Removal of Impulse Noise Using Eodt with Pipelined ADC

[1]Prof.Manju Devi,[2] Prof.Muralidhara, [3]Prasanna R Hegde
[1] Associate Prof, ECE, BTLIT Research scholar,[2] HOD, Dept. Of ECE, PES MANDYA.[3] VIII- SEM ECE, BTLIT,

Abstract

Corrupted Image and video signals due to impulse noise during the process of signal acquisition and transmission can be corrected. In this paper the effective removal of impulse noise using EODT with pipelined architecture and its VLSI implementation is presented. Proposed technique uses the denoising techniques such as Edge oriented Denoising technique (EODT) which uses 7 stage pipelined ADC for scheduling. This design requires only low computational complexity and two line memory buffers. It's hardware cost is quite low. Compared with previous VLSI implementations, our design achieves better image quality with less hardware cost. The Verilog code is successfully implemented by using FPGA Spatron-3 family.

Index Terms—Image denoising, impulse noise, pipeline architecture, VLSI.

1. Introduction

Most of the video and image signals are affected by noise. Noise can be random or white noise with no coherence, or coherent noise introduced by the capturing device's mechanism or processing algorithms. The major type of noise by which most of the signals are corrupted is salt and pepper noise. You might have observed the dark white and black spots in old photos, these kind of noise presented in images are nothing but the pepper and salt noise. Pepper and salt noise together considered as Impulse noise.

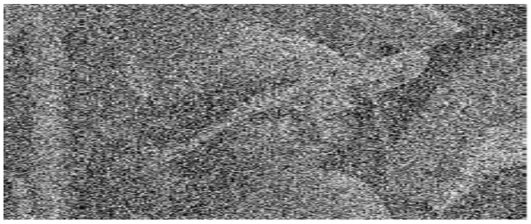


Fig1. Example of pepper and salt noise

The above pictures give us the insight of impulse noise. Number of dots in the pictures will bring down the clarity and quality of the image. In other applications such as printing skills, scanning, medical imaging and face recognition images are often corrupted by noise in the process of signal acquisition and transmission. It's more sophisticated in medical imaging when the edges of the object in image are affected by noise, which may lead to the misdetection of the problem. So efficient denoising technique is important in the field of image processing. many image denoising methods have[1]-[8] 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 both noisy and noise-free pixels are modified. The switching median filter consists of two steps:

1) Impulse Detection and
2) Noise filtering.

New Impulse Detector (NID) for switching median filter. NID used the minimum absolute Value 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 in. The impulse detector of DRID is based on a comparison of signal samples within a narrow rank window by both rank and absolute value. Another technique named efficient removal of impulse noise (ERIN)[8] based on simple fuzzy impulse detection technique.

2. Proposed Technique

All previous techniques involve high computational complexity and require large memory which affects the cost and performance of the system. So less memory consumption and reduced computational complexity are become main design aspects. To achieve these requirements Edge Oriented Denoising Technique (EODT) is presented. This requires only two line memory buffers and simple arithmetic operations like addition, subtraction.

EODT is composed of three components: extreme data detector, edge-oriented noise filter and impulse arbiter. The extreme 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 Result.

3. Vlsi Implementation Of Eodt

EODT has low computational complexity and requires only two line buffers, so its cost of VLSI implementation is low. For better timing performance, we adopt the pipelined architecture which can produce an output at every clock cycle. In our implementation, the SRAM used to store the image luminance values is generated with the 0.18µm TSMC/Artisan memory compiler. According to the simulation, we found that the access time for SRAM is about 6 ns. Since the operation of SRAM access belongs to the first pipeline stage of our design, we divide the remaining denoising steps into 6 pipeline stages evenly to keep the propagation delay of each pipeline stage around 6 ns. The pseudo code and the RTL schematic (Fig2) we obtained is given below

