Low-Power Implementation of Sobel Edge Detection Algorithm Using Verilog HDL

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Abstract -Edge detection is a fundamental operation inimage processing, widely used in applications such as object recognition, medical imaging, pattern recognition, and computer vision. It identifies significant intensity changes in an image that correspond to object boundaries and structural details. Among various techniques, the Sobel operator is commonly used due to its simplicity and efficiency in approximating image gradients using horizontal and vertical convolution masks. However, the conventional Sobel method has limitations, including sensitivity to noise, restricted directional detection, and reduced accuracy in capturing fine or diagonal edges.

To address these issues, this project proposes a low-power Sobel Edge-8 detection algorithm implemented using Verilog. The enhanced approach computes gradients in eight different directions, enabling better detection of edges with varying orientations and finer details. The system is designed using Verilog HDL and evaluated through simulation and synthesisusingXilinxVivadoandMATLABR2020a.Results show improved edge detection accuracy with low computational complexity, making the design suitable forreal-time image processing and embedded vision applications due to its high speed, efficiency, reliability, and low power consumption.

Keywords: Sobel**edgedetector**,Vivado,Matlab.

1.INTRODUCTION

Edge detectionisan essentialimage processing technique used to identify object boundaries and structural details in applications like object recognition, medical imaging, and computer vision. The Sobel Edge Detection Algorithm is widely used for its simplicity, but it is sensitive to noise and less effective in detecting fine edges. To overcome these limitations,thisprojectproposesanimprovedSobelalgorithm using VLSI technology, enhancing gradient calculations for better accuracy and noise reduction. Implemented in Verilog HDL on FPGA and validated using Xilinx Vivado and ModelSim, the design achieves faster, more efficient, and reliable performance, making it suitable for real-time image processing applications.

2. LITERATURESURVEY

The reviewed literature highlights advancements insecure image transmission, edge detection, and image processingtechniques,emphasizingbothperformanceand efficiency. The VLSI implementation of the Blowfish algorithm provides a high-speed, low-latency solution for secure image transmission using FPGA-based parallelism and pipelining. In edge detection, simple methods like Sobel and Prewitt are fast but sensitive to noise and less effective forfine details, whereas the Canny edge detector offers superior accuracy, localization, and noise resistance at the cost of highercomputationalcomplexity,establishingabenchmarkin computer vision. In image restoration, studies show that no single algorithm is universally optimal, with methods like Wiener filtering, median filtering, and constrained least squares performing best under specific noise conditions. AdvancedtechniquessuchasStructureTensorAdaptiveTotal Variation (STA-TV), high-order total variation with inverse gradient, and Gaussian-adaptive bilateral filtering enhance denoising while preserving edges by adapting to local image features. Additionally, statistical noise estimation methods improve denoising without prior knowledge of noise characteristics. Overall, these developments improve image quality and processing efficiency, supporting applications in medical imaging, industrial inspection, computer vision, and emerging Industry 5.0 systems that integrate AI, edge computing, and human–machine collaboration.

3. EXISTINGMETHOD

Edge detection is a key technique in Digital Image Processing used to identify sharp changes in image intensity, which often correspond to object boundaries, texture variations, or surface details. It plays an important role in applications such as computer vision, medical imaging, object recognition, and image segmentation. Among various methods, the Sobel Edge Detection Algorithm is widely used because of its simplicity and efficiency. It is a gradient-based approach that approximates the first derivative of image intensity, detecting edges by measuring changes in pixel values in both horizontal and vertical directions.

ThestandardSobelkernelsare:
HorizontalGradientKernel(Gx)
G_x=\begin {bmatrix}-1&0&1\-2&0&2\-1&0&1 \end{bmatrix} ------(5.1)

VerticalGradientKernel(Gy)
G_y=\begin{bmatrix}-1&-2&-1\0&0&0\1&2&1 \end{bmatrix} ------(5.2)

These kernels are applied to the image through a convolution process. The resulting gradients represent the intensity change along the x-axis and y-axis respectively.

Once the gradients are computed, the magnitude of the gradient is calculated to determine the edge strength at each pixel location.

