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# An Image Enhancement Approach to Achieve High Speed Using Adaptive Modified Bilateral Filter for Satellite Images using FPGA

**Sendamarai P*[1], Giriprasad MN[2]**
[1]Nagarjuna College of Engineering and Technology, Bangalore, India
[2]JNTU Anantpur, India
*Corresponding author, e-mail: sendamarai17@gmail.com[1], magendragiri1960@gmail.com[2]

***Abstract***

*For real time application scenarios of image processing, satellite imaginary has grown more interest by researches due to the informative nature of image. Satellite images are captured using high quality cameras. These images are captured from space using on-board cameras. Wrong ISO setting, camera vibrations or wrong sensory setting causes noise. The degraded image can cause less efficient results during visual perception which is a challenging issue for researchers. Another reason is that noise corrupts the image during acquisition, transmission, interference or dust particles on the scanner screen of image from satellite to the earth stations. If quality degraded images are used for further processing then it may result in wrong information extraction. In order to cater this issue, image filtering or denoising approach is required. Since remote sensing images are captured from space using on-board camera which requires high speed operating device which can provide better reconstruction quality by utilizing lesser power consumption. Recently various approaches have been proposed for image filtering. Key challenges with these approaches are reconstruction quality, operating speed, image quality by preserving information at edges on image. Proposed approach is named as modified bilateral filter. In this approach bilateral filter and kernel schemes are combined. In order to overcome the drawbacks, modified bilateral filtering by using FPGA to perform the parallelism process for denoising is implemented.*

***Keywords***: *satellite image, noise, filtering, bilateral filter, PSNR, FPGA*



## 1. Introduction
### 1.1. Background

Satellite images are widely used for various real time applications. Mostly these images are used for the weather forecasting, weather monitoring and atmosphere condition. The other applications includes in metrology, agriculture, forestry, super resolution. These images are captured from the low resolution cameras which causes lower illumination problem in images. Surveillance cameras would not have the ability to take accurate images.It is because of the relative motion between camera and vehicle. In today's scenario, resolution of image is critical issue and other issue which affects the intensity value including brightness, contrast of image and color variations. For resolution enhancement various approaches have been proposed by the researchers for enhancing the resolution. Most effective technique is interpolation based approach and which has grown attraction of the researchers in image processing techniques.
In recent years, several variations have been introduced as technology is growing faster which capture images at very high resolution.

### 1.2. Problem Definition

During the acquisition of satellite images, these images are corrupted by the noise which affects the quality of image. This degraded quality image causes analytical issues. This is the main challenge for the researchers to perform on-board operation in an efficient way to remove the noise or enhance the quality of image.

Satellite images are affected due to various aspects such as wrong setting of ISO, vibrations, motion in cloud and heat generation etc [2]. There are various other methods used by authorities to remove the noise from the satellite image while keeping the fine features. Keeping the fine features of noisy image during the denoising process is crucial for the

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researchers to achieve the better results. Bilateral Filter is one of the effective denoising algorithms for removing unwanted noise while preserving the edges and this algorithm receives two parameters from the user. The user must select the most suitable parameter values to achieve the most meaningful result.

Digital images procured through numerous gadgets items are regularly debased by Impulse commotion [2]. Images are regularly defiled by impulse noise because of errors produced in noisy sensors or channels. It is imperative to dispose of noise in the images before some processing, for example, detection of edges, segmentation and detection of objects. For this reason, numerous methodologies have been proposed [3]. It is understood that noise in the pictures may be presented amid the procedure of collection or transmission. Accordingly, image de-noising i.e. expulsion of noise from a picture is a critical piece of image processing [4]. Image processing is a procedure to improve images that is Edge/points of interest protection [7]. Image processing algorithms need to handle extensive measure of information. Programming usage will be tedious. For a few frameworks requiring ongoing handling, execution rate is frequently considered as a key component, so the image processing is suitable to be actualized in hardware. Field programmable gate array (FPGA) is suitable for pipelining and parallel information handling [1]. Prasetio, Barlian Henryranuet al [23] presented an encryption approach using FPGA to show the advantages of the FPGA kit.