Pseudo code

```
for(i=0; i<row; i=i+1)  /* input image size: row(height) × col(width) */

{
   for(j=0; j<col; j=j+1)
    {

 / * Extreme Data Detector * /
            Get W, the 3×3 mask centered on (i, j);
          Find MINinW and MAXinW in W;
/ * the minimum and maximum values from the first W to current W * /
$\varphi$=0;                                             / * initial values * /
if (($f_{i,j}$ = MINinW) or ($f_{i,j}$ = MAXinW))
$\varphi$=1;                                             / * $P_{i.j}$ is suspected to be a noisy pixel * /
if($\varphi$=0)
{
$\hat{f}_{i,j}$ = $f_{i,j}$;
break;                                          / * $P_{i,j}$ is a noise-free pixel * /
}
B = $b_1b_2b_3b_4b_5$ = “00000”;                  / * initial values * /
if (($f_{i,j-1}$ = MINinW) or ($f_{i,j-1}$ = MAXinW))
$b_1$=1;                                          / * $P_{i,j-1}$ is suspected to be a noisy pixel * /
if (($f_{i,j+1}$ = MINinW) or ($f_{i,j+1}$ = MAXinW))
$b_2$=1;                                          / * $P_{i,j+1}$ is suspected to be a noisy pixel * /
if (($f_{i+1,j-1}$ = MINinW) or ($f_{i+1,j-1}$ = MAXinW))
$b_3$=1;                                          / * $P_{i+1,j-1}$ is suspected to be a noisy pixel * /
if (($f_{i+1,j}$ = MINinW) or ($f_{i+1,j}$ = MAXinW))
$b_4$=1;                                          / * $P_{i+1,j}$ is suspected to be a noisy pixel * /
if (($f_{i+1,j+1}$ = MINinW) or ($f_{i+1,j+1}$ = MAXinW))
$b_5$=1;                                          / * $P_{i+1,j+1}$ is suspected to be a noisy pixel * /

/ * Edge-Oriented Noise Filter * /
Use B to determine the chosen directions across $P_{i,j}$ according to figure 4.;
if(B=”11111”)
 $\hat{f}_{i.j} = (\hat{f}_{i-1,j-1} + 2 \times \hat{f}_{i-1,j} + \hat{f}_{i-1,j+1})/4$;    / * no edge is considered * /
else
{
Find $D_{min}$ (the smallest directional difference among the chosen directions);
 $\hat{f}_{i.j}$ = the mean of luminance values of the two pixels which own $D_{min}$
```

```
}
/ * Impulse Arbiter * /
if($|f_{i,j} - \hat{f}_{i,j}| > T_s$)
        $\bar{f}_{i,j} = \hat{f}_{i,j}$;                    / * $P_{i,j}$ is judged as a noisy pixel * /
else
$\bar{f}_{i,j} = f_{i,j}$;                    / * $P_{i,j}$ is judged as a noise-free pixel *
   }
}
```

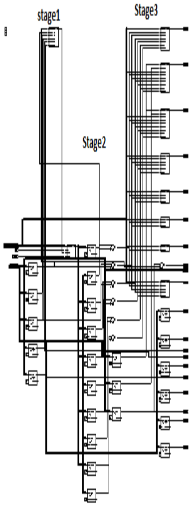


Fig2. RTL Schematic of EODT

3.1 Extreme data Detector

The extreme data detector detects the minimum and maximum luminance values (MIN in W and MAX in W) in those processed masks from the first one to the current one in the image. If a pixel is corrupted by the fixed value impulse noise, its luminance value will jump to be the minimum or maximum value in gray scale. If ($f_{i,j}$) is not equal to (MIN in W and MAX in W) , we conclude that ($P_{i,j}$)is a noise-free pixel and the following steps for de-noising ($P_{i,j}$) are skipped.
If $f_{i,j}$ is equal to MINinW or MAXinW, we set $\varphi=1$, check whether its five neighboring pixels are equal to the extreme data and store the binary compared results into B.

3.2 Edge-oriented noise filter

To locate the edge existed in the current W, a simple edge catching technique which can be realized easily with VLSI circuit is adopted. To decide the edge, we consider 12 directional differences, from D1toD2, as shown in fig 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 according to the variation in angle.

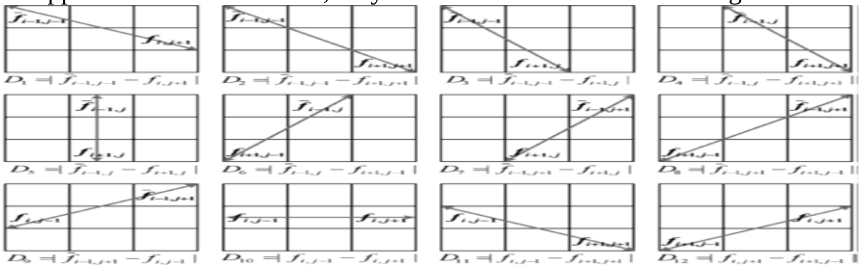
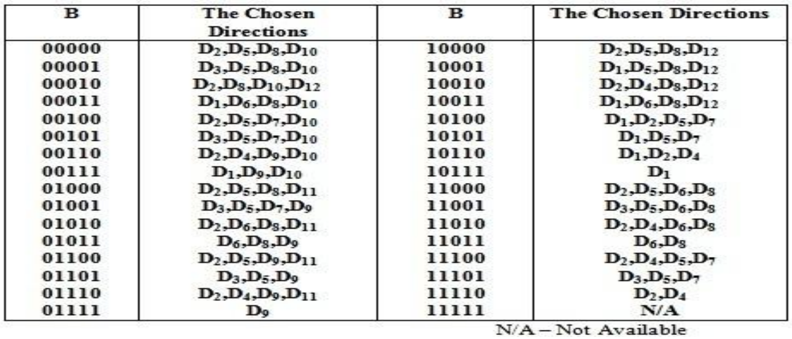


Fig3. 12 Directional difference of EODT



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

Table1. Thirty two possible values of B and their corressponding directions.

