Enhanced Fast Fourier transform Using Approximate Radix 8 Booth Multiplier

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INTRODUCTION

The Fast Fourier Transform (FFT) is an efficient algorithm to calculate the Discrete Fourier Transform (DFT), which is often employed in Digital Signal Processing (DSP) and communication. Fourier Analysis converts a signal from its origin domain to frequency domain. Fourier transform has a wide range of applications. But calculating it directly from the the definition is very slow. FFT reduces the complexity of computing Discrete Fourier transform from $O(N^2)$to $O(NlogN)$ where N is the data size. The difference in speed can be enormous, especially for long data sets where *N* may be in the thousands or millions. The applications often do not require precision but demands high speed computation. In such cases multiplications in FFT can be accelerated with approximate computing using probabilistic radix 8 booth multiplier. The proposed architecture is to be implemented in FPGA and the performance is to be demonstrated using image filtering in frequency domain.

OVERALL OBJECTIVES

Approximate computing is a concept applied to error-tolerant applications in which the accuracy of an operation is reduced to improve other measures of circuit performance.Accuracy are typically acceptable in applications such as digital signal processing, image processing, data mining, and pattern recognition Use of approximate circuits allow for improvements in performance measures such as power, area, delay. The objectives include:

1. To design approximate booth multiplier with improved speed and reduced area

2. Enhance the speed in Fast Fourier Transform using the Approximate Booth Multiplier designed

3. Improved image filtering using Enhanced Fast Fourier transform and Approximate radix-8 Booth multiplier.

