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Lecture:
IMAGE PROCESSING

Chapter 4:

Image Filtering

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Image Filtering

INTRODUCTION

-Image Filtering allows to apply various effects on images in order to filter noise or to smooth image.

-The 2D filter is a 2D filter matrix

*** Filtering in the frequency domain**

- Lots of noises: Gauss, impulse, etc.

- Filters: lowpass, highpass, bandpass.

*** Filtering in the spatial domain**

- Linear filtering is a weighted mask used to express the effects of the filter on each pixel of the image.

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IMAGE FILTERING IN THE SPATIAL DOMAIN

- A spatial filter means that a typical pixel in image is calculated based on neighborhood pixels. The filter is moved to all image pixels to create the output image.

Fig 4.1 describes a 3x3 spatial filter. Assume that one needs to calculate a image pixel (x, y) in an image, the corresponding pixel of output image $g(x, y)$ is calculated by the sum of products of coefficients (values) between the filter and image.

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Image Filtering

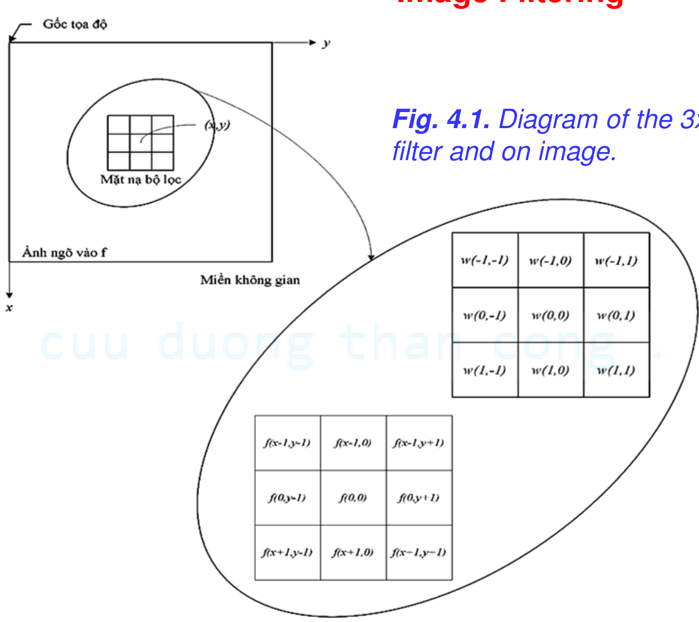

Fig. 4.1. *Diagram of the 3x3 spatial filter and on image.*

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IMAGE FILTERING IN THE SPATIAL DOMAIN

- Notice: the center coefficient of filter is $w(0,0)$, corresponding to the image pixel considered (x, y). With a filter of $m \times n$, assume that $m = 2a + 1$ and $n = 2b + 1$, in which a and b are positive integers. The size of the odd and smallest filter is 3×3).

- In general, the $m \times n$ spatial filter used on the $M \times N$ input image to produce the output image $g(x, y)$ is expressed as follows:

$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

$$g(x,y) = w(-1,-1)f(x-1,y-1) + w(-1,0)f(x-1,y) + \ldots + w(0,0)f(x,y) + \ldots + w(1,1)f(x+1,y+1)$$

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Correlation and convolution in spatial domain

- Correlation in image processing is to move a window (filter) on image and calculate the sum of products at every position.
- In convolution, except rotating the filter of 180^0.
- Notice: convolution means that a filter moves and rotate a degree of 180^0 and produce result rotated 180^0 as described in Figs 4.2(a) and 4.2(b).
- Fig. 4.2. is description of correlation and convolution methods between the 1D signal and the unit impulse. Notice of transposing.