### 1.3. Contribution of the paper

In this work we propose a new design for satellite image filtering or image enhancement to improve the quality of image by removing noise or unwanted signals [4]. During the image filtering, information related to images is lost due to the obscureness of sharp edges of image. In this work our main aim is to preserve the edges of image which provides better reconstruction. For image denoising median filter is a promising technique which is used widely for filtering operations. Median filter is an efficient technique which can remove the impulsive noise and salt & pepper noise [1]. Implementation complexity is also very less for median filters.

Still there are various challenges when median filters are implemented for satellite image system. To overcome these issues for satellite image denoising, here in this work we propose a modified bilateral filtering approach. This approach uses kernel based approach combined with bilateral filtering technique. The main contribution of this approach is to perform the denoising operation at high speed with lower resource utilization and efficient reconstruction. In the results section we demonstrate the performance of the proposed approach in terms of operating frequency, device utilization summary and image reconstruction parameters.

## 2. Related Work

This section describes about the relevant studies which are carried out by other researchers in the field of image denoising. According to the study presented in [9] median filtering is a promising technique in the field of noise removal applications for signals and image processing schemes. Experimental studies presented shows that median filtering scheme is an optimal solution which is a significant approach for noise removal and information preserving. Median is computed by considering the middle element of group of a pixel. During pixel sorting in median filtering, all odd numbers of pixel elements are considered for computation.

Figure 1 explains about the working steps of this approach by considering $n \times n$ $(3 \times 3)$ pixel window. In [10] Zhu et al. proposed another approach for median filtering using cross window for median pixel computation. According to Fu et al [11] sorting is a key component of median filtering approach. To address this component, in [11] sorting is applied for pixel columns, diagonal elements and rows in a 3x3 window. If the size of window is considered as 3 then, operations which compares the columns requires 9 iteration and rows also needs 9 iterations for comparison.

In order to improve the performance of image filtering, adaptive filter is proposed which is capable to encounter the issues related to impulsive noise. Moreover, the adaptive median filtering preserves the edge information during smoothing of image which is not addressed by the median filters. Pingjun Wei et al. [12] presented another study based on the adaptive median filtering. In their study they show that median filtering can perform image filtering if rectangular blocks are provided as an input. Novelty of other filters is that, it can adapt the window size during filtering operation which can vary based on the conditions.

An alternate methodology for the FPGA usage of a realtime two-sided channel has been proposed in [13]. The altered channel depends on the figuring of the channel coefficients from the photometric channel as it were. The spatial filtering is dispensed with because of the handling of the negligible window of 3 × 3 and raising of the determined photometric coefficients to the force of 8. As indicated by the researchers, for a moderate noise level, their altered reciprocal channel can accomplish marginally better results contrasted with the customary respective channel appeared in [14]. In any case, the first two-sided channel can be tuned by two parameters which are exceedingly in charge of the separating execution. Shockingly, no portrayal of the parameters utilized for this examination is given in [13].

Learning based approaches also being used by various researchers. Neural network is grown its significant in this field. In [15] Rezvanian et al. introduced two-pass scheme to remove impulse nose. This scheme uses two approaches i.e. switching based scheme and progressive method. According to switching scheme, impulse detection approach is applied before filtering the image. This helps to obtain only noisy data for filtering. According to progressive approach, impulse noise detection and filtering are applied progressively using iterative approach. Experimental study presented in this work proves the effectiveness of approach for more corrupted images. Al-Araji et al. [16] has implemented a new scheme for noise reduction by using occurrence rate estimation.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Figure 1. Median Filtering

Median filters and linear filters are main approaches for filtering the image. Median filters are applied for filtering so that the edge information can be preserved when compared to the linear filters [7]. Mainly impulsive noise can be classified into two main types: (a) salt and pepper noise and (2) random noise. According to salt and pepper noise either minimum pixel value or maximum pixel values are considered for processing whereas random valued noise can take any value of pixel which is complex when compared to salt and pepper noise.

