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Image Edge Enhancement In Spatial and Frequency Domains

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Abstract: *Filtering helps to enhance the image by removing noise. Spatial filtering for image edge detection and image edge enhancement and frequency filtering for image edge enhancement is presented. In spatial domain, eleven alternative combinations of Mean filtering function h_m, Gaussian filtering function h_g and three versions of Laplacian filtering functions h_{L1}, h_{L2} and h_{L3} are considered. Changes in Frequency Estimate, Brightness and Contrast produced by the eleven alternative combinations of filtering functions are measured. Laplacian functions are high pass filtering functions while Mean function and Gaussian function are low pass filtering functions. Low pass filtering functions are found to be more suitable for image edge enhancement than high pass filtering functions. The degree of image edge enhancement quality increases as scaling constant k increases from 0 to 0.8 beyond which diminishing returns set in. In frequency domain, both low pass and high pass filtering methods are performed. A low-pass filter is a filter that passes low-frequency signals and attenuates signals with frequencies higher than the cut-off frequency. There are several standard forms of low pass filters they are Ideal, Butterworth and Gaussian low pass filter. A high-pass filter is a filter that passes high frequencies well, but attenuates frequencies lower than the cut-off frequency. Sharpening is fundamentally a high pass operation in the frequency domain. There are several standard forms of high pass filters such as Ideal, Butterworth and Gaussian high pass filter.*

Keywords: edge, edge enhancement, spatial domain, frequency domain, low-pass filter, high-pass filter

1. INTRODUCTION

Image enhancement is among the simplest and most appealing areas of digital image processing. Basically, the idea behind enhancement techniques is to bring out detail that is obscured, or simply to highlight certain features of interest in an image. A familiar example of enhancement is when we increase the contrast of an image because "it looks better." It is important to keep in mind that enhancement is a very subjective area of image processing.

IMAGE ENHANCEMENT-The principal objective of image enhancement is to process a given image so that the result is more suitable than the original image for a specific application. It accentuates or sharpens image features such as edges, boundaries, or contrast to make a graphic display more helpful for display and analysis. The enhancement doesn't increase the inherent information content of the data, but it increases the dynamic range of the chosen features so that they can be detected easily.Image enhancement techniques can be divided into two broad categories:

1. Spatial domain methods, which operate directly on pixels.
2. Frequency domain methods, which operate on the Fourier transform of an image.

Unfortunately, there is no general theory for determining what is "good" image enhancement when it comes to human perception. If it looks good, it is good! However, when image enhancement techniques are used as pre-processing tools for other image processing techniques, then quantitative measures can determine which techniques are most appropriate.

LOW-PASS FILTERS-Low-pass filters are used for image smoothing and noise reduction. Their effect is an averaging of the current pixel with the values of its neighbors, observable as a "blurring" of the output image (they allow to pass only the low frequencies of the image). All elements of the kernels used for low-pass filtering have positive values. Therefore, a common practice used to scale the result in the intensity domain of the output image

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is to divide the result of the convolution with the sum of the elements of the kernel.

Example kernel matrices: Mean filter (3x3), Gaussian filter (3x3).

HIGH-PASS FILTERS-These filters will highlight regions with step intensity variations, such as edges (will allow to pass the high frequencies). The kernels used for edge detection have the sum of their elements equal to 0.

Example kernel matrix: Laplace filters (edge detection) (3x3).

3. METHODOLOGY

IN SPATIAL DOMAIN-filtering is accomplished by convolving the available image or input image x(m,n) with the filter function h(m,n) to obtain the filtered image y(m,n).

$$y(m,n) = x(m,n) * h(m,n)$$

Laplacian functions are high pass filtering functions while Mean function and Gaussian function are low pass filtering functions.

$$h_m = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

(a) Mean filter function

$$h_g = \frac{1}{273}\begin{bmatrix} 1 & 4 & 7 & 4 & 1 \\ 4 & 16 & 26 & 16 & 4 \\ 7 & 26 & 41 & 26 & 7 \\ 4 & 16 & 26 & 16 & 4 \\ 1 & 4 & 7 & 4 & 1 \end{bmatrix}$$

(b) Gaussian filter function

$$h_{L1} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

(c) first version of Laplacian filter function

$$h_{L2} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

(d) second version of Laplacian filter function

$$h_{L3} = \begin{bmatrix} -1 & 2 & -1 \\ 2 & -4 & 2 \\ -1 & 2 & -1 \end{bmatrix}$$

(c) third version of Laplacian filter function

IMAGE EDGE DETECTION-Image edge x_{edge} is such that those parts which are edges in the image x appear bright while all other parts remain dark.The output of the LPF y is blurred and is of lower frequency compared with the input x. LPF smoothens the edge of significant objects in x to obtain x_{smooth}. Subtracting x_{smooth} from x gives the image edge x_{edge} as illustrated in Eqn and h in Eqn is applicable to h_m and h_g.

