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Image Restoration - A Survey

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Abstract: *Image restoration is the process of restoring the degraded or corrupted image back to its original form. It is the initial step of image processing. Noise is added in the image while sending an image from one place to another via satellites, wireless, or during image acquisition process. There are various types of noises such as salt and pepper noise(impulse noise), Gaussian noise etc. The main goal of image restoration is to recover or improve the quality of an image, identifies the type of noise and attempts to reverse it. The restoration process improves the image by using a priori knowledge of the degradation process. The degradation process first identifies the type of noise, and then apply the inverse process to recover the corrupted image. In this paper various spatial domain filters are discussed which are used to remove noise from the images.*

I. Introduction

There are various factors which affect the quality of the image such as electrical interference during image acquisition, poor illumination etc. So the image restoration techniques are used to make the corrupted image as similar as that of the original image. Image enhancement is the process in which the degraded image is manipulated and the visual appearance of the image is improved. It increases the contrast of image and is subjective process. But image restoration is a more objective process than image enhancement.

In spatial domain methods, the technique operates directly on the pixels of an image. The spatial domain methods are used for removing additive noise only. The degradation/restoration process can be described as:

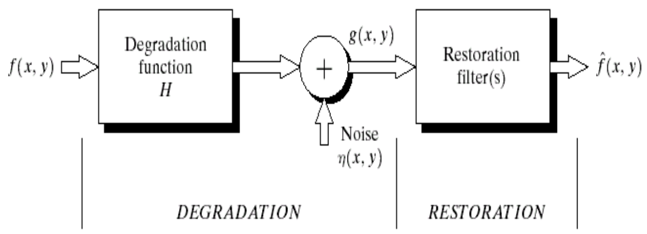

Fig.1. Shows the degradation/restoration model

This Fig.1 shows the original image f(x,y). The noise n(x,y) operates on input image and a degraded image g(x,y) is produced. The main aim of restoration process is to remove the degradation from the image and obtain the twin image $\hat{f}(x,y)$ of the original image. We want the output to be as same as possible to the original image. The Mathematical equation of Fig.1 is represented as follows, where h(x,y) is the function that causes distortion and n(x,y) is the noise. The symbol * represents convolution.

$$g(x,y) = h(x,y) * f(x,y) + n(x,y)$$

In the spatial space, we are intrigued by the parameters that characterize the spatial qualities of noise, and whether the noise is related with the picture/image.

This paper is organized as follows: Section II discusses various types of noise models and their respective PDF's (Probability Density Functions). In Section III, Spatial domain filters are explained. In section IV, Applications of filters are discussed. Conclusion is drawn in section V.

II. Various Noise Models.

The noise arises in an image due to various factors such as, while transmitting the images from one place to another or while image acquisition process. The other factors are sensor temperature, atmospheric problem, low/high light levels. These factors causes addition of various kind of noises in the image. The types of noises are discussed below:

A. Gaussian Noise : The Gaussian noise is also called normal noise and is occur most frequently. The Gaussian noise has random distributions of amplitudes over time. The probability density function of Gaussian noise[1] is given by :

$$p(z) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(-z-\mu)^2/2\sigma^2}$$

where z represents intensity , and σ is the standard deviation.

Gaussian noise arises in an image due to factors such as poor illumination/or high temperature and by electronic circuit noise. Gaussian noise is modelled by random values added to the image. It is caused by random disturbances or fluctuations in the signal.

B. Rayleigh Noise: The Rayleigh noise is basically found in range imaging. Range imaging is a collection of techniques which produces 2D images. Sometimes, the Rayleigh noise gets generated in 2D images. The probability density function of Rayleigh noise[1] is given by

$$p(z) = \begin{cases} \frac{2}{b}(z-a)e^{-\frac{(z-a)^2}{b}} & z \geq a \\ 0 & z < a \end{cases}$$

The mean and variance of Rayleigh noise density function is given by:

$z = a + \sqrt{\pi b/4}$ and $\sigma^2 = \frac{b(4-\pi)}{4}$

The Rayleigh density can be useful in approximating skewed histograms. The Rayleigh noise can also be found in Magnetic Resonance Imaging (MRI) which consist of medical images of human body.

