Review: Assessment of Working of Different Digital Spatial Filters in Digital Image Processing

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ABSTRACT

Digital image processing involves the manipulation and interpretation of digital images with the aid of a computer [1]. Digital image processing is an extremely broad subject, and it often involves procedures that can be mathematically complex. Different digital filters has been developed in image processing for better interpretation and to improve the visual interpretability of an image by increasing the apparent distinction between the features in the scene. This paper reviews working of different spatial digital filters in image processing.

Index Terms: CONVOLUTION, DERIVATIVE OPERATORS,DIGITAL IMAGE PROCESING, FILTERS , OPERATORS .

1.INTRODUCTION:

Digital filters in digital image processing has found wide applications in processing of digital images corrupted by noise. Filtering is one of the most important task in image processing. A variety of techniques has been developed to improve the visual interpretability of an image [1]. Although of great variety in the existing image noise filtering techniques, nearly all of them are based on spatial-domain processing of the distorted image. They generally process image data in the spatial domain to diminish the noise while preserve important image details such as edges and lines. Image noise filtering has been widely perceived as the spatial-domain estimation and processing. In this paper, a brief perspective on image noise filtering has been presented.

2.PRINCIPLE OF OPERATION OF DIFFERENT DIGITAL FILTERS:

A spatial filter is an image operation where each pixel value is changed by a function of the intensities of pixels in a neighborhood. The process involved in spatial filter is convolution.

Convolution is the most important filtering technique used in image processing. Convolution of an image involves moving of a window(e.g. .size of 3*3,5*5,7*7 etc) ,that contains an array of coefficients or weighting factors referred as kernels , throughout the original image and output image is obtained [2]. To begin with, the window is placed in the top left corner of the image to be filtered .The digital number at the center of output window is obtained by multiplying each coefficient in the kernel by the corresponding digital number in the original image and adding all the resulting products.

Once the output value from the filter has been calculated, the window is moved one column (pixel) to the right and the operation is repeated. The window is moved rightwards and successive output values are computed until the right-hand edge of the filter window hits the right margin of the image. At this point, the filter window is moved down one row and back to the left-hand margin of the image. This procedure is repeated until the filter window reaches the bottom right-hand corner of the input image. Figure A is original satellite digital image.

FIGURE A:ORIGINAL IMAGE

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2A. MOVING AVERAGE FILTER: The moving average filter replaces a data value by the average of the given data point and a specified number of its neighbors to the left and to the right [2].

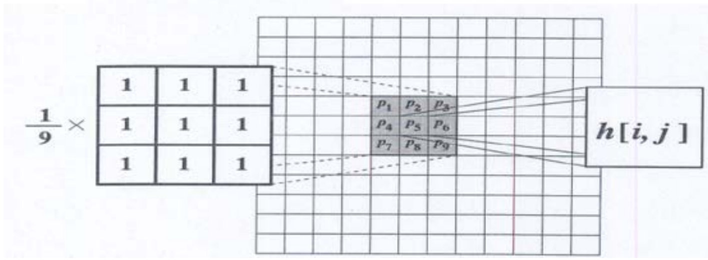

FIGURE B :SHOWS CONVOLUTION PROCESS

where,

h[i,j]= 1/9 {1*P1+1*P2+1*P3+1*P4+1*P5+1*P6+1*P7+1*P8+1*P9}

FIGURE C: OUTPUT OBTAINED AFTER APPLYING MOVING AVERAGE FILTER

The effect of the moving average filter reduces the overall variability of the image and lower its contrast. At the same time those pixels that have larger or smaller values than their neighborhood average are respectively reduced or increased in value so that local detail is lost. Noise components, such as the banding patterns evident in line-scanned images, are also reduced in magnitude by the averaging process, which can be considered as a smearing or blurring operation. In cases where the overall pattern of grey level values is of interest, rather than the details of local variation, neighborhood grey level averaging is a useful technique.

2B.MEDIAN FILTER: An alternative smoothing filter uses the median of the pixel values in the filter window rather than the mean [2]. For example if the nine pixel values corresponding to A,B,C,D,E,F,G,H & I be 3, 1, 2, 8, 5, 3, 9, 4, 27 respectively then the median is the central value , when the data are ranked in ascending or descending order of magnitude. In this example the ranked values are {1, 2, 3,3, 4, 5, 8, 9, 27} giving a median value of 4.

In general, an odd-size neighborhood is used for calculating the median. However, if the number of pixels is even, the median is taken as the average of the middle two pixels after sorting.

It is clear that, the median filter more successfully removes isolated spikes and better preserves edges, defined as pixels at which the gradient or slope of grey level value changes markedly. The median filter is also used to eliminate speckle in an image without unduly blurring the sharp features of the image .

