FPGA Based Image Enhancement and Noise Removal Using Bilateral Filter

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Abstract: **Image restoration refers to genre of techniques that aim to recover a high quality original image from degraded version of image which is given a specific model for degradation. The common forms of degradation that an image suffers are loss of sharpness and noise. The bilateral filter is a nonlinear filter that smoothens the noise while preserving the edge structure. This novel FPGA design architecture of bilateral filter is described in Register Transfer level (RTL). This feature of kernel based design is supported by input data into groups so that internal clock of the design is a multiple of pixel clock given by a target system.The bilateral filter is implemented by combining these features as highly parallelized pipeline structure. This method is non iterative and simple which combines both grey levels and colours based on their photometric similarity as well as geometric closeness and prefers near by values to distant values in both domain and range. The photometric component and the geometric component has been combined to form photo-geometric filter component which reduces the structural complexity while serving the process.This bilateral filtering operation is coded in VHDL and can be simulated using ModelSim and Matlab.**

***Index Terms*——Bilateral filter, Euclidean distance, Photo-Geometric component, Register matrix.**

I. INTRODUCTION

The bilateral filter is a technique of denoising the images while preserving its edges. It is be traced back to 1995 with the work of Aurich and Weule on nonlinear Gaussian filters. It has been rediscovered later by Smith and Brady in 1997 as part of their SUSAN frame work, and during 1998 Tomasi and Manduchi gave its name as bilateral filters. Since then, the use of bilateral filtering has grown tremendously and is now become ubiquitous in several image processing applications. It has been used in several contexts namely texture editing, denoising and relighting, tone management and optical flow estimation. The bilateral filter has various qualities that explain its acceptance .The filter formulation is simple where each pixel is replaced by an average of its neighbours. This aspect is very crucial as it makes it easy to acquire intuition about its behaviour to adapt it to several application specific requirements. It depends only on two parameters that indicate the contrast and size of the features of image to be preserved.

II. LITERATURE REVIEW

Image processing techniques are widely used in numerous applications namely scanning techniques, medical imaging, Fig. 1. Bilateral Filter with Spacial and Range Components printing skills and so on. The Images are corrupted by noises in the process of image transmission and reception. The noise may seriously affect quality of images and deteriorate its clarity. Thus, an efficient denoising technique becomes very significant in image processing. Image denoising plays the main role in image pre processing. But during denoising, the edges of the image gets blurred. Hence the bilateral filter is preferred because it filters the image as well as preserves the edges. Due to the numerous computations in this filter, the

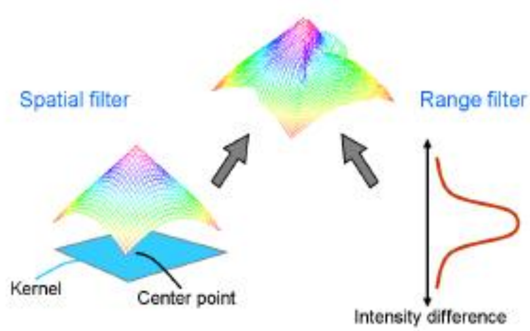

Fig.1 Bilateral Filter with Spacial and Range Components

Real time implementation of this filter is challenging Today, the denoising process are used in several fields of applications so that complexity has been reduced with simple enhancement technique which suitable for VLSI implementation is necessary. The bilateral filters smoothen the images while preserving its edges with nonlinear combination of nearby image values. This method is nonlinear, non iterative, local as well as simple. It combines gray levels or colors based on both their geometric closeness and photometric similarity. It prefers near values over distant values in both domain and range[2]. The fast bilateral filtering is a technique for the displaying high dynamic range images, which can reduce the contrast while preserving details. It is related with two scale decomposition of the image into a base layer which encodes the large scale variations and a detail layer. The base layer alone has its contrast reduced thereby preserving the edges of the image . The base layer is obtained using a bilateral filter . Then the bilateral filtering is accelerated by using a piecewise linear approximation in the intensity domain with appropriate subsampling[3]. The multi dimensional bilateral filtering is computationally expensive due to the presence of adaptive kernel that has to be recomputed at every pixel. The separable implementation offers the capability of equivalent adaptive filtering at a fraction of execution time compared to other traditional filters[4].

III. METHODOLOGY

A. *Bilateral Filter*

The basic idea underlying the bilateral filtering is to do in the range of an image what the traditional filters has done in its domain. The two pixels can be close to one another, that is, it can occupy nearby spatial location, or they can be similar to one another, that is they have nearby pixel values. The bilateral filter represents the idea of combining two filter components namely the domain and range filter components. First stage is register matrix followed by photometric filter and geometric filter. In the design concept, the resources of the bilateral filter are utilized effectively and thus is realized as a highly parallelized pipeline structure. The selected window size is 5x5 which is the tradeoff between low blurring effect and high noise reduction. The bilateral filter is divided mainly into three blocks in order to reduce the complexity.In Fig. 2 ,the input In is used for reading the input data in line by line manner and the input data is given to register matrix. The next stage of bilateral filter is the photometric component. The purpose of this filter is that the input data is weighted based on the intensity of the processed pixels. The last stage in the bilateral filter is the geometric filter. The photometric coefficients are processed by the geometric filter and it has the property of symmetry and separability of filter component that reduces the complexity of the design. The Out is used to represent filtered data of the image processed by the three stages of the bilateral filter.