Table 1 shows the mapping table between 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 edge can 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 $\hat{f}_{i.j} = (\bar{f}_{i-1,j-1} + 2 \times \bar{f}_{i-1,j} + \bar{f}_{i-1,j+1})/4$.

The smallest directional difference implies that it has the strongest spatial relation with, 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 $\hat{f}_{i.j}$.

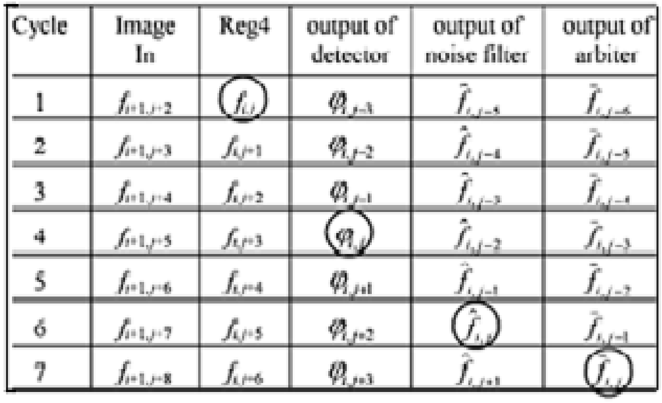
3.3 Impulse arbiter

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 MINinW or MAXinW. However, the conversion 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 other words, a pixel whose value is MINinW or MAXinW might be identified as 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 value is MINinW or MAXinW if $|f_{i,j} - \hat{f}_{i.j}|$ is small.

We measure $|f_{i,j} - \hat{f}_{i.j}|$ 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 proposed method.

A more appropriate threshold can achieve a better detection result. However, it is not easy to derive an optimal threshold through analttic formulation. According to our experimental result, we set the threshold T_s as 20. If $P_{i,j}$ is judged as a corrupted pixel, the reconstructed luminance value $f_{i,j} = \hat{f}_{i.j}$. The part of the scheduling of EODT is shown in Table 2.