Customarily, the salt-and-pepper noise is evacuated by applying median filtering scheme. At the point when the noise power is not exactly approx. 10% a straight forward middle using 3x3 or 5x5-pixel window is adequate. In any case, it was demonstrated that developmental configuration methods can create marginally preferable arrangements over standard medians for this noise power [2]. The images separated by developed channels are not all that smeared and the range on the chip can by diminished by approx. 60%. Among others, adaptive median filters give great results and at the same time with lower complexity in hardware and power consumption.

| | |
|---|---|
| $\mathcal{D}$ | Distance |
| $i, j$ | Spatial positions of pixels |
| $\sigma_D$ | Scaling parameter |
| $GK$ | Gaussian kernel |
| $LK$ | Lorentz Kernel |
| $\alpha$ | Standard deviation |
| $U$ | Unknown signal |
| $N_v$ | Noise vector |
| $Ck$ | Cosine kernel |
| $Fk$ | Flat Kernel |

## 3. Background of Bilateral Filtering

This section describes about the state-of-art bilateral filtering scheme. This approach was first introduced by Tomasi and Manduchi in 1998 [3]. According to bilateral filtering consideration it is assumed that close pixels in image have same as spatial domain which concludes that these pixels will have similar intensity value. Filtering range is defined based on the weight decay with the dissimilarity values. Weights of image depend on the intensity of image.

As discussed, range filters are the type of non-linear filters. In bilateral filtering scheme, both the filters domain filters and range filters are combined which results in better smoothing and edge preserving of image. Due to its nature of edge persevering nature of bilateral filter, it is used in various applications for image denoising. Such as Adobe Photoshop use bilateral scheme for surface blurring tool. Similarly, GIMP implements selective Gaussian blur using bilateral filtering. Another various application also uses bilateral filtering methodology such as digital still camera, surveillance camera and smart phones etc.

To improve the performance of the bilateral filter, we use kernel based approach for image smoothing as shown in Figure 1. A Gaussian kernel is easy to implement which can improve the filtering performance and optimizing the speed tradeoff. Use of kernel is advantageous because it can perform averaging operation even when the pixel weights allocation is small.

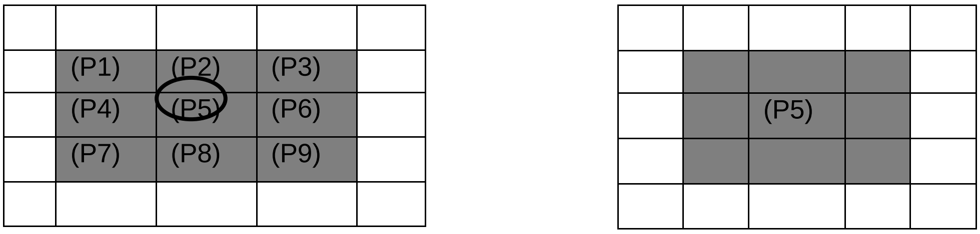


Figure 1. GIMP implements selective Gaussian blur using bilateral filtering

Selection of kernels is carried out according to the requirements of image smoothing and computational requirements. Conventional bilateral smoothing computes weight pixels by considering spatial distance from the center pixel. By using this constraint, domain filter weight pixels are computed based on the distance follows:

$$\mathcal{D}(x-y) = \frac{1}{2}\, e^{-\frac{(x-y)(x-y)}{2\sigma_D^2}} \quad (1)$$

$i$ and $j$ denotes the spatial position of the pixels and scaling of these pixels is fixed by using $\sigma_D$. Hence, by considering range filter weights, photometric difference can be computed as

$$\mathcal{W}(f(i)-f(j)) = \frac{1}{2}\, e^{-\frac{(f(i)-f(j))(f(i)-f(j))}{2\sigma_R^2}} \quad (2)$$

$f(.)$ is the intensity of the image and filtering is fixed by the $\sigma_R$. By using equation 1 and 2, bilateral filter can be defined as

$$BilateralFilter = \frac{\int R^d\, f(j)\mathcal{D}(i-j)\mathcal{W}\big(f(i)-f(j)\big)dy}{\int R^d\, d(i-j)\mathcal{W}\big(f(i)-f(j)\big)dy} \quad (3)$$

In [17] Weijer et al. proposed a generalized approached for bilateral approach using space-tonal convolution method. This technique addresses the basic problem of image smoothing and edge preserving of bilateral filters. If noise is added to any image, then the centered pixel also get affected which is used as a reference pixel for image filtering using tonal approach.