$$x_{smooth}(m,n) = y(m,n) = x(m,n) \otimes h(m,n)$$
$$x_{edge}(m,n) = x(m,n) - x_{smooth}(m,n)$$

Laplacian filter tends to amplify noise and detect false edges. The Laplacian filter is often applied to an image that has first been smoothed with smoothing filter in order to reduce its sensitivity to noise. Low pass filter function is applied first before the laplacian filter function is applied as shown inEqn. The image edge produced is related to input image x, low pass filtering function h1 and high pass function filtering function h2 as described by Eqn. h1 is either h_m or h_g. h2 can be any of h_{L1}, h_{L2} and h_{L3}.

$$x_{smooth}(m,n) = y_1(m,m) = x(m,n) \otimes h_1(m,n)$$
$$x_{edge}(m,n) = y_2(m,n) = x_{smooth}(m,n) \otimes h_2(m,n)$$

IMAGE EDGE ENHANCEMENT-The image edge image can be used for sharpening or image edge enhancement if it is added back to the original image signal as shown in Eqn.

$$x_{sharp}(m,n) = x(m,n) + k[x_{edge}(m,n)]$$

where k is a scaling constant.

IN FREQUENCY DOMAIN-LOWPASS FILTER (SMOOTHING)

Ideal low pass Filters-the simplest low pass filter is a filter that "cuts off" all high-frequency components of the Fourier Transform that are at a distance greater than a specified distance D from the origin of the Transform. The transfer function of an ideal low pass filter

$$H(u,v) = \begin{cases} 1 & if\ D(u,v) \le D0 \\ 0 & if\ D(u,v) > D0 \end{cases}$$

where $D(u,v)$: the distance from point (u,v) to the center of their frequency.

$$D(u,v) = \left[\left(u - \frac{M}{2}\right)^2 + \left(v - \frac{N}{2}\right)^2\right]^{\frac{1}{2}}$$

Butterworth Lowpass Filters: the Butterworth filter may be viewed as providing a transition between two "extremes". For high order values, the Butterworth filter approaches the ideal filter. For low order values, Butterworth filter is more like a Gaussian filter.The Butterworth filter has a parameter called the filter order.A frequency-domain filter designed to remove high-frequency noise with minimal loss of signal components in the specified pass-band with order n

$$H(u,v) = \frac{1}{1+\left[\frac{D(u,v)}{D0}\right]^{2n}}$$

Gaussian Lowpass Filters: Main advantage of a Gaussian LPF over a Butterworth LPF is that we are assured that there will be no ringing effects no matter what filter order we choose to work with.A low pass Gaussian filter is used to connect broken text .Different lowpass Gaussian filters used to remove blemishes in a photograph.The transfer function of a Gaussian lowpass filter is defined as:

$$H(u,v) = e^{-D^2(u,v)/2D_0^2}$$

HIGHPASS FILTERS (SHARPENING)

A high-pass filter is a filter that passes high frequencies well, but attenuates frequencies lower than the cut-off frequency. Sharpening is fundamentally a high pass operation in the frequency domain. There are several standard forms of high pass filters such as Ideal, Butterworth and Gaussian high pass filter. All high pass filter (H_{hp}) is often represented by its relationship to the low pass filter (H_{lp}):

$$Hhp = 1 - Hlp$$

Threshold for filters in frequency domain:

To find the threshold (D_0)for filters in frequency domain : $D_0=\sqrt(R^2+C^2)$.

For example: if image is 225*225 then R(rows)=0-224 and C(columns)=0-224

$D_0=\sqrt(224^2+224^2)=316.7$

We can take threshold with difference 20 i.e 100,120,140,160……300. If threshold is 100 then a low pass filter will give frequency components that are below 100 and a high pass filter will give frequency components that are above 100.

For these threshold values we can find frequency, brightness and contrast.

3. RESULTS AND ANALYSIS

FACTORS ON WHICH PERFORMANCE IS MEASURED

The **Frequency** Estimate F of an image is a measure of the spatial frequency of the image and it is the rate of change of intensity across the image. F is given as

$$F = \frac{1}{3MF(NF-1)} f_{rows} + \frac{1}{3NF(MF-1)} f_{columns}$$

where

$$f_{rows} = \sum_{i=1}^{MF} \sum_{j=2}^{NF} \sum_{t=1}^{3} \left| x(i,j,t) - x(i,j-1,t) \right|$$

and

$$f_{columns} = \sum_{j=1}^{MF} \sum_{i=2}^{NF} \sum_{t=1}^{3} \left| x(i,j,t) - x(i-1,j,t) \right|$$

Contrast C of an image is the range from the darkest regions of the image to the lightest regions. High-contrast images have large regions of dark and light. Images with good contrast have a good representation of all luminance intensities. As the contrast of an image increases, the viewer perceives an increase in detail. This is purely a perception issue as the amount of information in the image does not increase. Human beings' perception is sensitive to luminance contrast rather than absolute luminance intensities.

