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2-D Adaptive Image Processing Algorithm, Image Enhancement Technique & Its Hardware Implementation

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***Abstract**: Digital image processing (DIP) algorithms used in consumer electronics products have high computationalcomplexities. Therefore, in this paper, we propose a novel low complexity 2D adaptive DIP algorithm. The proposed algorithm reduces computational complexities of 2D DIP algorithms by exploiting pixel correlations in input image without reducing quality of output image. A low energy 2Dadaptive DIP hardware implementing the proposed algorithm can be useful for removing pixel noise mainly caused by thermal noise,impulsenoise due to image transformations from one format to another. The 2-D adaptive image processing algorithm can be more effective to perform well to remove noise without degrading quality of output image. The proposed hardware is verified to work correctly on an FPGAboard. It has significantly less energy consumption than original2D DIP hardware. Therefore, it can be used especially in portableconsumer electronics products.*

***Keywords**: Median Filter, Gaussian Blur, Image Sharpening, Image Enhancement, Hardware Implementation, FPGA, Low Energy.*

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I. INTRODUCTION

Digital image processing (DIP) algorithms and hardwareare used in many consumer electronics products [1]-[4].To improve visual qualityof the applications in theseproducts, image sizes and computational complexities of DIPalgorithms are increased. This increased energy consumptionsof DIP hardware mainly in area, power and additional hardware also. This trend is expected to continue in thefuture as wellwhenever there is huge demand of consumer electronic products tend to increase. Therefore, it is necessary to reducecomputational complexities of DIP algorithms and energyconsumptions of DIP hardware without reducing visual qualityespecially for portable consumer electronics products.Digital images are affected by the noise resulting fromimage sensors or transmission of images.

Image denoising isperformed to remove the noise from images.although non-linear filters are more complex than linearfilters, they are more commonly used for image denoisingbecause they reduce smoothing and preserve image edges. 2Dspatial median filter is the most commonly used non-linearfilter for image denoising. It is a non-linear sorting-basedfilter. It sorts pixels in a given window, determines the median value of every window or kernel by arranging the pixels values from ascending order to descending andtry to find out median value of RGB which is replaced by gray value.

This process will continue for next window upto entire image. Several other filters like Sobel filter, Weiner filter, mean filter, weighted mean filter are used depends upon the requirements.

In this paper, we have used this novel low complexityalgorithm for 2D adaptive digital image processing. We showthat the proposed algorithm reduces computationalcomplexities than 2D gaussian blur and 2-D image sharpeningwithout reducing quality of output image. These two DIPalgorithms also have high computational complexities than the median filtering algorithm. All the algorithms are implementing for image denoising

II. AN OVERVIEW OF VARIOUS FILTERS OF IMAGE PROCESSING

Several linearand non-linear filters are proposed for image denoising in [5].Based on spatial domain and frequency domain the spatial domain 2-D Median filter has highest computational complexity we proposed a novel low complexity 2D adaptivemedian filter algorithm 2D adaptive medianfilter algorithm in [6]. The proposed algorithm reduces thecomputational complexity of 2D median filter and produceshigher quality filtered images than 2D median filter byexploiting pixel correlations in input image. A low energy 2D adaptive median filter wasimplemented using the proposed 2-Dimensional median filteralgorithm for 5x5 window size. Thisalgorithm isimplemented using Verilog HDL.Minimum period 6.690ns (Maximum Frequency: 149.477MHz) Minimum input arrival time before clock 2.475nsMaximum output required time after clock:

0.877ns Maximum combinational path delay of 0.656ns,delay 0.656nsTotal memory usage is 354944 kilobytesWhich can be verified to workcorrectly on an FPGA board. It can work at 149.477 MHz, and itcan process 105 full HD (1920x1080) images per second inthe worst case on an FPGA implemented in 130 nm CMOStechnology. It has total area utilization of only54% & overall energy consumption of 12% less than original 2-Dimensional median filter on130nm FPGA.In this paper, we have used this novel low complexityalgorithm for 2D adaptive digital image processing. We showthat the proposed algorithm reduces computationalcomplexities than 2D gaussian blur and 2-D image sharpeningwithout reducing quality of output image. These two DIPalgorithms also have high computational complexities than the median filtering algorithm. All the algorithms are implementing for image denoising. 2Dimensionalgaussian blur is commonly used for image smoothing anddenoising. In this paper, 2-D gaussian kernel shown in equation (2) is used. Output image is generated by convolving inputimage with this kernel. 2-Dimensional image sharpening is used tosharpen images and enhance edges. In this paper, 2-Dimensional imagesharpening kernel shown in equation (2) is used. Output imageis generated by convolving input image with this kernel.

