Purdue University

ECE513 Final Project

Iterative Methods for Diffractive Optical Element Design

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Abstract

Diffractive optical elements serve a wide array of purposes in optical systems, such as splitting laser beam and correcting aberrations of a lens. A similar concept, computer generated holography allow us to store and reproduce the object's image in 3D, offering theoretically much superior experience than existing 3D visual representations such as 3D movies. In this report, we compare various iterative Fourier transform methods used in designing quantized DOEs that are able to shape incoming beam to result in a diffraction pattern like the desired test image, and also in designing quantized computer generated holograms that store and reproduce complex field like the given image. The compared iterative methods are Input-Output, Output-Output, Modified-Input-Output and Hybrid-Input-Output. We compare the listed methods in terms of convergence rate by plotting residue at each iteration and showcasing the quality of the reconstructed images.

Contents

Chapter 1

Introduction

Diffractive optical element (DOE) and computer generated hologram (CGH) provide powerful tools for various optical applications. Lohmann method was first proposed about a half century ago to design binary DOE computationally [1]. Project onto convex sets (POCS) is another useful approach in designing DOE, as it can tailor the design for even complex valued field or image.

The iterative POCS allows the optimization of individual DOE pixels based on the known information, such as image magnitude in target planes and spatial support. Although, the nonlinear optimization process may involve non-convex sets, which could prove to be difficult for POCS methods. There are extension of the alternating projection algorithms, commonly used for this type of problems, not only in DOE design but also in phase retrieval [2],

In this report, we compare the various iterative methods [3–6] that are essentially extension of the POCS, the algorithms compared are: Input-Output (IO), Output-Output (OO), Modified-Input-Output (MIO) and Hybrid-Input-Output (HIO).

Chapter 2

Principle of Fourier Iterative Methods

In beam shaping, the principle of all compared iterative methods is manifested in Fig. 2.1. As we know, far-field diffractive propagation of an object, is mathematically a Fourier transform operation. We can take the forward propagation and backpropagation as projection and backprojection operation in the form of Fourier transform and inverse Fourier transform respectively. At iteration k, g_k, the transverse plane where the diffraction occur, is propagated through Fourier transform to the far-field, G_k. The constraints in the far-field modifies G_k (in beam shaping, G_k is updated based on the magnitude of the desired complex beam pattern; in holography, G_k can be modified based on the desired magnitude of the complex diffraction pattern) to generate G'_k. G'_k is then backpropagated to the initial plane to become the output g'_k. The algorithms we compare differ in the rule of updating the input for the next iteration, g_{k+1}, but the input-output kernel as shown is the same. As quantization is needed in the design of beam shaping DOE and hologram, quantization process is applied in the corresponding plane accordingly to simulate realistic manufacturing requirement.

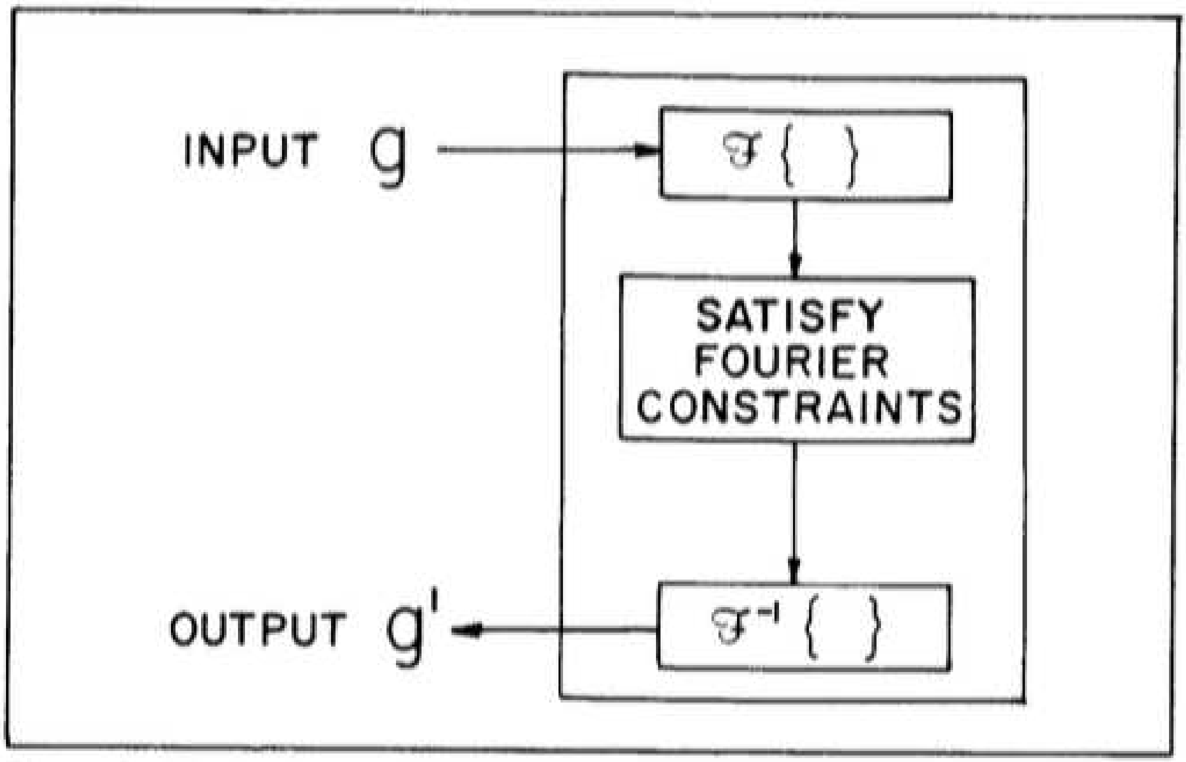


Figure 2.1: The principle of an input-output iterative Fourier transform algorithm. The compared algorithms differ in the choice of input for subsequent iteration [3].

The input-output algorithm we used, g_{k+1}, is with the following updating process according to [3]:

$$g_{k+1} = g_k + \Delta g(x) = g_k + \beta * \Delta g_d(x) \tag{2.1}$$

where $\Delta g_d(x)$ is defined as

$$\Delta g_d(x) = [|f(x)| * \frac{g'(x)}{|g'(x)|} - g'(x)] + [|f(x)| * \frac{g'(x)}{|g'(x)|} - |f(x)| * \frac{g(x)}{|g(x)|}] \tag{2.2}$$

Output-output method has a different equation than Eq. 2.1, instead of modifying the input of the previous iteration, the output of the iteration, g'_k is used [2]:

$$g_{k+1} = g'_k + \Delta g(x) \tag{2.3}$$

In the simulations in the following chapters, we used $\beta = 1$ for IO and OO implementations. Another modification on IO is MIO [5], where β from Eq. 2.1 is modified with an exponentially damping term, α, such that Eq. 2.1 becomes:

$$g_{k+1} = g_k + \Delta g(x) = g'_k + \frac{\beta}{\alpha^k} * \Delta g_d(x) \tag{2.4}$$

In our simulation for MIO, we chose $\beta = 1$ and $\alpha = 1.2$, Please note that the performance of MIO can be optimized further by exploring the performance of the different parameter pairs of β and α.

The last algorithm, HIO, differ in the sense that it apply different updating rule for g_{k+1} according to the spatial support. $g_{k+1} = g'_k$ if the updating area fall into the spatial support; $g_{k+1} = g_k + \beta * \Delta g(x)$, if the updating area is outside the spatial support [2] (β is chosen to be 0.9 for the two HIO simulations).

Figure 2.2: Original Lena image

Chapter 3

Beam Shaping DOE

The simulation for beam shaping DOE is defined as follows: we want to shape the illuminating plane wave incident on a DOE with quantized magnitude and quantized phase, so that the produced complex diffraction pattern is the same as the desired complex image. We generate a complex large image with random phases at each pixel as our desired image, the original magnitude of Lena image is placed in the first quadrant as shown in Fig. 2.2. Our goal is to design a DOE that is capable of generating this desired complex diffraction at far-field. The DOE is designed to only has quantized magnitude and quantized phase in the first quadrant to provide a spatial support.

The magnitude of the resulted DOEs and their corresponding magnitude of diffraction pattern are shown in Fig. 3.1 for 50 IO iterations; Fig. 3.2 for 50 OO iterations; and Fig. 3.3 for 50 HIO iterations, all with 256 magnitude quantization and 10 phase quantization. Please note that the diagonal line is a result of latex image display, there was no such line in MATLAB display.

The magnitude of the resulted DOE and the corresponding magnitude

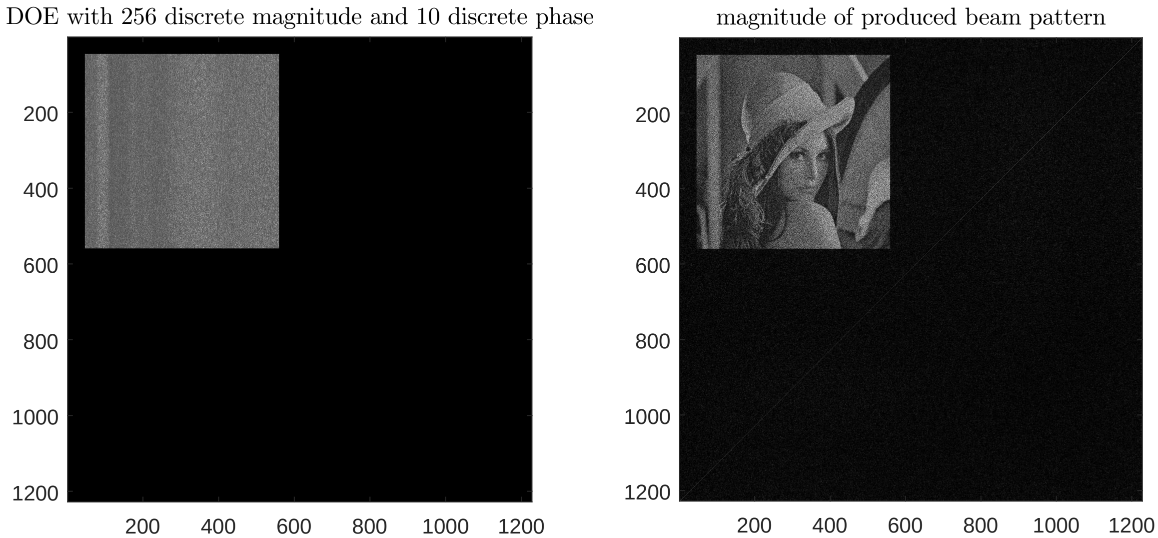


Figure 3.1: DOE and shaped diffraction pattern after 50 IO iterations.

of diffraction pattern for MIO algorithms are shown in 3.4, we also compare here the effect of using different number of levels of quantization. It clearly shows that more quantization lead to a better result.

