A NEW CONTENT BASED MEDIAN FILTER

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ABSTRACT

In this paper the hardware implementation of a content based median filter suitable for real-time impulse noise suppression is presented. The function of the proposed circuitry is adaptive; it detects the existence of impulse noise in an image neighborhood and applies the median filter operator only when necessary. In this way, the blurring of the image in process is avoided and the integrity of edge and detail information is preserved. The proposed digital hardware structure is capable of processing gray-scale images of 8-bit resolution and is fully pipelined, whereas parallel processing is used to minimize computational time. The architecture presented was implemented in FPGA and it can be used in industrial imaging applications, where fast processing is of the utmost importance. The typical system clock frequency is 55 MHz.

1. INTRODUCTION

Two applications of great importance in the area of image processing are noise filtering and image enhancement [1]. These tasks are an essential part of any image processor, whether the final image is utilized for visual interpretation or for automatic analysis. The aim of noise filtering is to eliminate noise and its effects on the original image, while corrupting the image as little as possible. To this end, nonlinear techniques (like the median and, in general, order statistics filters) have been found to provide more satisfactory results in comparison to linear methods. Impulse noise exists in many practical applications and can be generated by various sources, including a number of man made phenomena, such as unprotected switches, industrial machines and car ignition systems. Images are often corrupted by impulse noise due to a noisy sensor or channel transmission errors. The most common method used for impulse noise suppression for gray-scale and color images is the median filter (MF) [2]. The basic drawback of the application of the MF is the blurring of the image in process. In the general case, the filter is applied uniformly across an image, modifying pixels that are not contaminated by noise. In this way, the effective elimination of impulse noise is often at the expense of an overall degradation of the image and blurred or distorted features [3].

In this paper an intelligent hardware structure of a content based median filter (CBMF) suitable for impulse noise suppression is presented. The function of the proposed circuit is to detect the existence of noise in the image window and apply the corresponding MF only when necessary. The noise detection procedure is based on the content of the image and computes the differences between the central pixel and the surrounding pixels of a neighborhood. The main advantage of this adaptive approach is that image blurring is avoided and the integrity of edge and detail information are preserved [4, 5]. The proposed digital hardware structure is capable of processing gray-scale images of 8-bit resolution and performs both positive and negative impulse noise removal. The architecture chosen is based on a sequence of four basic functional pipelined stages, and parallel processing is used within each stage. A moving window of a 3×3 and 5×5-pixel image neighborhood can be selected. However, the system can be easily expanded to accommodate windows of larger sizes. The proposed structure was implemented using field programmable gate arrays (FPGA). The digital circuit was designed, compiled and successfully simulated using the MAX+PLUS II Programmable Logic Development System by Altera Corporation. The EPF10K200SFC484-1 FPGA device of the FLEX10KE device family was utilized for the realization of the system. The typical clock frequency is 55 MHz and the system can be used for real-time imaging applications where fast processing is required [6]. As an example, the time required to perform filtering of a gray-scale image of 260×244 pixels is approximately 10.6 msec.

2. ADAPTIVE FILTERING PROCEDURE

The output of a median filter at a point x of an image f depends on the values of the image points in the neighborhood of x. This neighborhood is determined by a window W that is located at point x of f including n points $x_1, x_2, \dots, x_n$ of f, with $n=2k+1$. The proposed adaptive content based median filter can be utilized for impulse noise suppression in gray-scale images. A block diagram of the adaptive filtering procedure is depicted in Fig. 1. The noise detection procedure for both positive and negative noise is as follows:

(i) We consider a neighborhood window W that is located at point x of the image f. The differences between the central pixel at point x and the pixel values of the n-1 surrounding points of the neighborhood (excluding the value of the central pixel) are computed.

(ii) The sum of the absolute values of these differences is computed, denoted as $f_{abs}(x)$. This value provides a measure of closeness between the central pixel and its surrounding pixels.

(iii) The value $f_{abs}(x)$ is compared to $f_{threshold}(x)$, which is an appropriately selected positive integer threshold value and can be modified. The central pixel is considered to be noise when the value $f_{abs}(x)$ is greater than the threshold value $f_{threshold}(x)$.