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

where Imax and Imin are the maximum and minimum intensities in the image.

Brightness B of an image is defined as the average of all the pixels within the image. B is given as

$$B = \frac{1}{NM} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} x(m,n)$$

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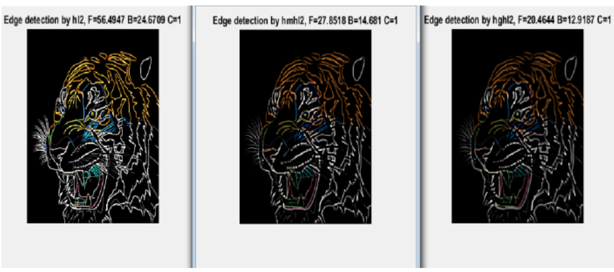
where M and N are the numbers of rows and columns respectively and NM is the total number of pixels in x(m,n).

In spatial domain:

Edge detection examples:

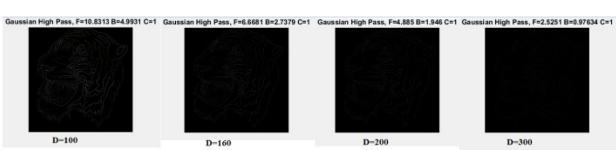


Edge enhancement examples:

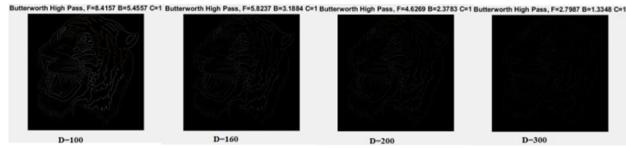
In frequency domain:

Low-pass and high-pass filters examples:

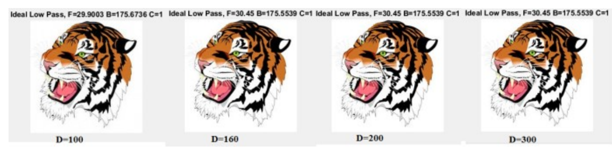
Gaussian filter:

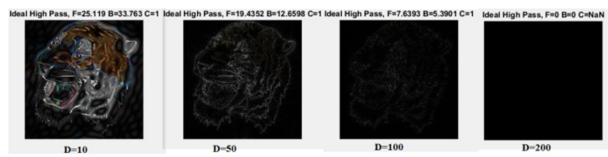


Butterworth filter:



Ideal filter:





TABULAR DATA FOR EDGE ENHANCEMENT,EDGE DETECTION:

EDGE ENHANCEMENT	NAME	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	Hm	27.6	68	1
2	Hg	27.7	69	1
3	Hl1	21.6	73	1
4	Hl2	21.8	77	1
5	Hl3	25.0	71	1
6	Hml1	25.3	70	1
7	Hml2	25.6	73	1
8	Hml3	25.8	68	1
9	Hgl1	24.5	69	1
10	Hgl2	22.9	73	1
11	Hgl3	25.5	68	1

EDGE DETECTION	NAME	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	Hm	10.8	4	1
2	Hg	10.9	4.7	1
3	Hl1	10.9	4.7	1
4	Hl2	56.4	24.6	1
5	Hl3	40.4	10.4	1
6	Hml1	10.6	5.2	1
7	Hml2	27.8	14.6	1
8	Hml3	5.1	1.6	1
9	Hgl1	7.4	4.5	1
10	Hgl2	20.4	12.9	1
11	Hgl3	2.8	1	1

GAUSSIAN

LOW PASS FILTER	D	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	100	20.8	174.4	1
2	160	24.7	174.9	1
3	200	26.1	175.1	1
4	300	28.1	175.3	1

HIGH PASS FILTER	D	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	100	10.8	4.9	1
2	160	6.6	2.7	1
3	200	4.8	1.9	1
4	300	2.5	0.9	1

BUTTERWORTH

LOW PASS FILTER	D	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	100	19.3	174.1	1
2	160	22.8	174.7	1
3	200	24.5	174.9	1
4	300	26.8	175.2	1

