A MULTICHANNEL FILTER FOR TV SIGNAL PROCESSING

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Abstract— **A multichannel filtering approach is introduced here. The framework is used to correct impulsive noise and other image impairments in TV signal transmission. The principles behind the new filter is explained in detail. Simulation results indicate that the new filter offers some flexibility and has excellent performance.**

I. Introduction

Image filtering refers to the process of noise reduction in an image. As such, it utilizes the spatial properties of the image and is characterized by memory. Filtering is an important part of any image processing system whether the final image is utilized for visual interpretation or for automatic analysis [1].

Filtering of multichannel images has recently received increased attention due to its importance in the processing of color images. It is widely accepted that color conveys information about the objects in a scene and that this information can be used to further refine the performance of an imaging system. The generation of high quality color images which are aesthetically pleasing is of great interest.

Noise in the image sequence may result from sensor malfunction, electronic interference, or flaws in the data transmission procedure. In considering the signal-to-noise ratio over practical mediums, such as microwave or satellite links, there would be a degradation in quality due to the low received signal. Degradation of the broadcasting quality can be also a result of processing techniques, such as aperture correction which amplifies both high frequency signals and noise.

The appearance of the noise and its effect is related to its characteristics. Noise signals can be either periodic in nature or random. Usually noise signals introduced during the transmission process are random in nature resulting in abrupt local changes in the image data. These noise signals cannot be adequately described in terms of the commonly used Gaussian noise models [2]. Rather, they can be characterized as 'impulsive' sequences which occur in the form of short time duration, high energy spikes attaining large amplitudes with probability higher than the probability predicted by a Gaussian density model.

There are various sources that can generate impulsive noise. Among others, man made phenomena, such as car ignition systems, industrial machines in the vicinity of the receiver, switching transients in power lines and various unprotected electric switches. In addition, natural causes, such as lightning in the atmosphere and ice cracking in the antarctic region, also generate impulsive noise.

Impulsive noise is frequently encountered during the transmission of TV signals through *UHF*, *VHF*, terestial microwave links and FM satellite links. It is therefore important to develop a digital signal processing technique that can remove such image impairment in real-time and thus, guarantee the quality of service delivered to the consumers. Such a system is proposed here. A new two-stage multidimensional color filter is developed. The color filter is applied on-line on the digitized image frames in order to remove image noise.

A number of digital techniques have been applied to the problem aiming to smooth out impulsive noise and restore TV images. In [3], [4] a multi-shell median filter has been introduced. The approach introduced in [4] is applicable only to gray-scale images. Since the TV signal is a color signal, such an approach can be applied only to the luminance component of the transmitted signal without any reference or association to the corresponding chrominance signals. However, there is some indication that noise correlation among the different image channels exists in real color im-

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ages. Particularly, in the case of NTSC television broadcast signal, if there is any degradation of the chrominance signal that is broadcast, both the I and Q components would be affected simultaneously [5]. Therefore, noise removal operations on only one channel are not adequate and a multichannel filter is necessary to remove the noise and restore the originally transmitted signal.

II. A MULTICHANNEL FILTER FOR IMPULSIVE NOISE REDUCTION

Impulsive noise can be classified as a short duration, high energy spike which results in the alteration of the digital value of the image pixel. After the effect of the noise, the altered value of the image pixel usually differs from the corresponding values of the neighboring pixels. However, in TV signals, any kinds of scenes, pictures or images are transmitted. Thus, it is important for the filter to differentiate between impulsive noise and other image features such as, intended dots or thin lines in the image, which may resemble this kind of noise.

The class of median filters is considered the most appropriate for the removal of impulsive noise [1]. However, repeated applications of a median filter in a filtering window centered around a pixel of the image will probably remove the noise but will also reduce the resolution of the image by filtering out thin lines and details. Similarly, using a larger size of filtering window (e.g., 5×5 instead of 3×3) might result in better noise removal, but will blur the fine details of the image. Thus, to filter out noise and preserve image details a different approach is necessary.