C. Erlang (gamma) Noise: This type of noise affects Laser imaging. The Laser images are used to get 3D images with the help of laser. The images are captured by sensors which are mounted on laser. The PDF for Gamma noise[1] is:

$$p(z) = \begin{cases} \frac{a^b z^{b-1}}{(b-1)!}(z-a)e^{-az} & z \geq 0 \\ 0 & z < 0 \end{cases}$$

where a > 0 and b is a positive integer. The mean and variance of gamma density is given by:

$z = b/a$ and $\sigma^2 = \frac{b}{a^2}$

D. Exponential Noise: The Exponential noise occurs most frequently in LASER imaging which is a process of capturing 3D images. Exponential noise sometimes affect these 3D images too. The PDF of Exponential noise[1] is:

$p(z) = ae^{-az}$

where a>0. The mean and variance of this PDF is given by

$z = 1/a$ and $\sigma^2 = \frac{1}{a^2}$

E. Uniform Noise: The Uniform noise is caused by quantizing the pixels of a sensed image to a number of discrete levels. It is also called quantization noise. The PDF expression for Uniform noise[1] is given by :

$$p(z) = \begin{cases} \frac{1}{b-a}, & \text{for } a \leq z \leq b \\ 0 & , \text{ otherwise} \end{cases}$$

The mean and variance of uniform noise is given by

$z = a + b/2$ and $\sigma^2 = \frac{(b-a)^2}{2}$

Uniform noise is not encountered in real world imaging systems, but helps in providing a comparison with Gaussian noise.

F. Impulse Noise(Salt and Pepper Noise): The salt noise means scattering of white dots in the image and Pepper noise is scattering of black dots in the image. Impulse noise occurs when faulty switching takes place during imaging. The PDF of Impulse noise[1] is given by :

$$p(z) = \begin{cases} p_a, & z = a \\ p_b, & z = b \\ 0 & \text{otherwise} \end{cases}$$

The intensity of b appears as a white dot in the image, if b>a . Alternatively, the intensity of a appears as a black dot or dark dot if a>b. If either P_a=0 or P_b=0, then impulse noise is known as Unipolar. If neither P_a or P_b are zero, then the values of Impulse noise are as similar to salt and pepper values which are randomly distributed in the image.

III. Spatial Domain Filters For Noise Removal

The spatial domain filters are classified into three categories -Mean Filters, Order statistic Filters, Adaptive Filters. These filters perform different operations on different types of noises. The filters are used to remove noise and disturbances from the images. The Spatial domain filters are used to operate directly on the pixels of an image, whereas the Frequency domain filters operates on intensities of an image.

The spatial domain filters are very efficient. They require less number of resources. Such as a simple filter mask for a filter effect, So it is less expensive to perform filtering in spatial domain. Frequency domain filtering is more appropriate if no straight forward or simple mask can be found in spatial domain. The spatial domain filters are discussed below:

A .Mean Filters

I. Arithmetic Mean Filters: The Arithmetic mean filter is also called Linear Filter. It averages all the values of pixels within the window.

$^{1}/_{9}$	$^{1}/_{9}$	$^{1}/_{9}$
$^{1}/_{9}$	$^{1}/_{9}$	$^{1}/_{9}$
$^{1}/_{9}$	$^{1}/_{9}$	$^{1}/_{9}$

Fig.2 Rectangular Sub image window of size 3*3

In Fig.2, S_{xy} represent the set of coordinates in a sub image window of size 3*3 , centred at (x,y) . The arithmetic mean filter computes the average value of the corrupted image g(x,y) in S_{xy} .The value of the restored image at point (x,y) is the arithmetic mean computed in the region S_{xy}.
It replaces the centre pixel value with the output generated after averaging all the pixels.