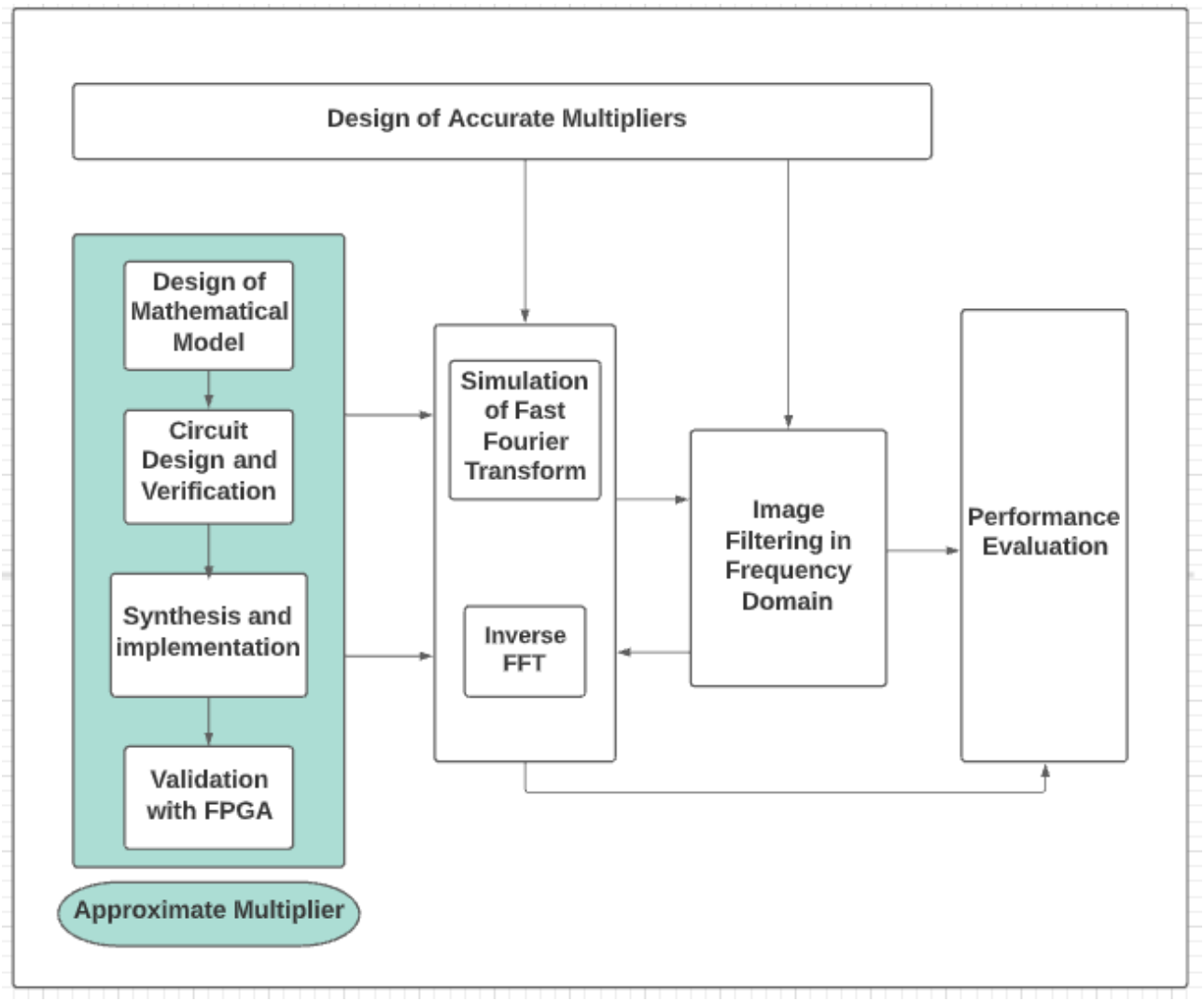
LITERATURE SURVEY

Y. C. Lim, "Single-precision multiplier with reduced circuit complexity for signal processing applications," in IEEE Transactions on Computers, vol. 41, no. 10, pp. 1333-1336, Oct. 1992, doi: 10.1109/12.166611.	**Problem Considered** When two numbers are multiplied, a double-word length product is produced. In applications where only single precision is required, the circuit introduces complexity.
	Proposed Solution The least significant part of the product is not computed exactly. It is only necessary to estimate the carries generated in the computation of the least significant part that will ripple into the most significant part of the product.
	Results Significantly reduced circuit complexity.
	Demerits The estimation of Least significant part is not sufficiently accurate. Correction introduces complexity.
Lan-Da Van, Shuenn-Shyang Wang and Wu-Shiung Feng, "Design of the lower error fixed-width multiplier and its application," in IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing, vol. 47, no. 10, pp. 1112-1118, Oct. 2000, doi: 10.1109/82.877155.	**Problem Considered** Truncation error in existing fixed width multipliers is high
	Proposed Solution A better error compensation bias is derived to reduce truncation error by properly choosing generalised index.
	Results 1. A lower error fixed-width multiplier, for VLSI realisation is constructed. 2. FIR for filter for speech processing is designed using the proposed model. The performance for consonant part is better than that using other fixed-width multipliers.
	Demerits Area requirement was higher
	Problem Considered 1.The post-truncation method wastes computation effort in terms of both computation time and hardware area. 2.Number of partial products to be calculated is high in case of Baugh-Wooley multipliers.

