Impulse Noise removal in Digital Images

[1]M.JayaManmadhaRao, [2]S.Anuradha, [3]Dr. KVVS Reddy

[1]Professor, Department of EIE, AITAM, Tekkali
[2]Assistant professor, Department of ECE, NIT Warangal
[3]Professor, Department of ECE, AU College of Engineering, Andhra University

Abstract:

In this paper, we introduce a new class of filter, the modified spatial median filter (MSMF) for the removal of impulse noise in digital images. The proposed filter is compared with four different filtering algorithms based on their ability to reconstruct noise-affected images. In-order to better appraise the noise cancellation behavior of our filter from the point of view of human perception, we perform edge detection using canny filter. Experimental results show that the filtering performance of the proposed approach is very satisfactory.

Keywords: Impulse noise, image enhancement, image restoration, image processing.

Introduction

Order statistics filters exhibit better performance as compared to linear filters when restoring images corrupted by impulse noise. Impulse noises are short duration noises which degrade an image. They may occur during image acquisition, due to switching, sensor temperature. They may also occur due to interference in the channel and due to atmospheric disturbances during image transmission.

The goal of the filtering action is to cancel noise while preserving the integrity of edge and detail information. In this paper, a new filter MSMF is introduced and compared with current image smoothing techniques. The color image is processed by first converting it from RGB to YIQ domain. Then, the filter is applied only to the chrominance (I and Q) component of YIQ domain and the filtered image is converted from YIQ into RGB domain.

The rest of the paper is organized as follows. Section II presents conversion of color image from RGB to YIQ domain, Section III presents six different smoothing filters, Section IV presents the modified spatial median filter (MSMF), and Section V discusses the experimental results and finally Section VI report conclusions.

Conversion from RGB to YIQ

A color image is usually represented in the RGB color space, because most of the computer input and output devices use this color system. Each vector consists of three components, which are the intensity values in the red, green and blue channel. The combination of these values delivers one particular color. The early approaches to color image processing are performed by processing each RGB components separately. A disadvantage of these methods is the loss of correlation between the color channels resulting in color shifts [1,2]. That is a substitution of a noisy pixel color through a new false color, which does not fit into the local neighborhood. This means that a noisy pixel is replaced by another noisy pixel. Other color systems like YIQ and HLS represent the color image according to the human visual perceptual attributes (luminance, hue and saturation) are often useful, since many color image processing tasks such as enhancement and filtering, require that only the color information components be processed leaving the luminance component. In our work, the YIQ system is used to process color image. The conversion from RGB to YIQ and YIQ to RGB is given as follow:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{pmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Figure: 1 Conversion from RGB to YIQ

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{pmatrix} 1 & 0.9563 & 0.6210 \\ 1 & -0.2721 & -0.6474 \\ 1 & -1.1070 & 1.7046 \end{pmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

Figure: 2 Conversion from YIQ to RGB

Smoothing Filters

The simplest of the smoothing algorithms is the mean filter as defined in (1). The mean filter is a linear filter which uses a mask over each pixel in the signal. Each of the components of the pixels which fall under the mask are averaged together to form a single pixel. This new pixel is then used to replace the signal.

$$\mathrm{MEAN}(x_1, x_2, \ldots\ldots x_N) = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad (1)$$

The mean filter is poor at maintaining edges within the image.

The median filter is performed by taking the magnitude of all the vectors within a mask, sorting the magnitudes and returns the middle magnitude value defined in (2). The pixel with the median magnitude is used to replace the pixel in the signal studied.

$$\text{MEDIANFILTER}(x_1,x_2,\ldots\ldots x_N) = \text{MEDIAN}(x_1,x_2,\ldots\ldots x_N) \qquad (2)$$

The median filter is more robust with respect to the presence of noise and has an advantage over the median filter. When filtering using the median filter, an original pixel and the resulting filtered pixel of the sample studied are sometimes the same pixel.

In the vector median filter (VMF) [3] for the ordering of the vectors in a particular kernel or mask a suitable distance measure is chosen. The vector pixels in the window are ordered on the basis of the sum of the distances between each vector pixel and the other vector pixels in the window. The sum of the distances is arranged in the ascending order and then the same ordering is associated with the vector pixels. The vector pixel with the smallest sum of distances is the vector median pixel. The vector median filter is represented as

$$X_{VMF} = \text{vectormedian (W)} \qquad (3)$$

If δ_i is the sum of the distances of the i^{th} vector pixel with all the other vectors in the kernel, then

$$\delta_i = \sum_{j=1}^{N} \Delta(X_i, X_j) \qquad (4)$$

where $(1 \le i \le N)$ and X_i and X_j are the vectors, N=9.

