An FPGA Based Practical Implementation of Stochastic Resonance For Image Enhancement

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***Abstract*—In this paper, a non-linear non-dynamic stochastic resonance (SR) based technique is proposed for enhancement of dark and low contrast images. Noise-enhanced signal processing theory is applied to a low contrast image to improve the contrast. Insufficient illumination is the major cause of low contrast of the image, which can be stated as internal noise. This internal noise is neutralized by the addition of some pre-calculated external noise. The low contrast image is added to different frames of random noise and is thresholded repeatedly against a fixed parameter. After that, averaging produces a high contrast (enhanced) image. Noise-induced resonance is obtained at a particular optimum noise intensity. This optimum intensity is obtained by varying the noise intensities. Performance of the proposed technique is investigated for Gaussian noise. Quantitative evaluation of the performance is done in terms of color enhancement, contrast enhancement factor, and perceptual quality measure.**

Furthermore, a hardware implementation of the proposed SR algorithm using NEXYS 4 DDR Artix-7, which is a low power FPGA device is done to show and validate the performance of the proposed algorithm in a practical environment. Power consumption and resource utilization of the proposed algorithm is also addressed. Finally, three different quantitative parameters *i.e.,* contrast enhancement factor (F), color enhancement factor (CEF) and perpetual quality metric (PQM) are calculated to compare the hardware and software result of the proposed method.

***Index Terms*—Image Enhancement, FPGA.**

I. INTRODUCTION

Image [1], [2] enhancement improves the interpretability or perception of information in images for human viewers, provide better input for other automated image processing techniques. Insufficient illumination causes many images to have a very low dynamic range of intensity. Hence, these images are processed before being displayed. Techniques such as gamma correction, histogram equalization, high pass filtering, homomorphic filtering, low pass filtering, *etc.,* have focussed on the enhancement of gray level images in the spatial domain [3], [4]. These methods have also been employed for color image enhancement in the RGB space. Jobson et al. [5] has reported retinex theory that also leads to good contrast enhancement of an image. Nevertheless, the requirement of filtering with multiscale Gaussian kernels and post-processing stages for adjusting colors makes it computationally intensive. Another technique has also been reported in RGB space which uses equalization of the 3-D histograms [6].

Noise (here low illumination) is usually considered to be a trouble that decreases the signal-to-noise ratio (SNR) of nonlinear systems. On the contrary, SR is a phenomenon in which external noise is added for enhancement rather than obstructing the system performance. Usually considered undesirable, noise can be constructively used in different application such as image processing, biomedical *etc.*

The first experimental work on visualization of stochastic resonance (SR) has been reported [7]–[13]. They report the outcome of a psychophysics experiment which shows that the human brain can interpret details present in an image contaminated with time-varying noise and the perceived image quality is determined by the noise intensity and its temporal characteristics. Jha et al. [14] used SR to enhance dark images by deriving a specific condition for threshold using Gaussian noise.

Field Programmable Gate Array (FPGA) with various hardware resources effectively fill the gap between application specific integrated circuit(ASIC) and microprocessors. FPGA has higher performance than microprocessors. Moreover, FPGA has higher programmability, flexibility, low cost and less development time than ASIC, although it consumes 9–12 times more power than ASIC. ASIC has been significantly replaced by FPGA in electronic industries, networking area to minimize the cost and time to market. Memory plays a critical role in FPGA for most applications like image processing, medical imaging, aerospace and defense systems, computer vision, signal processing, speech recognition, bioinformatics, cryptography and growing range of other areas. The processors with this application use traditional on-chip or off-chip memories. Since on-chip memory implemented inside FPGA has no external connections on the circuit board, it provides maximum access speed from memory and highest throughput. The use of on-chip memory is expected to increase continuously for enhancing the performance of future generations portable devices and high- performance processors [15].

Organization of the paper: Section II deals with the basic theory of non-dynamic stochastic resonance. Section III and Section IV deal with the software and hardware approach for the proposed method respectively. In the end, the conclusion has been presented in Section V.

II. NON DYNAMIC STOCHASTIC RESONANCE

In ordinary consciousness, the word noise relates to obstruction. It was a traditional belief that the presence of noise makes the system worse. But, recent studies have shown that in non-linear systems, noise can induce more ordered regimes, which cause the signal-to-noise ratio (SNR) to increase and amplification of weak signals [16]. In other words, noise can be used to enhance weak signals. Stochastic resonance is a phenomenon where the addition of noise to the input signals amplifies the output signals of some nonlinear systems. More technically, SR occurs if the SNR, input/output correlation has a well-marked maximum at a fixed noise level [17]. A system should possess three basic properties to exhibit SR. They are a non-linearity in terms of the threshold, a source of additive noise, and a sub-threshold signal similar to signal with small amplitude. This phenomenon often occurs systems with threshold-like behavior. The behavior of the SR mechanism reveals that at lower noise intensities the weak signal doesn't cross the threshold. Hence the output is a very low SNR. The output is dominated by the noise for high noise intensities which also leads to a low SNR. But, for moderate noise intensities, the noise allows the signal to cross the threshold. Hence maximum SNR at some optimum noise level is obtained.