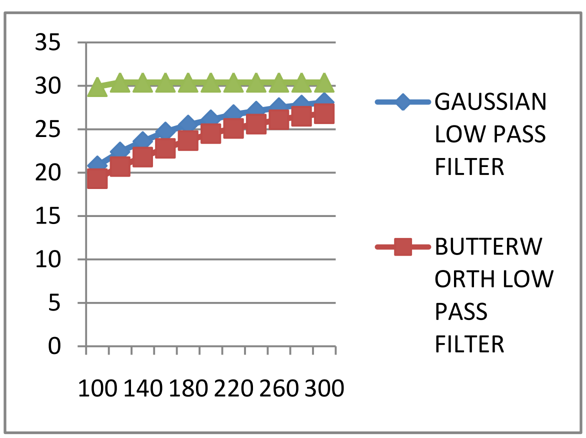
HIGH PASS FILTER	D	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	100	8.4	5.4	1
2	160	5.8	3.1	1
3	200	4.6	2.3	1
4	300	2.7	1.3	1

IDEAL

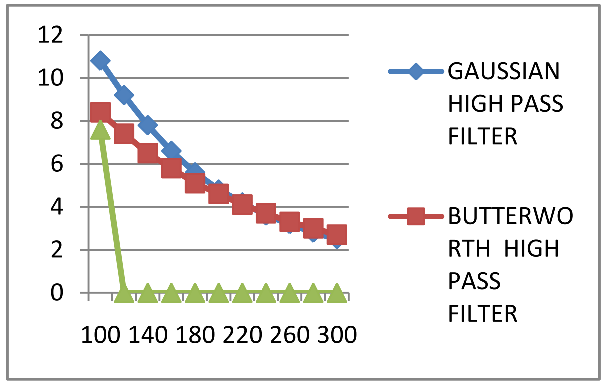
LOW PASS FILTER	D	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	100	29.9	175.6	1
2	160	30.4	175.5	1
3	200	30.4	175.5	1
4	300	30.4	175.5	1

HIGH PASS FILTER	D	FREQUENCY,F	BRIGHTNESS,B	CONTRAST,C
1	10	25.1	33.7	1
2	50	19.4	12.6	1
3	100	7.6	5.3	1
4	200	0	0	-

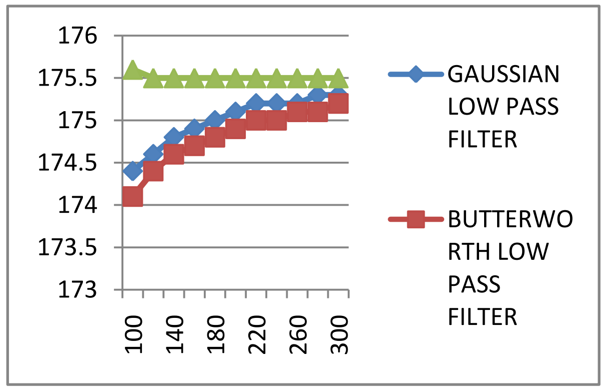
GRAPHICAL REPRESENTATION:



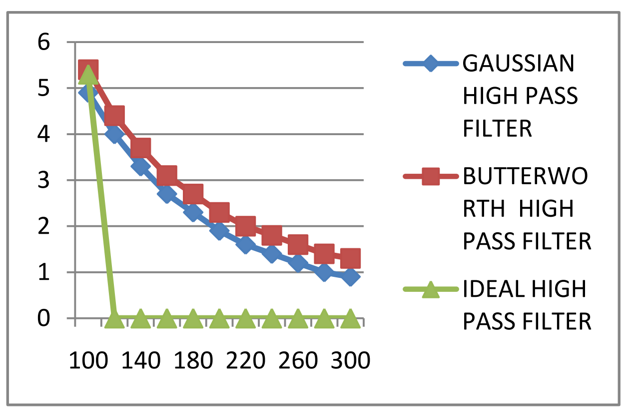
Low pass filters frequency analysis



High pass filter frequency analysis



Low pass filters brightness analysis



High pass filter brightness analysis

4. CONCLUSION

Image edge detection and image edge enhancement methods and their effects on input images have been studied in both domains .The output of h_{L2} has highest frequency estimate and brightness compared with h_{L1} and h_{L3}, h_{L2} is therefore considered to be the best among the three versions of Laplacian filtering functions. Among the eleven alternative combinations of filtering functions, $h_m h_{L2}$ is the best choice for image edge detection as it produced image edge of moderate frequency estimate and brightness. $h_m h_{L2}$ is closely followed by $h_g h_{L2}$. Edge enhanced images based on image edges produced by Laplacian filtering functions are characterized by poorer appearance. Laplacian Filtering functions are not suitable for image edge enhancement. On the other hand, Edge enhanced images based on image edges produced by Mean filtering function h_m and Gaussian filtering function hg are characterized by better appearance, higher frequency estimate, brightness and contrast.

In frequency domain, for low pass filters, as the threshold increases the values of frequency and brightness are increased whereas for high pass filters, as the threshold increases the values of frequency and brightness are decreased but contrast remains same for all the filters.

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