Design of Novel 2D Gaussian Smoothing Filter

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***Abstract*— The complexity of today's design is very high which result in high power and delay in the present devices and it is growing with increasing functionality on the same device. In order to develop energy efficient designs, the complexity of design has to be reduced which is a very challenging task. There are several applications where the approximate results are acceptable such as image/video processing. We can leverage this relaxation on the accuracy to reduce the complexity of the designs. In this paper, we propose a novel 2D Gaussian smoothing filter which provides approximate result at very high speed than the convention Gaussian smoothing filter for these applications. The proposed Novel 2D Gaussian smoothing filter provides improvement in delay, power and area at the cost of small loss in accuracy. Simulation result shows improvement in delay, power and area by 5%, 3.34% and 10.97% respectively, over existing approximate Gaussian smoothing filter.**

***Keywords*—digital signal processing (DSP), Adders, image processing, high-speed integrated circuits, VLSI, low power design.**

I. INTRODUCTION

With the growing development in the VLSI Technology more and more functionality are being implemented on the chip to satisfy user requirement. This increased functionality on the chip result in more complexity and are of the chip. The portable multimedia devices which demands high energy efficiency restrict the use of image/video processing applications [1]. Thus, there is a growing demand of the energy efficient design on the portable devices. The high power consumption within these image/video processing applications is due to large arithmetic operations. Thus, the complexity of these designs can be reduced by reducing the number of operations. In image processing noise signals may introduce during the stages of compression, acquisition, or even transmission. In addition to the noise at image capturing time, noise may occur during transmission and storage. To eliminate the effect of noise signals, we require filters in image/video applications. The noise reductions techniques generally involve local are pixels averaging, and/or generating a blurred or smoothed image, because of this it is also the noise reduction process is sometime called as smoothing process. Smoothing filter is used for blurring [2] and for noise reduction. In order to remove small details from an image prior to object extraction, and bridging of small gaps in line or curves, blurring is used in preprocessing step of image processing..

In edge detection [3], Gaussian smoothing is done prior to Laplacian to remove the effect of noise. Gaussian smoothing is a special case of weighted smoothing [4], where the coefficients of the smoothing kernel are derived from a Gaussian distribution. The Gaussian filter plays a main role in digital image processing tasks such as image blurring, image segmentation, and edge detection.

From above analysis, we found that we should design a novel 2D Gaussian filter that should provide a large range of noise reduction ability into hardware to advance the range of the noise immunity of the hardware-based edge detection algorithm. This is only possible by applying approximation technique into the Gaussian filters.

II. PRINCIPAL OF GAUSSIAN SMOOTHING FILTER

The image smoothing can be accomplished via different types of filters, the most common of which is the Gaussian smoothing filter that we will discussed in this paper. The multi-scale edge detection techniques adopt 2D Gaussian for mainly three most important reasons. The first reason is that when combined with a Laplacian operator, the 2D Gaussian filters are the only filters that do not make fake edges as the scale increase [5]. Further the Gaussian smoothing provides the finest tradeoff between localization in both spatial and frequency domains. And finally Gaussian filters are the only rotationally invariant 2D filters that are separate in the horizontal and the vertical information, which makes the convolution in the spatial domain very efficient.

A 2D Gaussian function with zero mean and standard deviation σ is be described by [6]:

$$g(x, y)=e^{\frac{-(x^2+y^2)}{2\sigma^2}} \qquad (1)$$

Where, the function ideally calculates to non-zero for all values of *x* and *y*.