A two stage adaptive median filter is introduced. As with any other nonlinear filter, a working area (window or template) is centered around an image pixel [1], [6]. To prevent thin lines and intended spots in the image from being altered through the nonlinear filtering process, we applied directional median filters inside the processing window. In other words, instead of a combined median filter applied to the whole window, four different median filters are applied across the four main directions at O^o, 45^o, 90^o, 135^o (see Fig. 1). Be aware that the pixel at the window center (pixel under consideration) belongs to all four sets. If the pixel under consideration has considerably larger or smaller values than those of the other pixels along a specific direction it will be treated as an outlier and it will be replaced by the median value across this specific direction. Otherwise the value remains unchanged during this operation. Thus, by employing filtering across the main directions, lines and other fine details will be preserved. In a second stage, another median operates on the four filtered results to generate the final output. The mathematical description of the filter can be summarized as follows:

Let $y(x)$: $Z^l \rightarrow Z^m$, represent a multichannel signal and let $W \in Z^l$ be a window of finite size $n \times n$ (square window with filter length n^2), where n is generally an odd number. The pixel under consideration $x_{i,j}$ is at the window center. The noisy vectors (n^2 in total) inside the window W are noted as (see Fig. 1):

$$x_{i+k,j+l} \qquad k,\ l = 0, \pm 1, \pm 2, \cdots, \pm\frac{(n-1)}{2} \tag{1}$$

The median filter applied along the 0^o direction operates on the horizontal pixels, across and including the center pixel $x_{i,j}$, noted as (see Fig. 1):

$$x_{i,j+l} \qquad l = 0, \pm 1, \pm 2, \cdots, \pm\frac{(n-1)}{2} \tag{2}$$

For simplification and clarity, let these vectors be $h_1 \dots h_n$ (h stands for horizontal direction). Now, according to standard vector median operation, a scalar distance d_p is associated with each vector h_p, $p = 1, \dots, n$, as follows:

$$d_p = \sum_{q=1}^{n} \|h_p - h_q\|_{L_1} \tag{3}$$

where $\|h_p - h_q\|_{L_1}$ is the L_1 *norm* or the *city block distance* between the vectors h_p and h_q. An ordering of the d_p's

$$d_{(1)} \leq d_{(2)} \leq \cdots \leq d_{(n)}, \tag{4}$$

implies the same ordering to the corresponding h_p's:

$$h_{(1)} \leq h_{(2)} \leq \cdots \leq h_{(n)}, \tag{5}$$

where, $h_{(p)}$ is the p^{th} order statistics [1]. The vector median y_1 along the 0^o direction is defined as:

$$y_1 = h_{(1)} \tag{6}$$

Similarly, the process is repeated for the other three directions. The vectors $f_p,\ p = 1,\ldots,n$ (f stands for 45° direction) representing those pixels along the 45° direction are (see Fig. 1):

$$x_{i-k,j+k} \qquad k = 0, \pm 1, \pm 2, \cdots, \pm\frac{(n-1)}{2} \qquad (7)$$

The vector median y_2 along the 45° direction is as follows:

$$y_2 = f_{(1)} \qquad (8)$$

For the 90° direction, the corresponding vectors $v_p,\ p = 1,\ldots,n$ (v stands for vertical, i.e. 90° direction) are (see Fig. 1):

$$x_{i-k,j} \qquad k = 0, \pm 1, \pm 2, \cdots, \pm\frac{(n-1)}{2} \qquad (9)$$

The vector median y_3 along the 90° direction is given as:

$$y_3 = v_{(1)} \qquad (10)$$

Finally, the vectors $r_p,\ p = 1,\ldots,n$ (r stands for reverse 45°, i.e. 135° direction) representing those pixels along the 135° direction are (see Fig. 1):

$$x_{i-k,j-k} \qquad k = 0, \pm 1, \pm 2, \cdots, \pm\frac{(n-1)}{2} \qquad (11)$$

The vector median y_4 along the 135° direction is defined as: of the ordered sequence of vectors r_p:

$$y_4 = r_{(1)} \qquad (12)$$

In the second stage, a vector median filter is applied to the four vector median outputs y_1, y_2, y_3 and y_4 obtained in the directional filtering of the previous stage. Hence, the final output x_{DVMF} of this Directional Vector Median Filter (DVMF) is derived as:

$$x_{DVMF} = y_{(1)} \qquad (13)$$

where, $y_{(1)}$ is the first order statistic of the ordered sequence of vectors $y_p,\ p = 1,\ldots,4$.