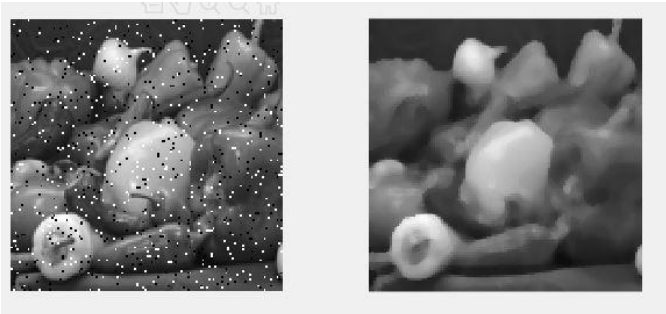


Figure.1 Example image for median filter

We also proposing a 2-Dimensional adaptive gaussian blur and 2-Dimensional adaptive image sharpening algorithms, respectively, for 5x5 window size. The proposed hardware is implemented using Verilog HDL. The proposed 2D adaptive gaussian blur hardware can work atSpeed Grade with Artix-7xc7a100tcsg324 -1 with Minimum period of 6.860ns (Maximum Frequency145.773MHz) Minimum input arrival time before clock 2.552ns Maximum output required time after clock0.877ns Maximum combinational path delay 0.733ns,Delay 6.860nsTotal memory usage is 354432 kilobytes and it can process 74 full HD (1920x1080) images per second in the worst case on an FPGA implemented in 130 nm CMOS technology. It has more than 13%energy consumption than adaptive median filter algorithm compared with 2D gaussian blur on the same FPGA.

The Gaussian blur is used to reduce noise in images 2-Dimensional gaussian kernel equation is used for gaussian blur which is square array of pixels where pixel values corresponds to value of gaussian curve. The lager the curve the more expensive the operation will become. So larger the radius of blur, longer the operation will take. convolution can be done by multiplying each input pixel with entire kernel. However, the kernel is symmetrical which you can also multiply each ‘x’ &’y’ axis independently which can decrease number of multiplications.

The Gaussian smoothing operator is a 2-Dimensional convolution operator that is used to `blur' images and remove detail and noise. In this sense it is similar to the mean filter, but it uses a different kernel that represents the shape of a Gaussian (`bell-shaped') hump. This kernel has some special properties which are detailed below.

The Gaussian distribution in 1-Dimensional has the form which is applied for gaussian blur algorithm in the equation-1 given below.

$$G(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} \quad (1)$$

where σ is the standard deviation of the distribution. We have also assumed that the distribution has a mean of zero (*i.e.* it is centred on the line *x*=0). The distribution is illustrated in Figure 2.

In 2-Dimensional, an isotropic (*i.e.* circularly symmetric) Gaussian has the form which is used for 2-D images by the equation-2 given below.

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (2)$$

This distribution is shown in Figure 2.

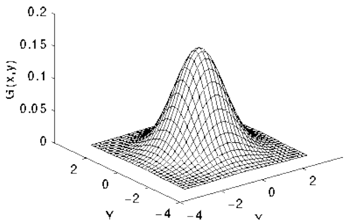


Figure 2 2-D Gaussian distribution with mean (0,0) and σ =1

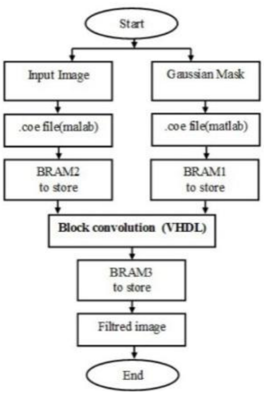
Gaussian mask is applied for Gaussian filter one of the most important and widely used filtering algorithms in image processing. where G is the Gaussian mask at the location with coordinates x and y, sigma is the parameter which defines the standard deviation of the Gaussian. If the value is large, the image smoothing effect will be higher.