(iv) When the central pixel is considered to be noise it is substituted by the median value of the image neighborhood, denoted as f_{k+1}, which is the normal operation of the median filter. In the opposite case, the value of the central pixel is not altered and the procedure is repeated for the next neighborhood window.

From the noise detection scheme described, it should be mentioned that the noise detection level procedure can be controlled and a range of pixel values (and not only the fixed values of 0 and 255, salt and pepper noise) is considered as impulse noise.

In Fig. 2 the results of the application of the median filter and the CBMF in the gray-scale image "Peppers" are depicted. More specifically, in Fig. 2(a) the original, uncorrupted image "Peppers" is depicted. In Fig. 2(b) the original image degraded by 5% both positive and negative impulse noise is illustrated. In Figs 2(c) and 2(d) the resultant images of the application of median filter and CBMF for a 3×3-pixel window are shown, respectively. Finally, the resultant images of the application of median filter and CBMF for a 5×5-pixel window are presented in Figs 2(e) and 2(f). It can be noticed that the application of the CBMF preserves much better edges and details of the images, in comparison to the median filter.

A number of different objective measures can be utilized for the evaluation of these results. The most widely used measures are the Mean Square Error (MSE) and the Normalized Mean Square Error (NMSE) [1]. The results of the estimation of these measures for the two filters are depicted in Table I. For the estimation of these measures, the resultant images of the filters are compared to the original, uncorrupted image. From Table I it can be noticed that the MSE and NMSE estimated for the application of the CBMF are considerably smaller than those estimated for the median filter, in all the cases.

Table I. Similarity measures.

Filter	Impulse Noise 5%			
	MSE		**NMSE ($\times 10^{-2}$)**	
	3×3	5×5	3×3	5×5
Median	57.554	130.496	0.317	0.718
CBMF	35.287	84.788	0.194	0.467

3. HARDWARE ARCHITECTURE

The structure of the adaptive filter comprises four basic functional units, the *moving window unit*, the *median computation unit*, the *arithmetic operations unit*, and the *output selection unit*. The input data of the system are the gray-scale values of the pixels of the image neighborhood and the noise threshold value. For the computation of the filter output a 3×3 or 5×5-pixel image neighborhood can be selected. Image input data is serially imported into the first stage. In this way, the total number of the input pins are 24 (21 inputs for the input data and 3 inputs for the clock and the control signals required). The output data of the system are the resultant gray-scale values computed for the operation selected (8 pins).

The moving window unit is the internal memory of the system, used for storing the input values of the pixels and for realizing the moving window operation. The pixel values of the input image, denoted as "IMAGE_INPUT[7..0]", are imported into this unit in serial. For the representation of the threshold value used for the detection of a noise pixel 13 bits are required. For the moving window operation a 3×3 (5×5)-pixel serpentine type memory is used, consisting of 9 (25) registers. In this way, when the window is moved into the next image neighborhood only 3 or 5 pixel values stored in the memory are altered. The "en5×5" control signal is used