In Fig. 3.5, we record the residual for the different algorithms at each iteration to compare their performance. The residual is defined as the ratio of the Euclidean norm of the difference between the diffraction pattern and goal image over the Euclidean norm of the goal image. We can see that HIO is the best performing algorithm and MIO is better than IO and OO after 20 iterations. We also notice that more quantization levels allow more accurate representation, and more accurate diffraction pattern generation.

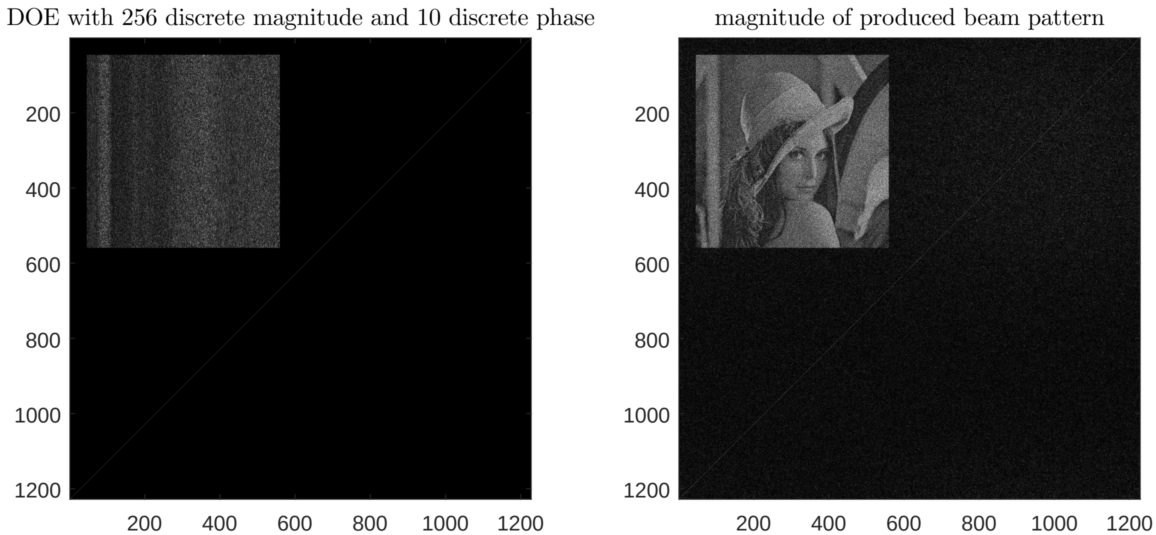


Figure 3.2: DOE and shaped diffraction pattern after 50 OO iterations.

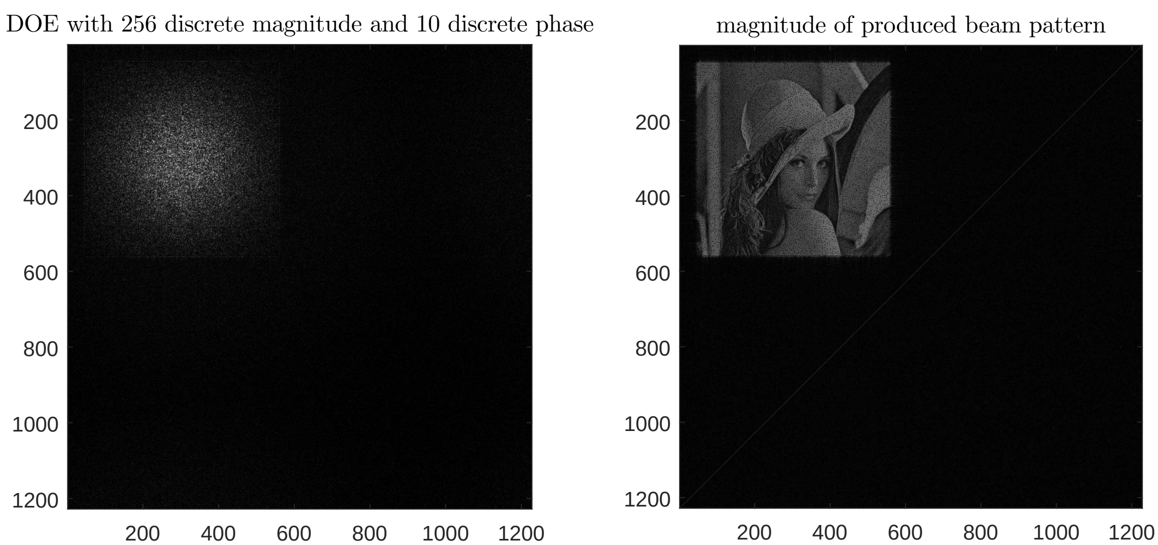
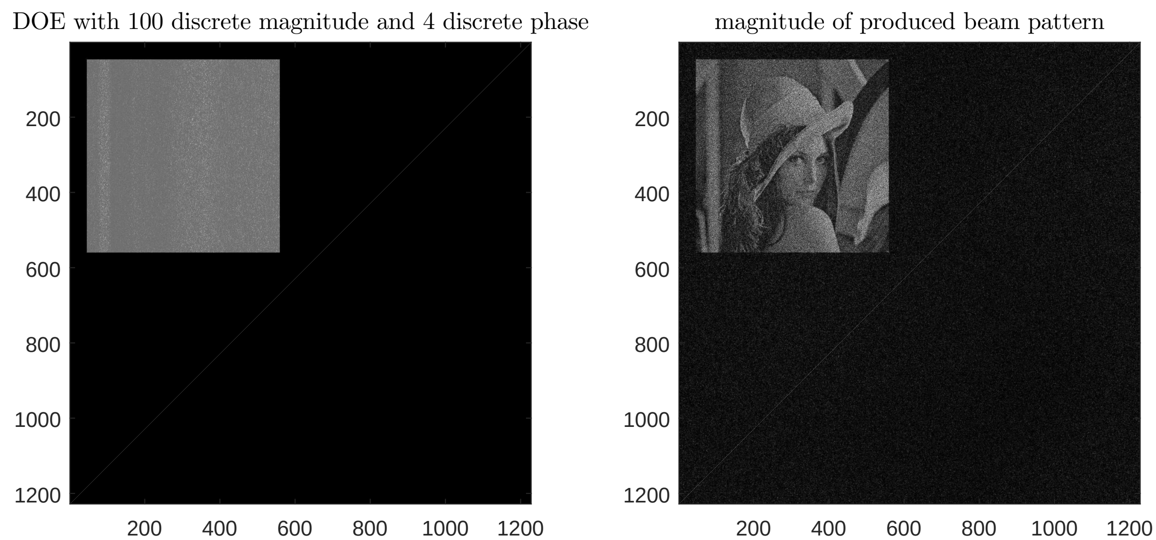
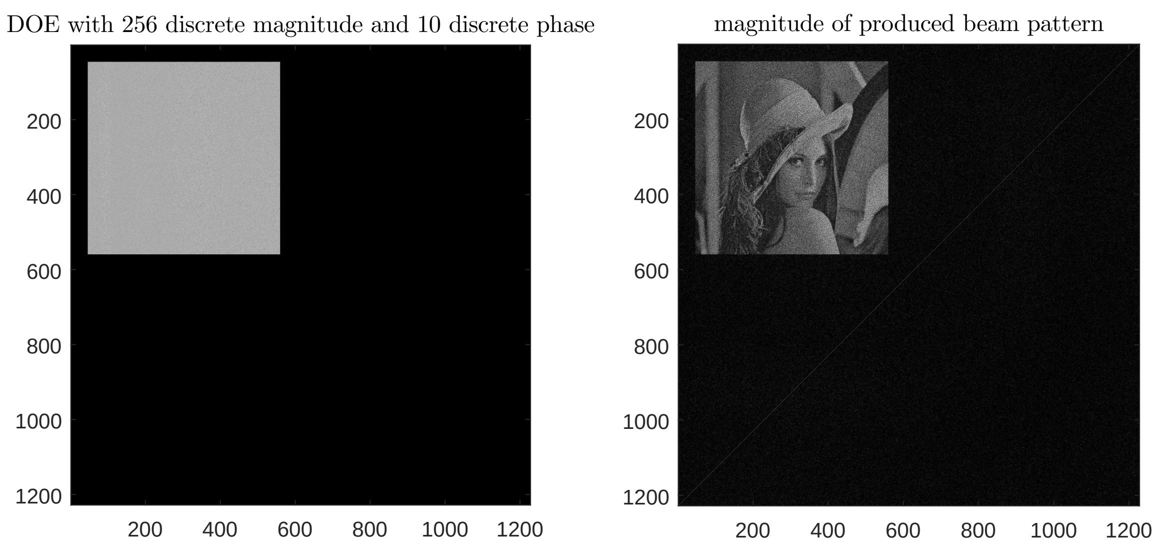


Figure 3.3: DOE and shaped diffraction pattern after 50 HIO iterations.



(a) 100 mangitude quantization and 4 phase quantization.



(b) 256 mangitude quantization and 10 phase quantization.

Figure 3.4: DOE and shaped diffraction pattern after 50 MIO iterations with different quantization choices.

