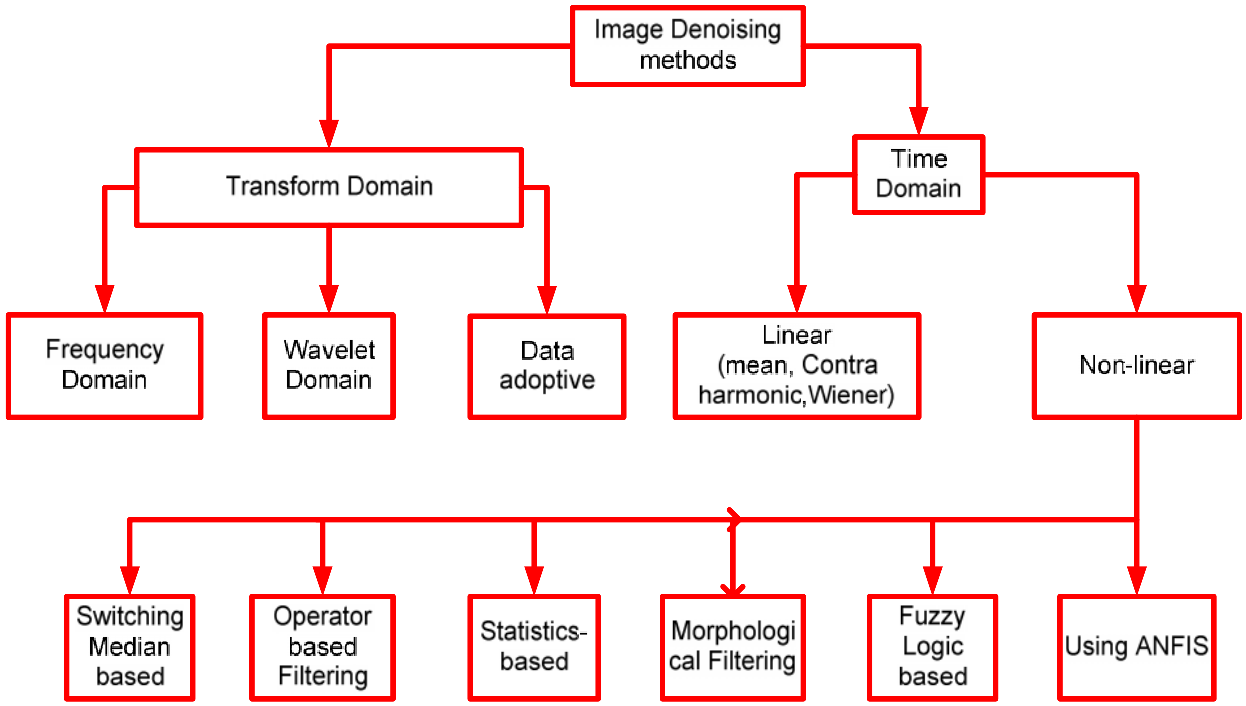

Fig. 3. Classification of impulse removal techniques.

Image denoising in spatial domain can be classified into five main categories: (i) techniques based on thresholding (ii) techniques employing some operator (iii) statistics-based (iv) method using morphology (v) filtering methods incorporating fuzzy logic and (v) ANFIS-based switching median filtering.

Median filtering is a non-linear process which helps to remove the impulse noise while preserving the edges. In median filtering, if the pixel under consideration is an outlier in the observation window, it is replaced by the median value of that window [16,17].

In time domain noise filtering for monochrome images, most of the filtering techniques use some kind of switching-based filtering in which, first of all, a decision is made about every pixel of the image weather the pixel under consideration is noisy or not. If the pixel is noisy, it is filtered by using a simple median or some of its variants like adaptive weighted median filter or center weighted median (CWM) filter [18-19].

IV. BLOCK DIAGRAM MEDIAN FILTRATION

The color image which is corrupted by impulsive noise is first decompose into RGB and each element of RGB is filtered through median filter and then recombine that RGB to make image block diagram is shown in figure 3.