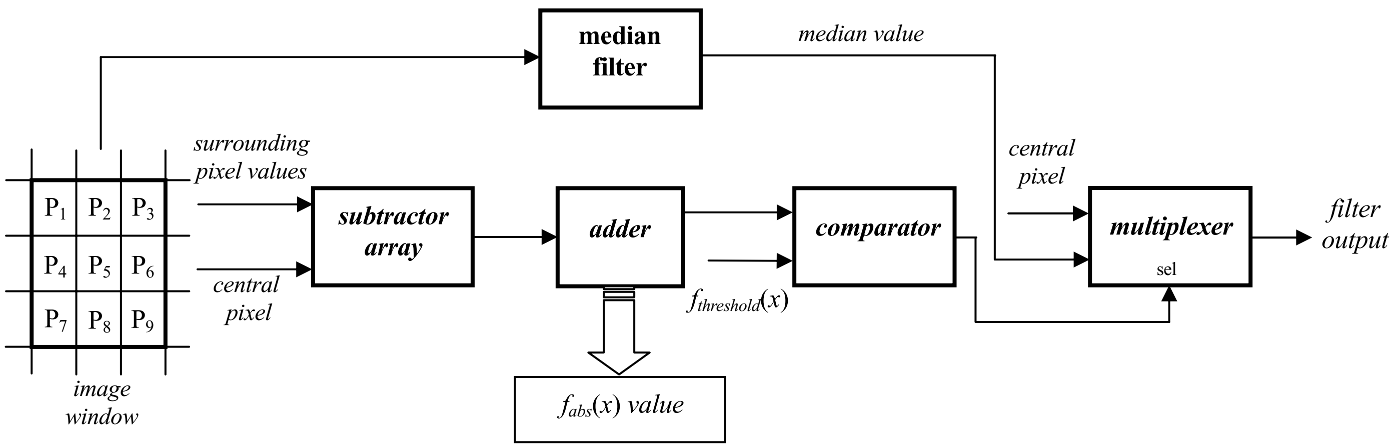

Figure 1: Block diagram of the filtering method.

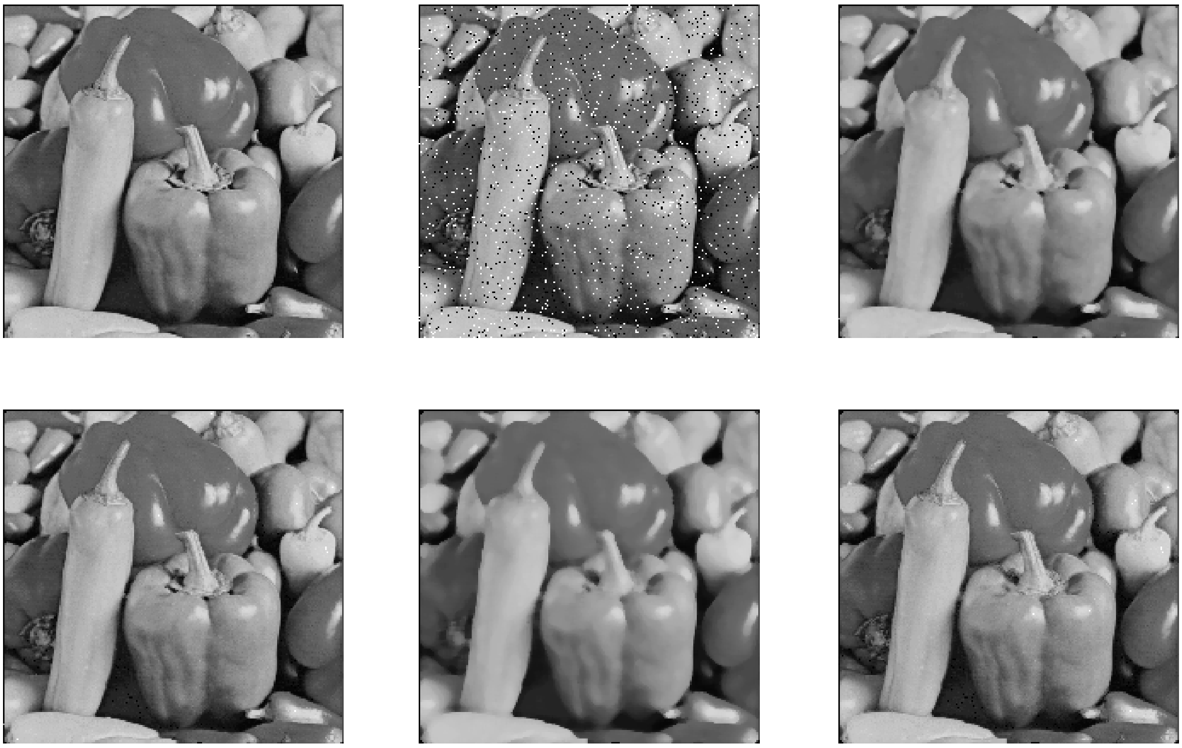

Figure 2: Results of the application of the CBMF: (a) Original image, (b) noise corrupted image (c) Restored image by a 3x3 MF, (d) Restored image by a 3x3 CBMF, (e) Restored image by a 5x5 MF and (f) Restored image by a 5x5 CBMF.

for the selection of the size of the image window, when "en5×5" is equal to "0" ("1") a 3×3 (5×5)-pixel neighborhood is selected. It should be mentioned that the modules of the circuit used for the 3×3-pixel window are utilized for the 5×5-pixel window as well. For these modules, 2-to-1 multiplexers are utilized to select the appropriate pixel values, where necessary. The modules that are utilized only in the case of the 5×5-pixel neighborhood are enabled by the "en5×5" control signal. The outputs of this unit are rows of pixel values (3 or 5, respectively), which are the inputs to the median computation unit.