The denoising method adopts the kernel based design and expensive exponential calculations in bilateral filter can be eliminated by the effective usage of lookup tables. The coefficients are based on Gaussian function with desired variance are precalculated and stored in lookup tables which are later invoked when needed. In fact, all the coefficients are floating points which lie between 0 and 1. But all values are being converted into integer numbers inorder to improve the operating speed.

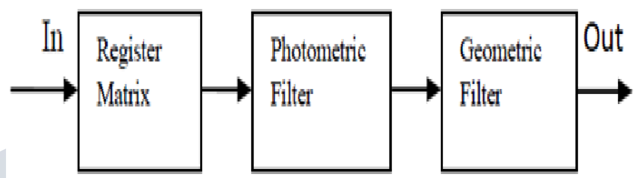

Fig.2 Block Diagram of Basic Bilateral Filter.

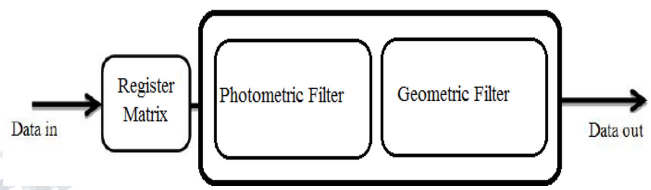

Fig. 3. Block Diagram of Modified Bilateral Filter

The pixel elements in kernel are grouped by considering the Euclidean distance between each pixel and the center pixel. This novel method of grouping will increase the speed and enhance the performance of the multiple grouping operation in a single pixel clock cycle. In order to improve the denoising capability of the bilateral filter, a conditional average filter is being incorporated into it before being applying the photometric component. The center pixel of the kernel is then replaced by the average value of the neighboring pixels when required. The desired condition is that, if the value of the center pixel of the kernel varies from the neighboring pixels by a certain amount, then the conditional average filter is being called. These the modifications produce an innovative bilateral filter with better result in noise removal in images without any compromise in the speed.

In the design of Modified Bilateral Filter shown in Fig. 3, the Euclidean distance is being used for the purpose of pixel grouping in the register matrix rather than taking horizontal and vertical distances from the central pixel. This grouping technique enables the minimisation the chip area of the whole FPGA architecture. Later the photometric filter component and the geometric filter component are amalgamated to form a single unit. In these filter components, the coefficients are then restored in the form of look up tables. The cofficients are multiplied with the image pixels in the proceeding steps. Thus there are two kinds of coefficients stored in two separate divisions. In order to reduce the complexity in the structure, these coefficients are precalculated separately and are multiplied together. Later the product is scaled by a factor of 255 followed by stored them into a specified unit which is called as the photo geometric filter component.

B. *Modified Register Matrix*

The photometric filter component can be also referred as a range filter in the context is a nonlinear filter. This implies that for every filter position, the filter coefficients also changes.

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

GROUP 0	8	12	14	18
GROUP 1	7	9	17	19
GROUP 2	3	11	15	23
GROUP 3	6	10	16	20
GROUP 4	2	4	22	24
GROUP 5	1	5	21	25

Fig.4 Pixel Grouping in Modified Register Matrix

Thus, in the filter window, the pixel weights for the photometric component has to be calculated separately for each and every pixel. The number of weights depends on the window size of the filter. Here, 24 weights have to be computed for the filtering of a single image pixel. Initially the filter window is shifted along the input lines representing the image rows, moving one row down every time the precedent row has been filtered. As a result, the importance of this type of filtering technique is that at least five lines have to be stored for the period of time during which a single line is filtered. The window size is a compromise between high noise reduction as well as low blurring effect. The old grouping has pitfall that it is required to have two separate parts for geometric filter component namely horizontal part and vertical part. Unless the Euclidean distance replaces the criterion for grouping up pixels at the register matrix level, there is no need to separate the geometric filter component into two and combine both photometric and geometric filter. All group elements must have same distance from the central pixel so geometric components are same.

This noval grouping technique contributes an idea for area reduction in FPGA architecture. The Photo-Geometric Filter merely the combination of both photometric filter component and geometric filter component. The photometric as well sa geometric filter coeffients are precalculated and multiplied together which is further scaled and stored in lookup tables of photo-geometric filter component. Further the grouped pixels from the register matrix are processed. Initially the absolute differences of the pixels with respect to the central pixel are found out using the comparator. These differences are then provided to the lookup tables as addresses for fetching the stored coefficients. Finally these differences and fetched coefficients are multiplied together .The grouped pixels and coefficients from the Photo-Geometric Filter are added separately in the Adder Tree.