G=sqrt{G_x^2+G_y^2} ---------- (5.3)

In practical implementations,a simplified version isoften used to reduce computational complexity:

[
G=|G_x|+|G_y|
]

Thedirectionoftheedgecanalsobeestimatedusingthe gradient direction:

[
\theta=\tan^{-1}\left(\frac{G_y}{G_x}\right)
]

Pixelswithgradientmagnitudevaluesaboveachosen threshold are classified as edges.

Onperformingconvolution oftheimagematrixwiththehorizontalandverticaldirection templates,wegettheapproximationofdifferenceinthe brightness as the gradients in X and Y directions.

AssumeAasaninputimage,

$$A=\begin{bmatrix}p0 & p1 & p2\\ p3 & p4 & p5\\ p6 & p7 & p8\end{bmatrix} \text{--- (5.4)}$$

UsingtheSobeloperator,wehavethegradientinXandY direction, $G_x$and $G_y$as:

$$G_x=\begin{bmatrix}-1 & 0 & 1\\ -2 & 0 & 2\\ -1 & 0 & 1\end{bmatrix} * A \;\&\; G_y=\begin{bmatrix}-1 & -2 & -1\\ 0 & 0 & 0\\ 1 & 2 & 1\end{bmatrix} * A \text{ --- (5.5)}$$

ToobtainthevalueofG,wemustcalculatethefollowingequation: G = sqrt(G_{x}^2 + G_{y}^2)----------(5.6)

Theequationsrequiredtoapplythetraditional Sobelfilterare:

G_x=(p2−p0)+((p5−p3)<<1)+(p8−p6) ---------- (5.7)

G_y=(p0−p6)+((p1−p7)<<1)+(p2−p8) --- (5.8)

Itisto benoted thatsome elements arenotpresent in the aboveequationsbecausethosearemultipliedto0intheXand Y Sobel matrices.

A) 8-SobelAlgorithm:

For 8-Sobel, the input matrix is of size 5x5, instead of 3x3asinthecaseofSobelandtheelementsofthematrixis from p0 to p24.

$$G_1=\begin{bmatrix}0 & 0 & 0 & 0 & 0\\ -1 & -2 & -4 & -2 & -1\\ 0 & 0 & 0 & 0 & 0\\ 1 & 2 & 4 & 2 & 1\\ 0 & 0 & 0 & 0 & 0\end{bmatrix} \quad G_2=\begin{bmatrix}0 & 0 & 0 & 0 & 0\\ 0 & -2 & -4 & -2 & 0\\ -1 & -4 & 0 & 4 & 1\\ 0 & 2 & 4 & 2 & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}$$

$$G_3=\begin{bmatrix}0 & 0 & 0 & -1 & 0\\ 0 & -2 & -4 & 0 & 1\\ 0 & -4 & 0 & 4 & 0\\ -1 & 0 & 4 & 2 & 0\\ 0 & 1 & 0 & 0 & 0\end{bmatrix} \quad G_4=\begin{bmatrix}0 & 0 & -1 & 0 & 0\\ 0 & -2 & -4 & 2 & 0\\ 0 & -4 & 0 & 4 & 0\\ 0 & -2 & 4 & 2 & 0\\ 0 & 0 & 1 & 0 & 0\end{bmatrix}$$

$$G_5=\begin{bmatrix}0 & -1 & 0 & 1 & 0\\ 0 & -2 & 0 & 2 & 0\\ 0 & -4 & 0 & 4 & 0\\ 0 & -2 & 0 & 2 & 0\\ 0 & -1 & 0 & 1 & 0\end{bmatrix} \quad G_6=\begin{bmatrix}0 & 0 & 1 & 0 & 0\\ 0 & -2 & 4 & 2 & 0\\ 0 & -4 & 0 & 4 & 0\\ 0 & 2 & -4 & 2 & 0\\ 0 & 0 & -1 & 0 & 0\end{bmatrix}$$

$$G_7=\begin{bmatrix}0 & 1 & 0 & 0 & 0\\ -1 & 0 & 4 & 2 & 0\\ 0 & -4 & 0 & 4 & 0\\ 0 & -2 & -4 & 0 & 1\\ 0 & 0 & 0 & -1 & 0\end{bmatrix} \quad G_8=\begin{bmatrix}0 & 0 & 0 & 0 & 0\\ 0 & 2 & 4 & 2 & 0\\ -1 & -4 & 0 & 4 & 1\\ 0 & -2 & -4 & -2 & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}$$