2C. Adaptive filters

Smoothing methods in which the filter weights are calculated anew for each window position, the calculations being based on the mean and variance of the grey levels in the area of the image underlying the window. Such filters are termed adaptive filters [2]..

Adaptive filtering uses the standard deviation of those pixels within a local box surrounding each pixel to calculate a new pixel value. Typically, the original pixel value is replaced with a new value calculated based on the surrounding valid pixels (those that satisfy the standard deviation criteria). Unlike a typical moving average and median low-pass smoothing filter, the adaptive filters preserve image sharpness and detail while suppressing noise [5] [6].

2C (i). SIGMA FILTERS

This filter is motivated by the sigma probability of the Gaussian distribution, and it smooth's the image noise by averaging only those neighborhood pixels which have the intensities within a fixed sigma range of the center pixel. Lee's method assumes that the grey level values in a digital image are normally distributed and, for each overlapping, rectangular window, computes estimates of the local mean ¯x and local standard deviations from the pixels falling within the window. A threshold value is computed from those pixels whose values lie within ±2s(where s is local standard deviation) of the window mean ¯x. Pixels outside this range are not included in the calculation. The method breaks down when only a few of the pixels in the window have values that are within ±2s of the window mean. A parameter k is used to control the procedure. If fewer than k pixels are selected by the threshold (i.e., fewer than k pixels lie in the range ¯x ± 2s) then the procedure is aborted, and the filtered pixel value to the left of the current position is used. Alternatively, the average of the four neighboring pixels replaces the window centre pixel. Consequently, image edges are preserved. The filter became popular because it improves noisy images and flattens local differences with minimal loss of sharpness [2][3] [7].

The filter smooth's an image by taking an average over the neighboring pixels, but only includes those pixels that have a value not deviating from the current pixel by more than a given range. The range is defined by the standard deviation of the pixel values within the neighborhood .

2C(ii). Nagao-Matsuyama Filter

The idea of edge-preserving smoothing, as used in the sigma filter, is also the basis of a filtering method proposed by Nagao and Matsuyama (1979). This method attempts to avoid averaging pixel values that belong to different 'regions' that might be present in the image. The boundary between two regions contained within a window area might be expected to be represented by an 'edge' or sharp discontinuity in the grey level values [4].

This filter works by analyzing a local neighborhood of pixels in varying orientations. firstly the variance of the nine sub-group has to be calculated including the central pixel each time using the formula given below. Then sub-group with lowest variance has to be determined. At last selecting the average for the orientation with the least variation, a new value for the centre pixel is assigned.

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

σ^2 – Variance ,μ – Mean and x – pixel value.

The above formula describes the simplest method for calculating variance, which requires pre-calculation of the mean.

Nagao-Matsuyama is effective at reducing the smoothing of edges, however, clearly there is a great cost in terms of computation due to the need to calculate nine separate variances for each pixel. Another limitation is that the smallest discernible angle is 45 degrees. For some images, this leads to visually perceptible "jagged" edges in curved regions of an image.

2D. Derivative filters:

Sharpening of the image can also be done by taking the first or second derivative of the image. Sharpening spatial filters seek to highlight fine detail by removing blurring from the images and by highlighting edges.Sharpening filters are based on spatial differentiation .As differentiation measures the rate of change of a function. At the pixel, the intensity changes from 0 to 255 at the direction of the gradient. The magnitude of the gradient indicates the strength of the edge.

The formula for the 1st derivative of a function is as follows:

$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

It's just the difference between subsequent values and measures the rate of change of the function.

The operators such as Prewitt operator, Sobel operator and Robert Cross operator etc uses first derivative of the image to highlight or to sharp the images .

2D (i).Prewitt operator

The Prewitt operator is used in edge detection. It is a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Prewitt operator is either the corresponding gradient vector or the norm of this vector. The Prewitt operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations [10].

In simple terms, the operator calculates the gradient of the image intensity at each point, giving the direction of the largest possible increase from light to dark and the rate of change in that direction. The result therefore shows how "abruptly" or "smoothly" the image changes at that point, and therefore how likely it is that that part of the image represents an edge, as well as how that edge is likely to be oriented. In practice, the magnitude calculation is more reliable and easier to interpret than the direction calculation.

Mathematically, the gradient of a two-variable function (here the image intensity function) is at each image point a 2D vector with the components given by the derivatives in the horizontal and vertical directions. At each image point, the gradient vector points in the direction of largest possible intensity increase, and the length of the gradient vector corresponds to the rate of change in that direction. This implies that the result of the Prewitt operator at an image point which is in a region of constant image intensity is a zero vector and at a point on an edge is a vector which points across the edge, from darker to brighter values.