Let the image with frequency response G(a,b) and Gaussian Kernel with its frequency domain impulse response is T(a,b) produces smooth image K(a,b) by multiplying G(a,b) and T(a,b)

$$K(a, b) = T(a, b) \times G(a, b) \qquad (2)$$

where K(a,b), T(a,b), and G(a,b) are respectively the frequency domain representations of $k(x,y)$, $t(x,y)$, and g(x,y). Similarly the smoothed image in the spatial domain using the convolution expression

$$K(x, y) = t(x, y)*g(x, y) \qquad (3)$$

Impulse response of the 2D GSF g(x, y) must be approximated by a finite number of coefficients, generally known as convolution kernel, or mask for efficient implementation [7]. For the index (x, y) of the center element is set to (0, 0) of a 5×5 mask, and the value of x and y are varied from (-2, -2) to (2, 2). From the definition of Gaussian distribution, the summation of the complete kernel should equal to 1. Therefore, each element must be normalized with reference to this sum of all elements.

$$g_n(x, y) = g(x, y) / N \qquad (4)$$

$$\text{Where} \quad N = \sum_{x=-2}^{2} \sum_{y=-2}^{2} g(x, y)$$

The 5x5 kernel coefficient values shown in Fig. 1 which are derive from equations (1) and (4) by varying x and y from -2 to 2 with slandered deviation (σ) = 1. Further the coefficients are rounded to the 4th decimal point.

$$\begin{pmatrix} 0.0030 & 0.0133 & 0.0219 & 0.0133 & 0.0030 \\ 0.0133 & 0.0596 & 0.0983 & 0.0596 & 0.0133 \\ 0.0219 & 0.0983 & 0.1621 & 0.0983 & 0.0219 \\ 0.0133 & 0.0596 & 0.0983 & 0.0596 & 0.0133 \\ 0.0030 & 0.0133 & 0.0219 & 0.0133 & 0.0030 \end{pmatrix}$$

Fig. 1 5x5 normalized Gaussian kernel coefficients with σ=1

III.FIXED-POINT OPERATION

The fixed-point data is represent in the (l, m) configuration where l indicate the number of bits used, and m indicate the location of the coefficient least significant bit. For example, the decimal equivalent of the coefficient $X_3X_2X_1X_0$ in a (4,-4) format is

$$X_3 * 2^{-1} + X_2 * 2^{-2} + X_1 * 2^{-3} + X_0 * 2^{-4}$$

The Fixed point operation of FIR filters with power of two coefficients. For the Gaussian smoothing filer, each coefficient is round to the nearby value within the available bit-width budget in any case of the number of non-zero coefficients. Due to complexity for avoid difficult multiplication and division operation, the coefficient multiplications are implement by shift and add operations. Where, the multiplication and the division operation which are in powers of two are implemented by right shift and left shift operation.

The Gaussian smoothing kernel [7] coefficients of Fig. 1 are rounded to the (2,-4) data format and are shown in Fig. 2

$$= \frac{1}{2^4} \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 2 & 3 & 2 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Fig. 2 Gaussian kernel with (2,-4) data format

Fig. 3(a) shows a Gaussian smoothing architecture of fig.2 and Fig. 3(b) represent the schematic architecture of Fig.3(a) on TANNER. Where we can see that it requires less number of adders to implement the design. Further the design does not require any other module such as multiplier.

