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EDGE PRESERVING TECHNIQUES FOR EFFICIENT REMOVAL OF IMPULSE NOISE

Mohammad Reza pourmir

Computer Engineering Department, Faculty of Engineering, Zabol University, Zabol, Iran

Corresponding author: Mohammad Reza pourmir

ABSTRACT: Image signals might be corrupted by Impulse noise in the process of signal acquisition and transmission. In this paper,an efficient VLSI implementation for removing impulse noise is presented.Our extensive experimental results show that the proposed technique preserves the edge features and obtains excellent performances in terms of quantitative evaluation and visual quality. The design requires only low computational complexity and two line memory buffers. Its hardware cost is quite low.Compared with previous VLSI implementations,our design achieves better image quality with less hardware cost. Synthesis results show that the proposed design yields a processing rate of about 167 M samples/second by using TSMC 0.18 m Technology.

Keywords: Edge, Efficient Removal, Impulse Noise.

INTRODUCTION

IN SUCH applications as printing skills, medical imaging,scanning techniques, image segmentation, and face recognition, images are often corrupted by noise in the process of image acquisition and transmission. Hence, an efficient denoising technique is very important for the image processing applications . Recently, many image denoising methods have been proposed to carry out the impulse noise suppression . Some of them employ the standard median filter or its modifications , to implement denoising process.However, these approaches might blur the image since bothnoisy and noise-free pixels are modified. To avoid the damage on noise-free pixels, an efficient switching strategy has been proposed in the literature .

In general, the switching median filter consists of twosteps: 1) impulse detection and 2) noise filtering. It locates thenoisy pixels with an impulse detector, and then filters themrather than the whole pixels of an image to avoid the damageon noise-free pixels. Generally, the denoising methods forimpulse noise suppression can be classified into two categories:lower-complexity techniques and higher-complexity techniques . The former uses a fixed-size local window and requires a few line buffers. Furthermore, its computational complexity is low and can be comparable to conventional median filter or its modification . The latter yields visually pleasing images by enlarging local window size adaptively, or doing iterations . In this paper, we focus only on the lower-complexity denoising techniques because of its simplicity and easy implementation with the VLSI circuit.In , Zhang and Karim proposed a new impulse detector(NID) for switching median filter. NID used the minimum absolutevalue of four convolutions which are obtained by using 1-D Laplacian operators to detect noisy pixels.A method named as differential rank impulse detector (DRID) is presented . The impulse detector of DRID is based on a comparison of signal samples within a narrow rank window by both rank and absolute value. Luo proposed a method which can efficiently remove the impulse noise (ERIN) based on simplefuzzy impulse detection technique. An alpha-trimmed mean based method (ATMBM) was presented . It used the alpha trimmedmean in impulse detection and replaced the noisy pixel value by a linear combination of its original value and the median of its local window. , a decision-based algorithm (DBA) is proposed to remove the corrupted pixel by the median or by its neighboring pixel value according the proposed decisions.For real-time embedded applications, the VLSI implementationof switching median filter for impulse noise removal is necessaryand should be considered. For customers, cost is usually the most important issue while choosing consumer electronic products. We hope to focus on low-cost denoising implementation in this paper. The cost of VLSI implementation depends mainly on the required memory and computational complexity.Hence, less memory and few operations are necessary for a low-cost denoising implementation. Based on these two factors,we propose a simple edge-preserved denoising technique (SEPD) and its VLSI implementation for removing fixed-value impulse noise. The storage space needed for SEPD is two line buffers rather than a full frame buffer. Only simple arithmetic operations, such as addition and subtraction, are used in SEPD. We proposed a useful impulse noise detector to detect the noisy pixel and employ an effective design to locate the edge of it. The experimental results demonstrate that SEPD can obtain better performances in terms of both quantitative evaluation and visual quality than other state-of-the-art lower-complexity impulse denoising methods. Furthermore, the VLSI implementation of our method also outperforms previous hardware circuits in terms of quantitative evaluation, visual quality, and hardware cost.The rest of this paper is organized as follows. In Section II,the proposed SEPD is introduced. The VLSI implementation of SEPD is described briefly in Section III. In Section IV, the implementation of reduced SEPD is introduced. The implementation results and comparison are provided in Section V. Conclusionsare presented in Section VI.