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Fig. 4.2(a) *correlation method.*

Original is the 1st pixel, to correlate to 5 values of w, one can add zeros as Step-3 and then shift 1 by 1 from left to right. Every correlation is calculated by the sum of products of every point and in this case, 12 times shifted as result of Step-6

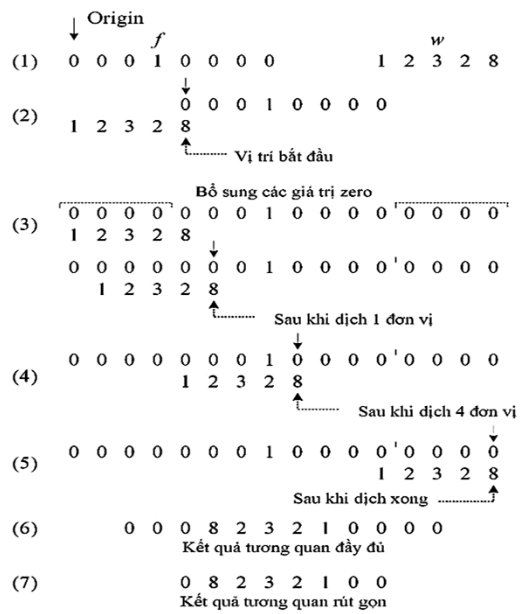

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Fig. 4.2(b) *convolution method*

Original is the 1st pixel, to convolute to 5 values of w, one can add zeros as Step-10 and rotate the window w with a degree of 180 and then shift 1 by 1 from left to right. It is calculated by the sum of products of every point and in this case, 12 times shifted and then as result of Step-14

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In general, the correlation expression is described as below equation, the filter $w(x,y)$ with the size of $m \times n$, the image $f(x,y)$ and called $w(x,y) \star f(x,y)$

$$w(x,y) \star f(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

Similarly, the convolution of $w(x,y)$ and $f(x,y)$, called $w(x,y) \bigstar f(x,y)$, is expressed as follows:

$$w(x,y) \bigstar f(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x-s, y-t)$$

The symbol *minus* means that the image f is rotated 180 degrees.

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Image Filtering

(a)

Origin $f(x,y)$

0	0	0	0	0
0	0	0	0	0
0	0	1	0	0
0	0	0	0	0
0	0	0	0	0

$w(x,y)$

1	2	3
4	5	6
7	8	9

(b)

f sau khi được đệm các giá trị 0

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

(b)

Vị trí bắt đầu với w

1	2	3	0	0	0	0	0	0
4	5	6	0	0	0	0	0	0
7	8	9	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

(d)

Kết quả tương quan

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	9	8	7	0	0	0
0	0	0	6	5	4	0	0	0
0	0	0	3	2	1	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Fig 4.3(a) *in similarity to Fig 4.2(a), correlation of an image f and the 3x3 filter w, result as (e)*

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Kết quả rút gọn (e)

0	0	0	0	0
0	9	8	7	0
0	6	5	4	0
0	3	2	1	0
0	0	0	0	0

Xoay w (f)

9	8	7	0	0	0	0	0	0
6	5	4	0	0	0	0	0	0
3	2	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Kết quả tích chập (g)

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	1	2	3	0	0	0
0	0	0	4	5	6	0	0	0
0	0	0	7	8	9	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Kết quả rút gọn (h)

0	0	0	0	0
0	1	2	3	0
0	4	5	6	0
0	7	8	9	0
0	0	0	0	0

Fig 4.3(b) *in similarity to Fig 4.2(b), convolution of an image f and the 3x3 filter w, result as (h)*

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Ex: Using the correlation and convolution methods to calculate the output image at the position g(2,1).