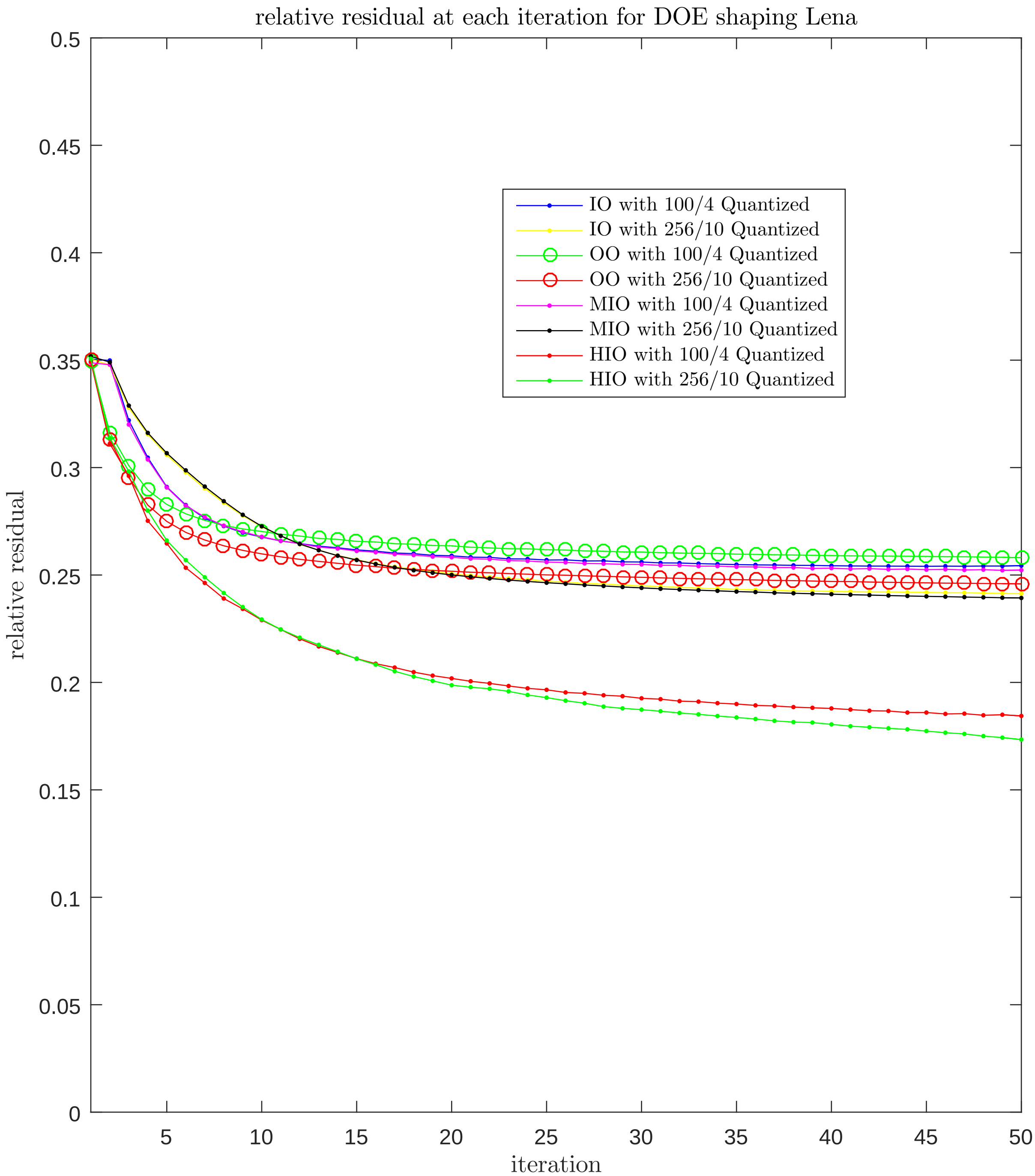


Figure 3.5: The performance of algorithms with different quantization after 50 iterations.

Chapter 4

Computer Generated Holography

Similarly, the algorithms can be used to generate holographic patterns that will reconstruct the desired image after backpropagation. The simulation for CGH is defined as follows: we want to design a holographic pattern with quantized magnitude and quantized phase, so that after backpropagation, the hologram will generate the desired complex image. We generate a complex large image with random phases at each pixel as our desired image, the original Lena image is placed in the first quadrant as shown in Fig. 2.2. The holograms have no special spatial support in this case so we compare IO, OO and MIO only.

The magnitude of the magnitude of the reconstructed images and the holograms that generated the images are shown in Fig. 4.1 for 20 IO iterations; Fig. 4.2 for 20 OO iterations; and Fig. 4.3 for 50 MIO iterations, all with 256 magnitude quantization and 10 phase quantization. Please note again, that the diagonal line is a result of latex image display, there was no such line in MATLAB display.

As we are comparing complex matrices, the showcased reconstructed images in figures are not a good indicators because they are absolute valued.

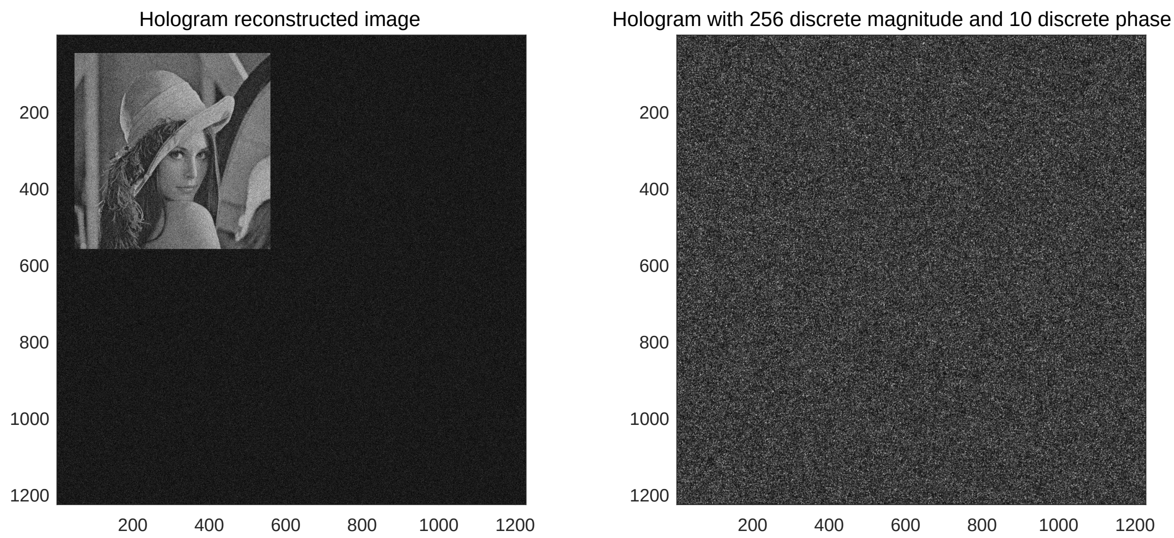


Figure 4.1: Reconstructed image and its hologram after 20 IO iterations.

We turn to comparing the residual convergence curve to determine which algorithm is better.

In Fig. 4.4, we record the residual for the different algorithms at each iteration to compare their performance. We can see that OO is the best performing algorithm and MIO is performing better than IO. We also notice that more quantization levels allow more accurate representation, and better holographic quality.

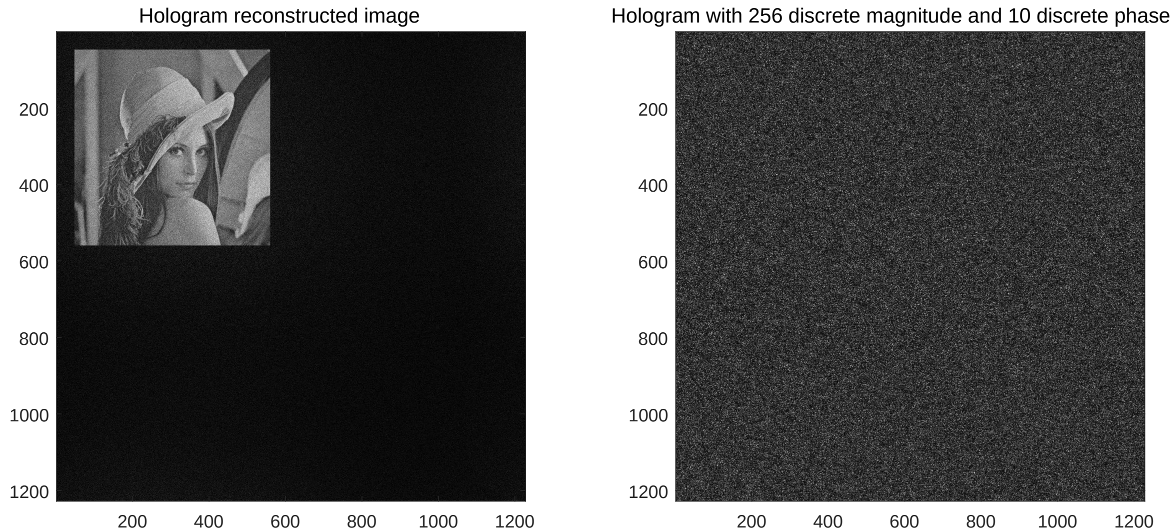


Figure 4.2: Reconstructed image and its hologram after 20 OO iterations.

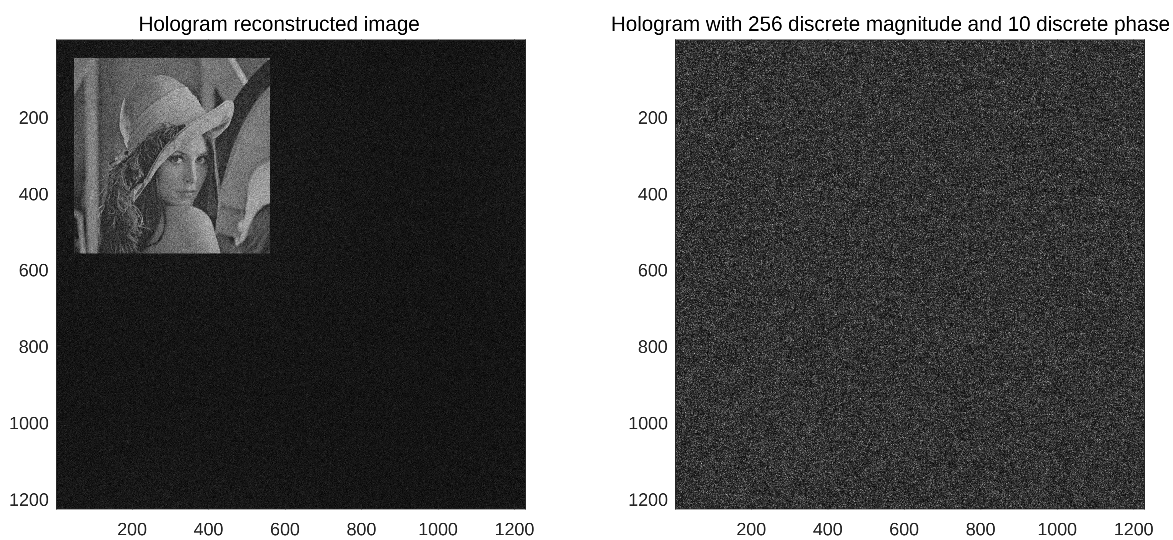


Figure 4.3: Reconstructed image and its hologram after 20 MIO iterations.