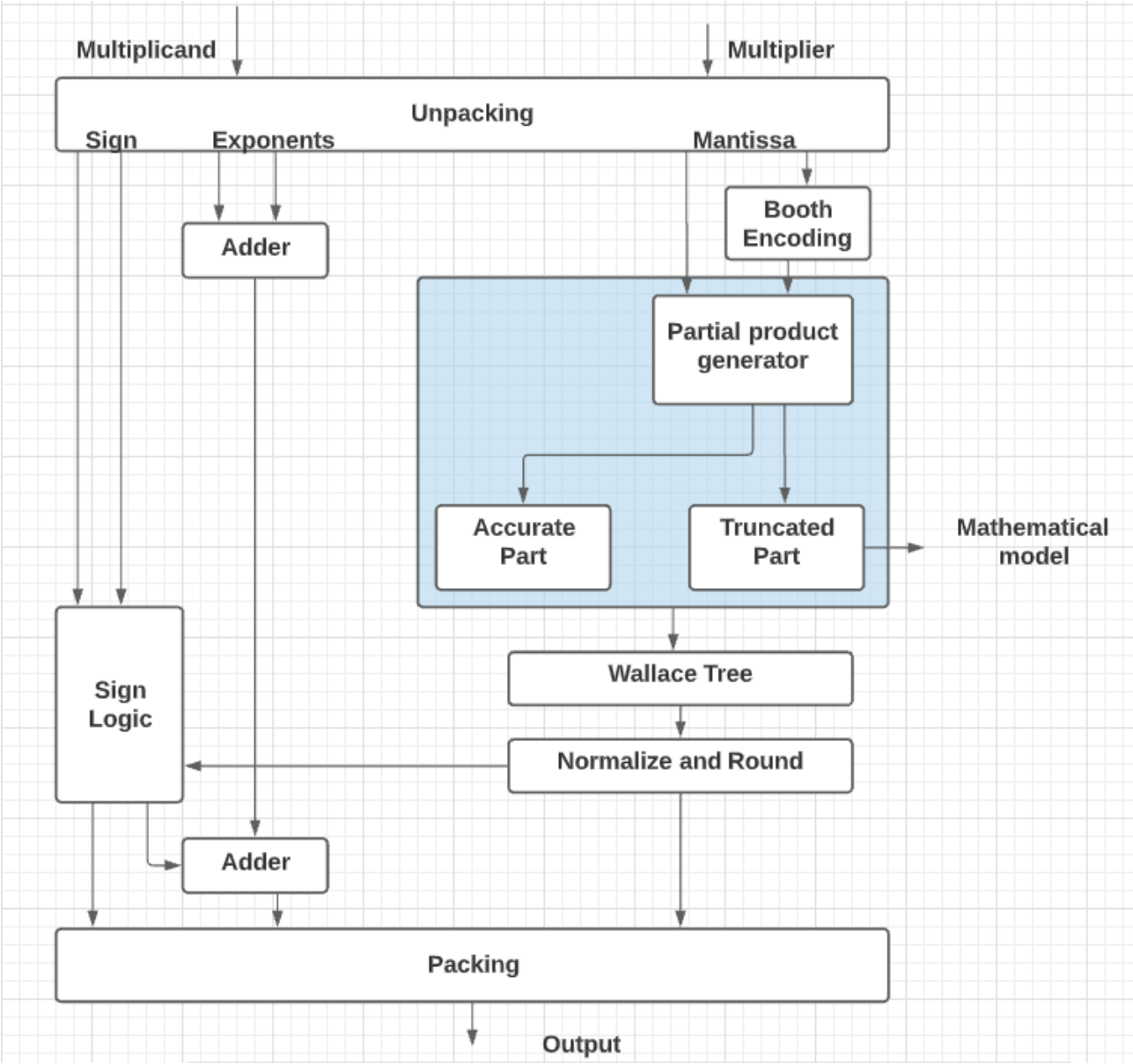
S. -J. Jou, Meng-Hung Tsai and Ya-Lan Tsao, "Low-error reduced-width Booth multipliers for DSP applications," in IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol. 50, no. 11, pp. 1470-1474, Nov. 2003, doi: 10.1109/TCSI.2003.817779.	**Proposed Solution** 1.A faster low-error reduced-width Booth multiplier using appropriate compensation vector is proposed to improve the limited performance of reduced-width array multipliers. 2.The number of partial products on average is reduced.
	Results The proposed reduced-width Booth multiplier has similar error performance as the array multiplier. However the operational speed is much faster
	Demerits The area of the proposed reduced-width Booth multiplier is 1.3 times that of the two's complement reduced-width array multiplier.
J. Wang, S. Kuang and S. Liang, "High-Accuracy Fixed-Width Modified Booth Multipliers for Lossy Applications," in IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 19, no. 1, pp. 52-60, Jan. 2011, doi: 10.1109/TVLSI.2009.2032289.	**Problem Considered** The mean error in truncation is not distributed symmetrically.
	Proposed Solution An effective error compensation function that makes the error distribution more symmetric and centralised in the error equal to zero, leading the fixed-width modified Booth multiplier to very small mean and mean-square errors.
	Results The proposed error compensation circuits offer at least 12.3% and 6.3% reductions in mean-square error over the previous circuits, respectively
J. Liang, J. Han and F. Lombardi, "New Metrics for the Reliability of Approximate and Probabilistic Adders," in IEEE Transactions on Computers, vol. 62, no. 9, pp. 1760-1771, Sept. 2013, doi: 10.1109/TC.2012.146.	**Problem Considered** There has been a lack of appropriate metrics to evaluate the efficacy of various inexact designs.
	Proposed Solution Reliability is analysed using sequential probability transition matrices (SPTMs)
	Results New metrics are proposed for evaluating the reliability as well as the power efficiency of approximate and probabilistic adders
H. Jiang, J. Han, F. Qiao and F. Lombardi, "Approximate Radix-8 Booth Multipliers for	**Problem Considered** Power dissipation in multipliers is high
	Proposed Solution The error detection, compensation and recovery circuits of the approximate multiplier is simplified.

