CHAPTER 1

Introduction

Noise is undesirable information which degrades image quality. The image can be noisy because of dust present on the lens, electronic noise in camera, imperfection present in the image sensor or can be introduced when image data is transmitted over communication channel [1]. The motive of image processing is to get rid of noise from a digital image while keeping its features unaltered. Image filter is the key blog of Image processing system.

Noise can be added when image data transmitted over an insecure communication channel [2]. This is called impulsive noise. It causes small size dots or dark/black spot on an image. Impulse noise is uniformly distributed and the most often mentioned noise in digital images. Further, Impulse noise can be divided into two parts. The first one is Salt & Pepper noise which is a type of impulse noise having noisy pixel intensity either 0 (minimum) or 255 (maximum) in the case of gray scale images. It appears as randomly scattered black or white dots over the images. The second one is the random-valued shot noise which has arbitrary valued noisy pixels. To remove these noises it is necessary that the acquired image must pass through an image preprocessing stage defined as a filter.

Spatial and frequency domain are two categories of the filtering operation [3]. In spatial domain filtering, the image pixel values are directly manipulated to achieve the desired result. Available spatial domain filters are: Mean, Order statistics and Adaptive filters [4]. Image filters have wide applications in the domain of image processing, satellite, and remote sensing, medical and microscopic imaging, geographic image surveillance and seismographic analysis [1] [2] [4].

Generally, filters are implemented by software in systems. As it is a well-known fact that software implementation offers less processing speed in comparison to hardware implementation [6]. Hardware implementation has become better alternative after the
boost in the VLSI technology. To reduce the power consumption in the systems, more cooling devices have to be incorporated results in the costly system. Keeping the same functional capabilities with the reduction in power factors are heavily demanding. Yet in that context, battery and power optimizing technology have not matured up to that target. Most of these products include embedded microprocessors, DSPs and ASICs [7]. It is a challenging task to achieve low power design of any VLSI circuit. There are different levels of optimization in VLSI design process for low power applications. For battery operated portable products, power has been the main concern. As System-on-Chip (SoC) moves to highly integrate it requires less power consumption. Power consumption reduction in highly integrated SoC cut down the heating problem. It reduces the cost of expensive packing and cooling mechanism [8].

To deal with the above issues of low power and cost reduction, in this work, VLSI architecture for noise reduction in different imaging applications is proposed.

1.1 Image Restoration and Degradation Model

Image restoration concept started in 1950 with the space program. Earlier the space images were blurred and not clear in vision. Lots of restoration techniques have been developed to make space images more clearly in vision. It has another major application in medical imaging including MRI, PET etc [9]. It requires restoration of blur image due to motion while capturing, restoration of old images and videos.

The image is a 2-D function f(x, y) of light intensities, where f is amplitude at any spatial coordinate x and y. The beam of light falls on an object and reflected light reaches to eyes. It makes human to see the object. The smallest element of the digital image is pixels. Each pixel represents intensity value at a particular location.

Mathematically, Image can be represented as equation 1.1.

\[ F(x, y) = I(x, y) \cdot R(x, y) \]  

Where, I(x, y) is intensity of incident light on object, R(x, y) = reflected light from object in intensity and F(x, y) = Intensity of resultant image.
Image restoration is the process to restore a digital image which has been distorted by prior knowledge of degradation model. Once the degradation model is known one can apply inverse process to recover the desired image. The typical objective of the restoration process is to enhance an image in some predefined sense. Image restoration is different than image enhancement techniques. Image enhancement is a subjective process and produces more pleasing results to an observer without using degradation model. Let Input image represent by function $f(x, y)$ and it is degraded by function $H$. The image degradation process is shown in Figure 1.1.

\[ g(x, y) = h(x, y) * f(x, y) + \eta(x, y) \] (1.2)

Corresponding degradation model in the frequency domain is represented by Fourier transform [10] and given by equation 1.3.

\[ G(u, v) = H(u, v) F(u, v) + N(u, v) \] (1.3)

At the process of image acquisition and transmission, some disturbance arises in digital images term as noise. An environmental condition during image acquisition and sensor quality affect the performance of imaging sensors [11]. Major factors which affect noise intensity in resulting images are sensor temperature and light levels. When the image acquired by any electronic optical means, it is degraded by sensing environment in the form of sensor noise. The interference present in the channel used for transmission is the
main reason of image noise during transmission. The image transmitted by the wireless network is corrupted by lighting effect or atmospheric disturbance. Film grain or electronic noise in input device sensor (scanner or digital camera) or noise of ideal photon detector can originate image noise [12].

1.2 Types of Noise Model

Digital images are inclined to a variety of noise. Some of the basic noise models are defined over spatial domain. These noise models are featured by probability density function (PDF). At each point in the sample space, a PDF for a continuous random variable can be calculated. This function describes the density of probability. Gaussian, Rayleigh, Gamma, Exponential, Impulsive and other are commonly encountered noises [5] [13] [14]. The different noise models $\eta(x, y)$ are shown in Figure 1.2.