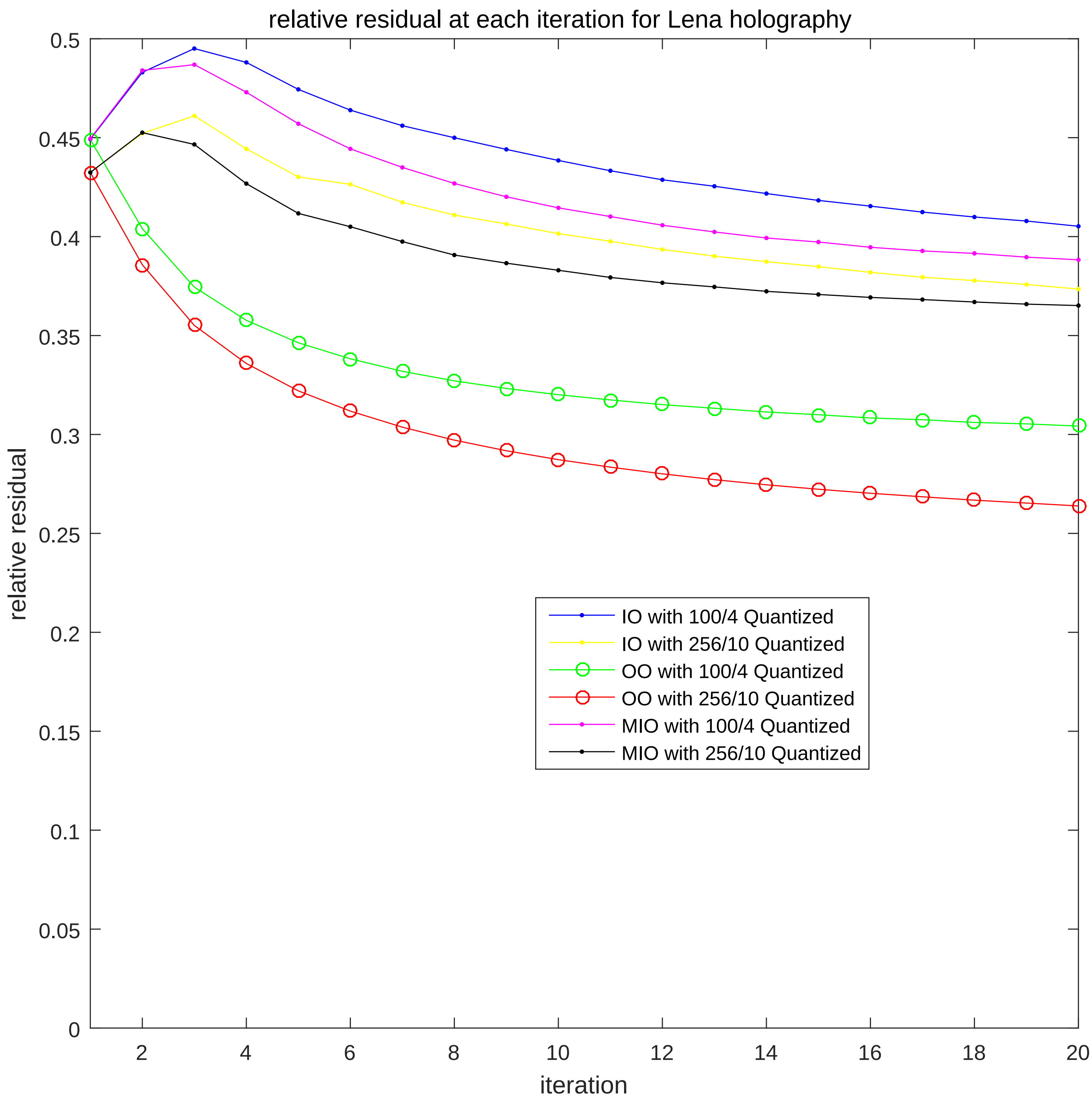


Figure 4.4: The performance of algorithms with different quantization after 50 iterations.

Chapter 5

Conclusion

The performance of the tested iterative algorithms are showing consistent characteristics in two different implementations: beam shaping DOE design and CGH design. Out of the compared algorithms, the two variances of the basic IO: MIO, OO performs better than the basic IO. MIO and HIO perform better in DOE design while OO performs better in hologram generation.

References

[1] A. W. Lohmann and D. P. Paris, "Binary Fraunhofer Holograms, Generated by Computer," Appl. Opt., AO **6,** 1739–1748 (1967).

[2] J. R. Fienup, "Phase retrieval algorithms: a comparison," Appl. Opt., AO **21,** 2758–2769 (1982).

[3] J. R. Fienup, "Iterative Method Applied To Image Reconstruction And To Computer-Generated Holograms," Opt. Eng **19,** 193297–193297– (1980).

[4] F. Wyrowski and O. Bryngdahl, "Iterative Fourier-transform algorithm applied to computer holography," J. Opt. Soc. Am. A **5,** 1058–1065 (1988).

[5] M. P. Chang and O. K. Ersoy, "The modified input-output algorithm for the synthesis of computer-generated holograms," Optik (1994).

[6] O. Ripoll, V. Kettunen, and H. P. Herzig, "Review of iterative Fourier-transform algorithms for beam shaping applications," Opt. Eng **43,** 2549–2556 (2004).

Appendix A

MATLAB Codes

Here, we attach report_script_beam_shaper.m for the DOE implementaion in Chap. 3 and report_script_image_generation.m for the CGH programming in Chap. 4.