Low-Power and High-Performance Operation," in IEEE Transactions on Computers, vol. 65, no. 8, pp. 2638-2644, 1 Aug. 2016, doi: 10.1109/TC.2015.2493547.	**Results** The proposed design outperforms the other approximate multipliers in the FIR filter operation, thus this design may be useful for low-power and imprecise operations in error-resilient systems.
	Demerits The error due to the recoding adder is more significant than the one caused by truncation
S. Venkatachalam, E. Adams, H. J. Lee and S. Ko, "Design and Analysis of Area and Power Efficient Approximate Booth Multipliers," in IEEE Transactions on Computers, vol. 68, no. 11, pp. 1697-1703, 1 Nov. 2019, doi: 10.1109/TC.2019.2926275.	**Problem Considered** The existing inexact multipliers have fixed accuracy. So the multipliers have to be designed specific to the needs.
	Proposed Solution Multiplication technique is mathematically modelled to allow various levels of approximation and performance trade-offs.
	Results An accuracy-adjustment fixed-width Booth multiplier that compensates the truncation error using a multilevel conditional probability is proposed.
H. Waris, C. Wang, W. Liu and F. Lombardi, "AxBMs: Approximate Radix-8 Booth Multipliers for High-Performance FPGA-Based Accelerators," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 68, no. 5, pp. 1566-1570, May 2021, doi: 10.1109/TCSII.2021.3065333.	**Problem Considered** The focus of existing designs on approximate radix-8 Booth multipliers has been on ASIC-based platforms. So they cannot achieve comparable performance gains when used for FPGA-based hardware accelerators
	Proposed Solution Approximation is implemented such that the 6-input lookup table (LUT) and the associated carry chains of the FPGAs are fully utilised
	Results The proposed multipliers are applied to the application of Sobel edge detection. The proposed solution detected 98.45% edges with energy savings of 26.41%.