PROPOSED SEPD

Assume that the current pixel to be denoised is located at coordinate (i,j) and denoted as $p_{i,j}$,and its luminance values before and after the denoising process are represented as $f_{i,j}$ and $\hat{f}_{i,j}$, respectively. If $p_{i,j}$ is corrupted by the fixed-value impulse noise, its luminance value will jump to be the minimum or maximum value in gray scale. Here, we adopt a 3×3 mask W centering on $p_{i,j}$ for image denoising. In the current W, we know that the three denoised values at coordinates(i-1,j-1),(i-1,j)and(i-1,j+1) are determined at the previous denoising process, and the six pixels at coordinates (i,j-1),(i,j),(i,j+1),(i+1,j-1),(i+1,j),,(i+1,j+1) are not denoised yet, as shown in Figureure 1. A pipelined hardware architecture is adopted in the design, so we assume that the denoisedvalue of $p_{i,j-1}$ is still in the pipeline and not available. Usingthe 3×3 values in W,SEPD will determine whether $p_{i,j}$ is anoisy pixel or not. If positive, SEPD locates a directional edge existing in W and uses it to determine the reconstructed value $\hat{f}_{i,j}$; otherwise,$\hat{f}_{i,j} = f_{i,j}$. SEPD is composed of three components: extreme data detector, edge-oriented noise filter and impulse arbiter. Theextreme data detector detects the minimum and maximum luminance values in W,and determines whether the luminance values of $p_{i,j}$ and its five neighboring pixels are equal to the extreme data. By observing the spatial correlation, the edge-oriented noise filter pinpoints a directional edge and uses it to generate the estimated value of current pixel. Finally, the impulse arbiter brings out the proper result.The three components of SEPD are described in detail in the following subsections.

Extreme Data Detector

The extreme data detector detects the minimum and maximum luminance values (MINinWandMAXinW) in those processed masks from the first one to the currentone in the image. If a pixel is corrupted by the fixed-valueimpulse noise, its luminance value will jump to be the minimumor maximum value in gray scale. If $f_{i,j}$ is not equal to MINinW/MAXinW, we conclude that $p_{i,j}$ is a noise-freepixel and the following steps for denoising $p_{i,j}$ are skipped. If is equal to MINinWorMAXinW ,we set φ to 1, check whether its five neighboring pixels are equal to the extreme data, and store the binary compared results into B.

Edge-Oriented Noise Filter

To locate the edge existed in the current W, a simple edge catchingtechnique which can be realized easily with VLSI circuit is adopted. To decide the edge, we consider 12 directional differences, from D1 to D12 , as shown in Figureure 3. Only those composed of noise-free pixels are taken into account to avoid possible misdetection. If a bit in B is equal to 1, it means that the pixel related to the binary flag is suspected to be a noisy pixel. Directions passing through the suspected pixels are discarded to reduce misdetection. In each condition, at most four directions are chosen for low-cost hardware implementation. If there appear over four directions, only four of them are chose accordingto the variation in angle. Figureure 4 shows the mapping table between B and the chosen directions adopted in the design.If $p_{i,j-1}$,$p_{i,j+1}$, $p_{i+1,j-1}$,$p_{i+1,j}$and $p_{i+1,j+1}$ are all suspected to be noisy pixels (B="11111"), no edgecan be processed, so $\hat{f}_{i,j}$ (the estimated value of $p_{i,j}$)is equal to the weighted average of luminance values of three previously denoised pixels and calculated as $(\bar{f}_{i-1,j-1} + 2 \times \bar{f}_{i-1,j} + \bar{f}_{i-1,j+1})/4$. In other conditionsexcept when " B=11111" the edge filter calculates thedirectional differences of the chosen directions and locates the smallest one (D_{min}) among them, as shown in Figureure 2. The smallest directional difference implies that it has the strongest spatial relation with $p_{i,j}$, and probably there exists an edge in its direction. Hence, the mean of luminance values of the two pixels which possess the smallest directional difference is treated as $\hat{f}_{i,j}$. For example, if is equal to "10011," it means that $f_{i,j-1}$,$f_{i+1,j}$ And $f_{i+1,j+1}$ are suspected to be noisy values. Therefore, D_2 –D_5 ,D_7 and D_9– D_{11} discarded because they contain those suspected pixels (see Figureure 3). The four chosen directional differences are D_1, D_6 ,