TABLE I: The parameters for symmetric Gaussian noise.

Noise	Gaussian
σ_o	25
F	125.8494
CEF	125.3829
PQM	8.4206

III. SOFTWARE APPROACH

The proposed algorithm has the following steps. The steps as shown through Fig. 1 should be applied to all the three planes (R, G and B) of a colored image in parallel.

Step 1:

1) A very low contrast image $P_{RGB}(x, y)$ is taken as an input image.
2) N frames of random noise, $\zeta(x, y)$, of mean zero and standard deviation σ_o are produced. Each of the noise frames is added to the low contrast image $P_{RGB}(x, y)$ to give N different noisy low contrast images (for single noise standard deviation (σ_o)).
3) Thresholding is done for each noisy image P_i using a fixed threshold (taken as the mean (μ_o) of input image itself). Enhanced image of good contrast is obtained when we take an average of all the thresholded frames (P_i'). Performance metrics F, CEF, and PQM are calculated for this output.
4) Standard deviation of the noise is increased by a unit and Step 1 to Step 3 is repeated. Values of performance metrics are analyzed. When CEF+F becomes maximum within the constraint that PQM is close to 10, the process is stopped.

IV. HARDWARE APPROACH

As the trend of programmable hardware chip for a particular application has increased significantly, we implement and show the proposed algorithm on low power FPGA NEXYS 4 DDR Artix - 7 device. It may be put to use for various other applications. The feasibility of the proposed stochastic resonance algorithm is also measured. Our focus is more on the accuracy of the proposed method. We have also mentioned about resources used during the implementation. However, our results of hardware implementation are optimized in terms of error but not in terms of resources.

Here, we mainly focus on the data path while implementing the proposed algorithm on the FPGA. We are not concerned about control signals in much detail. This hardware implementation is shown for a single color plane (P). We take N (here, N is 30) noise frames. Here, additional expenses of resources occur due to the processing of all the input data in parallel. The input data are fetched into register pixel by pixel at every clock event (Positive edge triggering). When the addition of the image pixel intensities with the noise frames is done at every clock event, it is sent to the comparator, which performs thresholding against a fixed parameter (mean of the input image, μ_o). The 30 (for a single plane) parallel additions are accepted in FPGA due to the flexibility of the clock management. The hardware component utilization of the module for the proposed algorithm is discussed in Table II.

TABLE II: Device utilization summary report.

Primitive and Black Box Usage	
Logic Utilisation	Used
BELS	1172
the GND	1
LUT2	990
LUT5	90
LUT6	90
VCC	1
FlipFlops/Latches	1
FDRE	1
Clock Buffers	1
BUFGP	1
IO Buffers	1458
IBUF	1395
OBUF	63

TABLE III: The quantitative parameters for different bit-width. Here, bit-width is for the integer part of input image and noise frames. The fractional part is fixed at 6.

Bit-width	F	CEF	PQM
4	0.8638	1.7143	15.0511
5	16.6190	17.5675	12.5715
6	27.1151	24.9691	11.6162
7	32.1034	26.7281	11.4358
8	32.1608	26.7675	11.4414
9	32.1311	36.7298	11.4352

