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DIGITAL IMAGE DE-NOISING FILTERS A COMPREHENSIVE STUDY

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***Abstract*:** This paper presents a framework for removing noise in digital images. Digital image processing means processing digital images with digital computers. An image gets corrupted with noise during image acquisition or transmission. Image noise is any unwanted or undesired information that can occur during the image acquisition or transmission. These unwanted signals/pixels decrease the image quality. Filters are used to filter unwanted things or objects. Digital images can be either spatial domain or frequency domain. This paper examines various filtering techniques used in spatial domain image processing.

Keywords: - Digital image, Spatial Domain, Spatial Domain Filters, Smoothing, Sharpening.

INTRODUCTION

An image is defined as a two-dimensional function f(x, y), where x and y are plane coordinates, and the amplitude of **f** at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point. When x, y, and the intensity values of f are all finite, discrete quantities, the image is digital image. The digital image consists of finite number of elements each of which has a particular location & values. These elements are called picture elements, image elements, pels & pixels. When an image is captured by a camera or other imaging device, often the vision system for which it is intended is unable to use it directly. The image gets corrupted by random noise which may be due to random variations in intensity, variations in illumination, or poor contrast. Removal of noise from an image is a common procedure in the digital image processing in order to suppress different types of noises such as Gaussian noise, Salt & Pepper noise, Speckle noise that might have corrupted an image during acquisition & transmission. Filters are used to remove unwanted noise or things in spatial domain.

This paper focus on the Spatial Domain Filtering Techniques. In Spatial Domain Techniques filtering is performed on image pixels directly. The main idea behind the spatial domain filtering is to convolve a mask with the whole image. At each point (x,y) the response of the filter at that point is calculated using a predefined relationship. Spatial filter can be classified into i) Smoothing spatial filters and ii) Sharpening spatial filters. These filters can be either linear or nonlinear. The main spatial-domain filtering activities are:

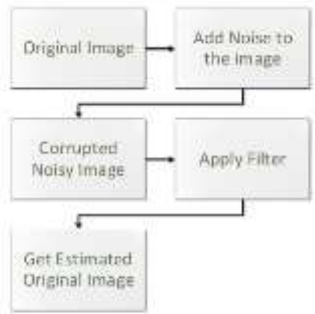

Fig. 1 Spatial domain filtering activities

TYPES OF NOISE

Image noise is an unwanted or undesired signal/pixel that may be added or subtracted during image acquisition, transmission/ reception, and storage/ retrieval. It is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera. It is generally regarded as an undesirable by-product of image capture. These unwanted pixels decrease the image quality.

The various types of noises are:-

- Gaussian noise
- Salt-and-pepper noise
- Speckle noise

Gaussian Noise

Gaussian noise is an amplifier noise which is independent at each pixel and independent of the signal intensity. Gaussian noise is statistical noise that has its probability density function equal to that of the normal distribution, which is also known as the Gaussian distribution. It arises due to electronic circuit noise & sensor noise due to poor illumination or high temperature. It is a constant power additive noise.

Salt & Pepper Noise

The salt-and-pepper noise are also called shot noise, impulse noise or spike noise .An image containing salt-and-pepper noise will have dark pixels in bright regions and bright pixels in dark regions . This type of noise can be caused by dead pixels, analog-to-digital converter errors, bit errors in transmission.

Speckle Noise

Speckle noise is a granular noise that inherently exists in and degrades the quality of the active radar and synthetic aperture radar (SAR) images. Speckle noise in conventional radar results from random fluctuations in the return signal from an object that is no bigger than a single image-processing element. It increases the mean grey level of a local area. It is a multiplicative noise.

FILTERING TECHNIQUES

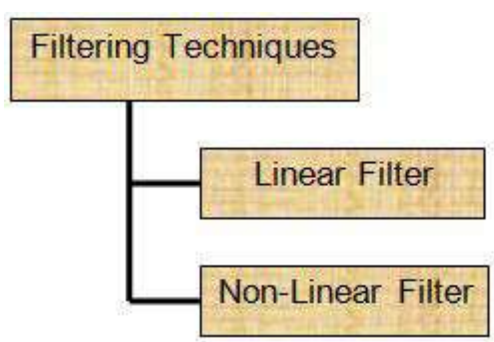

Fig. 2: Filtering Techniques

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Linear Filter

Linear filter is a weighted sum of pixels in the neighborhood and uses the window coefficients for sum of product. The linear filters are not able to preserve edges of images in a efficient manner. In linear filters edges are recognized as discontinuities and are removed or are blurred.

Non –Linear Filters

Non-Linear filters are based upon the values of pixels in the neighborhood not on their sum and do not use coefficients of window as in case of sum of products. They can handle edges in a much better way than linear filter.

SMOOTHING SPATIAL FILTERS

Smoothing filters are used for blurring and for noise reduction. For each pixel, a smoothing filter takes into account the pixels surrounding it in order to make a determination of a more accurate version of this pixel. Blurring refers to removal of small details from an image prior to large object extraction. In blurring we reduce the edge content in an image & try to make the transitions between different pixel intensities as smooth as possible. Blurring is increased by increasing the size of the mask. Smoothing spatial filters can be either linear or nonlinear filters.