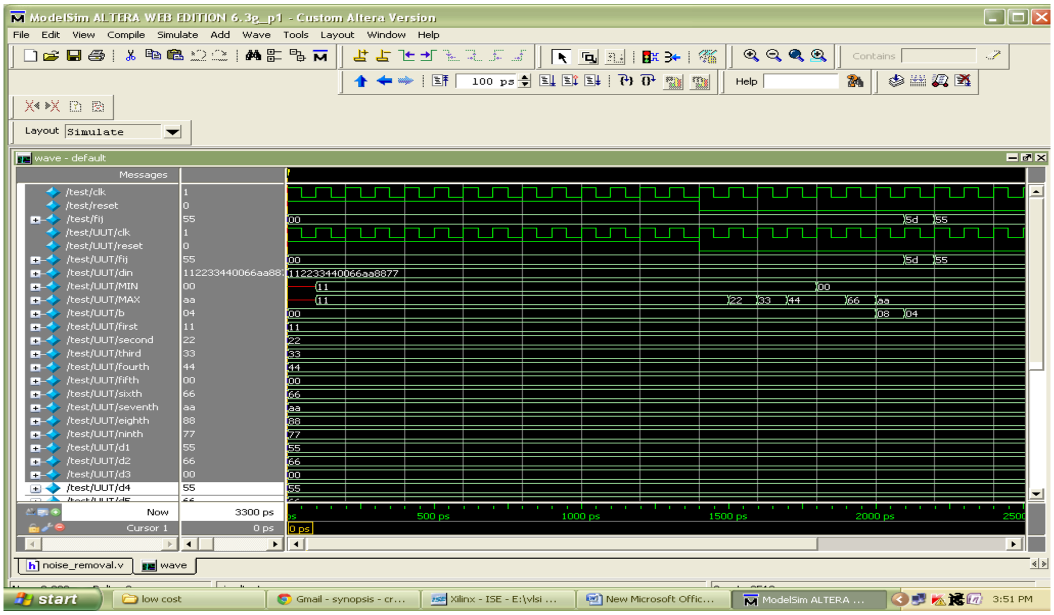


Cycle	Image In	Reg4	output of detector	output of noise filter	output of arbiter
1	$f_{i+1,j+2}$	$f_{i,j}$	$\varphi_{i,j-3}$	$\hat{f}_{i,j-5}$	$\hat{f}_{i,j-6}$
2	$f_{i+1,j+3}$	$f_{i,j+1}$	$\varphi_{i,j-2}$	$\hat{f}_{i,j-4}$	$\hat{f}_{i,j-5}$
3	$f_{i+1,j+4}$	$f_{i,j+2}$	$\varphi_{i,j-1}$	$\hat{f}_{i,j-3}$	$\hat{f}_{i,j-4}$
4	$f_{i+1,j+5}$	$f_{i,j+3}$	$\varphi_{i,j}$	$\hat{f}_{i,j-2}$	$\hat{f}_{i,j-3}$
5	$f_{i+1,j+6}$	$f_{i,j+4}$	$\varphi_{i,j+1}$	$\hat{f}_{i,j-1}$	$\hat{f}_{i,j-2}$
6	$f_{i+1,j+7}$	$f_{i,j+5}$	$\varphi_{i,j+2}$	$\hat{f}_{i,j}$	$\hat{f}_{i,j-1}$
7	$f_{i+1,j+8}$	$f_{i,j+6}$	$\varphi_{i,j+3}$	$\hat{f}_{i,j+1}$	$\hat{f}_{i,j}$

Table 2: Part of the scheduling of EODT

From Table 2 it is clear that one clock cycle is required to fetch the pixel from register bank, and three clock cycles are required for extreme data detector and 2 clock cycles needed for edge oriented noise filter and finally impulse arbiter needs one clock cycle to provide the result.

4. Simulation Results:



```
/test/clk            1
/test/reset          0
/test/fij            55
/test/UUT/clk        1
/test/UUT/reset      0
/test/UUT/fij        55
/test/UUT/din        112233440066aa88
/test/UUT/MIN        00
/test/UUT/MAX        aa
/test/UUT/b          04
/test/UUT/first      11
/test/UUT/second     22
/test/UUT/third      33
/test/UUT/fourth     44
/test/UUT/fifth      00
/test/UUT/sixth      66
/test/UUT/seventh    aa
/test/UUT/eighth     88
/test/UUT/ninth      77
/test/UUT/d1         55
/test/UUT/d2         66
/test/UUT/d3         00
/test/UUT/d4         55
Now                  3300 ps
Cursor 1             0 ps
```

Fig4: simulation results

If the current part of the image is corrupted by fixed value of impulse noise then the value will jump either to the minimum or to the maximum in gray scale. So in our approach we are considering the minimum value pixel is a noisy pixel. For example if the values of nine pixels of corrupted part of the image are 11_22_33_44_00_66_AA_88_77 then we assume 5th pixel is noisy as shown in Fig 4. So now we will take the average values of its neighboring pixels. Here neighboring pixels are having the values 44 and 66 (in hexadecimal) first these two pixels are added and then divided by 2. That is 66+44=AA, when AA divided by 2 will get 55. This new value will be restored in the place of corrupted pixel.

5. FUTURE WORK

In EODT we are using 12 directional differences and it's quite difficult to understand and more time consuming. This problem can be solved out by introducing new technology called Reduced EODT. This technique uses only 3 directional differences and only 5 clock cycles are needed to complete the process. But due to only three directional differences the image quality may not be as good as EODT

6. CONCLUSION

In this paper, an efficient removal of impulse noise using pipelined ADC is presented. The extensive experimental results demonstrate that our design achieves excellent performance in terms of quantitative evaluation and visual quality, even the noise ratio is as high as 90%. For real-time applications, a7-stage pipeline architecture for EODT is developed and implemented. As the outcome demonstrated, EODT outperforms other chips with the lowest hardware cost. The architectures work with monochromatic images, but they can be extended for working with RGB colour images and videos.

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Prof. Manju Devi

Working as an Associate Professor in the department of ECE at BTLIT,B’lore. Almost sixteen years of teaching experience in engineering colleges. Completed B.E in Electronics and Communication Engg. ,M.Tech in Applied Electronics and pursuing Ph.D from VTU in the field of analog and mixed mode VLSI.

Dr K.N.Muralidhara:

Obtained his B.E. In E&C engg from PES college of Engg , Mandya during 1981, ME during 1987from and Ph.D during 2002 from University of Roorkee. His field of interest is on semiconductor devices and presently working as professor and Head at the Dept. He is guiding 5 candidates for Ph.D programme and actively participated in all the developmental activities of the college. He has about 25 publications to his credit.

Prasanna R Hegde

Obtained B.E in Electronics and Communication Engineering from BTLIT in 2012. His field of interest is on Digital electronics and VLSI. Actively participated in National and International level conferences. Student member of IETE.