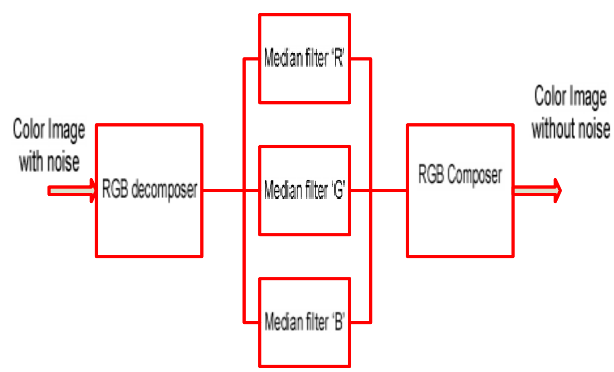

Fig. 4. Block diagram for image denoising.

The architecture of median filter uses Systolic array for sorting. There are different systolic designs which are used for sorting as shown in figures 5 & 6.

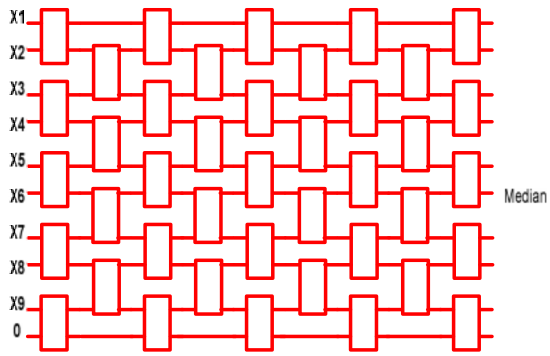

Fig. 5. Classical systolic array for shorting 9 pixel values using 41 nodes.

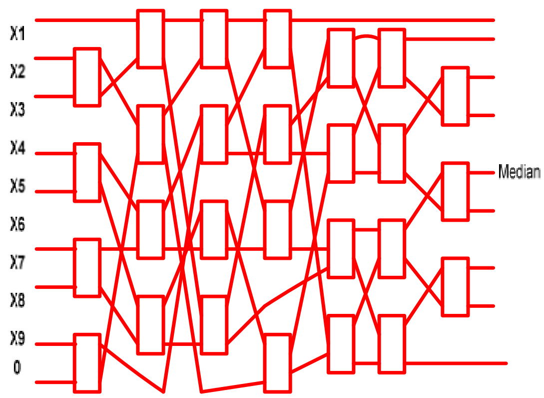

Fig. 6. Optimized systolic array for shorting 9 pixel values using 27 nodes.

V. PROPOSED SYSTOLIC ARRAY

Proposed systolic array is shown in figure 7 which use only 19 nodes as compared to conventional systolic array. This system increases the response of filtration by decreasing delay time and power consumption per window shift. A block diagram of basic node is shown in figure 8 and internal structure of basic node is shown in figure 9 which uses 8 bit comparator and two Mux.

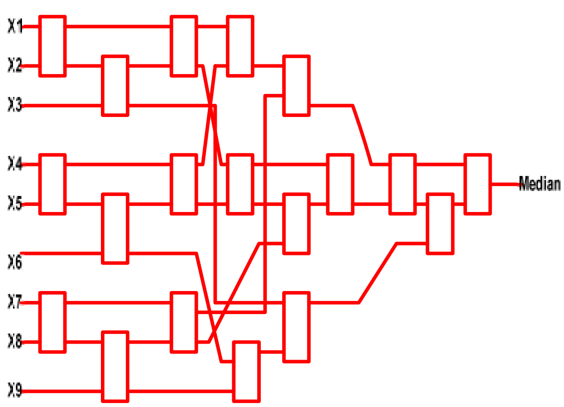

Fig. 7. Proposed systolic array for shorting 9 pixel values using 19 nodes.

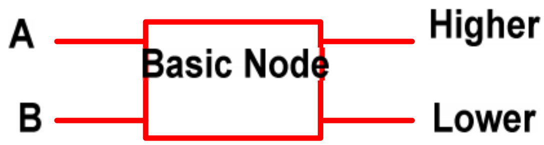

Fig. 8. Basic nodes used in systolic array.

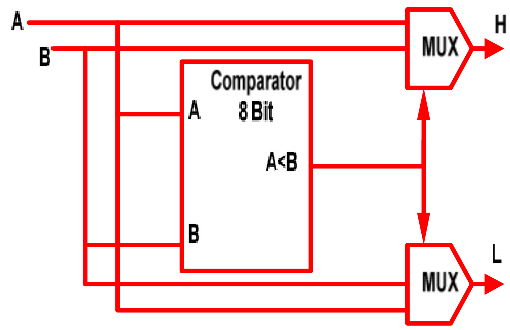

Fig. 9. Structure of Basic nodes.