Work presented in [17] used the process of replacing the center reference value by estimating other true values of pixel. In [18] P. Perona et al. discussed a similar approach for detection of noise reduction of noise using anisotropic [18]. In their approach they suggested a combined approach for image denoising using low pass filtering with kernel function at a smaller extent.

### 3.1. Modified Bilateral Filter

In this section we discuss about modified bilateral filter approach for satellite image denoising using kernel functions. Conventional methods compute the weighted average from the neighborhood pixel but still some noise content remains present there. So there is a need to implement a new approach for removing noise after applying bilateral filter. To address this, we implement these modifications which are as follows:

1. Employing the replacement of summation.
2. Defining new kernels based on the knowledge of domain and range filters.

These modifications provide various advantages during implementation of denoising. In this work, for satellite image denoising application, we use Gaussian kernel based approach for computing the optimal weights. The computation process of Gaussian kernels is denoted in Equation (4). To optimize the bilateral filtering the kernels are used which are given below:

$$GK : g(i,\alpha) = e^{-\frac{i^2}{2\alpha^2}} \tag{4}$$

$$Min - Max : g(i,\alpha) = f(x) = \begin{cases} \frac{1}{\alpha}, & |i| \le \alpha \\ i, & |i| \ge \alpha \end{cases} \tag{5}$$

$$LK : g(i,\alpha) = \frac{2}{2\sigma^2 + i^2} \tag{5}$$

$$Ck : g(i,\alpha) = \begin{cases} \cos\left(\frac{\pi i}{2\sigma}\right), & |i| \le \alpha \\ 0, & |i| \ge \alpha \end{cases} \tag{6}$$

$$FK : g(i,\alpha) = \begin{cases} \frac{1}{\alpha}, & |i| \le \alpha \\ 0, & |i| \ge \alpha \end{cases} \tag{7}$$

## 4. Noise Removal using Modified Bilateral Filter

In previous sections we have discussed about the proposed approach of image filtering and noise removal. This section deals with detection of noise and removal using proposed approach. Let us consider that an unknown image signal $U$ is denoted as a vector and degraded due to the Gaussian noise mixture into this. This is called a noisy image which can be represented as

$$Out = U + N_v \tag{8}$$

In this work, our main aim is to remove the noise from input signal and restore it as an original signal. According to bilateral approach weighted average of pixels are compute which is given as

$$U[k] \frac{\sum_{n=N}^{N} W[p,q] Out[p-q]}{\sum_{q=-N}^{N} W[p,q]} \tag{9}$$

This equation provides a normalized average value from the neighboring pixels from $[2N+1]$ neighborhood. Computation of weights is carried out based on the content of neighboring pixels. If a center pixel is given as $c[k]$, then weights for that pixels can be computed by multiplying the below mentioned factors.

$$W_s[p,q] = \exp\left\{-\frac{d^2\{[p],[p-q]\}}{2\alpha_S^2}\right\} \tag{10}$$

$$W_R[p,q] = \exp\left\{-\frac{d^2\{[k],[p-q]\}}{2\alpha_R^2}\right\} \quad (11)$$

The final weight is obtained by multiplying the two

$$W[p,q] = W_s[p,q].W_R[p,q] \quad (12)$$

Weight computation includes two components which are temporal and radiometric weights. Temporal weights provide the geometric distance between two different samples i.e. $[p]$ and the $[p-q]$ sample using euclidean distance computation method. Hence closer pixel values effects on the final output results. Radiometric weight computation is carried out using $Out[p]$ and the $[p-q]$ sample using euclidean method.