The following is from report_script_beam_shaper.m:

```
%% IO with 100/4
%% Preparations
clear;
close all;
%% parameters
itermax =50;
alpha = 1;
phasequantizer = 4;
magnitudequantizer = 100;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1   = zeros(imn11,imn22);   % image with zero paddings
start1   = round(1 + (imn11-imn1)/2);   % position of the true image
end1     = start1 + imn1 - 1;
start2   = round(1 + (imn22-imn2)/2);
end2     = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
```

```
imn11        = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22        = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                    % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% IO
N11           = Index(2,1); %size after zeropadding
N22           = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end    = end2;
N2start  = start2;
N2end    = end2;

%% initiation
Xk            = X0;      % Xk
XkP           = X0;      % Pf{Xk}
iterres       = [];      % record residual at each iteration
iterchange    = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

%% IO iteration
for iter = 1 : itermax  %iterate over IO
    TemMatrix = XkP;     % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP    = Xk; %new input modified
    FXk   = fft2(XkP);
    FXkP  = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP   = ifft2(FXkP); %new output
    %% calculate delta_g
    termA =  abs(ifft(image)).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(ifft(image)).*(Xk./abs(Xk)); termB(isnan(termB)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new      = zeros(N11,N22);
    %% apply IO on zero paddings
```

```
%     new(:,1:N2start-1)              = Xk(:,1:N2start-1) + ...
%     alpha * delta_g(:,1:N2start-1);
%     new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) + ...
%     alpha * delta_g(:,N2end+1:N22);
%     new(1:N1start-1,N2start:N2end)  = Xk(1:N1start-1,N2start:N2end)...
%     + alpha * delta_g(1:N1start-1,N2start:N2end);
%     new(N1end+1:N11,N2start:N2end)  = Xk(N1end+1:N11,N2start:N2end)...
%     + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
if imagetype == -2
    new(N1start:N1end,N2start:N2end) = Xk(N1start:N1end,N2start:N2end)...
        + alpha * delta_g(N1start:N1end,N2start:N2end);
    newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
        ./magnitudequantizer*max(max(abs(new)));
    newangle = floor(phasequantizer*angle(new)./(2*pi))...
        ./phasequantizer*2*pi;
    new_quant= newabs.*exp(i.*newangle);
    Xk             = new_quant;
end
%     new = Xk + + alpha * delta_g;
%     newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
%         ./magnitudequantizer*max(max(abs(new)));
%     newangle = floor(phasequantizer*angle(new)./(2*pi))...
%         ./phasequantizer*2*pi;
%     new_quant= newabs.*exp(i.*newangle);
%     Xk             = new_quant;

    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
        projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
        100*intensityerr,100*iterchange(iter))
end

Xrec   = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
```

```
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50IO_100_4.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50IO_100_4.fig')

iterres_100_4_IO = iterres;
save('50IO_100_4_residue.mat','iterres_100_4_IO')

%% IO First with 256/10
clear;
close all;
%% parameters
itermax =50;
alpha = 1;
phasequantizer = 10;
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);           % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);    % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;
```

```
%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);          % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2    + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2    + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% IO
N11           = Index(2,1); %size after zeropadding
N22           = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
Xk            = X0;      % Xk
XkP           = X0;      % Pf{Xk}
iterres       = [];      % record residual at each iteration
iterchange    = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

%% IO iteration
for iter = 1 : itermax  %iterate over IO
    TemMatrix = XkP;      % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk   = fft2(XkP);
    FXkP  = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP   = ifft2(FXkP); %new output
    %% calculate delta_g
    termA =  abs(ifft(image)).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
```

```
    termB =  abs(ifft(image)).*(Xk./abs(Xk)); termB(isnan(termB)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
%     new(:,1:N2start-1)              = Xk(:,1:N2start-1) + ...
%         alpha * delta_g(:,1:N2start-1);
%     new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) + ...
%         alpha * delta_g(:,N2end+1:N22);
%     new(1:N1start-1,N2start:N2end)  = Xk(1:N1start-1,N2start:N2end)...
%         + alpha * delta_g(1:N1start-1,N2start:N2end);
%     new(N1end+1:N11,N2start:N2end)  = Xk(N1end+1:N11,N2start:N2end)...
%         + alpha * delta_g(N1end+1:N11,N2start:N2end);
%% apply IO in support
if imagetype == -2
    new(N1start:N1end,N2start:N2end) = Xk(N1start:N1end,N2start:N2end)...
        + alpha * delta_g(N1start:N1end,N2start:N2end);
    newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
        ./magnitudequantizer*max(max(abs(new)));
    newangle = floor(phasequantizer*angle(new)./(2*pi))...
        ./phasequantizer*2*pi;
    new_quant= newabs.*exp(i.*newangle);
    Xk             = new_quant;
end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
        projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
        100*intensityerr,100*iterchange(iter))
end

Xrec   = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
```

```
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50IO_256_10.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50IO_256_10.fig')

iterres_256_10_IO = iterres;
save('50IO_256_10_residue.mat','iterres_256_10_IO')

%% MIO with 100/4

%% Preparations
clear;
close all;
%% parameters
itermax =50;
alpha = 1;
beta = 1.2;
phasequantizer = 4;
magnitudequantizer = 100;

lena512 = imread('lena512.bmp');
X = im2double(lena512);

i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);                  % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);           % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
```

```
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                    % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% MIO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end    = end2;
N2start  = start2;
N2end    = end2;

%% initiation
Xk           = X0;      % Xk
XkP          = X0;      % Pf{Xk}
iterres      = [];      % record residual at each iteration
iterchange   = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

%% MIO iteration
for iter = 1 : itermax  %iterate over MIO
    TemMatrix = XkP;     % record XkP from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk;
    FXk  = fft2(XkP);
    FXkP = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP  = ifft2(FXkP);
    %% calculate delta_g
```

```
    termA =  abs(ifft(image)).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(ifft(image)).*(Xk./abs(Xk)); termB(isnan(termB)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply MIO step
    new      = zeros(N11,N22);
%     %% apply MIO on zero paddings
%     new(:,1:N2start-1)               = Xk(:,1:N2start-1) +...
%         alpha/beta^(iter-1) * delta_g(:,1:N2start-1);
%     new(:,N2end+1:N22)               = Xk(:,N2end+1:N22) +...
%         alpha/beta^(iter-1) * delta_g(:,N2end+1:N22);
%     new(1:N1start-1,N2start:N2end)   = Xk(1:N1start-1,N2start:N2end) +...
%         alpha/beta^(iter-1) * delta_g(1:N1start-1,N2start:N2end);
%     new(N1end+1:N11,N2start:N2end)   = Xk(N1end+1:N11,N2start:N2end) +...
%         alpha/beta^(iter-1) * delta_g(N1end+1:N11,N2start:N2end);
%% apply MIO in support
if imagetype == -2
new(N1start:N1end,N2start:N2end) = ...
    Xk(N1start:N1end,N2start:N2end) + alpha/beta^(iter-1) * ...
    delta_g(N1start:N1end,N2start:N2end);
newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
    ./magnitudequantizer*max(max(abs(new)));
newangle = floor(phasequantizer*angle(new)./(2*pi))./phasequantizer*2*pi;
new_quant= newabs.*exp(i.*newangle);
Xk              = new_quant;
end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = projection(XkP(N1start:N1end,...
        N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',...
        iter,100*intensityerr,100*iterchange(iter))
end

Xrec    = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
```

```
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50MIO_100_4.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50MIO_100_4.fig')

iterres_100_4_MIO = iterres;
save('50MIO_100_4_residue.mat','iterres_100_4_MIO')

%% MIO with256/10

%% Preparations
clear;
close all;
%% parameters
itermax =50;
alpha = 1;
beta = 1.2;
phasequantizer = 10;
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);                  % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);           % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
```

```
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image   = zeros(imn11,imn22);                    % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% MIO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end    = end2;
N2start  = start2;
N2end    = end2;

%% initiation
Xk           = X0;      % Xk
XkP          = X0;      % Pf{Xk}
iterres      = [];      % record residual at each iteration
iterchange   = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

%% MIO iteration
for iter = 1 : itermax  %iterate over MIO
    TemMatrix = XkP;      % record XkP from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk;
    FXk  = fft2(XkP);
    FXkP = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP  = ifft2(FXkP);
    %% calculate delta_g
```

```
    termA =  abs(ifft(image)).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(ifft(image)).*(Xk./abs(Xk)); termB(isnan(termB)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply MIO step
    new      = zeros(N11,N22);
%     %% apply MIO on zero paddings
%     new(:,1:N2start-1)                = Xk(:,1:N2start-1) +...
%         alpha/beta^(iter-1) * delta_g(:,1:N2start-1);
%     new(:,N2end+1:N22)                = Xk(:,N2end+1:N22) +...
%         alpha/beta^(iter-1) * delta_g(:,N2end+1:N22);
%     new(1:N1start-1,N2start:N2end)   = Xk(1:N1start-1,N2start:N2end) +...
%         alpha/beta^(iter-1) * delta_g(1:N1start-1,N2start:N2end);
%     new(N1end+1:N11,N2start:N2end)   = Xk(N1end+1:N11,N2start:N2end) +...
%         alpha/beta^(iter-1) * delta_g(N1end+1:N11,N2start:N2end);
%     %% apply MIO in support
if imagetype == -2
new(N1start:N1end,N2start:N2end) = ...
    Xk(N1start:N1end,N2start:N2end) + alpha/beta^(iter-1) * ...
    delta_g(N1start:N1end,N2start:N2end);
newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
    ./magnitudequantizer*max(max(abs(new)));
newangle = floor(phasequantizer*angle(new)./(2*pi))./phasequantizer*2*pi;
new_quant= newabs.*exp(i.*newangle);
Xk              = new_quant;
end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = projection(...
        XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',...
        iter,100*intensityerr,100*iterchange(iter))
end

Xrec    = Xk;

hologram = fft2(Xrec);

%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
```

```
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50MIO_256_10.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50MIO_256_10.fig')

iterres_256_10_MIO = iterres;
save('50MIO_256_10_residue.mat','iterres_256_10_MIO')

%% HIO with 100/4
%% Preparations
clear;
close all;
%% parameters
itermax =50;

beta = 0.8;
phasequantizer = 4;
magnitudequantizer = 100;

lena512 = imread('lena512.bmp');
X = im2double(lena512);


i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);                  % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);           % position of the true image
end1      = start1 + imn1 - 1;
```

```
start2   = round(1 + (imn22-imn2)/2);
end2     = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11        = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22        = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                      % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index   = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0   = generatestart(imagetype,Index);

%% HIO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
Xk            = X0;      % Xk
XkP           = X0;      % Pf{Xk}
iterres       = [];      % record residual at each iteration