D_8 and D_{12} (see Figureure 4). Finally, is equal to the mean of luminance values of the two pixels which possess the smallest directional difference among D_1,D_6, D_8 and D_{12}.

Impulse Arbiter

Since the value of a pixel corrupted by the fixed-value impulse noise will jump to be the minimum/maximum value in gray scale, we can conclude that if $p_{i,j}$ is corrupted,$f_{i,j}$ is equal to MINinW orMAXinW . However, the converse is not true.If $f_{i,j}$ is equal to MINinW or MAXinW,$p_{i,j}$, may be corrupted or just in the region with the highest or lowest luminance.

In otherwords, a pixel whose value is MINinW or MAXinW might be identified as a noisy pixel even if it is not corrupted. To overcome this drawback, we add another condition to reduce the possibility of misdetection. If $p_{i,j}$ is a noise-free pixel and the current mask has high spatial correlation, $f_{i,j}$ should be close to $\hat{f}_{i,j}$ and $|f_{i,j}-\hat{f}_{i,j}|$is small. That is to say,$p_{i,j}$ might be a noise-free pixel but the pixel value is MINinW orMAXinW if $|f_{i,j}-\hat{f}_{i,j}|$ is small. We measure and $|f_{i,j}-\hat{f}_{i,j}|$ and compare it with a threshold to determine whether $p_{i,j}$ is corrupted or not. The threshold, denoted as T_s, is a predefined value. Obviously, the threshold affects the performance of the proposed method. A more appropriate threshold can achieve a better detection result.However, it is not easy to derive an optimal threshold through analytic formulation. According to our experimental results, we set the threshold Ts as 20. If $p_{i,j}$ is judged as a corrupted pixel,the reconstructed luminance value $\hat{f}_{i,j}$is equal to $\hat{f}_{i,j}$; otherwise, $\hat{f}_{i,j}=f_{i,j}$

IMPLEMENTATION OF REDUCED SEPD

In SEPD, we consider 12 directional differences to decide the proper edge. When more edges are considered, more complex computations are required. To further reduce the cost of implementation, we modify SEPD and propose another design,named as reduced SEPD (RSEPD). Only three directional differences,D_a, D_b, and D_c as shown in Figure, are considered in RSEPD. As demonstrated in Section V, RSEPD offers slightly poorer image quality but requires much lower cost than SEPD.