**5. Image Quality Assesment**

In this section we describe the formulas used to compute the quality of reconstructed image. In our model we are using 5 parameters of quality matrices for the assessing the image quality. These parameters are: (1) PSNR (Peak signal to noise ratio (2) MSE (Mean squared error) (3) Average difference (4) Maximum difference (5) Average Difference. These parameters can be computed by using below given equations.

$$PSNR_{dB} = 20.log_{10}\left(\frac{255}{\sqrt{MSE}}\right) \quad (13)$$

$$MSE = \frac{1}{MN}\sum_{M}\sum_{N}\left[Ref_{img}(m) - Out(m)\right]^2 \quad (14)$$

$$AverageDifference = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(x(i,j) - y(i,j)) \quad (15)$$

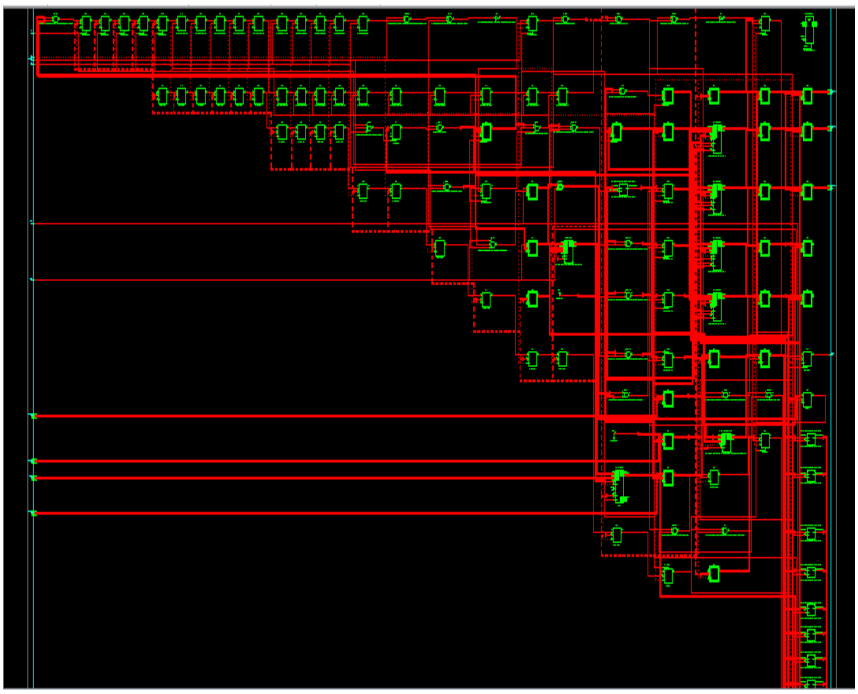

Figure 2. RTL schematic of proposed architecture

$$MaxDifference = MAX|x(i,j) - y(i,j)| \tag{16}$$

$$NormAbsError = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}|\,(x(i,j) - y(i,j)| \tag{17}$$

## 6. Results

The proposed architecture of the modified bilateral filter was implemented in VHDL and simulated with Xilinx system generator. A test image was filtered by Xilinx system generator simulation, and the filtered images were compared. The target device was a Xilinx Virtex 4 XC4VSX55 FPGA. For the satellite image higher embedded memories are require, to use higher embedded memories we have selected $SX$ family. For proposed model of image denoising, this platform is ideally efficient to perform the desired operation. This platform provides efficient number of logic elements, DSP blocks and reasonable memory requirements which makes implementation easier with reduced complexity.

The test image of port captured by satellite shown in Figure 3(a) is an grayscale image with a size of 64x64 pixels. In Figure 3(b) Gaussian noise added image is show and in Figure 3(c) speckle noise added image is shown. In Figure 4 port image with Gaussian noise and denoise image are shown Table 1.

Comparisons results of the proposed denoising model with other existing methods are shown in the Table 1. The result table shows that the proposed architecture outperforms compared to other methods. FPGA Synthesis Resultsas shown in Table 2. In Table 3 quality measurement results are tabulated to show the reconstruction efficiency of the proposed model.

