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Diamond Mask Improved Sobel Edge Detector based on FPGA

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Abstract: ***This paper describes a new improved sobel edge detection method which can process images with improved performance. We have applied Diamond masking method on sobel kernel and gradients are processed horizontal and vertical wise where negative values are made absolute. Performance wise it shows better with respect to Sobel conventional and other industrial application. In our experiment we use 5×5 mask which represents 4 to 5 fold accuracy compared to other techniques also the processing time could be within the acceptance level. The Proposed architecture is implemented on FPGA devices and comparison results shows improvement of 3 to 5 fold of conventional.***

Keywords: Edge detection, Sobel operator, diamond mask, absolute value, FPGA.

1. Introduction

In imaging science, image processing is any form of signal processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques to it. Modern digital technology has made it possible to manipulate multi-dimensional signals with systems that range from simple digital circuits to advanced parallel computers. The goal of this manipulation can be divided into three categories:

- Image Processing (image in -> image out)
- Image Analysis (image in -> measurements out)
- Image Understanding (image in -> high-level description out)

Edge detection is the name for a set of mathematical methods which aim at identifying points in a digital image at which the image brightness changes sharply or, more formally, has discontinuities. The points at which image brightness changes sharply are typically organized into a set of curved line segments termed *edges*. The same problem of finding discontinuities in 1D signals is known as step detection and the problem of finding signal discontinuities over time is known as change detection. Edge detection is a fundamental tool in image processing, machine vision and computer vision, particularly in the areas of feature detection examples of operators such as Canny, Sobel, Kayyali, etc. and feature extraction. Our proposed architecture is an optimization novel architecture. The Sobel instance is the basic building block of the Sobel processor and it is able to produce one output pixel. The instances are connected in a way that form one big combinational Sobel block that will exploit FPGA parallelism and I/O capabilities. The processor is multiplier free that avoids multiplication by one and replaces the multiplication by two with a shifting operation. Hence, the processor based only on simple additions, subtractions, shift registers and modulus operators.

2. Edge Detection Based On Sobel Operator

Standard Sobel operators, for a 3×3 neighborhood, each simple central gradient estimate is vector sum of a pair of orthogonal vectors. Each orthogonal vector is a directional derivative estimate multiplied by a unit vector specifying the derivative's direction. The vector sum of these simple gradient estimates amounts to a vector sum of the 8 directional derivative vectors. Thus a point on Cartesian grid and its eight neighboring density values as shown:

In the directional derivative estimate vector *G* was defined such as density difference /distance to neighbor. This vector is determined such that the direction of *G* will be given by the unit vector to the approximate neighbor. Note that, the neighbors group into antipodal pairs: (a,i), (b,h), (c,g), (f,d). Here, this vector is multiplied by 2 because of replacing the divide by 2. The resultant formula of the operator consists of a pair of 3×3 convolution masks as shown in Figure 1. One mask is simply the other rotated by 90°. These masks are designed to respond maximally to edges running vertically and horizontally relative to the pixel grid, one mask for each of the two perpendicular orientations.

In theory at least, the operator consists of a pair of 3×3convolution kernels as shown in Figure 1. One kernel is simply the other rotated by 90°. This is very similar to the Roberts Cross operator.

-1	0	+1
-2	0	+2
-1	0	+1

Gx

+1	+2	+1
0	0	0
-1	-2	-1

Gy

Figure 1: Sobel convolution kernels of order 3×3.

These kernels are designed to respond maximally to edges running vertically and horizontally relative to the pixel grid, one kernel for each of the two perpendicular orientations. The kernels can be applied separately to the input image, to produce separate measurements of the gradient component in each orientation (call these *Gx* and*Gy*). These can then be combined together to find the absolute magnitude of the gradient at each point and the orientation of that gradient. The gradient magnitude is given by:

$$|G| = \sqrt{Gx^2 + Gy^2}$$

Typically, an approximate magnitude is computed using:

$$|G| = |Gx| + |Gy|$$

which is much faster to compute.

3. Implementation of 5×5 Sobel Mask

To implement the enhanced version we remove the unwanted pixels from the given data before finding the edges of the Image. Noise can be removed by using Gaussian filter. In Gaussian Filter a suitable mask is chosen and convolved with image. Mask must be smaller than image size because larger the size of the mask can reduce the noise sensitivity of the detector. Localization error can also increase by increasing mask size.