$\Delta(X_i, X_j)$ is the distance measure given by the $L1$ norm or the city block distance which is more suited to non correlated noise. The ordering may be illustrated as

$$\delta_1 \le \delta_2 \le \delta_3 \le \ldots, \le \delta_9 \qquad (5)$$

and this implies the same ordering to the corresponding vector pixels i.e.

$$X_{(1)} \le X_{(2)} \le \ldots, \le X_{(9)} \qquad (6)$$

where the subscripts are the ranks. Since the vector pixel with the smallest sum of distances is the vector median pixel, it will correspond to rank 1 of the ordered pixels, i.e.,

$$X_{VMF} = X_{(1)} \qquad (7)$$

The VMF does not consider if the current pixel is original data or not. The disadvantage to replacing every point is that original data is sometimes overwritten.

The spatial median filter (SMF) [4] is a uniform smoothing algorithm with the purpose of removing noise and fine points of image data while maintaining edges around larger shapes. The SMF is based on the spatial median quantile function which is a L_1 norm metric that measures the difference between two vectors. The spatial depth between a point and a set of points is defined by

$$S_{depth}(X,x_1,x_2,\ldots\ldots x_N) = 1 - \frac{1}{N-1}\left\|\sum_{i=1}^{N}\frac{X - xi}{\|X - xi\|}\right\| \qquad (8)$$

Let $r_1,r_2,\ldots r_N$ represent $x_1,x_2,\ldots x_N$ in rank order such that

$$\begin{aligned} & S_{depth}(r_1,x_1,x_2,\ldots\ldots x_N) \\ \ge\ & S_{depth}(r_2,x_1,x_2,\ldots\ldots x_N) \\ \ge\ & \\ \ge\ & S_{depth}(r_N,x_1,x_2,\ldots\ldots x_N) \qquad (9) \end{aligned}$$

and let r_c represent the center pixel under the mask . Then

$$\text{SMF}(x_1,x_2,\ldots\ldots x_N) = r_1 \qquad (10)$$

The SMF is an unbiased smoothing algorithm and will replace every point that is not the maximum spatial depth among its set of mask neighbors.

ModifiedSpatialMedianFilter

In the Modified Spatial Median Filter, we first calculate the spatial depth of every point within the mask and then sort these spatial depths in descending order. After the spatial depth of each point within the mask is computed, an attempt is made to use this information to first decide if the mask's center point is an uncorrupted point. If the determination is made that a point is not corrupted, then the point will not be changed. If the point is corrupted, then the point is replaced with the point with the largest spatial depth.

We can prevent some of the smoothing by looking for the position of the center point in the spatial order statistic. Let us consider a parameter P (where $1 \le P \le N$, where N represents numbers of points in the mask), which represents the estimated number of original points under a mask of points. If the position of the center mask point appears within the first P ranks of the spatial order statistic, then we can argue that while the center point is not the best representative point of the mask, it is likely to be original data and should not be replaced. The MSMF is defined by

$$\text{MSMF}(T,x_1,x_2,\ldots\ldots x_N) = \begin{cases} r_c & c \le P \\ r_1 & c > P \end{cases} \qquad (11)$$

Experimental Results

This section presents the simulation results illustrating the performance of the proposed filter. The test image employed here is the true color image “parrot” with 290×290 pixels. To generate noise, a percentage of the image is damaged by changing a randomly selected point channel to a random value 0 to 255. The noise model I_n is given by

$$I_n = \begin{cases} I(i,j) & x \geq p \\ (I_r(i,j), Ig(i,j), z) \quad y < \frac{1}{3} & x < p \\ (I_r(i,j), z, I_b(i,j)) \quad \frac{1}{3} \leq y < \frac{2}{3} & x < p \\ (z, I_g(i,j), I_b(i,j)) \quad \frac{2}{3} \leq y & x < p \end{cases} \quad (12)$$

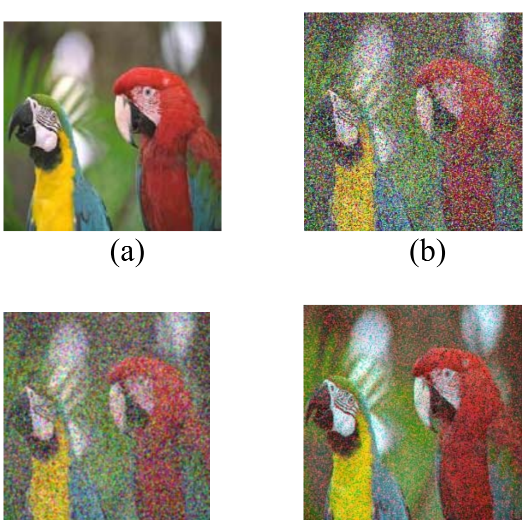
Where I is the original image, Ir, Ig and Ib represent the original red, green and blue component intensities of the original image, x,y ∈ [0,1] are continous uniform random numbers, z ∈ [0,255] is a discrete uniform random number and p ∈ [0,1] is a parameter which represents the probability of noise in the image.