iterchange    = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||


%% HIO iteration
for iter = 1 : itermax  %iterate over HIO
    TemMatrix = XkP;     % record XkP from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk;
    FXk   = fft2(XkP);
```

```
    FXkP = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP  = ifft2(FXkP);

    %% apply HIO step
    new      = zeros(N11,N22);
    %% apply HIO on zero paddings
    new(:,1:N2start-1)              = Xk(:,1:N2start-1) -...
        beta * XkP(:,1:N2start-1);
    new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) - ...
        beta * XkP(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = ...
        Xk(1:N1start-1,N2start:N2end) - ...
        beta * XkP(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = ...
        Xk(N1end+1:N11,N2start:N2end) - ...
        beta * XkP(N1end+1:N11,N2start:N2end);
    %% apply HIO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            XkP(N1start:N1end,N2start:N2end);
        newabs= floor(magnitudequantizer*...
            abs(new)./(max(max(abs(new))))))./...
            magnitudequantizer*max(max(abs(new)));
        newangle = floor(phasequantizer*...
            angle(new)./(2*pi))./phasequantizer*2*pi;
        new_quant= newabs.*exp(i.*newangle);
        Xk              = new_quant;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
        projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter)  = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',...
        iter,100*intensityerr,100*iterchange(iter))

end

Xrec    = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
```

```
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50HIO_100_4.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50HIO_100_4.fig')

iterres_100_4_HIO = iterres;
save('50HIO_100_4_residue.mat','iterres_100_4_HIO')

%% HIO with 256/10
%% Preparations
clear;
close all;
%% parameters
itermax =50;
ifer = 0;
beta = 0.9;
phasequantizer = 10;
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);                % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);         % position of the true image
```

```
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11        = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22        = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);          % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% HIO
N11           = Index(2,1); %size after zeropadding
N22           = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;
N1         = N1end - N1start + 1; %number of real data points 1D
N2         = N2end - N2start + 1;
P            = 1;


%% initiation
Xk            = X0;       % Xk
XkP           = X0;       % Pf{Xk}
iterres       = [];       % record residual at each iteration
iterchange    = [];       % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||
Y            = X0;
Y_abs_fro    = norm(Y,'fro')^2;
Y_abs        = abs(Y);               % Fourier intensity data
```

```
Y_abs_fro   = sqrt(Y_abs_fro);     % Euclidean norm

%% HIO iteration
for iter = 1 : itermax  %iterate over HIO
    TemMatrix = XkP;     % record XkP from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk;
    FXk  = fft2(XkP);
    FXkP = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP  = ifft2(FXkP);

    %% apply HIO step
    new     = zeros(N11,N22);
    %% apply HIO on zero paddings
    new(:,1:N2start-1)              = Xk(:,1:N2start-1) -...
        beta * XkP(:,1:N2start-1);
    new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) - ...
        beta * XkP(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = ...
        Xk(1:N1start-1,N2start:N2end) - ...
        beta * XkP(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = ...
        Xk(N1end+1:N11,N2start:N2end) - ...
        beta * XkP(N1end+1:N11,N2start:N2end);
    %% apply HIO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            XkP(N1start:N1end,N2start:N2end);
        newabs= floor(magnitudequantizer*...
            abs(new)./(max(max(abs(new))))))./...
            magnitudequantizer*max(max(abs(new)));
        newangle = floor(phasequantizer*...
            angle(new)./(2*pi))./phasequantizer*2*pi;
        new_quant= newabs.*exp(i.*newangle);
        Xk             = new_quant;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
        projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',...
        iter,100*intensityerr,100*iterchange(iter))
end

hiostep  = length(iterres);
```

```
Xrec   = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50HIO_256_10.fig')
figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50HIO_256_10.fig')

iterres_256_10_HIO = iterres;
save('50HIO_256_10_residue.mat','iterres_256_10_HIO')

%% OO with 100/4
%% Preparations
clear;
close all;
%% parameters
itermax =50;
alpha = 1;
phasequantizer = 4;
magnitudequantizer = 100;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
```

```
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);   % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);   % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                  % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% OO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
Xk           = X0;      % Xk
XkP          = X0;      % Pf{Xk}
iterres      = [];      % record residual at each iteration
iterchange   = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||
```

```
%% OO iteration
for iter = 1 : itermax  %iterate over IO
    TemMatrix = XkP;     % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk  = fft2(XkP);
    FXkP = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP  = ifft2(FXkP); %new output
    %% calculate delta_g
    termA =  abs(ifft(image)).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(ifft(image)).*(Xk./abs(Xk)); termB(isnan(termB)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
    %     new(:,1:N2start-1)                = Xk(:,1:N2start-1) + ...
    %     alpha * delta_g(:,1:N2start-1);
    %     new(:,N2end+1:N22)                = Xk(:,N2end+1:N22) + ...
    %     alpha * delta_g(:,N2end+1:N22);
    %     new(1:N1start-1,N2start:N2end)  = Xk(1:N1start-1,N2start:N2end)...
    %     + alpha * delta_g(1:N1start-1,N2start:N2end);
    %     new(N1end+1:N11,N2start:N2end)  = Xk(N1end+1:N11,N2start:N2end)...
    %     + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
if imagetype == -2
    new(N1start:N1end,N2start:N2end) = XkP(N1start:N1end,N2start:N2end)...
        + alpha * delta_g(N1start:N1end,N2start:N2end);
    newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
        ./magnitudequantizer*max(max(abs(new)));
    newangle = floor(phasequantizer*angle(new)./(2*pi))...
        ./phasequantizer*2*pi;
    new_quant= newabs.*exp(i.*newangle);
    Xk             = new_quant;
end
%     new = Xk + + alpha * delta_g;
%     newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
%         ./magnitudequantizer*max(max(abs(new)));
%     newangle = floor(phasequantizer*angle(new)./(2*pi))...
%         ./phasequantizer*2*pi;
%     new_quant= newabs.*exp(i.*newangle);
%     Xk             = new_quant;

    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
        projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
```

```
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
        100*intensityerr,100*iterchange(iter))
end

Xrec   = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_50OO_100_4.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_50OO_100_4.fig')

iterres_100_4_OO = iterres;
save('50OO_100_4_residue.mat','iterres_100_4_OO')

%% OO with 256/10
%% Preparations
clear;
close all;
%% parameters
itermax =50;
alpha = 1;
phasequantizer = 10;
```

```
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1   = zeros(imn11,imn22);   % image with zero paddings
start1   = round(1 + (imn11-imn1)/2);   % position of the true image
end1     = start1 + imn1 - 1;
start2   = round(1 + (imn22-imn2)/2);
end2     = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image   = zeros(imn11,imn22);                 % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;
% In the case where the image has a loose support,
S1end     = end2   + loose;
% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% OO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end    = end2;
N2start  = start2;
N2end    = end2;
```

```
%% initiation
Xk            = X0;       % Xk
XkP           = X0;       % Pf{Xk}
iterres       = [];       % record residual at each iteration
iterchange    = [];       % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

%% OO iteration
for iter = 1 : itermax  %iterate over IO
    TemMatrix = XkP;      % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk  = fft2(XkP);
    FXkP = abs(image).*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    XkP  = ifft2(FXkP); %new output
    %% calculate delta_g
    termA =  abs(ifft(image)).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(ifft(image)).*(Xk./abs(Xk)); termB(isnan(termB)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new      = zeros(N11,N22);
%% apply IO on zero paddings
%     new(:,1:N2start-1)               = Xk(:,1:N2start-1) + ...
%     alpha * delta_g(:,1:N2start-1);
%     new(:,N2end+1:N22)               = Xk(:,N2end+1:N22) + ...
%     alpha * delta_g(:,N2end+1:N22);
%     new(1:N1start-1,N2start:N2end)   = Xk(1:N1start-1,N2start:N2end)...
%     + alpha * delta_g(1:N1start-1,N2start:N2end);
%     new(N1end+1:N11,N2start:N2end)   = Xk(N1end+1:N11,N2start:N2end)...
%     + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
if imagetype == -2
    new(N1start:N1end,N2start:N2end) = XkP(N1start:N1end,N2start:N2end)...
        + alpha * delta_g(N1start:N1end,N2start:N2end);
    newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
        ./magnitudequantizer*max(max(abs(new)));
    newangle = floor(phasequantizer*angle(new)./(2*pi))...
        ./phasequantizer*2*pi;
    new_quant= newabs.*exp(i.*newangle);
    Xk              = new_quant;
end
%     new = Xk + + alpha * delta_g;
%     newabs= floor(magnitudequantizer*abs(new)./(max(max(abs(new)))))...
%         ./magnitudequantizer*max(max(abs(new)));
%     newangle = floor(phasequantizer*angle(new)./(2*pi))...
%         ./phasequantizer*2*pi;
%     new_quant= newabs.*exp(i.*newangle);
%     Xk              = new_quant;

    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
```

```
        projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-abs(image),'fro')^2;
    intensityerr = sqrt(intensityerr) / sqrt(norm(abs(image),'fro')^2);
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
        100*intensityerr,100*iterchange(iter))
end

Xrec   = Xk;

hologram = fft2(Xrec);
%% plot the magnitudes of the recovered image
figure(1)
subplot(1,2,1)
imagesc(abs(Xrec(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram(start1:end1,start2:end2)))
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('partial_5000_256_10.fig')

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['DOE with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
subplot(1,2,2)
imagesc(abs(hologram))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('magnitude of produced beam pattern')
savefig('full_5000_256_10.fig')

iterres_256_10_00 = iterres;
save('5000_256_10_residue.mat','iterres_256_10_00')

figure(3)
subplot(1,2,1)
```

```
imagesc(abs(image));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('original full image')
subplot(1,2,2)
imagesc(abs(image(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('original partial image')
savefig('original.fig')

load('50HIO_100_4_residue.mat')
load('50HIO_256_10_residue.mat')
load('50IO_100_4_residue.mat')
load('50IO_256_10_residue.mat')
load('50OO_100_4_residue.mat')
load('50OO_256_10_residue.mat')
load('50MIO_100_4_residue.mat')
load('50MIO_256_10_residue.mat')

figure(4)
plot(1:length(iterres_100_4_IO),iterres_100_4_IO,'.-b',...
    1:length(iterres_256_10_IO),iterres_256_10_IO,'.-y',...
    1:length(iterres_100_4_OO),iterres_100_4_OO,'-og',...
    1:length(iterres_256_10_OO),iterres_256_10_OO,'-or',...
    1:length(iterres_100_4_MIO),iterres_100_4_MIO,'.-m',...
    1:length(iterres_256_10_MIO),iterres_256_10_MIO,'.-k',...
    1:length(iterres_100_4_HIO),iterres_100_4_HIO,'.-r',...
    1:length(iterres_256_10_HIO),iterres_256_10_HIO,'.-g');
axis([1 length(iterres_100_4_IO) 0 0.5])
legend('IO with 100/4 Quantized','IO with 256/10 Quantized',...
    'OO with 100/4 Quantized','OO with 256/10 Quantized',...
    'MIO with 100/4 Quantized','MIO with 256/10 Quantized',...
    'HIO with 100/4 Quantized','HIO with 256/10 Quantized');
title('relative residual at each iteration for DOE shaping Lena')
xlabel('iteration')
ylabel('relative residual')
savefig('residualcompare.fig')
```