Gaussian noise is mathematically traceable in spatial and frequency domain. So it is used in frequent in practice. The brightness of digital image is increase or decrease due to Gaussian noise [15]. Gaussian noise occurs because of electronic circuit noise, sensor noise due to poor illumination or high temperature. Spatial domain filters are used to remove Gaussian noise in digital image processing. The filtered images have some blur outcomes due to removal of edges. The edges or boundary in images represent high frequency component and spatial filter blocks these high frequency component too. Conventionally, mean, median or Gaussian smoothing are spatial filtering techniques.
Rayleigh noise density characterizes noise phenomena in range imaging [16]. The example of Rayleigh distribution is when wind velocity is analyzed into its orthogonal 2-dimensional vector components [17]. Gamma noise can be obtained by low-pass filtering of laser based images [18]. In uniform noise model, the noise can take on values in an interval \([a, b]\) with uniform probability. It is least descriptive for practical situations [19].

1.2.1 Impulse Noise Model

The impulse noise is the most frequently referred type of noise. Salt and pepper impulse noise is called intensity spikes also. The noisy pixels have either the minimum or maximum value. It appears like “Salt and Pepper” in the image. For 8-bit gray scale images, salt and pepper noise have pixel intensity value of “255” and “0” respectively. The value of unaffected pixels remains unchanged. The main sources of impulse noise insertion in images are patches of dust present inside the camera, overheat or faulty CCD elements, malfunctioning of pixel elements in the camera sensors, faulty memory locations, data transmission error and timing errors in digitization process [12]. The Probability density function (PDF) of impulse noise is given in equation 1.4 and shown in Figure 1.3.

\[
p(z) = \begin{cases} 
  P_a & \text{for } z = a \\
  P_b & \text{for } z = b \\
  0 & \text{otherwise}
\end{cases} \quad (1.4)
\]

Where, \(P_a\) and \(P_b\) are the PDF and \(p(z)\) is distribution of Salt and Pepper noise in images. The specific case with either \(P_a\) or \(P_b\) is zero, represents unipolar impulse noise. If \(P_a\) and \(P_b\) have approximately equal non-zero values, it called Salt and Pepper impulse noise. For gray scale image, “a” and “b” equal to “0(black)” and “255(white)” is represent Salt and Pepper noise respectively.

![Figure 1.3: PDF of impulse noise](image-url)
1.3 Spatial filtering

Filtering can be performed in either spatial or frequency domain. Additive noise removal has been done in the spatial domain. Lots of filtering algorithms have been developed in spatial domain [20].

1.3.1 Mean Filter

Mean Filter is the easiest way to smooth images [21]. It reduces the variation of intensity level between alternative pixels. It is used to filter noises in digital images. The pixel value of each point is replaced by the mean of its surrounding pixels. This replaces the pixels which are not similar to its surrounding. Mean filtering is usually thought of as a convolution filter. It is based on a kernel, which represents the shape and size of the neighborhood to be sampled when calculating the mean. Different types of the mean filter have been reported from past years. This includes arithmetic, geometric, harmonic and contra harmonic mean filters. Contra harmonic and arithmetic mean filters are suitable for impulsive and random noise like Gaussian or uniform noise respectively [22] [23] [24].

1.3.2 Order Statistical Filter

Order statistics are the attributes of sorted data inside a sliding window. Minimum, maximum and median filters are the special case of order statistics filter. Order statistics are used when outlier data is problematic because it is extremely robust to outlier data. Order Statistics filters are non-linear and non-stationary (shift-variant). Order -statistics filters are spatial filters whose response is based on ordering (ranking) the pixels contained in the image area encompassed by the filter. The response of the filter at any point is determined by the ranking result. The traditional median filter is an example of order statistics filter. Some other in this category is max, min, midpoint, and alpha-trimmed mean filters [25]. The median filter used a certain size window to calculate intensity value of the corrupted pixel. It uses the median value of the window. Min and max filter replaced the noisy pixel with minimum and maximum gray levels of the window respectively. The midpoint filter just computes the midpoint between the greatest
and least values in the area encompassed by the filter. Median filters are especially powerful in the presence of impulse noise.

1.3.3 Adaptive filter

The statistical characteristics of the image inside filter window change adaptive filter's behavior. Adaptive filter performance is typically better to compare to non-adaptive counterparts. However, the enhanced performance added filter complexity. Adaptive filters can be designed based on two statistical measures of mean and variance [26]. Edges in the image have high variance. It should be necessary to preserve edges. So whenever local variance found to be high compared to overall image variance, similar pixel value as the present pixel is needed. Adaptive local noise reduction filter and adaptive median filter are the examples of the adaptive filter.