The noise model was computer simulated. The performance of the MSMF filter is compared with the four filters shown in Table (1). All filters considered operate using 3×3 processing window. The performance of filters was evaluated by computing the mean square error (MSE) between the original image and filtered image as follow:

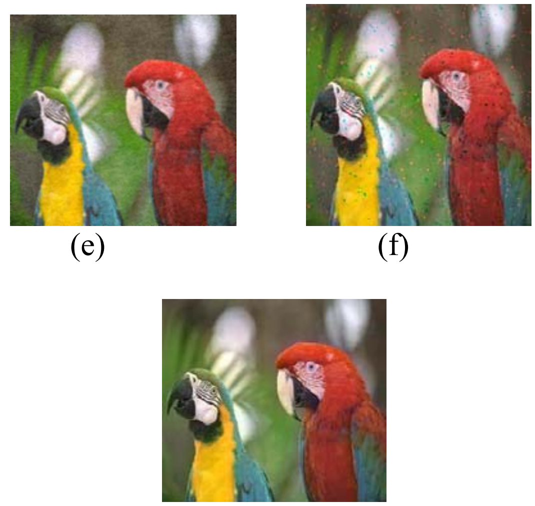
$$MSE = \left(\frac{1}{M}\right) \sum_{n \varepsilon F} (I(x,y) - I^1(x,y))^2 \quad (13)$$

Where F denotes the set of M processed pixels, I(x,y) denotes the vector pixel value in the original image and $I^1(x,y)$ denotes the vector pixel value in the filtered image.

Figure 3 shows the results of filtering the color image parrot which is corrupted by impulse noise. First the color image is converted from RGB to YIQ domain. The filters are applied for the removal of noise in I and Q components and the resultant image is converted from YIQ to RGB domain.



(a) (b) (c) (d)



(e) (f) (g)

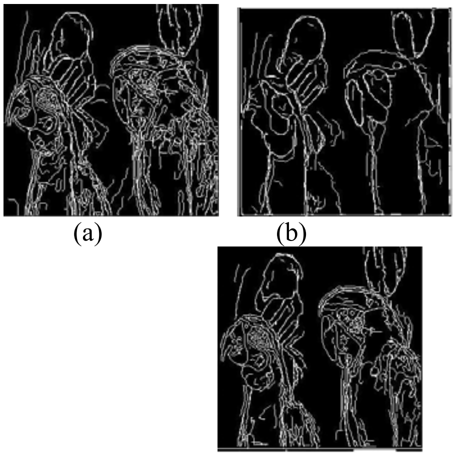
Figure 3 a) original image, b) impulse noise image corrupted by noise density 0.4, c) mean filter, d) median filter, e) vector median filter, f)spatial median filter and g) Proposed method(MSMF) with P=4.

Table (1) shows the results of MSE values of our proposed filter, compared with four different existing filters. As it can be seen, the minimum mean square error (MSE) was obtained by our proposed filtering approach.

Table 1: MSE values

IMAGES	MSE
Noise image	40.3457
Mean filter	31.3675
Median filter	24.2896
Vector median filter	18.4789
Spatial median filter	13.1356
MSMF	11.6743

Edges define the boundaries between regions in an image, which helps with segmentation and object recognition. In order to better appraise the noise cancellation behavior of our filter from the point of view of human perception, we perform edge detection mechanism for the MSMF filtered image. We used canny filter[5] for detection of edges in our "parrot" image. Figure 4 shows that our filter significantly reduces impulse noise and the image details have been satisfactorily preserved.



(a) (b) (c)

Figure 4. Edge detection using canny filter

a) Original noise free image b) Noise image c) Resultant image by our method

Conclusion

A new filter MSMF is proposed for removing impulse noise from digital images and shown how they compare to four well known techniques for noise removal. The MSMF performed the best over four noise removal techniques. This restoration of image data is very likely to find potential applications in a number of different areas such as electromagnetic imaging of objects, medical diagnostics, remote sensing, robotics, etc.

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