IMPLEMENTATION RESULTS

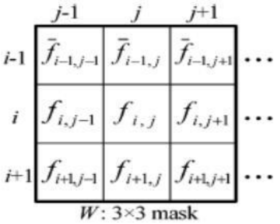


Figure 1. 3× 3 mask centered on $p_{i,j}$

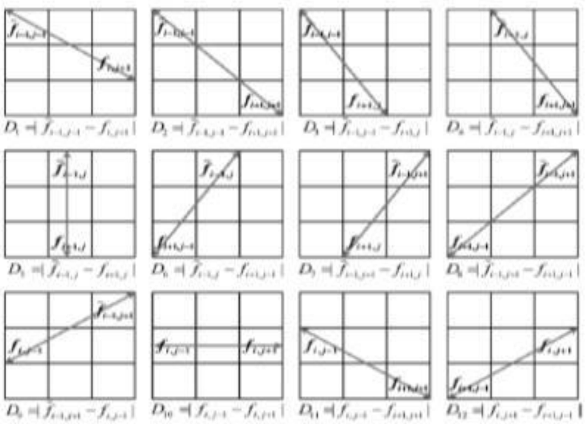
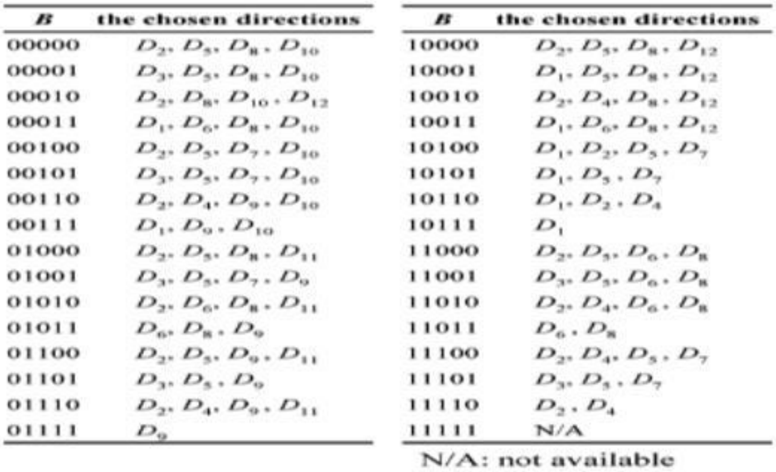


Figure 2. Twelve directional differences of SEPD



B	the chosen directions	B	the chosen directions
00000	D_2, D_5, D_8 , D_{10}	10000	D_2, D_5, D_8 , D_{12}
00001	D_3, D_5, D_8 , D_{10}	10001	D_1, D_5, D_8 , D_{12}
00010	D_2, D_8, D_{10} , D_{12}	10010	D_2, D_4, D_8 , D_{12}
00011	D_1, D_6, D_8 , D_{10}	10011	D_1, D_6, D_8 , D_{12}
00100	D_2, D_5, D_7 , D_{10}	10100	D_1, D_2, D_5 , D_7
00101	D_3, D_5, D_7 , D_{10}	10101	D_1, D_5 , D_7
00110	D_2, D_4, D_9 , D_{10}	10110	D_1, D_2 , D_4
00111	D_1, D_9 , D_{10}	10111	D_1
01000	D_2, D_5, D_8 , D_{11}	11000	D_2, D_5, D_6 , D_8
01001	D_3, D_5, D_7 , D_9	11001	D_3, D_5, D_6 , D_8
01010	D_2, D_6, D_8 , D_{11}	11010	D_2, D_4, D_6 , D_8
01011	D_6, D_8 , D_9	11011	D_6 , D_8
01100	D_2, D_5, D_9 , D_{11}	11100	D_2, D_4, D_5 , D_7
01101	D_3, D_5 , D_9	11101	D_3, D_5 , D_7
01110	D_2, D_4, D_9 , D_{11}	11110	D_2 , D_4
01111	D_9	11111	N/A

N/A: not available

Figure 3. Thirty-two possible values of B and their corresponding directions in SEPD

CONCULSION

The extensive experimental resultsdemonstrate that our design achieves excellent performancein terms of quantitative evaluation and visual quality, eventhe noise ratio is as high as 90%. For real-time applications, a7-stage pipeline architecture for SEPD and a 5-stage pipelinearchitecture for RSEPD are also developed and implemented.As the outcome demonstrated, RSEPD outperforms otherchips with the lowest hardware cost. Thearchitectures work with monochromatic images, but they canbe extended for working with RGB color images.

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