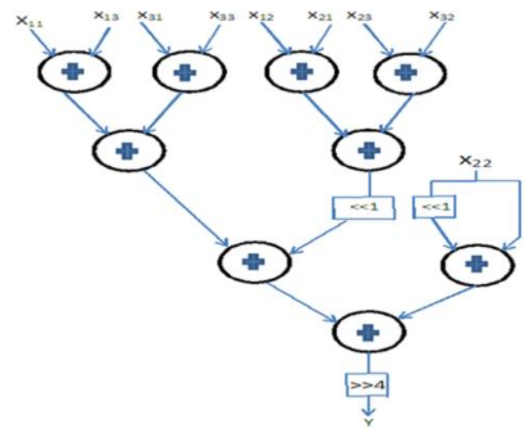

Fig. 3(a) Architecture of Kernel 5x5 with (2,-4) data format

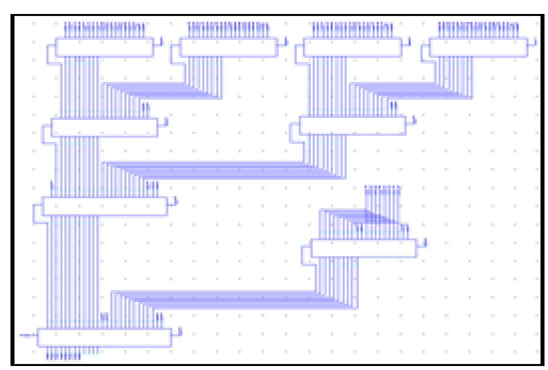

Fig.3(b) Schematic diagram of 5x5 Kernel

IV.PRAPOSED WORK

Prior work on Gaussian smoothing provides various filter but they have limitation of:

1. Large area requirement due to complex kernel coefficients

2. High power and delay requirement

In order to remove these limitations, we represent a novel 2D Gaussian smoothing filter with a small change in kernel coefficient. We can design energy efficient filter compared to conventional design kernel, with small loss in accuracy. It provides tremendous improvement in power, delay and area.

In this paper, we represent a proposed novel 2D Gaussian smoothing kernel of fig. 2. Fig. 4 shows the proposed Gaussian smoothing kernel

$$= \frac{1}{2^4}\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 2 & 4 & 2 & 0 \\ 0 & 1 & 2 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Fig. 4 Proposed approximate Kernel

The architecture of the proposed kernel is shown in fig. 5. It requires less hardware compared to the original design.

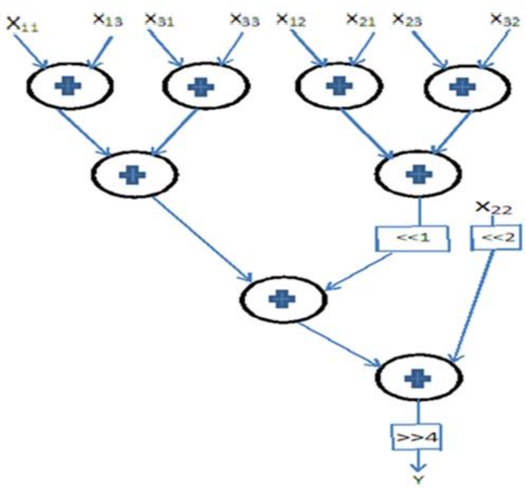

Fig. 5: Proposed GSF architecture of kernel

In order to evaluate all the design metrics we implemented all the above mentioned architectures for the Gaussian smoothing kernels, we utilize the tanner 14.1 EDA tool.

The schematic diagram of full-adder with 28 transistors is shown in Fig. 5(a). We utilize this full adder to design different bit-width ripple carry adder (RCA) and it schematic diagram is shown in Fig. 5(b). These adders of different bit-width are used to design the architecture of the proposed filter as shown in Fig. 5(c).