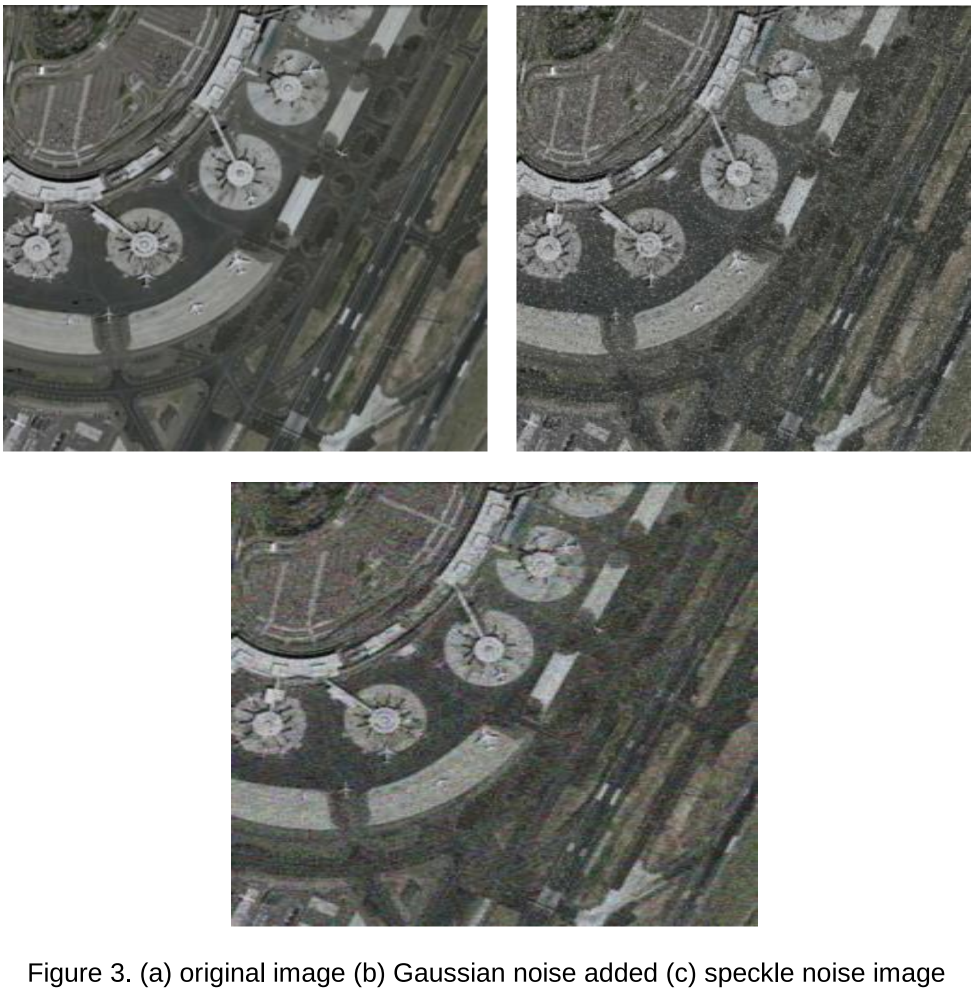

Figure 3. (a) original image (b) Gaussian noise added (c) speckle noise image

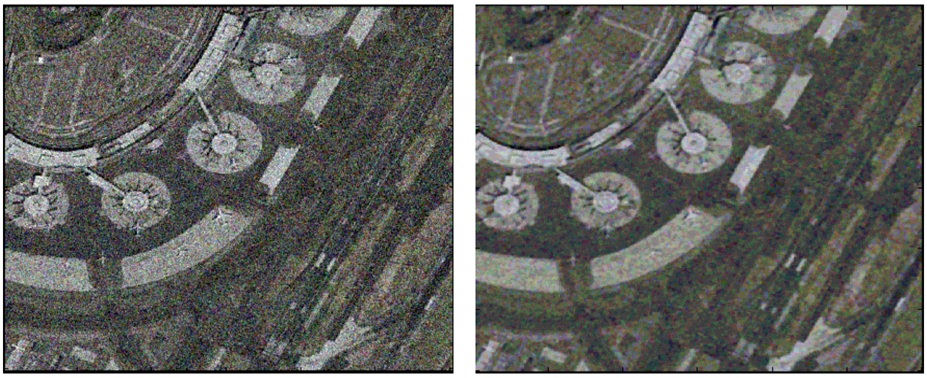

Figure 4. (a) Noisy image (b) Denoise image

Table 1. FPGA Results Performance Comparison

| Filtering Method | Bilateral Filter [19] | Modified Bilateral Filter [20] | Bilateral Filter [21] | Bilateral Filter [22] | Modified bilateral (Proposed Design) |
|---|---|---|---|---|---|
| Kernel Size | 15x15 | 3x3 | 3x3 | 5x5 | 5x5 |
| FPGA Family | Xilinx-Spartan 3 | Altera Cyclone -II | Xilinx Virtex-II | Xilinx Virtex -V | Xilinx Virtex-IV |
| Max. Clock frequency | 72.2 MHz | 159 MHz | 87.65 MHz | 220 MHz | 269.807MHz |
| Clockcycles Resources | 15 | 1 | 1 | 1 | 1 |
| Logic elements | - | 567 | 1447 | 1060 | |
| Logic slices | 2150 | - | 9 | 23 | 898 |
| Multipliers | NA | 32 | - | - | |

Table 2. FPGA Synthesis Results

| Device utilization summary | | | |
|---|---|---|---|
| Logic Utilization | Used | Available | Utilization (%) |
| Number of slices | 898 | 5472 | 16% |
| Number of slice flip-flops | 1273 | 10944 | 11% |
| Number of 4 input LUTs | 926 | 10944 | 8% |
| Number of bonded IOBs | 62 | 240 | 25% |
| Number of FIFO 16 | 12 | 36 | 33% |
| Number of GCLKS | 1 | 32 | 3% |

Table 3. Image Quality Performance

| | MSE | PSNR | Average Difference | Maximum Difference | Normalized Absolute Error |
|---|---|---|---|---|---|
| Port Image | 1.02E+03 | 18.0511 | 0.2328 | 200 | 0.2704 |

## 7. Conclusion

In this work we address image denoising problem by applying image filtering scheme for satellite image systems. Main aim of the work is to reduce the complexity by limiting the required hardware components and optimizing the operating speed. This method is implemented on FPGA using