Convolution operation is performed in image processing domain. The process of convolution is given below and equation is used for performing the operation is given in equation-3.

$$f(x,y) = \sum_{i=0}^{h-1} \sum_{j=0}^{w-1} G(i,j) I(x-i, y-j) \quad (3)$$

Figure 3. Example image of Gaussian filter

Block diagram of image filtering Figure 3 illustrates the block diagram of image filtering. First, the input image and the Gaussian mask are read and saved by MATLAB. Next, these values are converted into a vector in a text file extension *.coe using the MATLAB tool and loaded the text file in block RAM (BRAM). The text file of Gaussian mask and image is stored respectively in BRAM1 and BRAM2. After that, the convolution operation is affected between these pixel values of two BRAM (1 & 2) using VHDL tool and saving the obtain results in another block (BRAM3). Finally, the text file of BRAM3 is converted by MATLAB tool in order to display the results form an image



The proposed 2D adaptive image sharpening hardware can work at 194.288 MHz, and it can process 105 full HD (1920x1080) images per second in the worst case on an FPGA implemented in 130 nm CMOS technology.Minimum period5.147ns (Maximum Frequency 194.288MHz) Minimum input arrival time before clock 2.345ns Maximum output required time after clock 0.877ns. Maximum combinational path delay of 0.670ns,delay 5.147ns, Offset 0.877ns. Total memory usage is 256576 kilobytes. It has total area consumption of11% less than gaussian blur on the same FPGA.

This example shows how to implement a front-end module of an image processing design. This front-end module removes noise and sharpens the image to provide a better initial condition for the subsequent processing.

An object out of focus results in a blurred image. Dead or stuck pixels on the camera or video sensor, or thermal noise from hardware components, contribute to the noise in the image. In this example, the front-end module is implemented using two pixel-stream filter blocks from the Vision HDL Toolbox™. The median filter removes the noise and the image filter sharpens the image. The example compares the pixel-stream results with those generated by the full-frame blocks from the Computer Vision System Toolbox™.

This example model provides a hardware-compatible algorithm. You can implement this algorithm on a board using a Xilinx ISE 14.7, XC7A100TCSG324-1 Artix-7 FPGA.

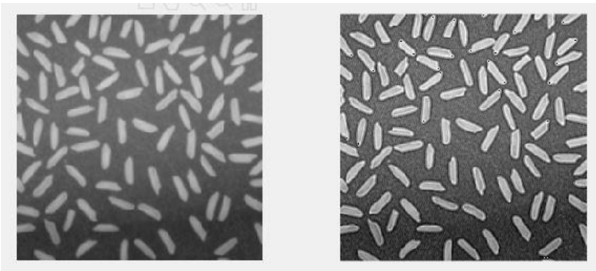


Figure.4 Example of Image Sharpening

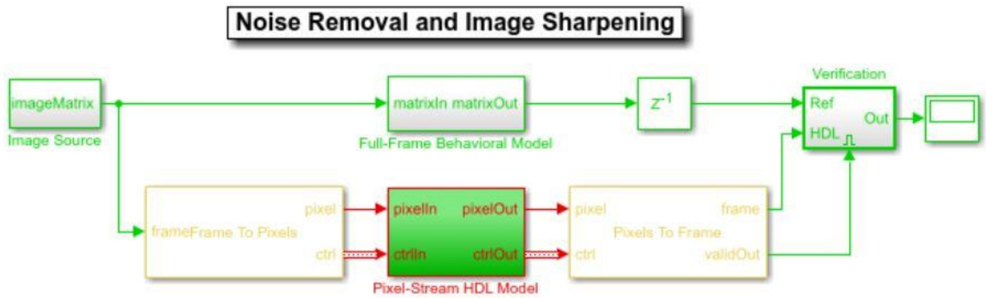


Figure-5 Noise removal using MATLAB to HDL model

Several median filter algorithms are proposed in theliterature [7]-[9]. These algorithms can be classified into twogroups. Median filter algorithms proposed in [7], [8] optimizesorting process to reduce computational complexity of medianfilter algorithm without reducing quality of filtered images.Median filter algorithms proposed in [9] increase qualityof filtered images without increasing computationalcomplexity of median filter algorithm. These algorithms try todetect noisy pixels and adaptively filter only these noisypixels. However, the 2D adaptive DIP algorithm proposed inthis paper both reduces computational complexity of medianfilter algorithm and increases quality of filtered images byexploiting pixel correlations in input image.