The following is code from the file named report_script_image_generation.m:

```
%% IO with 100/4
%% Preparations
clear;
close all;
%% parameters
itermax = 20;
alpha = 1;
phasequantizer = 4;
```

```
magnitudequantizer = 100;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);   % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);   % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                  % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start    = start1 - loose;% In the case where the image has a loose support,
S1end      = end2   + loose;% only a loose position of the true image is given
S2start    = start2 - loose;
S2end      = end2   + loose;

Index   = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0   = generatestart(imagetype,Index);

%% IO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
```

```
Xk            = X0;       % Xk
XkP           = X0;       % Pf{Xk}
iterres       = [];       % record residual at each iteration
iterchange    = [];       % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

Y_abs = abs(fft2(image));

%% IO iteration
for iter = 1 : itermax  %iterate over IO
    TemMatrix = XkP;      % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk   = fft2(XkP);
    FXkP = Y_abs.*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    FXkP_abs= floor(magnitudequantizer*abs(FXkP)./(max(max(abs(FXkP)))))...
      ./magnitudequantizer*max(max(abs(FXkP)));
    FXkP_angle = floor(phasequantizer*angle(FXkP)./(2*pi))...
      ./phasequantizer*2*pi;
    FXkP_quant= FXkP_abs.*exp(i.*FXkP_angle);
    XkP   = ifft2(FXkP_quant); %new output
    %% calculate delta_g
    termA =  abs(image).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(image).*(XkP./abs(XkP)); termB(isnan(termA)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
    new(:,1:N2start-1)              = Xk(:,1:N2start-1) + ...
    alpha * delta_g(:,1:N2start-1);
    new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) + ...
    alpha * delta_g(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = Xk(1:N1start-1,N2start:N2end)...
    + alpha * delta_g(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = Xk(N1end+1:N11,N2start:N2end)...
    + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            Xk(N1start:N1end,N2start:N2end)+ ...
            alpha * delta_g(N1start:N1end,N2start:N2end);
        Xk             = new;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
    projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-Y_abs,'fro')^2;
    intensityerr = sqrt(intensityerr)/norm(Y_abs,'fro');
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
```

```
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
        100*intensityerr,100*iterchange(iter))
    Xrec   = XkP;
    figure(1)
    subplot(1,2,1)
    imagesc(abs(Xrec(start1:end1,start2:end2)));
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram reconstructed image')
    subplot(1,2,2)
    imagesc(abs(FXkP_quant))
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram')
    drawnow;
end



%% plot the magnitudes of the recovered image

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('Hologram reconstructed image')
subplot(1,2,2)
imagesc(abs(FXkP_quant))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['Hologram with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
savefig(['h_full_' num2str(itermax) 'IO_'...
    num2str(magnitudequantizer) '_' num2str(phasequantizer) '.fig'])

iterres_100_4_IO = iterres;
save(['h_' num2str(itermax) 'IO_' num2str(magnitudequantizer)...
    '_' num2str(phasequantizer) '_residue.mat'],'iterres_100_4_IO')

%% IO First with 256/10
%% Preparations
clear;
close all;
%% parameters
itermax = 20;
alpha = 1;
phasequantizer = 10;
```

```
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);   % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);   % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                  % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start    = start1 - loose;% In the case where the image has a loose support,
S1end      = end2   + loose;% only a loose position of the true image is given
S2start    = start2 - loose;
S2end      = end2   + loose;

Index   = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0   = generatestart(imagetype,Index);

%% IO
N11           = Index(2,1); %size after zeropadding
N22           = Index(2,2); %size after zeropadding
N1start    = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
```

```
Xk            = X0;       % Xk
XkP           = X0;       % Pf{Xk}
iterres       = [];       % record residual at each iteration
iterchange    = [];       % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

Y_abs = abs(fft2(image));

%% IO iteration
for iter = 1 : itermax  %iterate over IO
    TemMatrix = XkP;      % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk   = fft2(XkP);
    FXkP = Y_abs.*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    FXkP_abs= floor(magnitudequantizer*abs(FXkP)./(max(max(abs(FXkP)))))...
      ./magnitudequantizer*max(max(abs(FXkP)));
    FXkP_angle = floor(phasequantizer*angle(FXkP)./(2*pi))...
      ./phasequantizer*2*pi;
    FXkP_quant= FXkP_abs.*exp(i.*FXkP_angle);
    XkP   = ifft2(FXkP_quant); %new output
    %% calculate delta_g
    termA =  abs(image).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(image).*(XkP./abs(XkP)); termB(isnan(termA)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
    new(:,1:N2start-1)              = Xk(:,1:N2start-1) + ...
    alpha * delta_g(:,1:N2start-1);
    new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) + ...
    alpha * delta_g(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = Xk(1:N1start-1,N2start:N2end)...
    + alpha * delta_g(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = Xk(N1end+1:N11,N2start:N2end)...
    + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            Xk(N1start:N1end,N2start:N2end)+ ...
            alpha * delta_g(N1start:N1end,N2start:N2end);
        Xk             = new;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
    projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-Y_abs,'fro')^2;
    intensityerr = sqrt(intensityerr)/norm(Y_abs,'fro');
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
```

```
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
    100*intensityerr,100*iterchange(iter))
    Xrec    = XkP;
    figure(1)
    subplot(1,2,1)
    imagesc(abs(Xrec(start1:end1,start2:end2)));
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram reconstructed image')
    subplot(1,2,2)
    imagesc(abs(FXkP_quant))
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram')
    drawnow;
end

%% plot the magnitudes of the recovered image

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('Hologram reconstructed image')
subplot(1,2,2)
imagesc(abs(FXkP_quant))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['Hologram with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
savefig(['h_full_' num2str(itermax) 'IO_'...
    num2str(magnitudequantizer) '_' num2str(phasequantizer) '.fig'])

iterres_256_10_IO = iterres;
save(['h_' num2str(itermax) 'IO_' num2str(magnitudequantizer)...
    '_' num2str(phasequantizer) '_residue.mat'],'iterres_256_10_IO')

%% OO with 100/4
%% Preparations
clear;
close all;
%% parameters
itermax = 20;
alpha = 1;
phasequantizer = 4;
magnitudequantizer = 100;
```

```
lena512 = imread('lena512.bmp');
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);   % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);   % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                  % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;% In the case where the image has a loose support,
S1end     = end2   + loose;% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% OO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
Xk           = X0;      % Xk
XkP          = X0;      % Pf{Xk}
```

```
iterres      = [];      % record residual at each iteration
iterchange   = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

Y_abs = abs(fft2(image));


%% OO iteration
for iter = 1 : itermax  %iterate over OO
    TemMatrix = XkP;      % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk  = fft2(XkP);
    FXkP = Y_abs.*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    FXkP_abs= floor(magnitudequantizer*abs(FXkP)./(max(max(abs(FXkP)))))...
      ./magnitudequantizer*max(max(abs(FXkP)));
    FXkP_angle = floor(phasequantizer*angle(FXkP)./(2*pi))...
      ./phasequantizer*2*pi;
    FXkP_quant= FXkP_abs.*exp(i.*FXkP_angle);
    XkP  = ifft2(FXkP_quant); %new output
    %% calculate delta_g
    termA =  abs(image).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(image).*(XkP./abs(XkP)); termB(isnan(termA)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
    new(:,1:N2start-1)              = XkP(:,1:N2start-1) + ...
    alpha * delta_g(:,1:N2start-1);
    new(:,N2end+1:N22)              = XkP(:,N2end+1:N22) + ...
    alpha * delta_g(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = XkP(1:N1start-1,N2start:N2end)...
    + alpha * delta_g(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = XkP(N1end+1:N11,N2start:N2end)...
    + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            XkP(N1start:N1end,N2start:N2end)+ ...
            alpha * delta_g(N1start:N1end,N2start:N2end);
        Xk             = new;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
    projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-Y_abs,'fro')^2;
    intensityerr = sqrt(intensityerr)/norm(Y_abs,'fro');
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
```

```
        100*intensityerr,100*iterchange(iter))
    Xrec   = XkP;
    figure(1)
    subplot(1,2,1)
    imagesc(abs(Xrec(start1:end1,start2:end2)));
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram reconstructed image')
    subplot(1,2,2)
    imagesc(abs(FXkP_quant))
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram')
    drawnow;
end


%% plot the magnitudes of the recovered image
figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('Hologram reconstructed image')
subplot(1,2,2)
imagesc(abs(FXkP_quant))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['Hologram with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
savefig(['h_full_' num2str(itermax) 'OO_'...
    num2str(magnitudequantizer) '_' num2str(phasequantizer) '.fig'])

iterres_100_4_OO = iterres;
save(['h_' num2str(itermax) 'OO_' num2str(magnitudequantizer)...
    '_' num2str(phasequantizer) '_residue.mat'],'iterres_100_4_OO')

%% OO with 256/10
%% Preparations
clear;
close all;
%% parameters
itermax = 20;
alpha = 1;
phasequantizer = 10;
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
```

```
X = im2double(lena512);
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1   = zeros(imn11,imn22);   % image with zero paddings
start1   = round(1 + (imn11-imn1)/2);   % position of the true image
end1     = start1 + imn1 - 1;
start2   = round(1 + (imn22-imn2)/2);
end2     = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                 % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;% In the case where the image has a loose support,
S1end     = end2   + loose;% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% OO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end    = end2;
N2start  = start2;
N2end    = end2;

%% initiation
Xk           = X0;      % Xk
XkP          = X0;      % Pf{Xk}
iterres      = [];      % record residual at each iteration
```

```
iterchange   = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||

Y_abs = abs(fft2(image));

%% OO iteration
for iter = 1 : itermax  %iterate over OO
    TemMatrix = XkP;     % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk  = fft2(XkP);
    FXkP = Y_abs.*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    FXkP_abs= floor(magnitudequantizer*abs(FXkP)./(max(max(abs(FXkP)))))...
      ./magnitudequantizer*max(max(abs(FXkP)));
    FXkP_angle = floor(phasequantizer*angle(FXkP)./(2*pi))...
      ./phasequantizer*2*pi;
    FXkP_quant= FXkP_abs.*exp(i.*FXkP_angle);
    XkP  = ifft2(FXkP_quant); %new output