Theequationsrequiredtoapplythe8-Sobelfilterare:

G_1=((p19+p15−p5−p9)+((p16+p18−p8−p6)«1)+((p17−p7) <<2)).---(5.9)

G_2=((p14−p10)+((p16+p18−p6−p8)<<1)+((p13+p17−p11−p7) <<2)).---(5.10)

G_3=((p21+p9−p3−p15)+((p18−p6)<<1)+((p17+p13−p7)<<2)). ---(5.11)

G_4=((p22−p2)+((p18−p6)<<1)+((p13+p17−p7)<<2)).---(5.12)

G_5=((p23+p3−p21−p1)+((p18+p8−p6−p16)<<1)+((p13−p11)< <2)). ---(5.13)

G_6=((p2−p22)+((p16+p18−p6+p8)<<1)+((p13−p17−p11+p7)< <2)). ---(5.14)

G_7=((p1+p19−p5−p23)+((p8−p16)<<1)+((p7+p13−p11−p17)< <2))).---(5.15)

G_8=((p14−p10)+((p16−p18+p6+p8)<<1)+((p13−p17p11+p7)< <2)). ---(5.16)

B)AlgorithmusedtoimplementSobeland8-Sobelusing Verilog:

Thegivenflowchartshowstheimplementationoftraditional Sobelandtheimproved Sobeleightdirections.

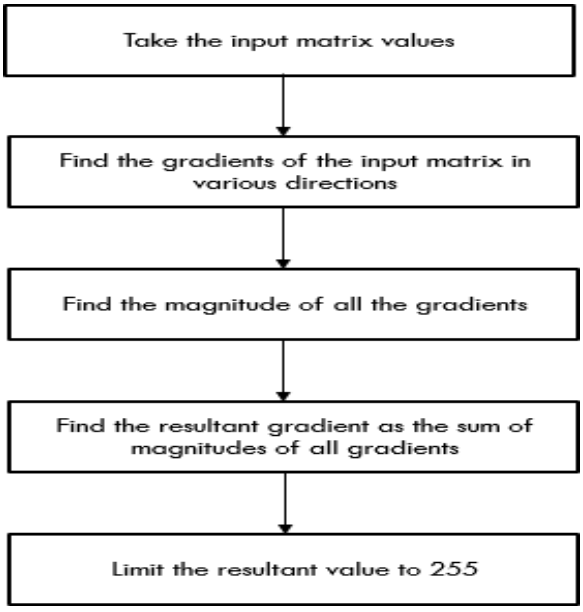

Fig.1:AlgorithmforSobeland8-Sobel.

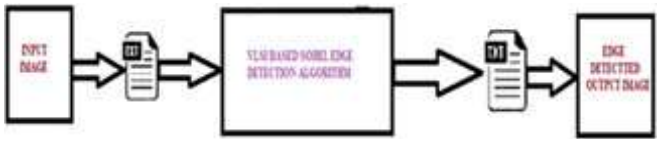

Fig.2:ExistingMethod

The above Fig 2 showsthe workflow of a VLSI-based Sobel edge detection system. The diagram shows a simple process of edge detection. First, an input image is given to the system. It is then processed using the Sobel edge detection algorithm implemented in VLSI. After processing, the system produces an output image where only the edges (boundaries) of objects are highlighted.

Limitations: Sensitivity to Noise,Limited Directional Detection,Thick Edge Output,Poor Performance in Low-Contrast Images,Fixed Kernel Size,Lack of Adaptive Thresholding,Edge Localization Errors.