Input image (x: 0 to 4, y: 0 to 4)

1	1	1	2	2
1	1	1	2	2
1	**1**	1	2	2
2	2	2	2	2
2	2	2	2	2

Mask (filter) (s: -1 to 1, t: -1 to -1)

1	1	1
1	1	1
1	1	1

Output image (x, y)

	12			

$g(x,y)=g(2,1)$

$$g(2,1)=\omega(-1,-1)f(1,0)+\omega(-1,0)f(1,1)+\omega(-1,1)f(1,2)$$
$$+\omega(0,-1)f(2,0)+\omega(0,0)f(2,1)+\omega(0,1)f(2,2)$$
$$+\omega(1,-1)f(3,0)+\omega(1,0)f(3,1)+\omega(1,1)f(3,2)=12$$

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Image Filtering

IMAGE FILTERING IN THE SPATIAL DOMAIN

Some functions in MATLAB

- *Ones:* matrix 1.
- imfilter(f,h,'Boundary Options','OutputSize','Correlation and Convolution Options')
- 'Boundary Options' : allow to select a boundary of the output image
- 'Output Size': select the output size with 'Correlation and Convolution Options'.
- More functions in Table. 4.1 of Image Processing book

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Image Filtering

Some filters expressed by mathematic methods:

* Gaussian

$$h_g(n_1,n_2)=e^{\frac{-(n_1^2+n_2^2)}{2\sigma^2}}$$

or

$$h(n_1,n_2)=\frac{h_g(n_1,n_2)}{\sum n_1 \sum n_2 h_g}$$

* Laplacian

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

or

$$\begin{bmatrix} \frac{\alpha}{1+\alpha} & \frac{1-\alpha}{1+\alpha} & \frac{\alpha}{1+\alpha} \\ \frac{1-\alpha}{1+\alpha} & \frac{-4}{1+\alpha} & \frac{1-\alpha}{1+\alpha} \\ \frac{\alpha}{1+\alpha} & \frac{1-\alpha}{1+\alpha} & \frac{\alpha}{1+\alpha} \end{bmatrix}$$

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* Log (Laplacian of Gaussian)

$$h(n_1,n_2)=\frac{\left(n_1^2+n_2^2-2\sigma^2\right)h_g(n_1,n_2)}{2\pi\sigma^6\sum n_1\sum n_2 h_g}$$

* Prewitt

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

* Sobel

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

Image Filtering

Ex 4.1: Express image filtering using filters in toolbox of MATLAB

```
clear all;
f=imread('cameraman.bmp');
ha=fspecial('average');
ga=imfilter(f,ha,'replicate');
hd=fspecial('disk');
gd=imfilter(f,hd,'replicate');
hg=fspecial('gaussian');
gg=imfilter(f,hg,'replicate');
hlap=fspecial('laplacian');
glap=imfilter(f,hlap,'replicate');
hlog=fspecial('log');
glog=imfilter(f,hlog,'replicate');
```

```
hm=fspecial('motion');
gm=imfilter(f,hm,'replicate');
hp=fspecial('prewitt');
gp=imfilter(f,hp,'replicate');
hs=fspecial('sobel');
gs=imfilter(f,hs,'replicate');
```

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Image Filtering


(a)

(b)

(c)


(d)

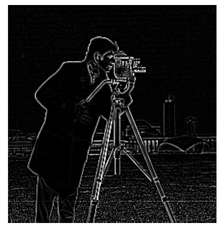
(e)

(f)

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Image Filtering


(g)

(h)

(i)

Fig 4.4. *Express images with different filters*
(a) Original image; (b) Average; (c) Disk; (d) Gaussian; (e) Laplacian; (f) Log; (g) Motion; (h) Prewitt; (i) Sobel

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

- Some applications in frequency domain, one often uses the FT.
- Image filtering in the frequency domain