The task of the median computation unit is to compute the median value of the image neighborhood in order to substitute the central pixel value, if necessary. For this purpose a 25-input sorter is utilized. The structure of the sorter has been proposed by Batcher and is based on the use of CS blocks. A CS block is a max/min module; its first output is the maximum of the inputs and its second output the minimum. The implementation of a CS block includes a comparator and two 2-to-1 multiplexers. The outputs values of the sorter, denoted as "OUT_0[7..0]"…. "OUT_24[7..0]", produce a "sorted list" of the 25 initial pixel values. A 2-to-1 multiplexer is used for the selection of the median value for a 3×3 or 5×5-pixel neighborhood.

The function of the arithmetic operations unit is to compute the value $f_{abs}(x)$, which is compared to the noise threshold value in the final stage of the adaptive filter. The inputs of this unit are the surrounding pixel values and the central pixel of the neighborhood. For the implementation of the mathematical expression of $f_{abs}(x)$, the circuit of this unit contains a number of adder modules. Note that registers have been used to achieve a pipelined operation. An additional 2-to-1 multiplexer is utilized for the selection of the appropriate output value, depending on the "en5×5" control signal. From the implementation point of view, the use of arithmetic blocks makes this stage hardware demanding.

The output selection unit is used for the selection of the appropriate output value of the performed noise suppression operation. For this selection, the corresponding noise threshold value calculated for the image neighborhood, "NOISE_THRESHOLD[12..0]", is employed. This value is compared to $f_{abs}(x)$ and the result of the comparison classifies the central pixel either as impulse noise or not. If the value $f_{abs}(x)$ is greater than the threshold value $f_{threshold}(x)$ the central pixel is positive or negative impulse noise and has to be eliminated. For this reason, the output of the comparison is used as the selection signal of a 2-to-1 multiplexer whose inputs are the central pixel and the corresponding median value for the image neighborhood. The output of the multiplexer is the output of this stage and the final output of the circuit of the adaptive filter.

The structure of the CBMF, the computation procedure and the design of the four aforementioned units are illustrated in Fig. 3.

4. IMPLEMENTATION ISSUES

The proposed structure was implemented in FPGA, which offer an attractive combination of low cost, high performance and apparent flexibility, using the software package+PLUS II of Altera Corporation. The FPGA used is the