Several median filter hardware are proposed in the literature[10]-[14]. In [10], an adaptive median filter hardware thatdetects noisy pixels in several iterations and filters only thesenoisy pixels are proposed. The proposed median filter hardwareuses different sorting algorithms like bitonic and odd-evenmerge sort [11].1-D median filter is used for finding out the median values either in row wise or column wise[12]. The proposed median filter hardware only findscorrect positions of input pixels in the sliding window insteadof sorting all pixels in the window. In [13], a histogram basedmedian filter algorithm is proposed. It only performs well forlarge window sizes. In [14], low complexity bit-pipelinealgorithm is proposed to decrease hardware area and increaseperformance.

Several gaussian blur algorithms are proposed in theliterature [15], [16]. These algorithms increase quality ofoutput image by increasing computational complexity ofgaussian blur algorithm. However, the 2D adaptive DIPalgorithm proposed in this paper reduces computationalcomplexity of gaussian blur algorithm without reducing quality of output image by exploiting pixel correlations ininput image.

Image sharpening is another form of removing the noise from the pixels. Here 2-D image sharpening equations which are used for denoising operation. It helps in enhancing edges and increase the pixels output image quality without making it blur. The input image is first taken in form of matrices and then median filtering operation is performed where all the median values are taken by approximating the kernel applied over the image and then it is given for filtering the high pass filter filters the high frequency image noise from the images and then perform Fourier analysis for it and then inverse fast Fourier transforms are applied to the image. Originally a Laplacian filter is applied over the image for image sharpening.
First order and second order derivatives are given below in equations (4) & (5)

$$\frac{\partial f}{\partial x} = f(x+1) - f(x) \quad (4)$$

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x) \quad (5)$$

III. ADAPTIVE MEDIAN FILTERING ALGORITHM

Adaptive median filter algorithm which is used for performing the denoising operation will take the image in MATLAB domain and then kernel or array of matrix is applied on the image which process the image to remove noise in the matrix of image. For every image there is some contrast, kelvin value and blur value which are represented by salt and pepper noise i.e salt has highest value of 255 & pepper has lowest value of zero which is we call as 0 & 1 in binary. Median values of whole image are calculated and then arranged in lowest to highest order and median value is calculated, each pixel input value noise is removed by using command in MATLAB to control & denoise the operation. Pixels in input image are converted into stream of bits which requires some DSP blocks and memories and input output buffers, flip flops for storing the pixel values. then converted into frame by removing noise from the image free from salt and pepper noise.

In this paper we have calculated the PSNR values of input image and output image to find out how much of noise has been removed the PSNR can be calculated by using MSE value of the image which is given in equation (6) & (7). SSIM is also calculated by taking a image which is taken with row and column of size with same dimension's.Image has to be resized if not in equal dimensions. Here we have calculated the PSNR values for the images taken for median filter for image shown above in Figure.1. PSNR values & SSIM for 2-Dimensional median filter proposed are given in table 1.

Hardware results are calculated as well proposing this algorithm using Verilog HDL. Verilog HDL coder can convert the algorithm-based results from MATLAB domain to VHDL/VERILOG domain followed by test bench file. Hardware results calculated from adaptive median filter algorithm using ARTIX-7 having slice registers of 714,slice LUT's of 715, LUT's-FF pairs 372. Bounded IOB's 30, 2 in number BRAM's/FIFO's, 1 BUFG/BUFG CTRLS.

$$MSE = \frac{1}{M \times N} \sum_{m=1}^{M} \sum_{n=1}^{N} (I_1(m,n) - I_2(m,n))^2 \quad (6)$$

$$PSNR = 10 \log_{10}\left(\frac{255^2}{MSE}\right) \quad (7)$$

Table.1. PSNR & SSIM index values for images

Image	Window size	Original PSNR value	Proposed PSNR value	SSIM index
Pepper	5×5	28.601	17.825	0.3856
Lena	5×5	28.457	18.693	0.3986
zebra	5×5	29.157	19.576	0.4105