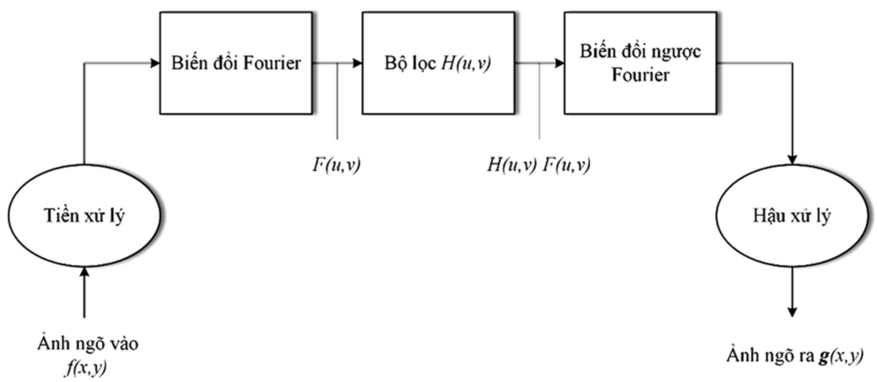

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

According to diagram of Fig above, frequency filtering can be expressed in MATLAB using the following functions:

```
function g=dftfilt(f,H)
F=fft2(f,size(H,1),size(H,2));
G=H.*F;
g=ifft2(G);
f=real(g);
g=g(1:size(f,1),1:size(f,2))
end
```

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

- H is the impulse response of filter with frequency, assume that its size is 4 times of the input image. In the spatial domain, one uses convolution, but in the frequency, the multiplication is used. After filtering, the output values (matrix) of the filter will be converted using IFT to obtain the image with the same size of the original image.

- Building the frequency filter using functions in MATLAB as freqz2 with FIR (Finite Impulse Response)

- H=freqz2(h,R,C)
In which h is the 2D spatial filter, H is the 2D frequency filter response, R and C are the number of rows and columns of H.

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

Ex 4.2: Express image filtering in the spatial domain using Sobel and in the frequency domain using DFT

```
clear all;
f=imread('cameraman.tif');
h=fspecial('sobel');
sizeH=size(f)*2;
H=freqz2(h,sizeH);
H1=ifftshift(H);
gd=dftfilt(f,H1);
gs=imfilter(double(f),h);
d=abs(gd-gs);
gd=uint8(gd);imshow(gd);
gd=uint8(gd);imshow(gs);
```


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IMAGE FILTERING IN THE FREQUENCY DOMAIN

Checking homologous between two methods:

$$d = |gs - gd|$$

In which *gs* is the image filtered in the spatial and *gd* is filtered in the frequency, results as in Fig. 4.6

***Fig. 4.6.** Sobel filter*
(a). in the frequency
(b) in the spatial
(c) differential $\max d = 3.4106 \times 10^{-13}$

IMAGE FILTERING IN THE FREQUENCY DOMAIN

Build function dftuv for calculation of distance with grid of .

```
function [U,V]=dftuv(m,n)
u=0:(m-1);
v=0:(n-1);
idx=find(u>m/2);
u(idx)=u(idx)-m;
idy=find(v>n/2);
v(idy)=v(idy)-n;
[V,U]=meshgrid(v,u);
end
```

Ex of an image with 8×5 :

```
[U,V]=dftuv(8,5);
D=U.^2+V.^2
D =
   0    1    4    4    1
   1    2    5    5    2
   4    5    8    8    5
   9   10   13   13   10
  16   17   20   20   17
   9   10   13   13   10
   4    5    8    8    5
   1    2    5    5    2
```

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

Using function fftshift (D) move coordinate to the center of the frequency rectangular image (frequency retangle) and the result:

ans =

20	17	16	17	20
13	10	9	10	13
8	5	4	5	8
5	2	1	2	5
4	1	0	1	4
5	2	1	2	5
8	5	4	5	8
10	9	10	13	

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Image Filtering

Lowpass Filter: blurring image

* Ideal LowPass Filter - ILPF) : the transfer functions is described as:

$$H(u,v) = \begin{cases} 1 & D(u,v) \le D_0 \\ 0 & D(u,v) > D_0 \end{cases}$$

where D_0 is the cut-off frequency with non-negative value, $D(u,v)$ is the distance from (u,v) to the filter center. Orbit of $D(u,v) = D_0$ is a circle.

* Butterworth LowPass Filter - BLPF) with *n* orders, the cut-off frequency D_0, the transfer functions is described as:

$$H(u,v) = \frac{1}{1 + [D(u,v)/D_0]^{2n}}$$

Often define the cut-off frequency at positions of $H(u,v) = 0.5$ (reduce 50% compared with the max value 1) when $D(u,v) = D_0$.