This new Directional Vector Median Filter (DVMF) is applied to different color images, namely Lenna, Pepper and Lake to assess qualitatively the performance. First, the original images are corrupted with 4% impulsive noise and 50% noise correlation between the Red, Green, and Blue channels using an appropriate noise generator [1]. Then, the DVMF, with a window size of 3 × 3 (small window), is applied to the corrupted images and the filtered output images are displayed and compared visually with the original images. In all three images, no impulsive noise is visible. In addition, all the edge information, thin lines and fine details, are well preserved.

III. Removal of Missing Lines

An additional motivation to introduce directional filtering, is the presence of missing lines in TV signals in addition to impulsive noise which have been observed to be a common problem in TV signals transmitted over satellite or microwave links. Usually, the signal along a horizontal line of one pixel width will be lost and appears as either a white or black line along the image. In other words, these lines appear like continuous impulsive noise along the horizontal direction. On a single frame (image), normally, around one or more such lines can appear. Since, such lines are horizontal and, most of the time, have a width of one pixel, the horizontal direction filtering within the filtering window W is not considered in such cases. Therefore, the DVMF for images having missing lines is re-defined as:

$$y_1 = f_{(1)} \qquad (14)$$

$$y_2 = v_{(1)} \qquad (15)$$

$$y_3 = r_{(1)} \qquad (16)$$

$$x_{DVMF} = y_{(1)} \qquad (17)$$

where, $f_{(1)}$, $v_{(1)}$ and $r_{(1)}$ are the first order statistics of the ordered vector sequences f_p, v_p and r_p respectively as before, and $y_{(1)}$ is the first order statistics of the ordered sequence of vectors $y_p,\ p = 1,\ldots,3$.

Two types of simulations are made to assess the performance of this modified DVMF for removing missing lines. First, only some missing lines are inserted at random positions in the original image without adding any impulsive noise and the filter is then applied. Results showed that the missing lines are perfectly removed and nothing atypical could be visually detected on those locations where those lines were introduced (Figs. 2-3).

In order to examine the robustness of the proposed filter, an extreme case was investigated in another simulation experiment by adding 4% impulsive noise to the random missing line. Again, the filter performed well in removing the impulsive noise as well as the missing lines. However, at some positions where missing lines existed, the filter failed to remove the noise completely and few pixels with impulsive noise are visible. This could be attributed to the fact that both missing lines and noisy pixels are contained within the filter window at those locations, and thus more than 50% of the pixel values are outliers. Since the break-down point ϵ^* of the median filter is 0.5 [1], the directional median filter failed to remove the noise when the filter window contained more than 50% outliers. Nevertheless, the results seem to be fairly acceptable for viewing (Figs. 4-5). If the impulsive noise percentage is around to 2%, an actual figure for most real systems, then the filter performance improved further and almost no noise could be detected visually.

IV. Comments

The proposed methodology can be applied online for any of the existing TV systems. Since it is a digital image processing technique, analog-to-digital (A/D) converters are necessary to transform the in-coming analog TV signal to its digital form. After that, a real-time digital signal processor board can be designed to implement the method.

Due to its inherent parallel structure and high regularity, the filter has regular computational structure, and can be implemented using array processors on VLSI hardware. Alternatively, a network of dedicated multiple microprocessors can be devised for its implementation.

Each of the block in Fig. 6 can be implemented using an odd-even transportation network suitable for VLSI implementation. The two fundamental blocks required for its implementation are delays (T) and compare-and-swap (CS) circuits. The VLSI structure for median filtering of 3 elements and 5 elements are depicted in Fig. 7.