IV. 2-D GAUSSIAN BLUR ALGORITHM

Gaussian Blur algorithm proposed in this paper also for removing noise in the image and preserves edges makes the image blur making the image softer by increasing the intermediate value of pixel value closer and closer. It cannot keep the edges sharp but can make edges of image smoothened depends upon the gaussian function value which is called sigma. the more the sigma value is applied over the image the more the blurring occurs. Blurring makes the edges softer and reduces the noise. For 2-D images the 1st order derivative as well as 2nd order derivatives are used for calculating the gaussian value for the image. Gaussian mask is used for the operation of blurring. As well as the sigma value gets high the more smoothing occurs which decreases the PSNR value. PSNR value has to be high around 40dB for a good image.

Previously the image has to be taken and apply the derivative for the image. Performing 2-D kernel is anyway easy but performing 1_D kernels for 2_D image may create partitioned values but take lotof time. The kernel which we apply performs 3×3 size and append zeros all over the kernel and then find the median value for that. The second order derivative as shown below has to be applied for convolution operation. Each kernel will get a value which is replaced by original value in image, same process is applied for the entire image where we gets new value for entire image. In this way the noise of the image is calculated by MSE and PSNR values of images taken in MATLAB. The operation is performed by taking the row vector and column vectors each at a time. MATLAB commands are used for image resizing and adding salt and pepper noise. As usually the pixels of a image are converted into frame, noise is added into the image then again frame of image is converted to pixels which are useful to store in binary format in memories, buffers, flip flops etc. The hardware results obtained are 2352nslice registers,1186 LUT's,1017 LUT-FF's,30IOB's, 06 in number RAM/FIFO,01 in number BUFG/BUFGCTRLS, 11 in number DSP48E1s

Table.2 PSNR values and SSIM values

.

Image	Window size	Original PSNR value	Proposed PSNR value	SSIM index
Pepper	5×5	26.709	34.707	0.9627
Barbara	5×5	26,313	32.678	0.8542
cameraman	5×5	26.434	31.686	0.8125

V. 2-D IMAGE SHARPENING ALGORITHM

sharpening involves the addition of a signal that is proportional to a high- passfiltered version of the originalimage to the original image. The critical factor here is the option of the high pass filtering operation. In the conventional approach linear filters were used to implement the high pass filter. In case of the original image being corrupted with noise the linear approaches may provide us with unexpected and improper results.Digitized images usually face's problem of lack of quality, which includes specifically problem with contrast and occurrence of shading and artefacts which is caused due to the deficiencies in focusing, lighting and various other constraints. Hence the image quality has to be improved using the basic image enhancement techniques. Image enhancement is the processing of an image to bring out specific features explicitly. The available methods for image contrast enhancement concentrates on the features of the image to be processed and eliminating the user characteristics Image sharpening is one of the prominent image enhancement techniques applied in every field where images are ought to be understood and analysed In this paper different approaches of Image sharpening using Unsharp masking(UM) are compared.

These algorithms are analysed with different filtering techniques.The results show that majority of these algorithms are very sensitive to the enhancement factor and can be used for image Sharpening.Image sharpening is one among the image enhancement approach performed on images. In general, the edges and fine details of images should be preserved since they are composed basically by high frequency modules. The chances for these modules to be degraded in case of these high frequency being removed or attenuated is more. Hence, the high frequency modules of an image need to be enhanced in order to improvethe visual quality ofthe image. Image sharpening refers to any enhancement technique that highlights edges and fine details in a image. Image sharpening is widely used in printing and photographic industries for increasing the local contrast and sharpening the images. Image sharpening can be applied in Medical imaging also like in face recognition where public security should be ensured. Hardware results obtained are 999 slice registers, 589 slice-LUT's, 425 LUT-FF pairs.30 bonded IOB's,02 RAM/FIFO,01 BUFG/BUFGCTRLS,03 DSP-48E1s are utilized.

Table-3 PSNR& SSIM values of image sharpening filter

.