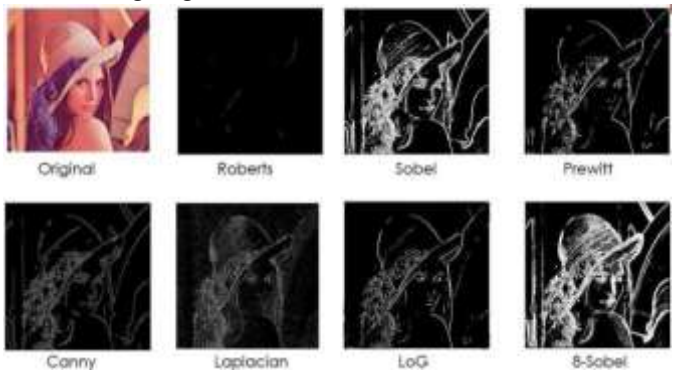

Fig.3:ResultForLennainputimageusingvarious Algorithms.

4. PROPOSEDMETHOD

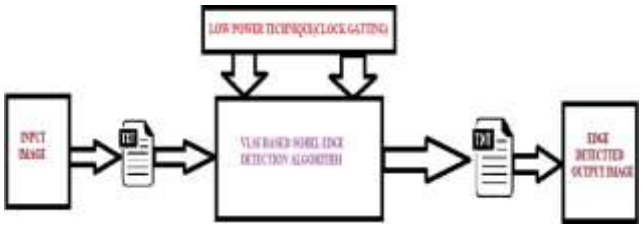

Fig.4:ProposedBlockdesign

The system is designed with scalability, allowing adjustment of image resolution and processing speed through configurable parameters, making it suitable for a wide rangeof devices and performance requirements. It begins with an input image, typically in grayscale, where each pixel representsintensityvaluesusedforedgedetection.Thisimage is converted into a text (.txt) format so that hardware simulation tools can process the numerical pixel data. The converted data is then fed into the VLSI-based Sobel Edge Detection algorithm, which serves as the core processing unit. In this stage, pixel values are analyzed using Sobel convolution masks to compute horizontal and vertical gradients, enabling accurate edge detection through efficient parallel processing in FPGA hardware.

To enhance energy efficiency, a low-power technique called clock gating is implemented, which reduces unnecessary switching activity by disabling inactive circuit components, thereby lowering dynamic power consumption. After processing, the edge-detected pixel values are stored again in a text file and later converted back into an image format. The final output image highlights edges as bright regions while non-edge areas remain darker, clearly revealing objectboundariesandstructuraldetails,anddemonstratingthe effectiveness, speed, and reliability of the hardware-based improved Sobel edge detection system.

A) Comparison Between Existing method andProposed method

Table1:ComparisonTable

METHODS	AREA(LUT'S)	POWER(W)	DELAY(ns)
BASE	38	14.424	15.591
PROPOSED	39	7.693	15.591

5.RESULTS

Fig.5:OriginalInput Image

Fig.6:OutputImage

Fig.7:PowerReportofProposedAlgorithm

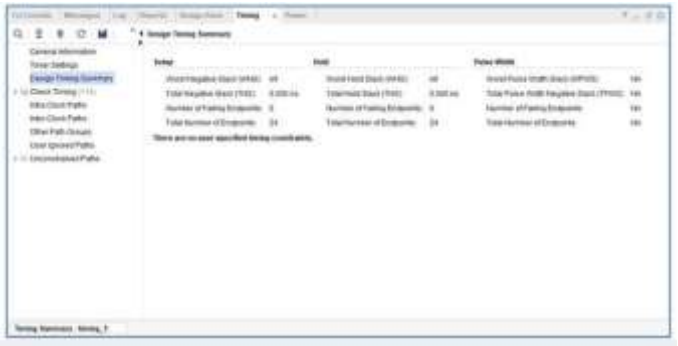

Fig.8:TimeReportofProposedAlgorithm

CONCLUSION

Edge detection is a key technique in imageprocessing for identifying object boundaries and structural details in applications like computer vision and medical imaging. Although the Sobel algorithm is simple and efficient, it is sensitive to noise and lesseffective forfine or diagonal edges. This project proposes an improved Sobel method using VLSI technology, enhancing gradient computation for better accuracy and noise resistance. Implemented in Verilog HDL on FPGA, the design enables high-speed, low-power, andreal-time processing. Simulation results using Xilinx Vivado showimprovededgeclarityandefficiency,makingthesystem areliableandscalablesolutionforadvancedimageprocessing applications.