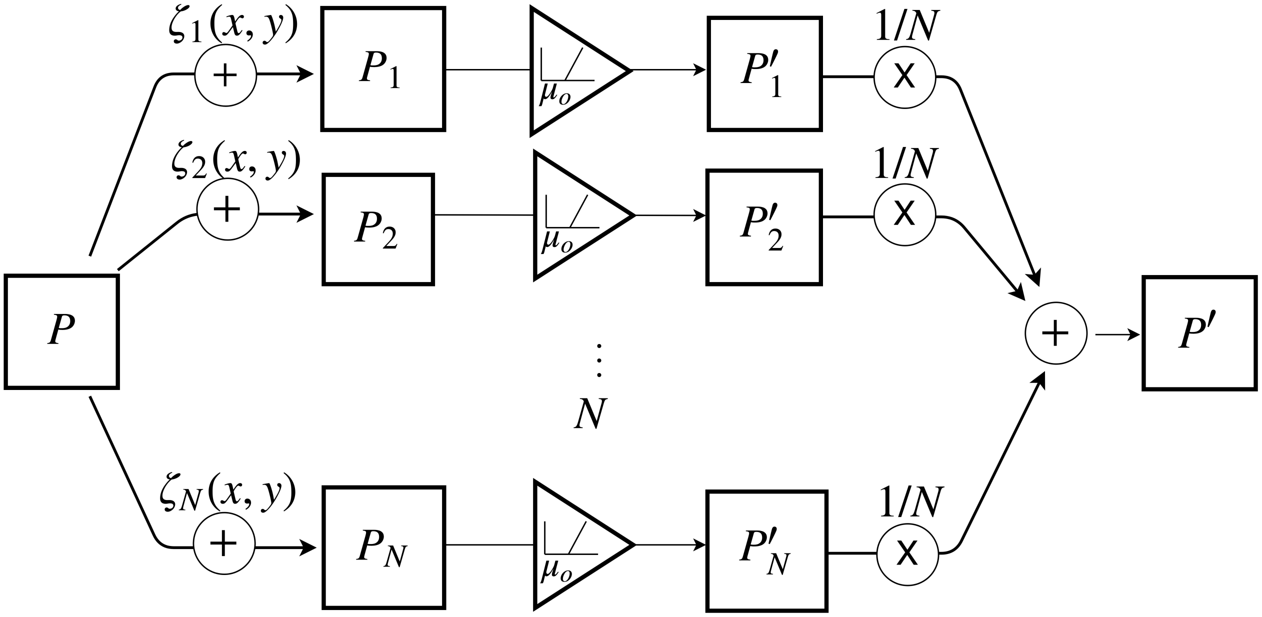

Fig. 1: P represents one color plane. $i.e$ R, G or B. $\zeta_i(x,y)$ is the random noise with zero mean and standard deviation as σ_o. These noises are added to the color plane to produce N different noisy images. The noisy low contrast images obtained are indicated by P_i. Further, each of the P_is is thresholded against the mean (μ_o) to produce different P'_i. Finally, all the P'_is are averaged to get the increased contrast image for the particular plane P. This algorithm is implemented for each of the planes, R, G and B. Results of each plane are concatenated to produce the final output image.

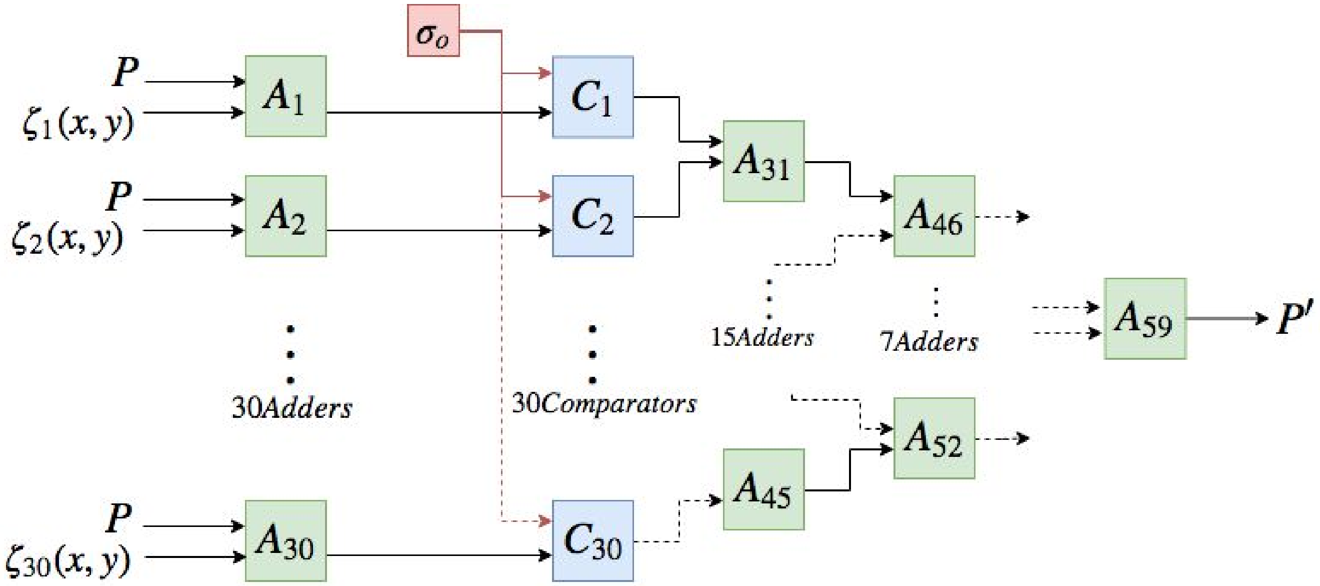

Fig. 2: The size of image is taken as 256×256. Adder block is represented by A_i and comparator block is represented by C_i. Different bits are chosen for integer and fractional part of the noise frames and input image.


(a) (b) (c)

Fig. 3: (a) Input low contrast image, (b) Software result, (c) Hardware result.

V. CONCLUSION

A non-dynamic stochastic resonance-based technique has been investigated in this paper for the enhancement of dark images. By treating a low contrast image as subthreshold and adding random noise followed by hard-thresholding and averaging, the contrast of the image was found to remarkably increasing. Addition of symmetric noise is used. Gaussian distribution is used for symmetric for image improvement.

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