pipeline method which uses filtering on row and column operators with pipeline filtered architecture. We have presented a high speed implementation of the bilateral filter, targeted towards satellite image denoising.Proposed image denoising scheme uses pipeline and parallel architecture for FPGA which makes it fully configurable to achieve the desired results.

For performance improvement we use a kernel based scheme combined with bilateral filters. This approach results in number of flip-flop reduction and resource utilization which make it feasible to implement. This architecture uses fully scaled BRAM which helps to improve the operating frequency of 270 MHz. In this work we show that the5x 5 kernel size uses resources efficiently which can be implemented for medium size of FPGAs. Kernel architecture reduce the use of external storage to improve the performance of logic utilization and achieve higher clock frequency.

## References


[1] Minjae Kim, Dubok Park, Han D, Hanseok Ko. "A novel approach for denoising and enhancement of extremely low-light video". In *IEEE Transactions on Consumer Electronics*. 2015; 61(1): 72-80.

[2] Kenny Kal Vin Toh, Haidi Ibrahim, Muhammad Nasiruddin Mahyuddin. Salt-and-Pepper Noise Detection and Reduction Using Fuzzy Switching Median Filter. ‖*IEEE Transactions on Consumer Electronics*. 2008; 54(4).

[3] Andreadis I, Louverdis G. "Real-time adaptive image impulse noise suppression". In *IEEE Transactions on Instrumentation and Measurement*. 2004; 53(3): 798-806.

[4] Cadenas J, Megson GM, Sherratt RS, Huerta P. "Fast median calculation method", In *Electronics Letters*. 2012; 48(10): 558-560.

[5] Crookes D. ‘Architectures for high performance image processing: the future’. *J. Syst. Archit*. 1999; 45(10): 739.