1.4 Hardware Implementation Technologies for Real Time imaging System

A real-time imaging system consists of a number of electronics devices. It typically includes image acquisition system, signal processing units and memory with the display. Drivers are under pressure to fulfill market demands of faster, smarter and more interconnected products. Adopting appropriate technologies among other alternatives gives better results in the same direction. The decision of selecting the right architecture for the devices and this thesis has been with elaborations on the plus and minus sides of each of the technologies. Few technologies available to implement core devices of real-time embedded systems are Field Programmable Gate Array (FPGA), Application Specific Integrated Circuits (ASIC), the general-purpose processor, application specific signal processor, artificial neural network, and microcontroller units [27] [28]. ASIC and FPGA can accomplish improve system performance compared to other technologies with the full flexibility to modify the hardware to the last single bit of logic. The inner structure of logic blocks building in FPGA and ASIC differs. This difference leads to variant matrices in speed, hardware resources, power, logic integration and unit cost etc. FPGA provides full flexibility to reprogram logic components and interconnects. In contrast, designs implemented with ASIC are optimized using an available range of logic cells with different sizes and strengths by dedicated interconnection.
A typical structure of an FPGA with configurable logic blocks and interconnection is shown in figure 1.4 (a) [29]. The programmable logic elements and interconnections of typical FPGA described in figure 1.4 (b) [29]. Look up tables programming can be used to form logic blocks. The routing resources can control by SRAMs configuration.

FPGA hardware implementation technology comes with few advantages which are the source of motivation in this thesis.

- The FPGAs are flexible and reprogrammable. This ability is very helpful in video applications as algorithms may need minor modifications in the long run. Also, the FPGA platform is highly portable.

- Some modern FPGAs have robust built-in IP blocks which are thoroughly verified. This built-in IPs enhances ease of design and speeds up system design process.

- Microprocessors are also available as built-in IP. This facilitates hardware-software co-design paradigm. In video surveillance system, the software implementation is more preferable and thus an FPGA with built in microprocessor proves very effective.
• The routine tasks like floor planning, place and route, timing analysis etc. are automated in FPGAs. This enables the system designers to focus on architecture and logic design task.

The aforementioned points suggest that FPGAs are a better implementation technology due to its viability, performance, and facilities.

1.5 Objectives of present research work

Different algorithms for Image filtering have been reported from past few years. Impulse noise is focused more, as it is the most frequent type of noise encountered in digital images. The median filter is the most basic building block to remove both types of impulse noise. But as the noise increases, the median filter is not able to remove it efficiently. Some basic filtering algorithms are min-max median filter (MMF), center weighted median filter (CWMF), adaptive median filter (AMF), progressive switching median filter (PSMF), tri-state median filter (TSMF), decision-based algorithm (DBMF) etc. Various noise detection algorithms have been suggested for random valued impulse noise. So, the objectives of proposed topic are as follows:

1. Exhaustive study and implementation of Simple median filter (SMF), Adaptive Median filter (AMF), Decision based Median Filter (DBMF), Decision Based Untrimmed Median filter (DBUTM) and edge preserving filter.

2. To find best algorithm for filtering based on the computation of processing time, Mean Square Error, Peak Signal to Noise Ratio, Image Enhancement Factor.

3. Designing of digital domain circuit of selected Image filter algorithms found in step2.


5. Hardware Implementation with Verilog HDL of the optimized algorithm.
1.6 Thesis organization

Chapter 1 presents a brief introduction to the sources of noises present in image processing and how it can be corrected in real time application. These theoretical discussions serve as a foundation for discussing the current research work. A concise overview of the ways in which noise affects the quality of high-level image processing operation is also presented.

A detailed summary of empirical findings from the past studies on different filters related to impulse noise is presented in chapter 2. The hardware implementation of filters for real-time application is also discussed.

Chapter 3 presents the exhaustive study of nonlinear image filters for Fixed Valued Impulse Noise using MatLab R2013a. The SMF, SAMF, DBMF, DBUTM, and edge preserving filter algorithms have been taken to do the analysis. PSNR, MSE, IEF and computational time parameters have been recorded to have an analytical study. The analysis of the results has been shown and described.

Chapter 4 explores filtering algorithm for Random Valued Impulse noise (RVIN). The comparative studies of restoration by different kind of scheme have been done. A modified algorithm with efficient impulse detector and decision-based median filter has been proposed with less complexity of filtering steps and less computational time at high noise level.

Chapter 5 explores hardware implementation and digital circuits of Image filters for impulse noise. The new serial sorting algorithm is proposed to sort data input and finding the median. The results are analyzed in terms of power, speed, and area. Optimization has been done to improve the overall performance of circuits in term of power, speed or area. The Switching median and decision based median filter is implemented using proposed serial sorting algorithm. The results are calculated in terms of speed, power, and area.

At the end, chapter 6 discusses the applied value of present work and possible direction for future development.