FLOW DIAGRAM



ARCHITECTURE DIAGRAM

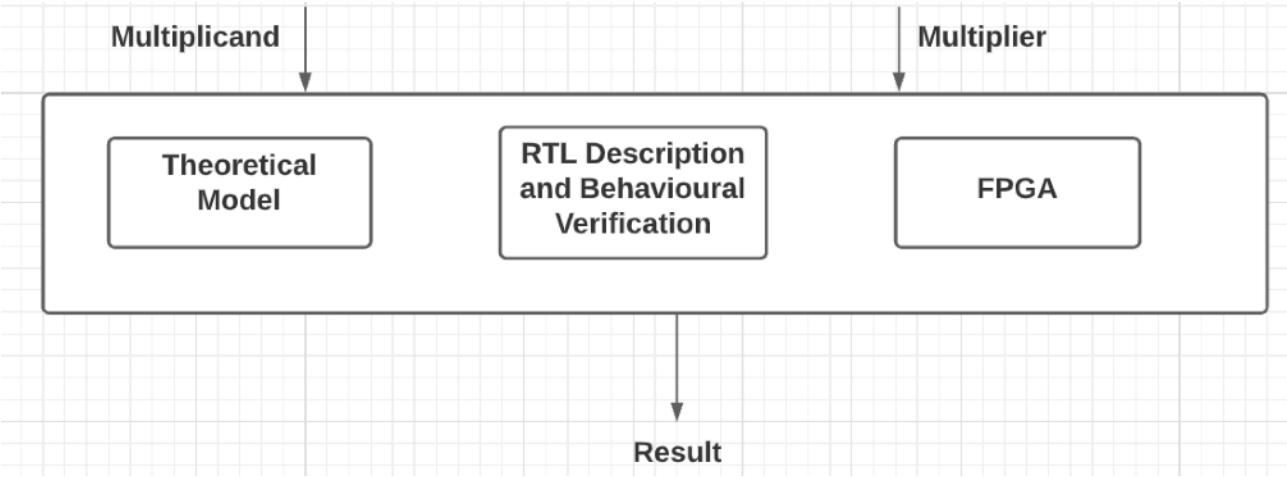


MODULES

I. Design and Analysis of Multipliers
II. FFT using Designed Multipliers
III. Filtering Using FFT

MODULE 1: Design and Analysis of Multipliers

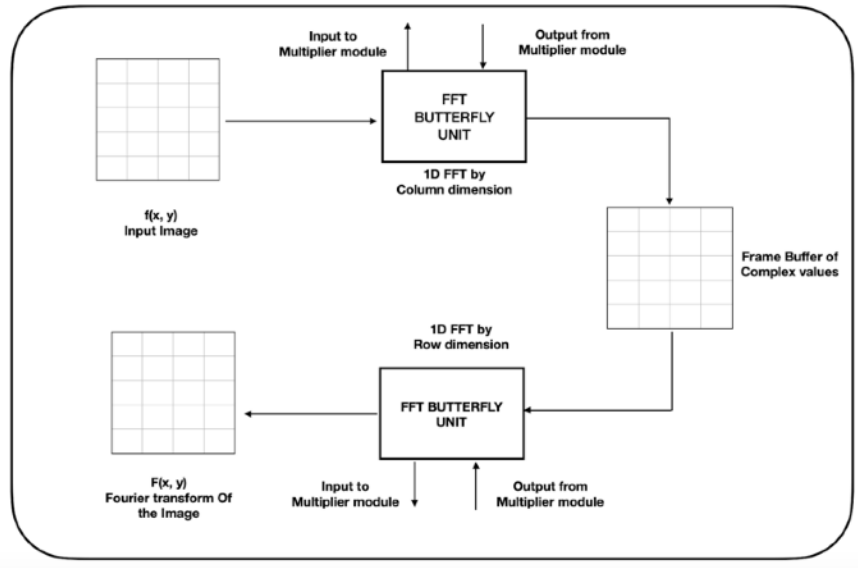
Theoretical modelling of the approximate multiplier architecture using python is done. RTL description of multiplier is carried out using VHDL. It is followed by behavioural simulation and verification of the HDL code. Finally validation is done using FPGA.



INPUT: MULTIPLIER AND MULTIPLICAND
OUTPUT: RESULT

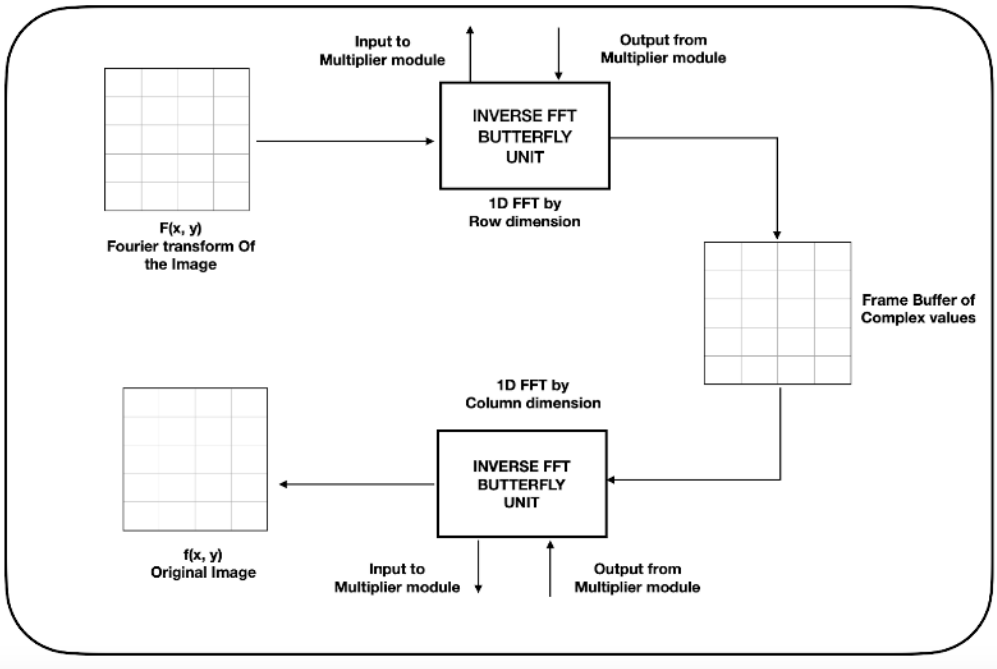
MODULE 2: FFT Using Designed Multipliers