The operator uses two 3×3 kernels which are convolved with the original image to calculate approximations of the derivatives - one for horizontal changes, and one for vertical. If we define $\mathbf{A}$ as the source image, and $\mathbf{G_x}$ and $\mathbf{G_y}$ are two images which at each point contain the horizontal and vertical derivative approximations, the latter are computed as:

$$\mathbf{G_x} = \begin{bmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G_y} = \begin{bmatrix} +1 & +1 & +1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} * \mathbf{A}$$

where $*$ here denotes the 2-dimensional convolution operation.

Since the Prewitt kernels can be decomposed as the products of an averaging and a differentiation kernel, they compute the gradient with smoothing. For example, $\mathbf{G_x}$ can be written as

$$\begin{bmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \begin{bmatrix} -1 & 0 & 1 \end{bmatrix}$$

The x-coordinate is defined here as increasing in the "right"-direction, and the y-coordinate is defined as increasing in the "down"-direction. At each point in the image, the resulting gradient approximations can be combined to give the gradient magnitude, using:

$$\mathbf{G} = \sqrt{\mathbf{G}_x{}^2 + \mathbf{G}_y{}^2}$$

Using this information, we can also calculate the gradient's direction:

$$\mathbf{\Theta} = \operatorname{atan2}(\mathbf{G}_y, \mathbf{G}_x)$$

where, for example, Θ is 0 for a vertical edge which is darker on the right side.

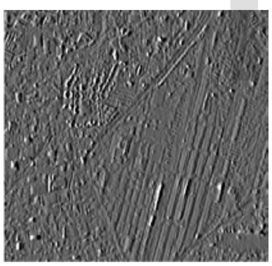

FIGURE E: OUTPUT OBTAINED AFTER APPLYING PERWITT OPERATOR

2D (ii).SOBEL OPERATOR :

The Sobel operator is used in image processing is also a discrete differentiation operator computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Sobel operator is either the corresponding gradient vector or the norm of this vector. The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations. On the other hand, the gradient approximation that it produces is relatively crude, in particular for high frequency variations in the image [11].

The operator uses two 3×3 kernels which are convolved with the original image to calculate approximations of the derivatives - one for horizontal changes, and one for vertical. If we define A as the source image, and Gx and Gy are two images which at each point contain the horizontal and vertical derivative approximations, the computations are as follows:

$$\mathbf{G}_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G}_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * \mathbf{A}$$

where $*$ here denotes the 2-dimensional convolution operation.

Since the Sobel kernels can be decomposed as the products of an averaging and a differentiation kernel, they compute the gradient with smoothing. For example, $\mathbf{G_x}$ can be written as

$$\begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \begin{bmatrix} +1 & 0 & -1 \end{bmatrix}$$

The x-coordinate is defined here as increasing in the "right"-direction, and the y-coordinate is defined as increasing in the "down"-direction. At each point in the image, the resulting gradient approximations can be combined to give the gradient magnitude, using:

$$\mathbf{G} = \sqrt{{\mathbf{G}_x}^2 + {\mathbf{G}_y}^2}$$

Using this information, we can also calculate the gradient's direction:

$$\mathbf{\Theta} = \operatorname{atan}\left(\frac{\mathbf{G}_y}{\mathbf{G}_x}\right)$$

where, for example, Θ is 0 for a vertical edge which is darker on the right side.


FIGURE F: OUTPUT FROM SOBEL OPERATOR**.**

2D (iii).Robert cross

It was one of the edge detectors and was initially proposed by Lawrence Roberts in 1963 the idea behind the Robert's Cross operator is to approximate the gradient of an image through discrete differentiation which is achieved by computing the sum of the squares of the differences between diagonally adjacent pixels [12].

According to Roberts, an edge detector should have the following properties: the produced edges should be well-defined, the background should contribute as little noise as possible, and the intensity of edges should correspond as close as possible to what a human would perceive. With these criteria in mind and based on then prevailing psychophysical theory Roberts proposed the following equations:

$$y_{i,j} = \sqrt{x_{i,j}}$$

$$z_{i,j} = \sqrt{(y_{i,j} - y_{i+1,j+1})^2 + (y_{i+1,j} - y_{i,j+1})^2}$$

where x is the initial intensity value in the image, z is the computed derivative and i,j represent the location in the image.