Image	Window size	Original PSNR value	Proposed PSNR value	Proposed SSIM index
Rice blurred	5×5	23.715	12.131	0.9627
cameraman	5×5	23.336	12.132	0.8542
Barbara	5×5	24.050	11.250	0.8125

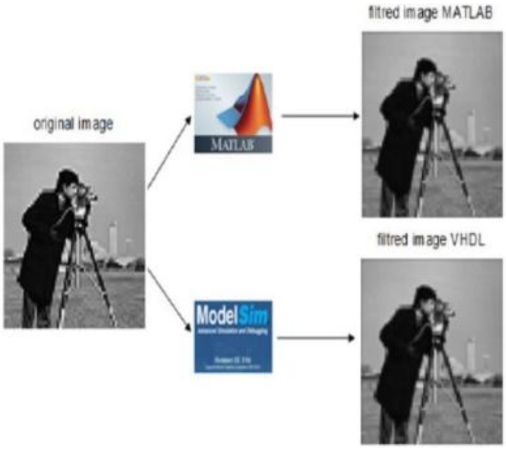


Figure-6MATLAB to HDL code generation for an image

VI. IMAGE ENHANCEMENT TECHNIQUE

Image enhancement technique is process of adjusting digital images so that results are more suitable for display of further image analysis. We can remove noise, sharpen or brighten image making it easier to identify key features. We require image enhancement to improve interpretability or perception of information in image for human viewers or to provide better input for other automated image processing techniques. Frequency domain methods which operate on Fourier transform of image. The process of contrast enhancement or process of producing image of higher contrast than the original by darkening particular levels. Some of useful examples and methods of image enhancement are filtering with morphological operators, histogram equalization, noise removal using wiener filter, linear contrast adjustment using median filter etc.

Figure-7 Example of Input image VS Enhanced image

contrast adjustments remaps intensity values to full display range of data type. An image with good contrast has sharp differences between black and white. The left side image has poor contrast with intensity values limited to middle portion of image. The image on right hand side has higher contrast with intensity values that fill entire range [0,255]. In high contrast image highlights look brighter and shadows look darker. The process of histogram equalization where adjusting the intensity value that involves transforming intensity values so that histogram of output image approximately matches a specified histogram. Several MATLAB commands are used to get an enhanced output image. Image enhancement algorithm can be implemented by HDL coder from MATLAB to Artix-7 XC7a100tcsg-324-1 runs at maximum frequency of 161.486 MHz minimum input arrival time before clock is 3.278ns,maximum output time arrived after clock is 0.936ns, with path delay of 0.556ns & total memory usage of 239936 kilobytes with gate delay of 0.55 which can occupy 54 slice registers, 95 slice LUT's, 40 LUT Flip flop pairs, 44 Bonded IOB's, 01 Block RAM/FIFO,01 number of BUFG/BUFGCTRLs, with total area utilization of 59%.

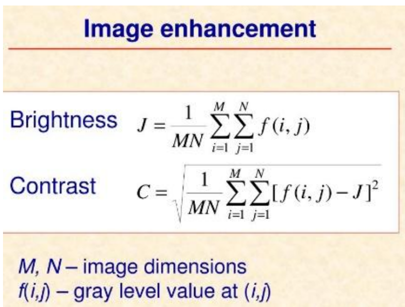


Table.4,5,6. Comparisons of PSNR (dB)for values of Median, Sharpening & Gaussian filters

S.NO	2-D Median filter			
Image	Window Size	Original	Proposed	PSNR in (dB)
pepper	5×5	28.601	17.825	10.776
Lena	5×5	28.457	18.693	9.764
Zebra	5×5	29.157	19.576	9.581

S.NO	2-D Sharpening filter			
Image	Window Size	Original	proposed	PSNR in (dB)
Rice blurred	5×5	23.715	12.131	11.584
Cameraman	5×5	23.336	12.132	11.204
Barbara	5×5	24.050	11.250	12.802

S.NO	2D Gaussian Blur			
Image	Window Size	Original	proposed	PSNR in (dB)
peppers	5×5	26.709	34.707	7.998
Barbara	5×5	26.313	32.678	6.365
Lena	5×5	26.434	31.686	5.252