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

Transfer function of the Gaussian Lowpass Filter (GLPF) is expressed as follows:

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

In which σ is the standard deviation. If $\sigma = D_0$, we have :

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

When $D(u,v) = D_0$, the value at the cut-off frequency is 0.0607. Fig. 4.7 describes the 3-D shapes of the frequency response of every filter.

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Image Filtering

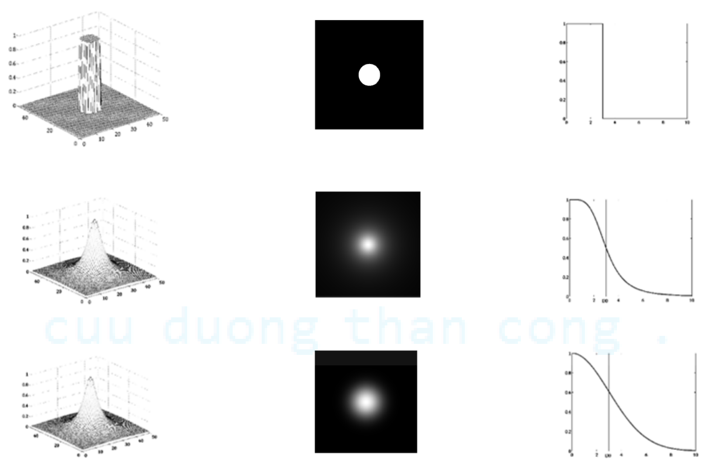

Fig. 4.7. *left column: 3-D shape of the window filter; middle columns: images of the filters; right one: the frequency response D_0 of the ideal filters. First row: the ideal lowpass filter; middle one: the Butterworth lowpass filter; last one: the Gaussian lowpass filter*

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Image Filtering

EX: *Build* a *lowpass filter function* as lpfilter with 3 basic *filter.*

```
function [H,D]=lpfilter(type,M,N,DO,n)
[U,V]=dftuv(M,N);
D=sqrt(U.^2+V.^2);
switch type
    case 'ideal'
        H=double(D<=DO);
    case 'btw'
        if nargin==4
            n=1;
        end
        H=1./(1+(D./DO).^(2*n));
    case 'gaussian'
        H=exp(-
(D.^2)./(2*(DO^2)));
    otherwise
        error('Unknown filter
type');
end
```

Some functions in toolbox:
- mesh(H): express information in 3D such as x=1:M và y=1:N, with [M,N]=size(H).
- mesh(H(1:k:end,1:k:end))
- colormap([0 0 0]): black-white

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

Ex 4.3*: express the plot using mesh for the Butterworth lowpass filter with different orders.*

```
clear all;
BLPF1=fftshift(lpfilter('btw',500,500,5
0,1));
mesh(BLPF1(1:10:500,1:10:500));
axis([0 50 0 50 0 1]);
saveas(gcf, 'Hinh3.7a.tif', 'tif');

BLPF2=fftshift(lpfilter('btw',500,500,5
0,2));
figure;mesh(BLPF2(1:10:500,1:10:50
0));
axis([0 50 0 50 0 1]);
saveas(gcf, 'Hinh3.7b.tif', 'tif');
BLPF3=fftshift(lpfilter('btw',500,500,
50,3));
figure;mesh(BLPF3(1:10:500,1:10:5
00));
axis([0 50 0 50 0 1]);
saveas(gcf, 'Hinh3.7c.tif', 'tif');

BLPF4=fftshift(lpfilter('btw',500,500,
50,4));
figure;mesh(BLPF4(1:10:500,1:10:5
00));
axis([0 50 0 50 0 1]);
saveas(gcf, 'Hinh3.7d.tif', 'tif');
```