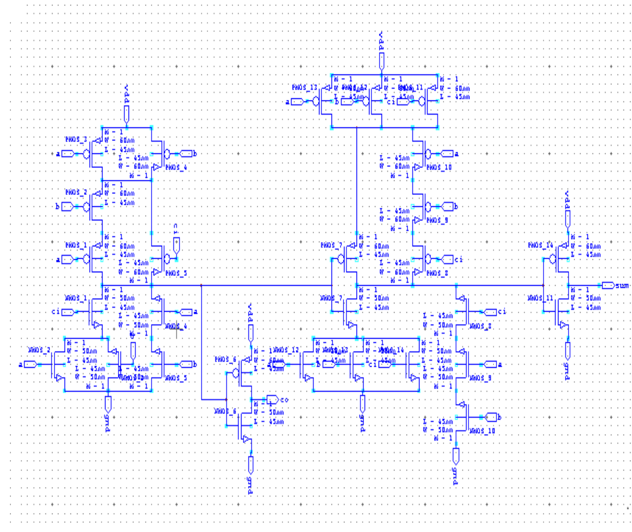

Fig. 5(a) Schematic 28T diagram of Full Adder

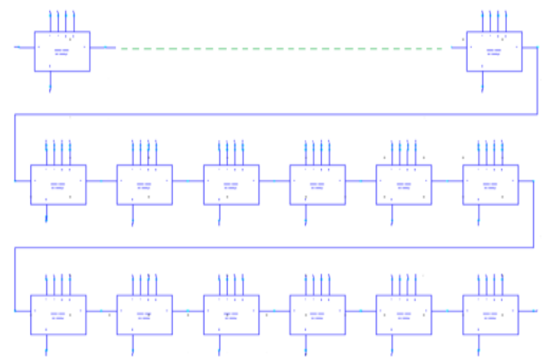

Fig. 5(b) Schematic of Ripple Carry Adder

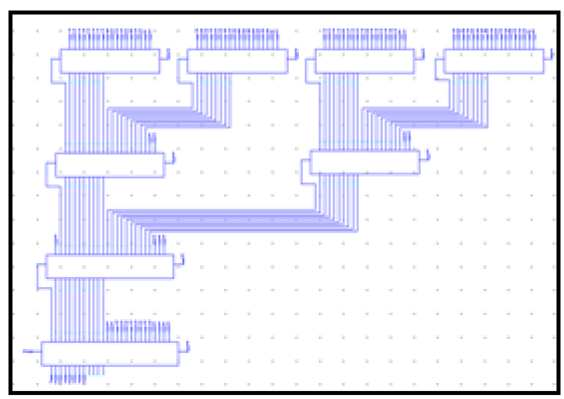

Fig. 5(c) Schematic diagram of fig. 5

Furthermore, all the designs are modelled on the MATLAB to evaluate the error metrics. Lena (512x512) noisy image is filter via filter reported in [7] and via proposed GSF.

V. EXPERIMENTAL RESULT & ANALYSIS

This section first provides design metrics and then error metrics to evaluate the proposed design.

Design Metrics: In order to estimate the design metrics the proposed Gaussian smoothing filter is implemented on the tanner 14.1 and simulated with 45nm technology file. To have fair comparison transistor sizing are taken identical with same power supply for the proposed and reference design.

Table I: Comparison of design metrics

Design	**Area (#MOSFET)**	**Power (µw)**	**Delay (ns)**
GSF [7]	2296	75.13	0.10
Prop.	2044	72.62	0.095

It can be seen that proposed filter reduces the area, power and delay by 10.97%, 3.34%, and 5% respectively over the GSF reported in the paper [7].

Error Metrics: The error metrics after simulating noisy Lena image is shown in Table 2. Moreover the noisy Lena image after smoothing via GSF reported in [7] and proposed filter is shown in Fig. 5. It can be seen that though the error metrics look poor over conventional but the noise in completely acceptable in the proposed design.

Table II: Error metrics comparison

Design	**Mean Error (µ)**	**MSE**	**PSNR (dB)**	**Std. dev. (σ)**
GSF [7]	1.39	12.91	85.23	3.59
Prop.	2.63	21.54	80.12	4.64

(a) (b)

(c) (d)

Fig. 6 Lena (512x512) images (a) original image, (b) noisy image, (c) filter by GSF [6], and (d) filter by proposed GSF.

VII. CONCLUSION

In this paper, we proposed a novel 2D Gaussian smoothing filter that provides tremendous improvement in power, delay and area with small loss in accuracy. The novel 2D Gaussian smoothing filter provides high the speed by the approximating the kernel coefficient. Comparisons with conventional Gaussian smoothing filters showed that the proposed novel 2D Gaussian smoothing filter performed better than the all conventional Gaussian smoothing filters in both power consumption and speed performance. Novel 2D Gaussian smoothing filter can be utilized in all those applications where there is no exact requirement of accuracy or where ultra low power and high-speed are more important than accuracy. The proposed design is best suited in low power battery operated devices such as mobile and other gadgets.

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