Smoothing Linear filter

The response of a smoothing linear spatial filter is simply the average of the pixels contained in the neighborhood of the filter mask. These kinds of filters are called averaging filters or low pass filters. Mean filter, wiener filter and Gaussian filter are the types of smoothing spatial linear filters.

Mean filter: It is a sliding window filter that replaces the center value in the window with the average mean of all the pixel values in the filter or window.

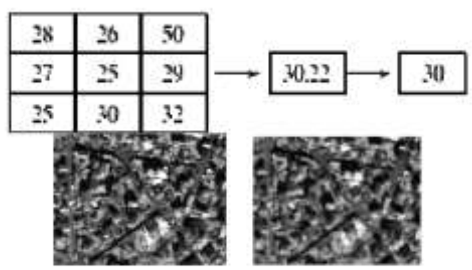

Fig. 3 Mean filter

Wiener filter:Also called Minimum Mean Square Error (MMSE) or Least-Square (LS) filtering.Its purpose is to reduce the amount of noise in the signal by comparing the received signal with a estimation of desired noiseless signal.The wiener filter method requires the information about the spectra of the noise & the original signal.The Wiener filter has two separate parts, an inverse filtering part and a noise smoothing part. It not only performs the DE convolution by inverse filtering (high pass filtering) but also removes the noise with a compression operation (low pass filtering).

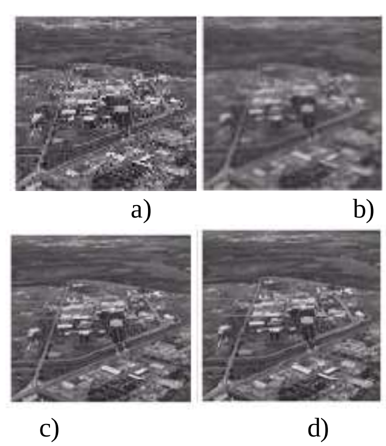

Fig. 4 Wiener filter applied to a noise image. (a) Original image. (b) Image blurred (c) Image after inverse filter. (d) Image after the Wiener filter.

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Gaussian filter: A Gaussian filters smoothens an image by calculating weighted averages in a filter box. Weights are assigned to the filter according to the distance of neighbor from the center of the mask.

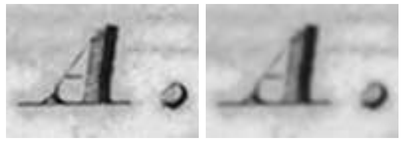

Fig. 5 Gaussian smoothing

Smoothing Nonlinear filter

Order statistics filter: Order-statistics filters are nonlinear spatial filters whose result is based on ordering (ranking) the pixels contained in the image area covered by the filter, and then replacing the value of the center pixel with the value determined by the ranking result. The various order statistic filters are:-
*Min and Max Filter:*Min filter is used to locate the darkest point in an image. It is a 0th percentile filter and removes pepper noise.

g(x,y)=min{f(x+a, y+b)} for a,b= -1,0,+1

Max filter is used to locate the brightest point in an image. It is a 100th percentile filter and removes salt noise.

g(x,y)=max{f(x+a, y+b)} for a,b = -1,0,+1

Midpoint Filter: This filter combines order statistics & averaging. The Midpoint filter blurs the image by replacing each pixel with the average of the highest pixel and the lowest pixel (with respect to intensity) within the specified window size. It works best for randomly distributed noise like Gaussian noise.

Midpoint = (darkest + lightest)/2

Table I : **The example and description of max, min and midpoint filters**

EXAMPLE IMAGE	FILTER TYPE	DESCRIPTION
	Max Filter	The center pixel would be changed from 77 to 219 as it is the brightest pixel within the current window.
	Min Filter	The center pixel would be changed from 77 to 0 as it is the darkest pixel within the current window.
	Midpoint Filter	The center pixel would be changed from 77 to 109 as it is the midpoint between the brightest pixel 219 and the darkest pixel 0 within the current window.

Median filter: Median filter is good for removing impulsive (salt & peeper) noise from an image while preserving edges. This filter replaces the value of the central pixel with the median of the intensity values in the neighborhood of that pixel including the central pixel.

g(x,y)=median{f(x+a, y+b)}for a,b= -1,0,+1

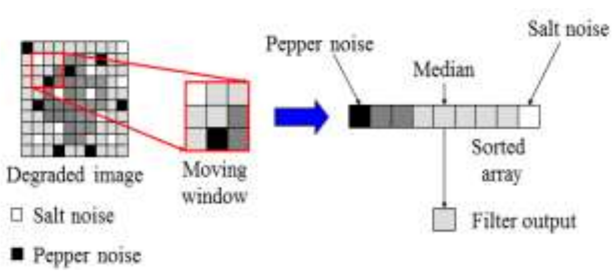

Fig. 6 Median filter

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Alpha-Trimmed mean filter: This filter is useful in situations where multiple types of noise is present such as salt & pepper and Gaussian noise. The alpha-trimmed mean filter varies between a median and mean filter. It is so named because, rather than averaging the entire data set, a few data points are trimmed and the remainders are averaged. The points which are removed are most extreme values, both low and high, with an equal number of points dropped at each end. In practice, the alpha-trimmed mean is computed by sorting the data low to high and summing the central part of the ordered array. The number of data values which are dropped from the average is controlled by trimming parameter alpha which is being expressed as:

$$\hat{f}(x,y) = \frac{1}{mn-d} \sum_{(s,t)\in S_{xy}} g_r(s,t)$$

Where $g_r(s,t)$ represent the remaining mn-d pixels after removing the $d/2$ highest and $d/2$ lowest values of $g(s,t)$.