V. Conclusions

A new adaptive filter was introduced in this paper. The new filter perfectly suitable for real time implementation was used to remove impulsive noise and other impairment from color TV signals. Experimental results have been used to illustrate our discussion and to demonstrate the effectiveness of our method. In addition, we have outlined its hardware implementation which makes the proposed solution particularly attractive. With the advent of the all-digital TV system, such filters can lead to systems which would retain accurate image reproduction fidelity despite any unforeseen transmission developments.

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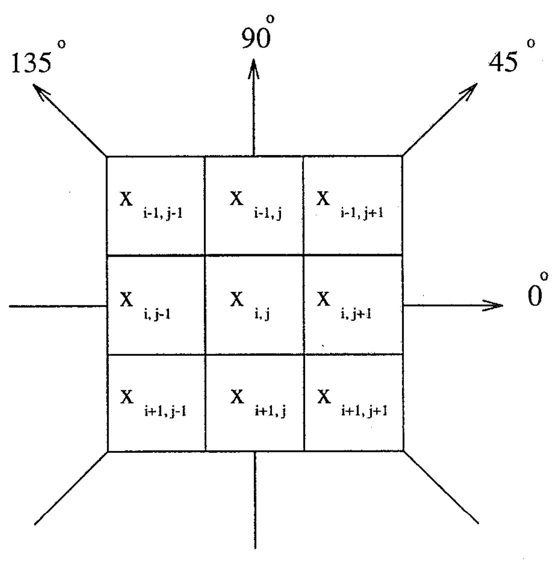

Fig. 1. The New Filter

Fig. 2. Lenna image with missing line

Fig. 4. Corrupted image (4% impulsive noise and missing line

Fig. 3. Filtered result of (2)

Fig. 5. Filtered result of (4)

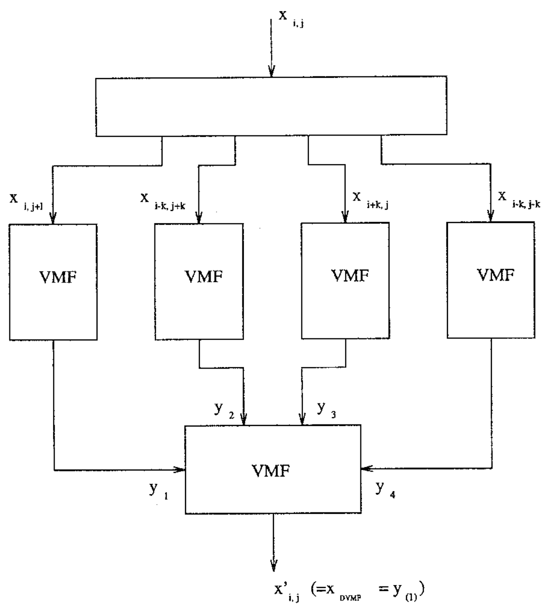

Fig. 6. Parallel Implementation

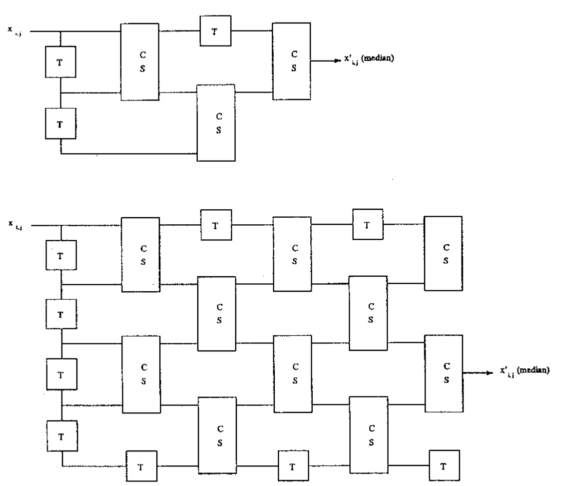

Fig. 7. Circuit implementation of the median filter (3x3) or (5x5)

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