VI. SIMULATION RESULTS

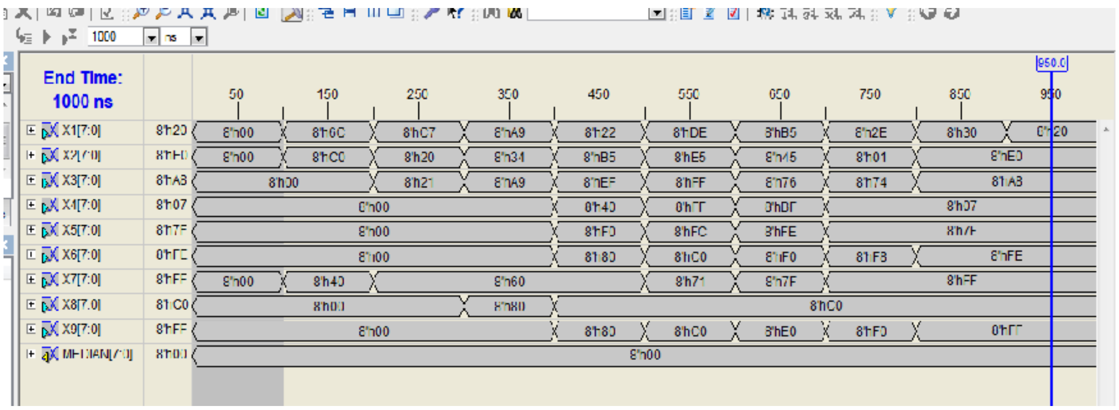

Fig. 10. Simulation waveforms.

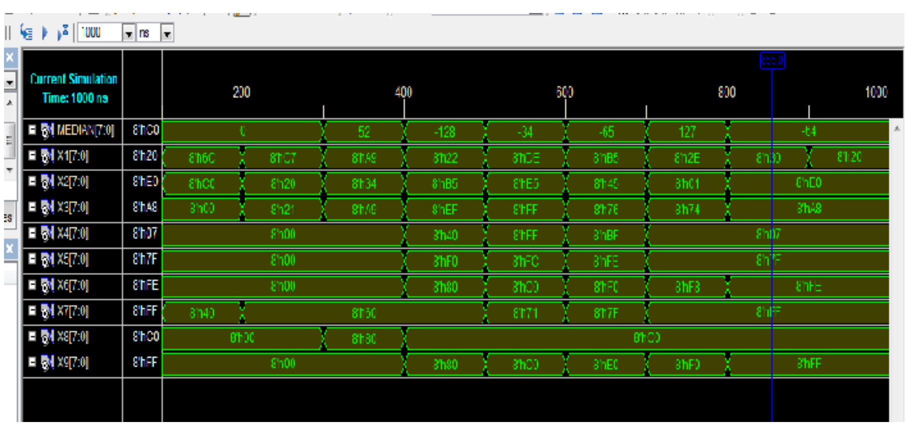

Fig. 11. Simulation waveforms with median values.

Table 1: Utilization of FPGA.

FPGA family	SPARTEN 3E			
Device selected	**3s1200efg320-4**			
Sr. No.	**FPGA Resources**	**Available**	**Used**	**% utilization**
1	Number of Slices	8672	214	2%
2	Number of 4 input LUTs	17344	392	2%
3	Number of bonded IOBs	250	80	32%
4	Delay	46.418ns		

Fig.12. Original Image.

Fig.13. Image with impulse noise.

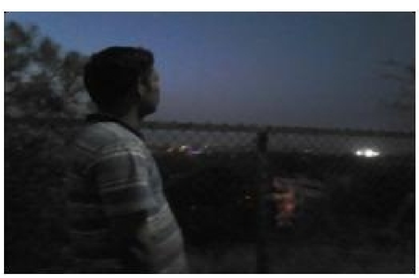

Fig. 14. Median Filtered image.

VII. CONCLUSION

Systolic array for median filter is designed using Xilinx in Spartan 3 the table 1 shows the designing result on Spartan kit. And MATLAB code is also used for verification of median filter. Figure 10 & 11 shows the median filter systolic array result using 3*3 window to find the median of 9 pixels.

Figure 12 shown the input color image to filter. Figure 13 shows noisy image with salt and pepper noise and Figure 14 shows removed noise from noisy image using Non-linear median filter.

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