SHARPENING SPATIAL FILTERS

The main objective of image sharpening is to highlight fine details and transitions in intensity that has been blurred. Sharpening filter uses derivatives to remove noise. The strength of the response of a derivative operator is related to the degree of discontinuity of the image at the point at which the operator is applied.

Sharpening linear filter: These filters are high pass spatial filter. Laplacian filter comes under sharpening linear filter.

Laplacian filter: Laplacian is the simplest isotropic derivative operator .It is based on second derivative. Isotropic means rotation invariant which means that rotating the image and then applying the filter gives same result as applying the filter and then rotating the result. It generally highlights point, lines, and edges in the image and suppresses uniform and smoothly varying regions.

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}.$$

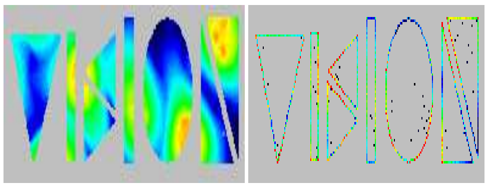


Fig. 7 Initial image and Laplacian image

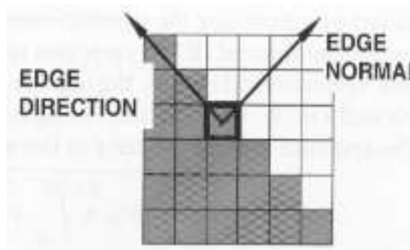
Sharpening Nonlinear filter: Gradient filter comes under the category of sharpening nonlinear filter. Nonlinear sharpening filters are uses various operators like Sobel, prewitt and Robert.

Gradient filter: This filter is based upon first derivative. It is used to enhance the line structure and other details. The gradient is a **vector** which has magnitude and direction .Magnitude provides information about edge strength. Direction is perpendicular to the direction of the edge. For a function f(x, y), the gradient of *f*at coordinates (x, y) is defined as the two-dimensional column *vector*

$$\nabla \mathbf{f} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}.$$

The magnitude of this vector is given by

$$\begin{aligned} \nabla f &= \text{mag}(\nabla \mathbf{f}) \\ &= [G_x^2 + G_y^2]^{1/2} \\ &= \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 \right]^{1/2}. \end{aligned}$$



Z1	Z2	Z3
Z4	Z5	Z6
Z7	Z8	Z9

$$\frac{\partial f}{\partial x} = z_6 - z_5$$

$$\frac{\partial f}{\partial y} = z_5 - z_8$$

$$mag(grad(f)) = \sqrt{(z_5 - z_6)^2 + (z_5 - z_8)^2}$$

Fig. 9 Gradient filter

Un-sharp Masking and High boost filtering: Un-sharp masking is used in printing and publishing industries to sharpen images. It consist of subtracting an un-sharp-(smoothed) image from the original image. This process is called un-sharp masking.

It consists of following steps:-

- Blur the original image.
- Subtract the blurred image from the original. The difference is called the mask.
- Add the mask to the original image

Un-sharp mask is given by

$g_{mask}(x,y)=f(x,y)-f'(x,y)$

where f '(x,y) is the blured image

Add a weighted portion of the mask back to the original image:

$g(x,y)=f(x,y)+k* g_{mask}(x,y)$

When k=1, we have unsharp masking

When k>1, the process is referred to as highboost filtering.

High-boost filter can be used to enhance high frequency components without eliminating low frequency components.

Table2: Filters name with properties

Filter name	Noise type
Mean filter	Gaussian noise
Weiner filter	Additive noise
Gaussian filter	Gaussian noise
Max filter	Salt noise(Brightest point)
Min filter	Pepper noise(Darkest point)
Midpoint filter	Gaussian and uniform noise
Median filter	Impulsive noise(salt & pepper)
Alpha trimmed mean filter	Multiple noise (such as combination of salt & pepper and Gaussian noise)
Laplacian filter	Edge detection
Gradient filter	Noise reduction
Highboost filter	Sharp image

CONCLUSION

From the above study we analyze that enhancement helps in bringing forward the useful important details from the image by reducing irrelevant information. This paper presents various spatial domain filtering techniques used to remove different types of noise. These spatial domain filters operates on small neighborhood such as 3*3 to 11*11. Based on the type of image and the noise with which it is corrupted, different filtering techniques are applied to remove noise. A little change in the individual method or combination of any two or more methods further improves the visual quality.

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