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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

```
BLPF3=fftshift(lpfilter('btw',500,500,50,3));
figure;mesh(BLPF3(1:10:500,1:10:500));
axis([0 50 0 50 0 1]);
saveas(gcf, 'Hinh3.7c.tif', 'tif');

BLPF4=fftshift(lpfilter('btw',500,500,50,4));
figure;mesh(BLPF4(1:10:500,1:10:500));
axis([0 50 0 50 0 1]);
saveas(gcf, 'Hinh3.7d.tif', 'tif');
```


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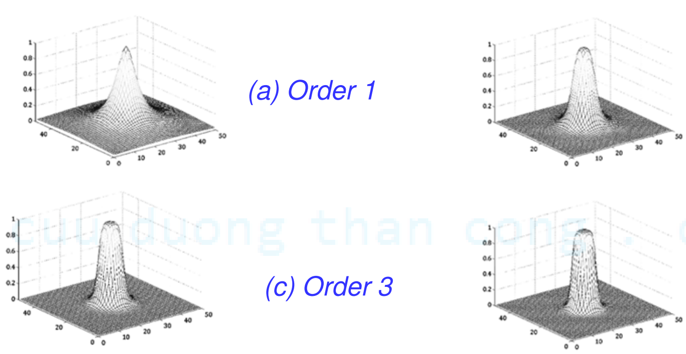
Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN



(a) Order 1 *(b) Order 2*

(c) Order 3 *(d) Order 4*

Fig 4.8. *Plots of the Butterworth lowpass filters with different orders.*

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

***Ex 4.4**: express the lowpass filter with different cut-off frequencies and compare results*

```
clear all;
f=imread('cameraman.bmp');

D01=1/5*size(f,1);
[M,N]=size(f);
[H,D]=lpfilter('ideal',2*M,2*N,D01);
g=dftfilt(f,H);

D02=2/5*size(f,1);
[M,N]=size(f);
[H,D]=lpfilter('ideal',2*M,2*N,D02);
g=dftfilt(f,H);

D03=3/5*size(f,1);
[M,N]=size(f);
[H,D]=lpfilter('ideal',2*M,2*N,D03);
g=dftfilt(f,H);

D04=4/5*size(f,1);
[M,N]=size(f);
[H,D]=lpfilter('ideal',2*M,2*N,D04);
g=dftfilt(f,H);

D05=size(f,1);
[M,N]=size(f);
[H,D]=lpfilter('ideal',2*M,2*N,D04);
g=dftfilt(f,H);
```


Image Filtering

(a) Original image

(b) $D_0 = \frac{M}{5}$

(c) $D_0 = \frac{2M}{5}$

(d) $D_0 = \frac{3M}{5}$

(e) $D_0 = \frac{4M}{5}$

(f) $D_0 = M$

***Fig 4.9.** cameraman* $M \times N$ *image after the ideal lowpass filter with different cut-off frequencies*

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Image Filtering

Ideal highpass filter

The ideal highpass filter is often implemented to filter image sharper by eliminating the low frequencies

If the transfer of the lowpass filter is $H_{lp}(u,v)$, we have the highpass filter as follows:

$$H_{hp}(u,v) = 1 - H_{lp}(u,v)$$

Build the highpass filter function using Matlab

```
function H=hpfilter(type,M,N,D0,n)
if nargin==4
    n=1;
End
Hlp=lpfilter(type,M,N,D0,n);
H=1-Hlp;
end
```


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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

Ex 4.5: Express the highpass filter using the function *mesh* for image.

```
clear all;close all;clc
ILPF=fftshift(hpfilter('ideal',500,500,50));
mesh(ILPF(1:10:500,1:10:500));
axis([0 50 0 50 0 1]);

BLPF=fftshift(hpfilter('btw',500,500,50));
mesh(BLPF(1:10:500,1:10:500));
axis([0 50 0 50 0 1]);

GLPF=fftshift(hpfilter('gaussian',500,500,50));
mesh(GLPF(1:10:500,1:10:500));
axis([0 50 0 50 0 1]);
```