Standard Sobel operators, for a 5×5 neighborhood, each simple central gradient estimate is vector sum of a pair of orthogonal vectors. Each orthogonal vector is a directional derivative estimate multiplied by a unit vector specifying the derivative’s direction. The vector sum of these simple gradient estimates amounts to a vector sum of the 25 directional derivative vectors. Thus a point on Cartesian grid and its 25 neighboring density values.

Here proposed algorithm first calculates Horizontal Gradient and Vertical Gradient by using of proposed Horizontal and Vertical mask. Input image is applied and image is convert into number of 5X5 matrix, then it will convolved with Horizontal mask and generates the vector directional derivates, in same way the vertical mask is applied to generate Vertical gradient.
The main assumption of masking is made by considering the concept of inter pixel correlation. The pixel values in an image are very close to each other and the variation is almost equal to one. Instead of processing the entire pixel in 5×5 kernels, a suitable mask is applied as a filter which passes horizontal and vertical pixels as shown in below figure.

Proposed Horizontal Mask

$$Gx = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Figure 2: Horizontal mask of order 5×5

Proposed Vertical Mask

$$Gy = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Figure 3: Vertical mask of order 5×5

Overall 5×5 mask is following Diamond Structure

$$Gx + Gy = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Figure 4: Filter mask kernel for Sobel operator

Gx1=Absolute (Gx)
Gy1=Absolute (Gy)
Sobel Edge Pixel = Gx1+Gy1

Generated filter mask consists of few values which are to be processed which results in fast computation and low area and power consumption at architectural level. The new filter mask consists of negative and positive values. By applying absolute on the result values and summing up them generates the same conventional function with reduces complexity.

During first stage the proposed method is implemented on MATLAB to thoroughly investigate the required time to detect edges with in an object and compare output image with various parameters.

4. FPGA Hardware Implementation

The figure shows 4x4 parallel Sobel instances connected and are able to produce sixteen 8-bit output pixels at once. In fig, each four vertical, consecutive instances are considered as a row. Fig details the connection of the first and second rows of the Sobel instances. The thick black vertical connection lines indicate computation results reuse within the same row. And the thicker black horizontal connection lines indicate computation data reuse from previous rows. The number of Sobel instances rows can be increased as needed and is limited by the available FPGA resources.