DICUSSION

The proposed low-power Sobel Edge-8 detection algorithm improves upon the traditional Sobel method by enabling gradient computation in eight directions, allowing better detection of fine and diagonal edges while reducing noise sensitivity. Implemented using Verilog HDL on FPGA and validated with Xilinx Vivado and MATLAB R2020a, the system achieveshighspeed,lowlatency,andefficientparallel processing. The results demonstrate improved accuracy with low computational complexity and power consumption, making it suitable for real-time and embedded image processing applications.

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REFERENCES

1. Canny, J. (1986). A computational approach to edge detection. IEEE Transactions on pattern analysis and machine intelligence, (6), 679-698.
2. Gota,A.,&Min,Z.J.(2013).AnalysisandComparison on Image Restoration Algorithms Using MATLAB. InternationalJournalofEngineeringResearch& Technology(IJERT)Vol,2,1350-1360.
3. Mahalakshmi, A.,& Shanthini, B. (2016, January). A survey on image deblurring. In 2016 International Conference on Computer Communication and Informatics (ICCCI) (pp. 1-5). IEEE.
4. Flusser, J., Farokhi, S., Hoschl, C., Suk, T., Zitov ¨ a,B., ´ & Pedone, M. (2015). Recognition of images degraded by Gaussian blur. IEEE transactions on Image Processing, 25(2), 790-806.
5. Ramya, S.,&Christial, T. M. (2011, March).Restoration of blurred images using Blind Deconvolution Algorithm. In 2011 International Conference on Emerging Trends in Electrical and Computer Technology (pp. 496-499). IEEE.
6. Sada, M. M., & Mahesh, M. G. (2018). Image deblurring techniques—a detail review. Int. J. Sci. Res. Sci. Eng. Technol, 4(2), 15.
7. Ansari, M. A., Kurchaniya, D., & Dixit, M. (2017). A comprehensive analysis of image edge detection techniques. International Journal of Multimedia and Ubiquitous Engineering, 12(11), 1-12.
8. Syahrian, N. M., Risma, P., & Dewi, T. (2017). Vision-based pipe monitoring robot for crack detection using canny edge detection method as an image processing technique. Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control, 243- 250.
9. Jain, S., & Goswami, M. S. (2015). A comparativestudy of various image restoration techniques with different types of blur. International Journal OfResearch In Computer Applications And Robotics.
10. Yadav, S., Jain, C., &Chugh, A. (2016). Evaluation of image deblurring techniques. International Journal of Computer Applications, 139(12), 32- 36.
11. Verma, R., & Ali, J. (2013). A comparative study of varioustypesofimagenoiseandefficientnoiseremoval techniques. International Journal of advanced researchin computer science and software engineering, 3(10).
12. Sekehravani,E.A.,Babulak,E.,&Masoodi,M.(2020). Implementing canny edge detection algorithm for noisy image. Bulletin of Electrical Engineering and Informatics, 9(4), 1404-1410.
13. Saini, S., Kasliwal, B., & Bhatia, S. (2013). Comparative study of image edge detection algorithms. arXiv preprint arXiv:1311.4963
14. (Jan. 2021). European Commission, Industry 5.0: Towards a Sustainable, Human-Centric and Resilient European Industry. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/468a892a-5097-11eb-b59f-01aa75ed71a1/
15. P. K. R. Maddikunta, Q.-V. Pham, B. Prabadevi, N. Deepa, and K. Dev, ‘‘Industry 5.0: A survey onenabling technologies and potential applications,’’ J. Ind. Inf. Integr., vol. 26, pp. 1–31, Mar. 2022, doi: 10.1016/j.jii.2021.100257.