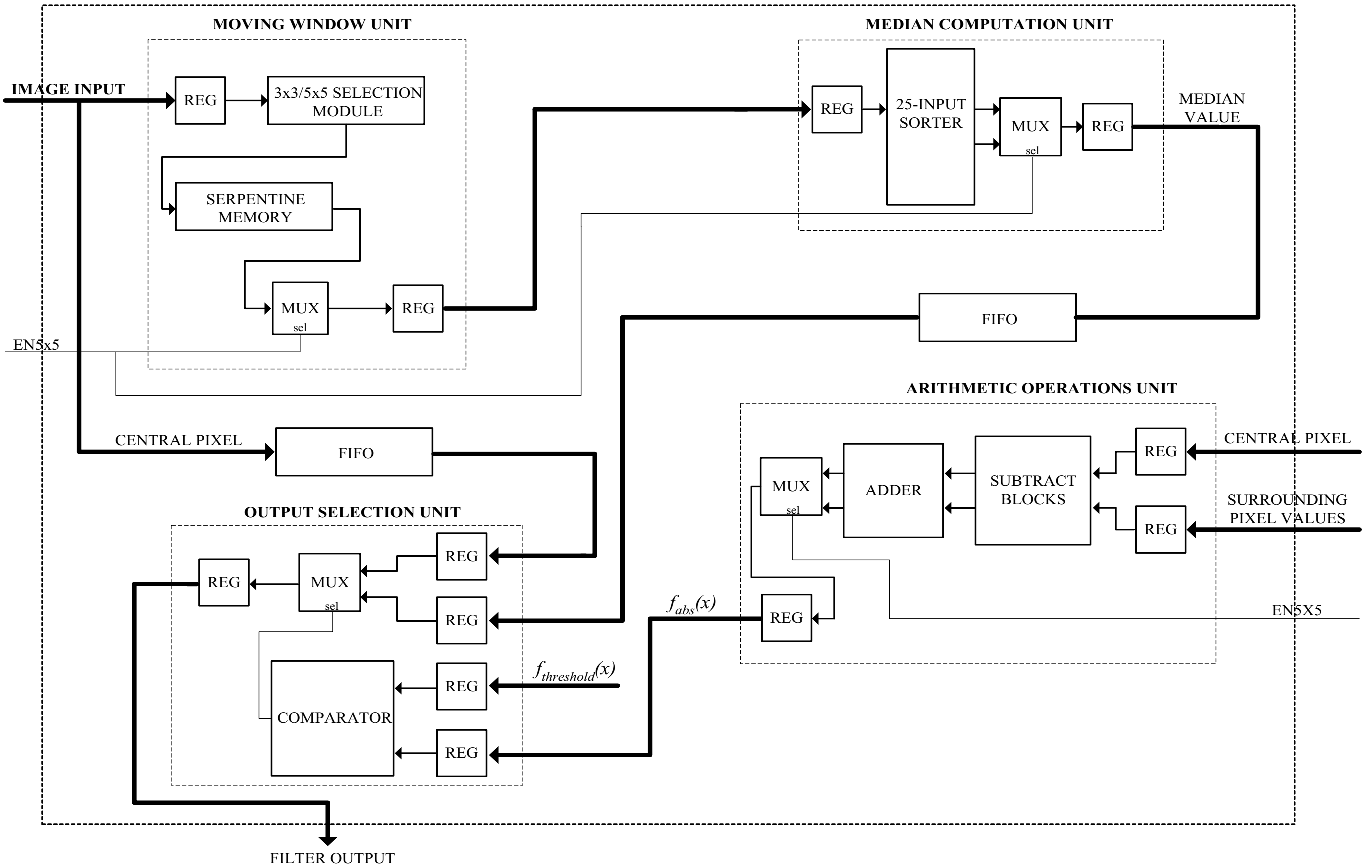

Figure 3: Structure of the hardware implementation of the proposed filter

EPF10K200SFC484-1 device of the FLEX10KE device family, a device family suitable for designs that require high densities and high I/O count. The 99% of the logic cells (9965/9984 logic cells) of the device was utilized to implement the circuit . The typical operating clock frequency of the system is 55 MHz. As a comparison, the time required to perform filtering of a gray-scale image of 260×244 pixels using Matlab® software on a Pentium 4/2.4 GHz computer system is approximately 7.2 sec, whereas the corresponding time using hardware is approximately 10.6 msec.

The modification of the system to accommodate windows of larger sizes can be done in a straightforward way, requiring only a small number of changes. More specifically, in the first unit the size of the serpentine memory and the corresponding number of multiplexers increase following a square law. In the second unit, the sorter module should be modified, and in the third unit the number of the adder devices increases following a square law. In the last unit no changes are required.

5. CONCLUSIONS

This paper presents a new hardware structure of a content based median filter, capable of performing adaptive impulse noise removal for gray-scale images. The noise detection procedure takes into account the differences between the central pixel and the surrounding pixels of a neighborhood. The proposed digital circuit is capable of processing gray-scale images of 8-bit resolution, with 3×3 or 5×5-pixel neighborhoods as options for the computation of the filter output. However, the design of the circuit is directly expandable to accommodate larger size image windows. The adaptive filter was designed and implemented in FPGA. The typical clock frequency is 55 MHz and the system is suitable for real-time imaging applications.

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