The hardware implementation of parallel FFT is directly mapped from the butterfly scheme. 1D FFT is calculated using butterfly unit along column dimension followed by row dimension to obtain 2D FFT.



FFT Using Approximate Multipliers

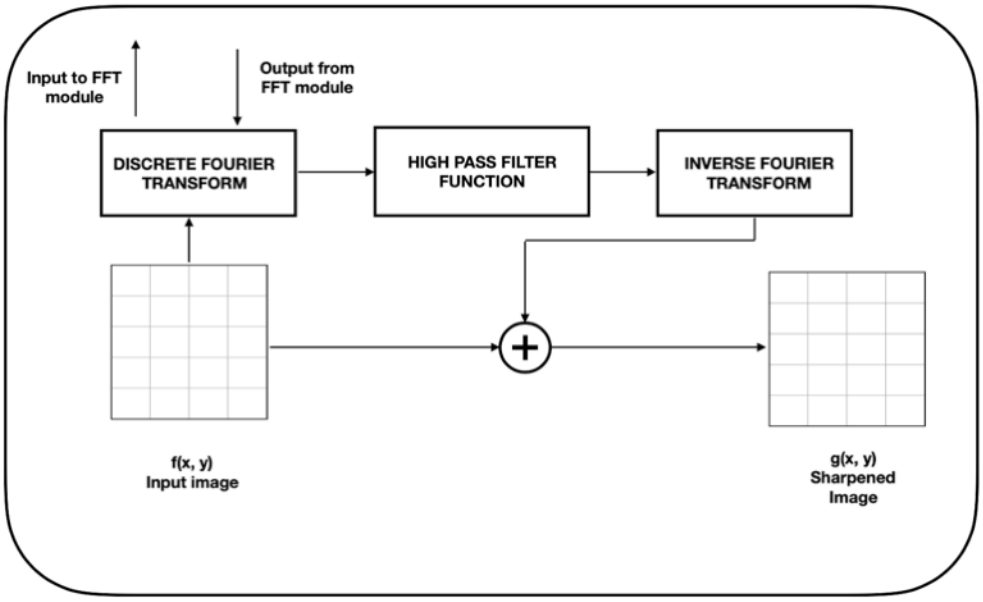
INPUT: IMAGE
OUTPUT: DFT OF THE IMAGE



INPUT: DFT OF THE IMAGE
OUTPUT: ORIGINAL IMAGE

MODULE 3: Filtering Using FFT

The image is converted into frequency domain using the proposed Fast Fourier transform using approximate multipliers. A high pass filter is applied to enhance the edges. The image is converted back to spatial domain using Inverse Fast Fourier transform using approximate multipliers, which is then added with the original image to obtain the sharpened image.



INPUT: IMAGE
OUTPUT: SHARPENED IMAGE

PERFORMANCE MEASURES

Reliability is analysed using the so-called sequential probability transition matrices (SPTMs). Error distance (ED) is initially defined as the arithmetic distance between an erroneous output and the correct output for a given input. The mean error distance (MED) and normalised error distance (NED) are then proposed as unified figures that consider the averaging effect of multiple inputs and the normalisation of multiple-bit adders.

Following metrics are to be calculated for accurate and approximate radix 8 Booth multipliers and a detailed comparison of the architectures is to be analysed.

Area
Power
Mean Square Error

REFERENCES

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5. J. Liang, J. Han and F. Lombardi, "New Metrics for the Reliability of Approximate and Probabilistic Adders," in IEEE Transactions on Computers, vol. 62, no. 9, pp. 1760-1771,

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