[6] Ren-Der Chen, Pei-Yin Chen, Chun-Hsien Yeh. "A Low-Power Architecture for the Design of a One-Dimensional Median Filter". In *IEEE Transactions on Circuits and Systems II: Express Briefs*. 2015; 62(3): 266-270.

[7] Ren-Der Chen, Pei-Yin Chen, Chun-Hsien Yeh, "Design of an Area-Efficient One-Dimensional Median Filter". In *IEEE Transactions on Circuits and Systems II: Express Briefs*. 2013; 60(10): 662-666.

[8] Gabiger-Rose A, Kube M, Weigel R, Rose R. "An FPGA-Based Fully Synchronized Design of a Bilateral Filter for Real-Time Image Denoising", in *IEEE Transactions on Industrial Electronics*. 2014; 61(8): 4093-4104.

[9] Leiou Wang. "A new fast median filtering algorithm based on FPGA". in *2013 IEEE 10th International Conference on ASIC (ASICON)*. 2013: 1-4.

[10] Zhu Jie, Zhu Xiao-juan, He Ming. Design of Real-Time Image Median Filtering Based on FPGA. *Computer Measurement & Control*. 2007.

[11] Fu Yiqiang. Master Dissertation of Nan Chang University. 2006.

[12] Pingjun Wei, Liang Zhang, Changzheng Ma, Tat Soon Yeo. “Fast MF Algorithm Based on FPGA”. Proceeding *IEEE journal, ICSP*. 2010.

[13] TQ Vinh, JH Park, YC Kim, SH Hong. “*FPGA implementation of real-time edge-preserving filter for video noise reduction*”. In Proc. IEEE ICCEE. 2008: 611–614.

[14] C. Tomasi and P. Manduchi. “*Bilateral filtering for gray and color images*”. In Proc. IEEE ICCV. 1998: 839–846.

[15] Rezvanian A, K Faez, F Mahmoudi. *A twopass method to impulse noise reduction from digital images based on neural networks*. Proceedings of the International Conference on Electrical and Computer Engineering, Dec. 20-22, IEEE Xplore Press, Dhaka. 2008: 400-405.

[16] Al-Araji SR, MA Al-Qutayri, K Belhaj, N Al-Shwawreh. *Impulsive noise reduction techniques based on rate of occurrence estimation*. Proceedings of the 9th International Symposium on Signal Processing and Its Applications, IEEE Xplore Press, Sharjah. 2007: 1-4.

[17] Rein van Boomgaard and Joost van de Weijer. *On the equivalence of local-mode finding, robust estimation and mean-shift analysis as used in early vision tasks*. In R. Kasturi, D. Laurendeau, and C Suen, editors, Proceedings 16th International Conference on Pattern Recognition, Quebec City, Quebec, Canada. IEEE Compututer Society. 2002; 3: 27–930,

[18] P Perona, J Malik. Scale-space filtering and edge detection using anisotropic diffusion. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 1990; PAMI-12(7): 629 – 639.

[19] C Charoensak, F Sattar. "*FPGA design of a real-time implementation of dynamic range compression for improving television picture*". In Proc. IEEE ICICS. 2007: 1–5.
[20] TQ Vinh, JH Park, YC Kim, SH Hong. "*FPGA implementation of real-time edge-preserving filter for video noise reduction*". In Proc. IEEE ICCEE. 2008: 611–614.
[21] H Dutta, F Hannig, J Teich, B Heigl, H Hornegger. "*A design methodology for hardware acceleration of adaptive filter algorithms in image processing*". In Proc. IEEE ASAP. 2006: 331–340.
[22] Gabiger-Rose A, Kube M, Weigel R, Rose R. "An FPGA-Based Fully Synchronized Design of a Bilateral Filter for Real-Time Image Denoising". In *IEEE Transactions on Industrial Electronics*. 2014; 61(8): 4093-4104.
[23] Prasetio, Barlian Henryranu, Setiawan Eko, Muttaqin, Adharul. "Image Encryption using Simple Algorithm on FPGA". *Telkomnika*. 2015; 13(4): 1153.