    %% calculate delta_g
    termA =  abs(image).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(image).*(XkP./abs(XkP)); termB(isnan(termA)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
    new(:,1:N2start-1)                = XkP(:,1:N2start-1) + ...
    alpha * delta_g(:,1:N2start-1);
    new(:,N2end+1:N22)                = XkP(:,N2end+1:N22) + ...
    alpha * delta_g(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = XkP(1:N1start-1,N2start:N2end)...
    + alpha * delta_g(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = XkP(N1end+1:N11,N2start:N2end)...
    + alpha * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            XkP(N1start:N1end,N2start:N2end)+ ...
            alpha * delta_g(N1start:N1end,N2start:N2end);
        Xk              = new;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
    projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-Y_abs,'fro')^2;
    intensityerr = sqrt(intensityerr)/norm(Y_abs,'fro');
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
    100*intensityerr,100*iterchange(iter))
    Xrec    = XkP;
```

```
    figure(1)
    subplot(1,2,1)
    imagesc(abs(Xrec(start1:end1,start2:end2)));
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram reconstructed image')
    subplot(1,2,2)
    imagesc(abs(FXkP_quant))
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram')
    drawnow;
end

%% plot the magnitudes of the recovered image

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('Hologram reconstructed image')
subplot(1,2,2)
imagesc(abs(FXkP_quant))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['Hologram with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
savefig(['h_full_' num2str(itermax) 'OO_'...
    num2str(magnitudequantizer) '_' num2str(phasequantizer) '.fig'])

iterres_256_10_OO = iterres;

save(['h_' num2str(itermax) 'OO_' num2str(magnitudequantizer)...
    '_' num2str(phasequantizer) '_residue.mat'],'iterres_256_10_OO')
%% MIO 100/4
%% Preparations
clear;
close all;
%% parameters
itermax = 20;
alpha = 1;
beta = 1.2;
phasequantizer = 4;
magnitudequantizer = 100;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
```

```
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11        = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22        = round(Sample * (imn2+2*loose));
image1    = zeros(imn11,imn22);   % image with zero paddings
start1    = round(1 + (imn11-imn1)/2);   % position of the true image
end1      = start1 + imn1 - 1;
start2    = round(1 + (imn22-imn2)/2);
end2      = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11        = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22        = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                  % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;% In the case where the image has a loose support,
S1end     = end2   + loose;% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% MIO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
Xk           = X0;      % Xk
XkP          = X0;      % Pf{Xk}
iterres      = [];      % record residual at each iteration
iterchange   = [];      % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||
```

```
Y_abs = abs(fft2(image));


%% MIO iteration
for iter = 1 : itermax  %iterate over MIO
    TemMatrix = XkP;     % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk  = fft2(XkP);
    FXkP = Y_abs.*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    FXkP_abs= floor(magnitudequantizer*abs(FXkP)./(max(max(abs(FXkP)))))...
      ./magnitudequantizer*max(max(abs(FXkP)));
    FXkP_angle = floor(phasequantizer*angle(FXkP)./(2*pi))...
      ./phasequantizer*2*pi;
    FXkP_quant= FXkP_abs.*exp(i.*FXkP_angle);
    XkP   = ifft2(FXkP_quant); %new output
    %% calculate delta_g
    termA =  abs(image).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(image).*(XkP./abs(XkP)); termB(isnan(termA)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new     = zeros(N11,N22);
    %% apply IO on zero paddings
    new(:,1:N2start-1)              = Xk(:,1:N2start-1) +...
        alpha/beta^(iter-1) * delta_g(:,1:N2start-1);
    new(:,N2end+1:N22)              = Xk(:,N2end+1:N22) +...
        alpha/beta^(iter-1) * delta_g(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)  = Xk(1:N1start-1,N2start:N2end) +...
        alpha/beta^(iter-1) * delta_g(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)  = Xk(N1end+1:N11,N2start:N2end) +...
        alpha/beta^(iter-1) * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            Xk(N1start:N1end,N2start:N2end) + alpha/beta^(iter-1) * ...
            delta_g(N1start:N1end,N2start:N2end);
        Xk             = new;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
    projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-Y_abs,'fro')^2;
    intensityerr = sqrt(intensityerr)/norm(Y_abs,'fro');
    iterres(iter)  = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
    100*intensityerr,100*iterchange(iter))
    Xrec   = XkP;
```

```
    figure(1)
    subplot(1,2,1)
    imagesc(abs(Xrec(start1:end1,start2:end2)));
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram reconstructed image')
    subplot(1,2,2)
    imagesc(abs(FXkP_quant))
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram')
    drawnow;
end


%% plot the magnitudes of the recovered image
figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('Hologram reconstructed image')
subplot(1,2,2)
imagesc(abs(FXkP_quant))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['Hologram with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
savefig(['h_full_' num2str(itermax) 'MIO_'...
    num2str(magnitudequantizer) '_' num2str(phasequantizer) '.fig'])

iterres_100_4_MIO = iterres;
save(['h_' num2str(itermax) 'MIO_' num2str(magnitudequantizer)...
    '_' num2str(phasequantizer) '_residue.mat'],'iterres_100_4_MIO')

%% MIO 256/10
%% Preparations
clear;
close all;
%% parameters
itermax = 20;
alpha = 1;
beta = 1.2;
phasequantizer = 10;
magnitudequantizer = 256;

lena512 = imread('lena512.bmp');
X = im2double(lena512);
```

```
i = sqrt(-1);
Sample = 1.2;
loose = 0;
[imn1, imn2] = size(X);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image1   = zeros(imn11,imn22);   % image with zero paddings
start1   = round(1 + (imn11-imn1)/2);   % position of the true image
end1     = start1 + imn1 - 1;
start2   = round(1 + (imn22-imn2)/2);
end2     = start2 + imn2 - 1;
image1(start1:end2,start2:end2) = X;

%% build quadrant put into first quardrant
Sample = 2;
loose = 0;
[imn1, imn2] = size(image1);
imn11       = round(Sample * (imn1+2*loose));
% size of the image with zero paddings
imn22       = round(Sample * (imn2+2*loose));
image    = zeros(imn11,imn22);                 % image with zero paddings
image(start1:end2,start2:end2) = X;

imagetype = -2;
image     = image.*exp(i*unifrnd(0,2*pi,imn11,imn22));
% complex images have random phases in [0,2*pi]


S1start   = start1 - loose;% In the case where the image has a loose support,
S1end     = end2   + loose;% only a loose position of the true image is given
S2start   = start2 - loose;
S2end     = end2   + loose;

Index  = [imn1 , imn2 ; imn11 , imn22 ; S1start , S1end; S2start , S2end];
% data to input

X0  = generatestart(imagetype,Index);

%% MIO
N11          = Index(2,1); %size after zeropadding
N22          = Index(2,2); %size after zeropadding
N1start   = start1; %index where the true image start
N1end     = end2;
N2start   = start2;
N2end     = end2;

%% initiation
Xk           = X0;       % Xk
XkP          = X0;       % Pf{Xk}
iterres      = [];       % record residual at each iteration
iterchange   = [];       % record ||XkP{k}-XkP{k-1}||/||XkP{k-1}||
```

```
Y_abs = abs(fft2(image));

%% MIO iteration
for iter = 1 : itermax  %iterate over MIO
    TemMatrix = XkP;     % record XkP input from the previous iteration
    %% compute Pf{Xk}
    XkP   = Xk; %new input modified
    FXk  = fft2(XkP);
    FXkP = Y_abs.*exp(i*angle(FXk)); %*(FXk./abs(FXk));
    FXkP_abs= floor(magnitudequantizer*abs(FXkP)./(max(max(abs(FXkP)))))...
      ./magnitudequantizer*max(max(abs(FXkP)));
    FXkP_angle = floor(phasequantizer*angle(FXkP)./(2*pi))...
      ./phasequantizer*2*pi;
    FXkP_quant= FXkP_abs.*exp(i.*FXkP_angle);
    XkP  = ifft2(FXkP_quant); %new output
    %% calculate delta_g
    termA =  abs(image).*(XkP./abs(XkP)); termA(isnan(termA)) = 0;
    termB =  abs(image).*(XkP./abs(XkP)); termB(isnan(termA)) = 0;
    delta_g = termA -XkP+termA-termB;
    %% apply IO step
    new      = zeros(N11,N22);
    %% apply IO on zero paddings
    new(:,1:N2start-1)                = Xk(:,1:N2start-1) +...
        alpha/beta^(iter-1) * delta_g(:,1:N2start-1);
    new(:,N2end+1:N22)                = Xk(:,N2end+1:N22) +...
        alpha/beta^(iter-1) * delta_g(:,N2end+1:N22);
    new(1:N1start-1,N2start:N2end)   = Xk(1:N1start-1,N2start:N2end) +...
        alpha/beta^(iter-1) * delta_g(1:N1start-1,N2start:N2end);
    new(N1end+1:N11,N2start:N2end)   = Xk(N1end+1:N11,N2start:N2end) +...
        alpha/beta^(iter-1) * delta_g(N1end+1:N11,N2start:N2end);
    %% apply IO in support
    if imagetype == -2
        new(N1start:N1end,N2start:N2end) = ...
            Xk(N1start:N1end,N2start:N2end) + alpha/beta^(iter-1) * ...
            delta_g(N1start:N1end,N2start:N2end);
        Xk              = new;
    end
    %% record residual
    Xtem = zeros(N11,N22);
    Xtem(N1start:N1end,N2start:N2end) = ...
    projection(XkP(N1start:N1end,N2start:N2end),imagetype);
    intensityerr = norm(abs(fft2(Xtem))-Y_abs,'fro')^2;
    intensityerr = sqrt(intensityerr)/norm(Y_abs,'fro');
    iterres(iter)   = intensityerr;
    %% record the change of XkP
    iterchange(iter) = norm(TemMatrix-XkP,'fro')/norm(TemMatrix,'fro');
    %% display data
    fprintf('%6.0f residual = %6.4f p change = %6.6f p \n',iter,...
    100*intensityerr,100*iterchange(iter))
    Xrec   = XkP;
    figure(1)
```

```
    subplot(1,2,1)
    imagesc(abs(Xrec(start1:end1,start2:end2)));
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram reconstructed image')
    subplot(1,2,2)
    imagesc(abs(FXkP_quant))
    axis equal
    axis([1 end1-start1 1 end2-start2])
    colormap(gray)
    title('Hologram')
    drawnow;
end


%% plot the magnitudes of the recovered image

figure(2)
subplot(1,2,1)
imagesc(abs(Xrec));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('Hologram reconstructed image')
subplot(1,2,2)
imagesc(abs(FXkP_quant))
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title(['Hologram with ' num2str(magnitudequantizer)...
    ' discrete magnitude and ' num2str(phasequantizer) ' discrete phase'])
savefig(['h_full_' num2str(itermax) 'MIO_'...
    num2str(magnitudequantizer) '_' num2str(phasequantizer) '.fig'])

iterres_256_10_MIO = iterres;
save(['h_' num2str(itermax) 'MIO_' num2str(magnitudequantizer)...
    '_' num2str(phasequantizer) '_residue.mat'],'iterres_256_10_MIO')

figure(3)
subplot(1,2,1)
imagesc(abs(image));
axis equal
axis([1 imn11 1 imn22])
colormap(gray)
title('original full image')
subplot(1,2,2)
imagesc(abs(image(start1:end1,start2:end2)));
axis equal
axis([1 end1-start1 1 end2-start2])
colormap(gray)
title('original partial image')
```

```
savefig('h_original.fig')


load('h_20IO_100_4_residue.mat')
load('h_20IO_256_10_residue.mat')
load('h_20OO_100_4_residue.mat')
load('h_20OO_256_10_residue.mat')
load('h_20MIO_100_4_residue.mat')
load('h_20MIO_256_10_residue.mat')

figure(4)
plot(1:length(iterres_100_4_IO),iterres_100_4_IO,'.-b',...
    1:length(iterres_256_10_IO),iterres_256_10_IO,'.-y',...
    1:length(iterres_100_4_OO),iterres_100_4_OO,'-og',...
    1:length(iterres_256_10_OO),iterres_256_10_OO,'-or',...
    1:length(iterres_100_4_MIO),iterres_100_4_MIO,'.-m',...
    1:length(iterres_256_10_MIO),iterres_256_10_MIO,'.-k')
axis([1 length(iterres_100_4_IO) 0 0.5])
legend('IO with 100/4 Quantized','IO with 256/10 Quantized',...
    'OO with 100/4 Quantized','OO with 256/10 Quantized',...
    'MIO with 100/4 Quantized','MIO with 256/10 Quantized');
title('relative residual at each iteration for Lena holography')
xlabel('iteration')
ylabel('relative residual')
savefig('h_residualcompare_20.fig')
```