II. Geometric Mean Filters: The Geometric mean filter is same as that of Arithmetic mean filter but it loses less image detail while processing the image, like when an arithmetic mean filter is applied, not only noise is removed but some of the image detail is also removed.
III. Harmonic Mean Filters: The harmonic mean filter is best suited for some kind of noise such as Gaussian noise and salt noise. It can give a true picture of average of a data.
IV. Contraharmonic Mean Filter: This filter is best for eliminating salt and pepper noise. It can't remove both the noises at the same time.
If we choose wrong values then the filter can behave as a dragon. The Fig A and Fig B shows [1] the negative impact of this filter .

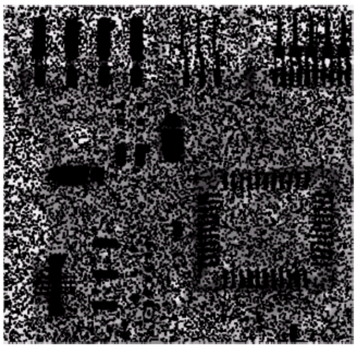
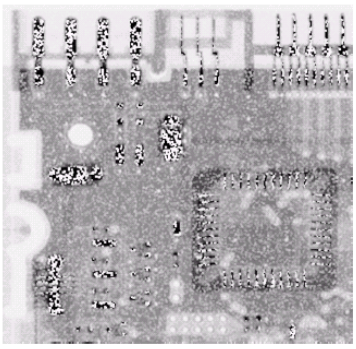

Fig (A)-pepper noise filtered by Q = -1.5 **Fig(B)-** Salt noise filtered by Q= +1.

B. Order Statistic Filters

In these type of filters, the values of the pixels of an image are ranked in order. Only those pixel values are ranked whose area or region is enclosed in the filter.
I. Median Filter: This filter first calculates the median of the intensity levels of the pixels Suppose we have pixel values from 1-9, so the median will be 5, that is, the midpoint of the pixel values. Then after calculating the median, it replaces the corrupted pixel value with the new value(median value).

II. Max and Min Filter: These filters are used to find the brightest and darkest points in the image. The Max filter replaces the pixel value with the brightest point and the Min filter replaces the pixel with the darkest point.
III. Midpoint Filter: The Midpoint filter computes the midpoint between the maximum and minimum values of the image. The midpoint filter is widely used for noises like Gaussian noise and uniform noise.
IV. Alpha trimmed Mean Filter: As the name implies, this filter trims the d/2 highest and d/2 lowest intensity values of the corrupted image in S_{xy}. Let $g_r(s,t)$ represents remaining mn-d pixels. Then the alpha trimmed mean filter averages the value of these remaining pixels. The value of d ranges from 0 to mn-1. When d=0, then alpha trimmed filter becomes arithmetic mean filter. If d=mn-1 then, the filter becomes median filter

A. Mean Filters: **Table I**

Mean Filters	Equations	Advantages	Disadvantages
1. Arithmetic Mean filter	$\hat{f}(x,y)\frac{1}{mn}\sum_{(s,t)\in s} g(s,t)$	1. The Arithmetic mean filter is the simplest form of mean filter. 2. This filters helps in smoothing the variations in an image and it blurs the image.	1. It normally blurs the edges. This may be a problem if sharp edges are required in the desired output .
2. Geometric Mean Filter	$\hat{f}(x,y) = [\prod_{(s,t)\in s_{xy}} g(s,t)]^{\frac{1}{mn}}$	1. The Geometric mean filter is same as that of Arithmetic mean filter 2. It loses less image detail while processing the image.	1. The larger filter size provides a stronger filter effect with a drawback of some blurring.
3. Harmonic Mean Filter	$\hat{f}(x,y) = \frac{mn}{\sum_{(s,t)\in s_{xy}} \frac{1}{g(s,t)}}$	1. It is used in situations in which there are extreme values in data.	1. Its disadvantage is that it does not works well for pepper noise.
4. Contraharmonic Mean Filter	$\hat{f}(x,y) = \frac{\sum_{(s,t)\in s_{xy}} g(s,t)^{Q+1}}{\sum_{(s,t)\in s_{xy}} g(s,t)^{Q}}$	1. Q denotes the order of the filter. For the positive value of Q, the filter removes pepper noise and for its negative value it destroys salt noise.	1. If we choose wrong values of Q then the filter gives the worst results.