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Image Filtering

IMAGE FILTERING IN THE FREQUENCY DOMAIN

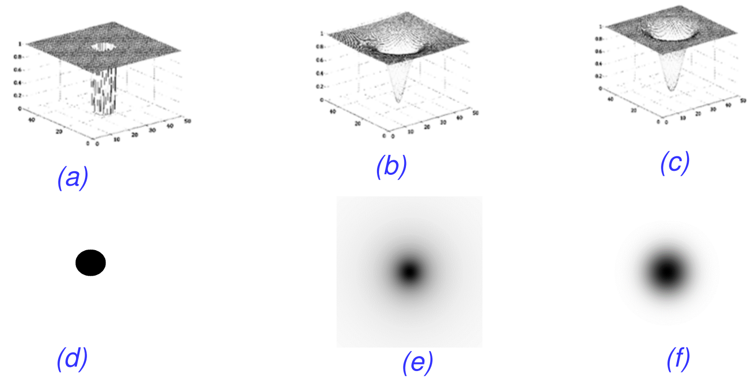

Fig. 4.10. *Express the highpass filter. Top row: mesh with the 3-D shape; bottom row: 2D images of the mesh; left column: the ideal highpass filter, middle columns: the Butterworth highpass filter, right one: the Gaussian highpass filter*

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- The highpass filter is normalized to be zero to the DC components. Thus, this will reduce the average value of the image onto zero.
- For improvement, the DC offset components are added to the highpass filter.
- The high frequency emphasis filtering with offset is expressed as follows:

$$H_{hfe}(u,v) = a + bH_{hp}(u,v)$$

In which a is the offset, b denotes the multiplication constant and $H_{hp}(u,v)$ describes the transfer of the highpass filter.

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Ex 4.6: express the high frequency emphasis filtering using Matlab.

```
clear all;
f=imread('satellite.tiff');
[M N]=size(f);
D0=0.1*size(f,1);
HBW=hpfilter('btw',2*M,2*N,D0);
H=0.5+2*HBW;
gbw=dftfilt(f,HBW);
gbw=gscale(gbw);
ghf=dftfilt(f,H);
ghf=gscale(ghf);
ghe=histeq(ghf,256);
```


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In the Ex 4.6, the *gscale* allows to normalize and change data type containing the gray intensity in image. The *gscale* function is proposed:

```
function g=gscale(f)
fmin=min(f(:));
fmax=max(f(:));
for i=1:size(f,1)
    for j=1:size(f,2)
g(i,j)=255*(f(i,j)-fmin)/(fmax-fmin);
    end
end
g=uint8(g);
end
```


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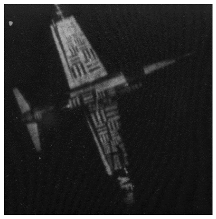
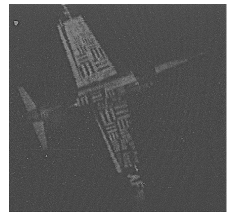
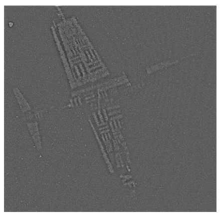


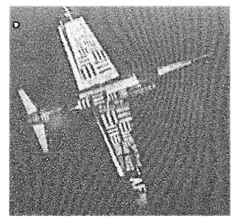
(a) Blurring satellite image



(c) Image after the emphasis highpass filter



(b) Image after the Butterworth highpass filter



(d) Image after the histogram equalization of image (c)

Ex 4.11. *Satellite image after the* highpass filter

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Image Filtering

Problem: Calculate the convolution of the image A and the mask h.

- Suppose the input image is

```
A = [17  24   1   8  15
     23   5   7  14  16
      4   6  13  20  22
     10  12  19  21   3
     11  18  25   2   9]
```


- And the kernel (mask)

```
h = [8   1   6
     3   5   7
     4   9   2]
```

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Image Filtering

The End

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