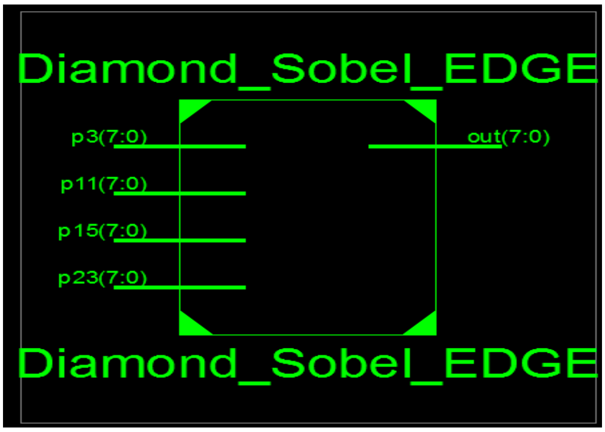


Figure: Block diagram Representation

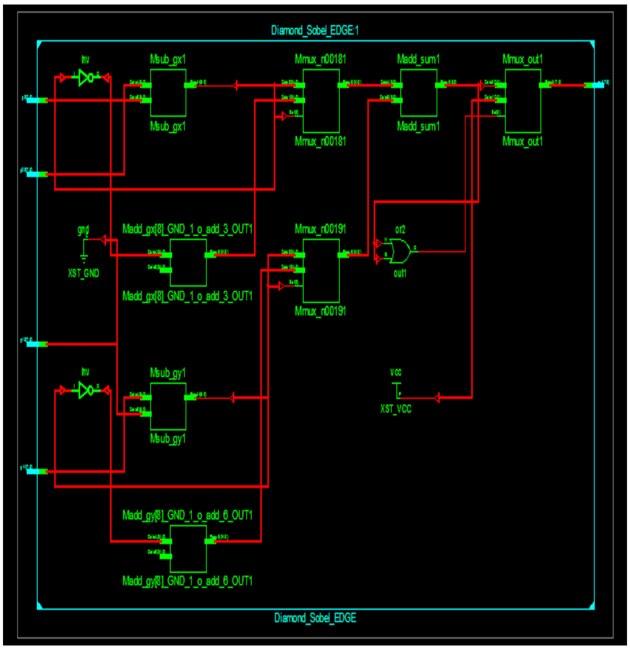


Figure: Internal representation of Block Diagram

5. Parameter Comparison

Various parameters are used to evaluate the proposed algorithm. The various parameters are

1. PSNR (Peak Signal-To-Noise Ratio)
2. SSIM(Structural-Similarity-Based Image Quality Assessment)
3. FSIM (Feature Similarity Index for Image Quality Assessment)

DIGITAL images are subject to a wide variety of distortions during acquisition, processing, compression, storage, transmission and reproduction, any of which may result in a degradation of visual quality. For applications in which images are ultimately to be viewed by human beings, the only "correct" method of quantifying visual image quality is through subjective evaluation. In practice, however, subjective evaluation is usually too inconvenient, time-consuming and expensive.

1. PSNR (Peak signal-to-noise ratio)

Peak signal-to-noise ratio, often abbreviated PSNR, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale. PSNR is most commonly used to measure the quality of reconstruction of lossy compression codecs (e.g., for image compression). The signal in this case is the original data, and the noise is the error introduced by compression. When comparing compression codecs, PSNR is an *approximation* to human perception of reconstruction quality. Although a higher PSNR generally indicates that the reconstruction is of higher quality, in some cases it may not. One has to be extremely careful with the range of validity of this metric; it is only conclusively valid when it is used to compare results from the same codec (or codec type) and same content. PSNR is most easily defined via the mean squared error (*MSE*). Given a noise-free $m \times n$ monochrome image I and its noisy approximation K, *MSE* is defined as:

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

The PSNR is defined as

$$\begin{aligned} PSNR &= 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \\ &= 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right) \\ &= 20 \cdot \log_{10}(MAX_I) - 10 \cdot \log_{10}(MSE) \end{aligned}$$

2. SSIM (Structural-Similarity-Based Image Quality Assessment)

Natural image signals are highly structured: their pixels exhibit strong dependencies, especially when they are spatially proximate, and these dependencies carry important information about the structure of the objects in the visual scene. The Minkowski error metric is based on point wise signal differences, which are independent of the underlying signal structure. Although most quality measures based on error sensitivity decompose image signals using linear transformations, these do not remove the strong dependencies, as discussed in the previous section. The motivation of our new approach is to find a more direct way to compare the structures of the reference and the distorted signals.

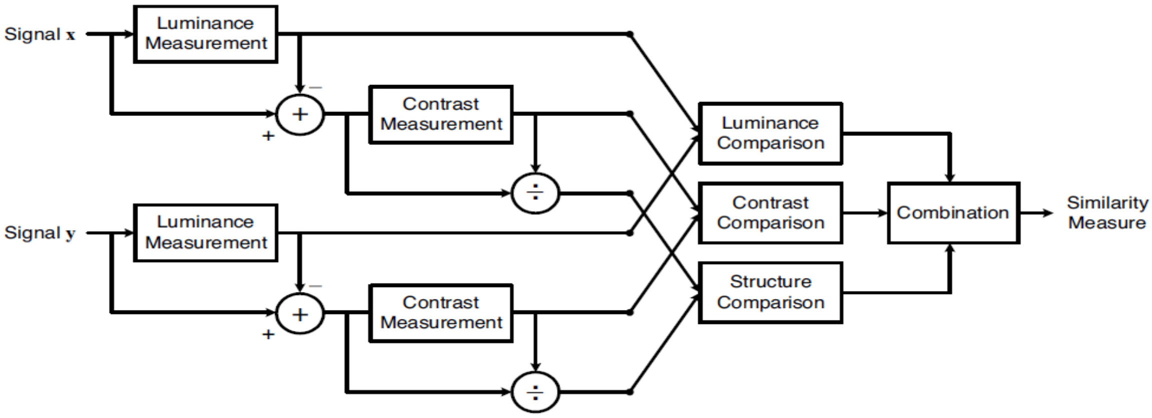


Figure 1: Diagram of the structural similarity (SSIM) measurement system.