B. Order Statistic Filters : **Table II**

Order Statistic Filters	Equations	Advantages	Disadvantages
1. Median Filter	$\hat{f}(x,y) = \text{median}_{(s,t)\in s_{xy}}\{g(s,t)\}$	1. This filter is more robust because a single pixel in neighbourhood never affects the median value. 2. The median filter is much better at preserving sharp edges than other filters.	1. It is more expensive and complex to execute. 2.More time is spent calculating the median of each window.
2. Max Filter	$\hat{f}(x,y) = \max_{(s,t)\in s_{xy}}\{g(s,t)\}$ $\hat{f}(x,y) = \min_{(s,t)\in s_{xy}}\{g(s,t)\}$	1. The Max filter finds the light colored points in the image. 2. 1. Min filter is used to find the dark colored points in the image.	1. This filter is unable to find out the black colored or dark colored pixels in an image. 2.The Min filter can't locate the light or white colored points in an image.
3 Midpoint Filter	$\hat{f}(x,y)=\frac{1}{2}\left[\max_{(s,t)\in S_{xy}}\{g(s,t)\}+\min_{(s,t)\in S_{xy}}\{g(s,t)\}\right]$	1. This filter is very effective in removing gaussian and uniform noise while preserving image detail.	1. It works well only for randomly distributed noise.
4. Alpha-trimmed mean	$\hat{f}(x,y)=\frac{1}{mn-d}\sum_{(s,t)\in S_{xy}} g_r(s,t)$	1. It is useful in situations such as which multiple types of noises, for eg, combination of salt and pepper and Gaussian noise.	1. Used only where noise density is high. These are not used for low noise density images.

C. Adaptive Median Filter

This filter is the third type of spatial domain filters. In Adaptive median filters, we can change the size of the filter. The other filters discussed above can only be used for the images where the density of the noise is less. But this filter is used especially to remove high density noise from corrupted images. The following algorithm shows the working of this filter. This filter works in two stages (i.e stage A and stage B) as discussed below:

Stage A: $A1 = z_{med} - z_{min}$

$A2 = z_{med} - z_{max}$

If A1 > 0 ND A2 < 0, go to stage B
Else increase the window size
If window size ≤ S_{max} repeat stage A
Else output z_{med}
Stage B: B1 = z_{xy} - z_{min}
B2 = z_{xy} - z_{max}
If B1 > 0 AND B2 < 0, output z_{xy}
Else output z_{med}

This algorithm [1] is used for three purposes:

- To eliminate the distortion of the edges or boundaries of the image.
- It also removes Impulse noise(salt and pepper noise).
- To provide smoothing effect in the images.

IV. Applications Of Filters

The spatial domain filters have their applications in various fields. These filters helps in removing the various types of noises from the corrupted or degraded images. The filters have various efficient noise removing capabilities. Each filter perform different operation on different kind of noise effectively. Table III shows various filters along with their applications.

Table III

FILTERS	APPLICATIONS
1.Arithmetic mean filter	Removes Gaussian and Uniform noise
2. Geometric mean filter	Eliminates impulse and Gaussian noise
3. Harmonic mean filter	Efficiently Removes salt and Gaussian noise
4.Contrs harmonic mean filter	Removes salt and pepper noise
5.Median filter	Helps in removing Gaussian and Impulse noise
6.Max and Min filter	Max removes only salt noise and Min removes only pepper noise
7. Midpoint filter	Eliminates Gaussian and Uniform noise
8. Adaptive Median filter	It is used to remove Impulse noise

V. Conclusion

Various filters and techniques are used in image restoration to restore the corrupted image to its original form. The restoration results in the improved quality of image. The types of noises are explained and discussed along with their probability density functions(PDF).Various spatial filtering techniques are used for reducing these noises from images.

The noises such as Gaussian, Rayleigh, Gamma, Exponential, Impulse noise can be removed by using these filters. Various filters with their advantages and disadvantages are discussed in Table I and Table II. In the end the applications of all the filters are discussed.

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