In order to perform edge detection with the Roberts operator , firstly convolve the original image, with the following two kernels:

$$\begin{bmatrix} +1 & 0 \\ 0 & -1 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} 0 & +1 \\ -1 & 0 \end{bmatrix}.$$

Let $I(x,y)$ be a point in the original image and $G_x(x,y)$ be a point in an image formed by convolving with the first kernel and $G_y(x,y)$ be a point in an image formed by convolving with the second kernel. The gradient can then be defined as:

$$\nabla I(x,y) = G(x,y) = \sqrt{G_x^2 + G_y^2}.$$

The direction of the gradient can also be defined as follows:

$$\Theta(x,y) = \arctan\left(\frac{G_y(x,y)}{G_x(x,y)}\right).$$

2D (iv).Scharr operator

One of the popular gradient operators is Scharr operator 3x3

$$\begin{bmatrix} +3 & +10 & +3 \\ 0 & 0 & 0 \\ -3 & -10 & -3 \end{bmatrix} \qquad \begin{bmatrix} +3 & 0 & -3 \\ +10 & 0 & -10 \\ +3 & 0 & -3 \end{bmatrix}$$

Scharr operators result from an optimization minimizing weighted mean squared angular error in Fourier domain. This optimization is done under the condition that resulting filters are numerically consistent. Therefore they really are derivative kernels rather than merely keeping symmetry constraints [8] [9] .

2D (v).Canny operator

The Canny edge detector is susceptible to noise present in raw unprocessed image data, it uses a filter based on a Gaussian , where the raw image is convolved with a Gaussian filter. The result is a slightly blurred version of the original which is not affected by a single noisy pixel to any significant degree. Here is an example of a 5x5 Gaussian filter, used to create the image to the right, with standard deviation(σ)= 1.4. (The asterisk denotes a convolution operation.)

$$\mathbf{B} = \frac{1}{159}\begin{bmatrix} 2 & 4 & 5 & 4 & 2 \\ 4 & 9 & 12 & 9 & 4 \\ 5 & 12 & 15 & 12 & 5 \\ 4 & 9 & 12 & 9 & 4 \\ 2 & 4 & 5 & 4 & 2 \end{bmatrix} * \mathbf{A}.$$

An edge in an image may point in a variety of directions, so the Canny algorithm uses four filters to detect horizontal, vertical and diagonal edges in the blurred image. The edge detection operator(Robert, Prewitt, Sobel for example) returns a value for the first derivative in the horizontal direction (Gx) and the vertical direction (Gy). From this the edge gradient and direction can be determined:

$$\mathbf{G} = \sqrt{{\mathbf{G}_x}^2 + {\mathbf{G}_y}^2} \qquad \& \qquad \mathbf{\Theta} = \arctan\left(\frac{\mathbf{G}_y}{\mathbf{G}_x}\right).$$

The edge direction angle is rounded to one of four angles representing vertical, horizontal and the two diagonals (0, 45, 90 and 135 degrees for example) [13].

2D (vi).Second derivative operator: Laplacian Operator

The Laplacian is defined as follows:

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

where the partial 1st order derivative in the x direction is defined as follows:

$$\frac{\partial^2 f}{\partial^2 x} = f(x+1,y) + f(x-1,y) - 2f(x,y)$$

and in the y direction as follows:

$$\frac{\partial^2 f}{\partial^2 y} = f(x, y+1) + f(x, y-1) - 2f(x, y)$$

So, the Laplacian can be given as follows:

$$\nabla^2 f = [f(x+1, y) + f(x-1, y) \ + f(x, y+1) + f(x, y-1)] \ - 4f(x, y)$$

filter based on this above formula is

0	1	0
1	-4	1
0	1	0

The result of a Laplacian filtering is not an enhanced image ,in order to get final image , the output from the moving average filter is subtracted from the original image, on a pixel-by-pixel basis, This filter i.e. the original image minus its smoothed version is a Laplacian filter. It has had the effect of emphasizing edges in the image.

$$g(x, y) = f(x, y) - \nabla^2 f$$

$$= f(x,y) - [f(x+1,y) + f(x-1,y) \ + f(x, y+1) + f(x, y-1) \ - 4f(x, y)]$$

$$= 5f(x,y) - f(x+1,y) - f(x-1,y) \ - f(x, y+1) - f(x, y-1)$$

Therefore a new filter which does the whole job in one step is as follows

0	-1	0
-1	5	-1
0	-1	0

FIG G: NEW LAPLACIAN FILTER. **FIG H: OUTPUT OBTAINED BY APPLYING LAPLACIAN OPERATOR**

3.CONCLUSION

This paper serves as assessment of working of the different digital filters . The field of image processing are constantly evolving in the last decade, but still improvements in filtering methods are needed . This paper serves as a review of advantages of different spatial domain filtering and highlights the working of each digital filters image processing.

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