$$\mathrm{SSIM}(\mathbf{x},\mathbf{y}) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)},$$

3. FSIM (Feature Similarity Index for Image Quality Assessment)

The computation of FSIM index consists of two stages. In the first stage, the local similarity map is computed, and then in the second stage, pools the similarity map into a single similarity score. The separation of the feature similarity measurement between $f1(\mathbf{x})$ and $f2(\mathbf{x})$ into two components, each for PC or GM. First, the similarity measure for $PC1(\mathbf{x})$ and $PC2(\mathbf{x})$ is defined as

$$\mathrm{FSIM} = \frac{\sum_{\mathbf{x}\in\Omega} S_L(\mathbf{x}) \cdot PC_m(\mathbf{x})}{\sum_{\mathbf{x}\in\Omega} PC_m(\mathbf{x})}$$

Where

$$S_G(\mathbf{x}) = \frac{2G_1(\mathbf{x}) \cdot G_2(\mathbf{x}) + T_2}{G_1^2(\mathbf{x}) + G_2^2(\mathbf{x}) + T_2}$$

$$S_{PC}(\mathbf{x}) = \frac{2PC_1(\mathbf{x}) \cdot PC_2(\mathbf{x}) + T_1}{PC_1^2(\mathbf{x}) + PC_2^2(\mathbf{x}) + T_1}$$

$$S_L(\mathbf{x}) = [S_{PC}(\mathbf{x})]^\alpha \cdot [S_G(\mathbf{x})]^\beta$$

where Ω means the whole image spatial domain.

6. Result Analysis

Standard Test images (Baboon,Barbara, AirPlane) are used for study of proposed approach and different parameters are used for calculation of quality of proposed approach with existing approaches that are 3X3 Sobel Accurate approach and 3X3 Sobel Absolute approach. Here Peak Signal to Noise Ratio (PSNR), Structural Similarity Index Metric (SSIM) and Absolute Percentage Similarity is used. PSNR is ratio between the maximum possible power of a signal and the power of corrupting noise, Structural similarity (SSIM) index is based on similarities of local luminance, contrast, and structure between a reference image and a distorted image. I the structural similarity (SSIM) index value is between 0 to 1.

Original Test Images:

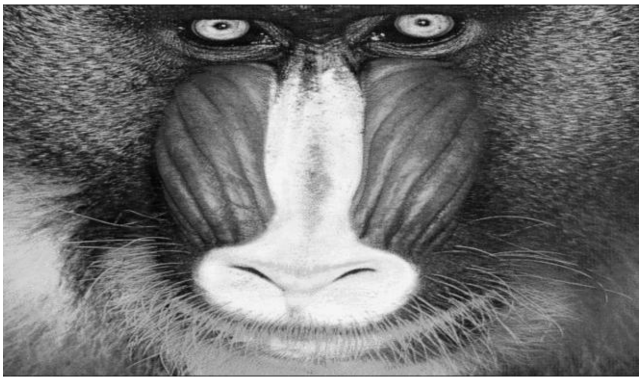


Figure Baboon

Figure Barbara

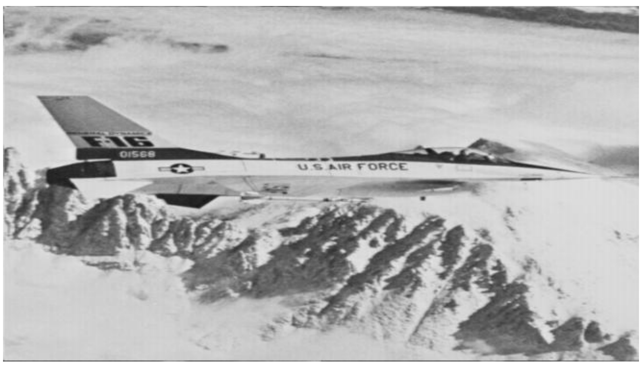
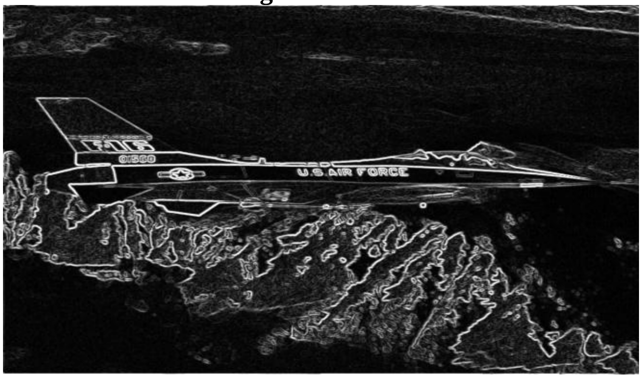
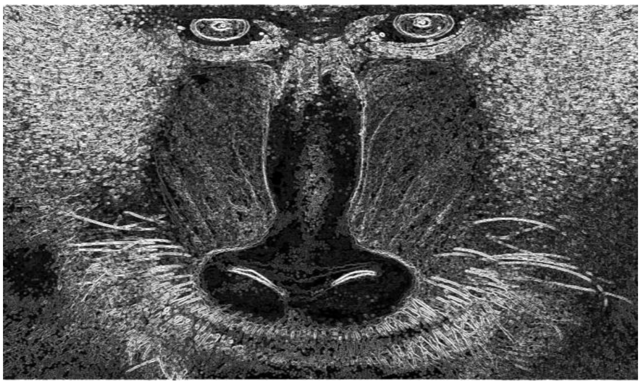


Figure Airpalne

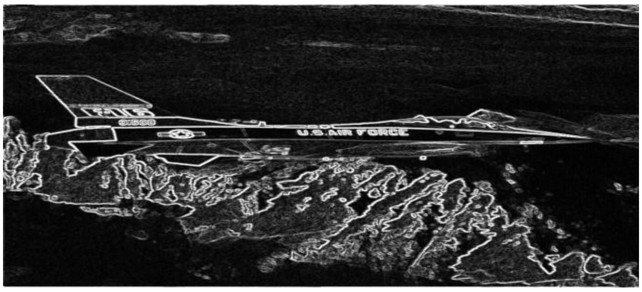
Analysis:

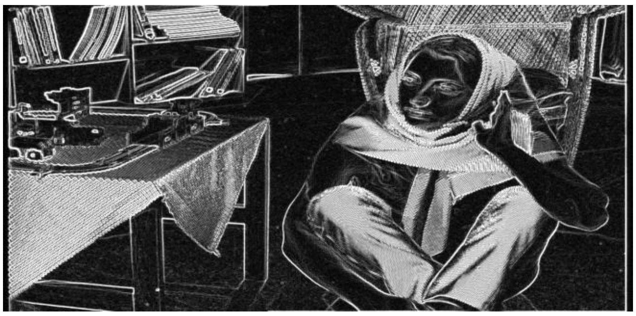
3X3 Accurate Sobel Edge Detection:-





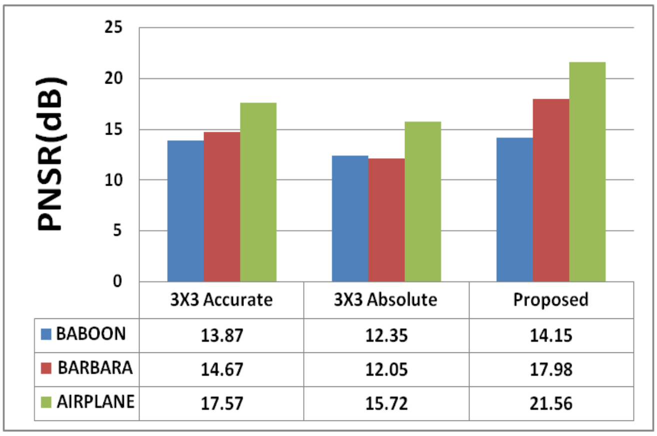
3X3 Absolute Sobel Edge Detection:-



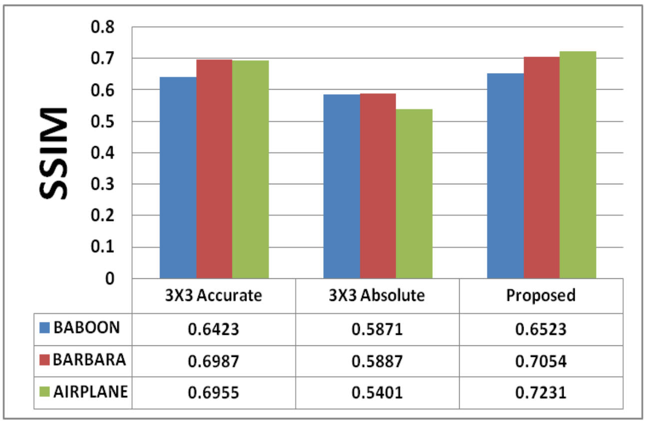


5X5 Proposed Sobel Edge Detection

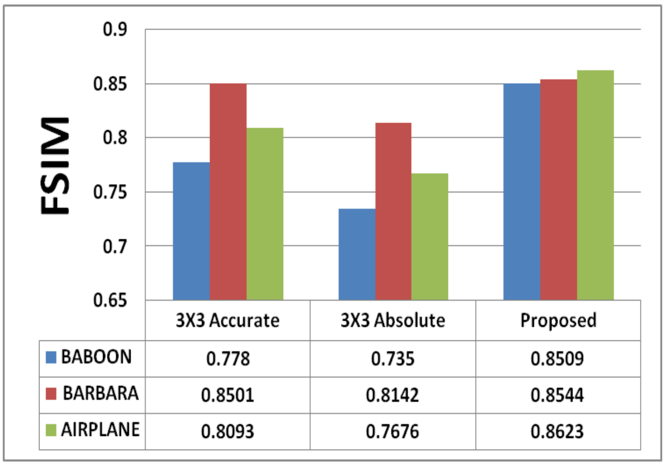
7. Comparative Result of PNSR(dB)



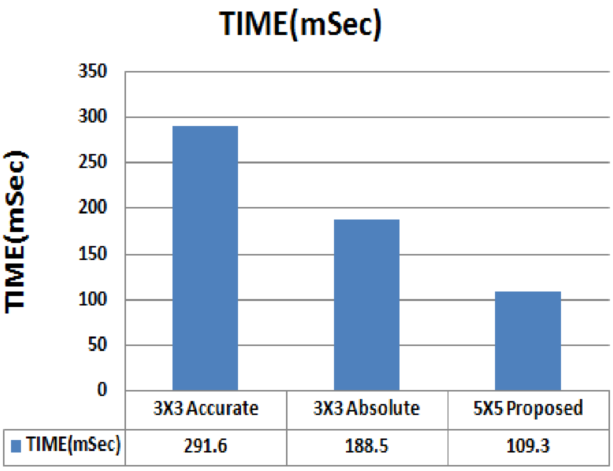
COMPARATIVE RESULT OF SSIM



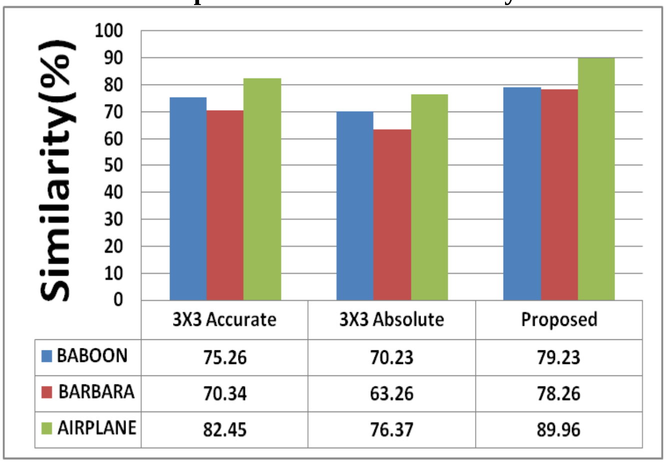
COMPARATIVE RESULT OF FSIM



Comparative Result of Time (m Sec)