VII. SYNTHESIS RESULTS OF IMAGE ENHANCEMENT

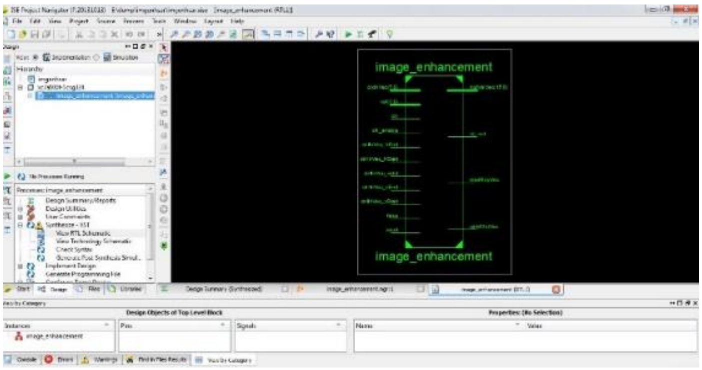


Figure 8.RTL structure of Image Enhancement

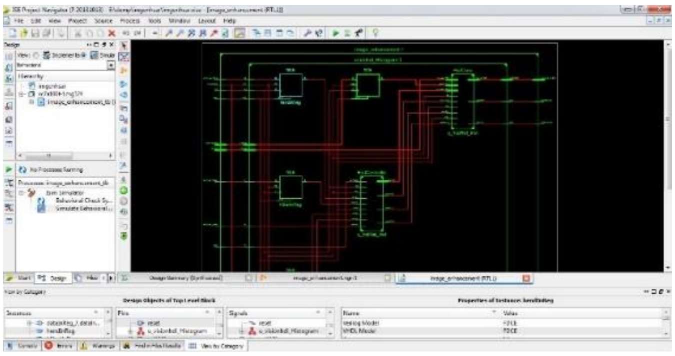


Figure 9. Internal structure of Image Enhancement

VIII. SIMULATION RESULTS OF IMAGE ENHANCEMENT

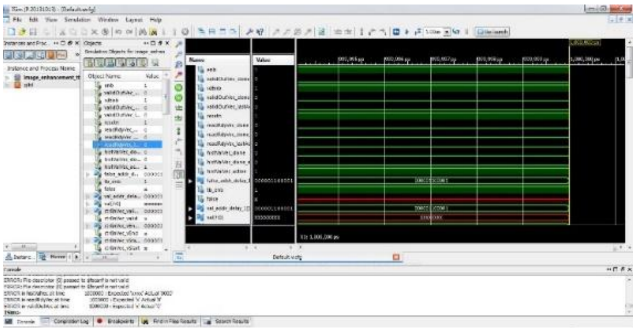


Figure 10. Simulation Results

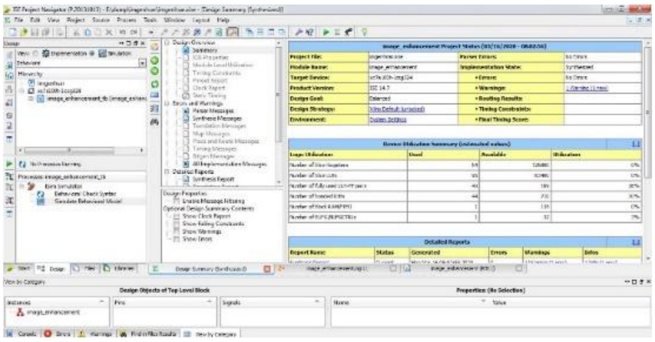


Figure 11. Total Area Report.

IX.HARDWARE IMPLEMENTATION

The synthesis process would also produce a bit stream file that can be downloaded in the FPGA board. The bit stream file of the Programmable Verilog file has been successfully downloaded to diligent FPGAfamily of board after installing necessary drivers on PC. The results has been done by simply interfacing a board Nexys4DDR kit

X.CONCLUSION

In this paper we have compared four different algorithms for image filtering and noise removing by use of various techniques which are useful for image processing applications in medicine, consumer products like cameras, smart phones and other image processing domain applications. The proposed techniques discussed in this paper which are useful in reducing area and frequency. Among them the median filter algorithm which has lowest area utilization when compared to remaining algorithms. All these algorithms have their own behavior's and unique feature of denoising which can exploits the pixel correlation and process the output image without any degradation.

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