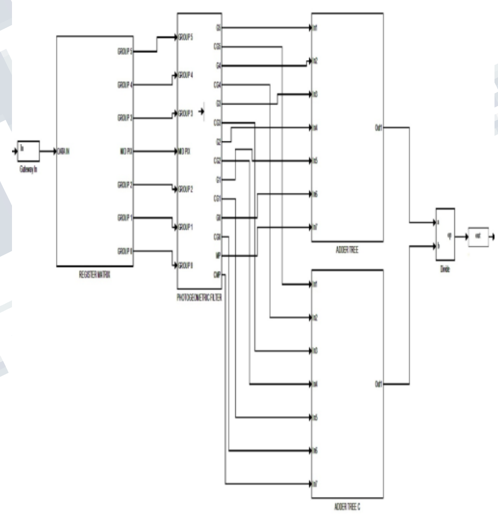

Fig.5 Structure of Modified Bilateral Filter.

The kernal result constitutes the added sum of grouped pixels. On the other hand, norm result comprises of the sum of coefficients.At the final stage, the kernel result has to be normalized by dividing the kernal result by norm result so as to form the filtered pixel.

IV. EXPERIMENTAL RESULTS

The Photo-Geometric module has been modelled and simulated using Verilog in ModelSim SE 6.5 Design. A sample image was filtered by Matlab implementation with the aid of Bilateral filter equation and images were compared with those with modified photo-geometric filter component. Simulation of basic bilateral filter done in Matlab 2014a has obtained PSNR value as 28.2590 and SSIMvalue as 0.8753

Simulation of Modified bilateral filter Simulation of modified bilateral filter done in Matlab 2014a has obtained PSNR value 22.7364 and SSIMvalue as 0.8430.
The simulation results are follows.

- ***Simulation of Basic Bilateral filter***
- ***Simulation of Modified Bilateral filter***
- ***Simulation of Photo-Geometric section***

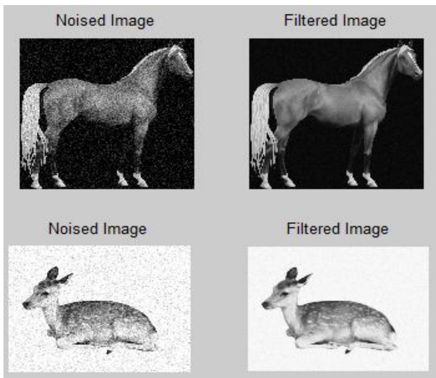

Fig. 6. Simulation of Basic Bilateral filter

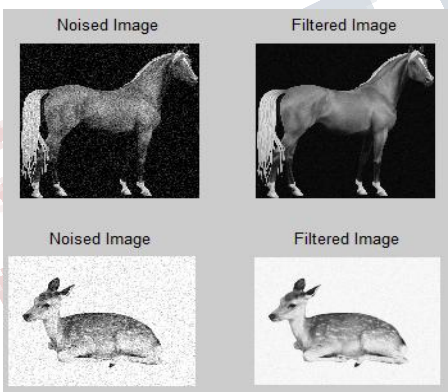

Fig. 7. Simulation of Modified bilateral filter

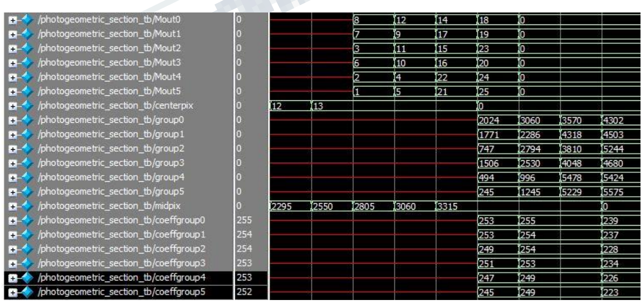

Fig. 8. Simulation of PhotoGeometric Section.

IV. CONCLUSION

The grouping of pixels in register matrix can be done by employing the Euclidean distance rather than taking the horizontal and vertical distances from the central pixel. This grouping technique provides an idea for reducing the area of whole FPGA architecture. Later the photometric filter component and geometric filter component are combined into a single unit. In these filter components, the coefficients must be stored in the look up tables. They are multiplied with the image pixels in subsequent steps. Thus there are two kinds of coefficients stored in separate sections. While reducing the structure ,the coefficients are precalculated separately and are multiplied together which is then scaled by factor of 255 and are stored in a single unit. This section can be named as the photo-geometric filter unit which reduced overall design complexity. The design of basic bilateral filter has been successfully compiled in Matlab. Then the idea of photo-geometric unit has been implemented by coding a prototype design in Matlab. The variances of the photometric filter component and the geometric component have been taken as 60 and 1 respectively for the testing purpose. This could denoise the noisy images with Gaussian noise of variance 0.01.

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