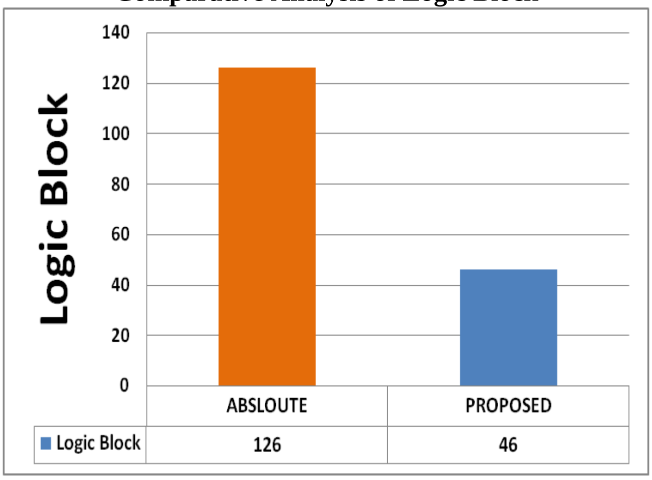


Comparative Result of Similarity

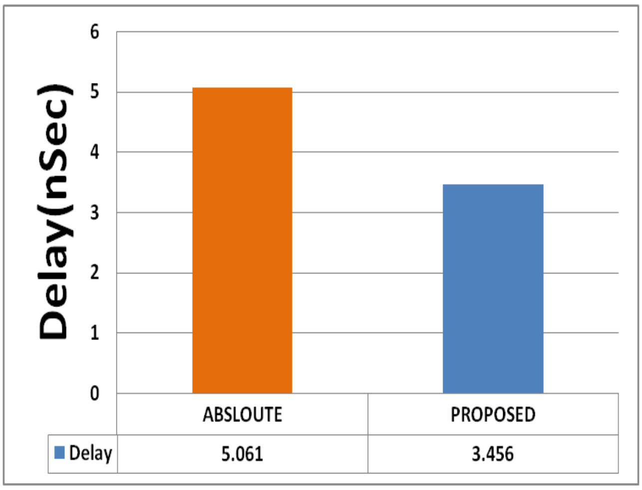


Architecture level FPGA Analysis

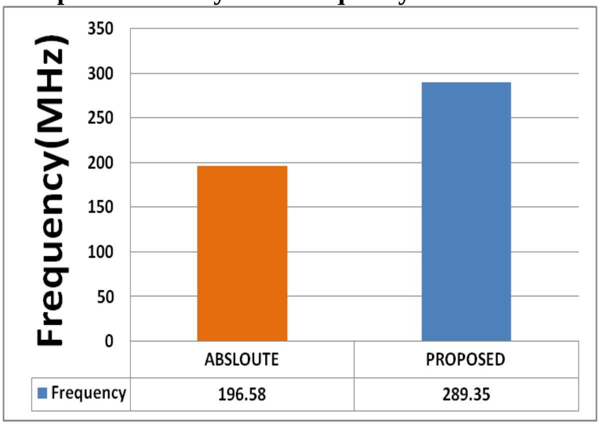
Comparative Analysis of Logic Block



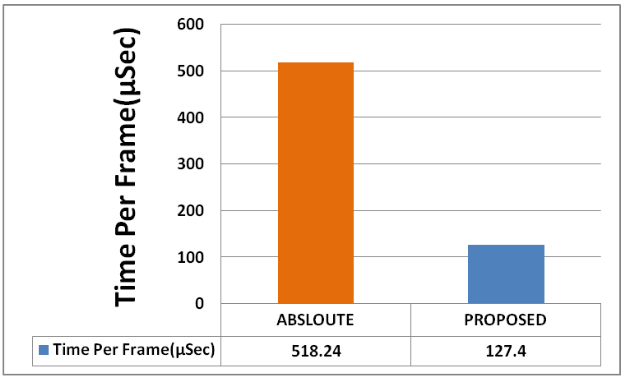
Comparative Analysis of Delay:



Comparative Analysis of Frequency



Comparative Analysis of Time Per Frame



8. Conclusion

The key contribution of this paper is to develop a new improved sobel edge detection method which can process images with improved performance. We have applied Diamond masking method on sobel kernel and gradients are processed horizontal and vertical wise where negative values are made absolute. Performance wise it shows better with respect to Sobel conventional and other industrial application. Our experiment has shown 4 to 5 fold accuracy compared to other techniques. The processing time is within the acceptance level. The various parameter analyses at algorithmic level show an improvement upto 3 times in comparison with conventional.

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