**Week 1~2**

**Lab: Array Communications & Processing**

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**Task 1:**

图表

中度可信度描述已自动生成

The best direction is 90 degrees and the gain is 6.99 dB .

*Code*:

array=[-2 0 0; -1 0 0; 0 0 0; 1 0 0; 2 0 0];

directions=[30,0; 35,0; 90,0];

%% task1

Z=pattern1(array);

figure(1)

plot2d3d(Z,0:180,0,'gain in dB','initial pattern');

**Task 2**

Three sources are uncorrelated and of equal powers, meaning the covariance matrix Rmm is a 3\*3 unity matrix.

Rxx\_theoretical is a 5-rank square matrix with complex elements. If the geometry of the matrix changes, the S will change but still be a 5\*5 matrix. So, the form of the Rxx\_theoretical will not change.

图形用户界面, 应用程序, 表格, Excel

描述已自动生成

*Code*:

%% task2

S=spv(array,directions);

Rmm=eye(3,3); % (A,A) (B,B) (C,C) are 1, others are 0

sigma2=0.0001;

Rxx\_theoretical=S\*Rmm\*S'+sigma2\*eye(5,5);

**Task 3**

The audio is a little noisy overlapped with several different parts together and the picture looks like different layers of pictures overlapping each other.

图形用户界面

描述已自动生成

文本

描述已自动生成

文本, 信件

描述已自动生成

*Code*:

%% task 3

load Xaudio.mat;

load Ximage.mat;

soundsc(real(X\_au(2,:)),11025);

displayimage(X\_im(2,:),image\_size,201,'The received signal at 2nd antenna');

Rxx\_au=X\_au\*X\_au'/length(X\_au(1,:));

Rxx\_im=X\_im\*X\_im'/length(X\_im(1,:));

**Task 4**

*Code*:

%% task 4

directions=[];

Rmm=[];

S=[];

sigma2=[];

**Task 5**

**5.1.**

**文本

描述已自动生成**

The values of the first two elements are very small, and they are equal to the set sigma which represents the value of the added noise with a power of -40dB (0.0001). Then, there are 3 rows left which present that there are 3 sources.

**5.2.** The eigenvalue got is the diagram of the Rxx matrix and its elements could be listed below. The elements are consists of elements represents signals and noise respectively.

日历

描述已自动生成

“P27. 4\_ACT\_Array Receivers\_SIMO\_MIMO\_2019, A.Manikas”[1]

**5.3.**

文本

中度可信度描述已自动生成文本

描述已自动生成

They also show that there should be 3 signals and the power of the noise are quite small which is close to 0.

*Code*:

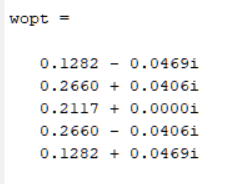
%% task 5

val\_theo=eig(Rxx\_theoretical);

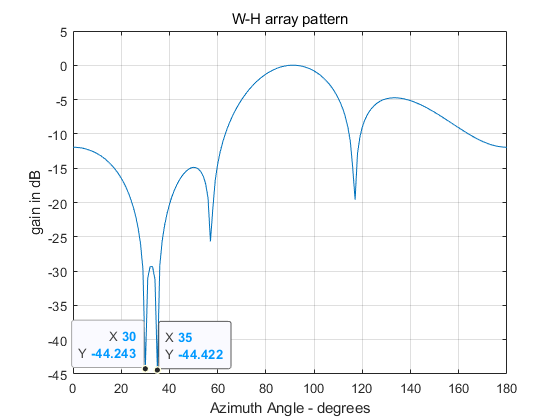
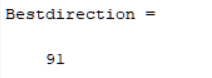
val\_au=eig(Rxx\_au); val\_im=eig(Rxx\_im);

**Task 6**

Set gain factor a to be 1 and the wopt is



Hence the Wiener-Hopf array pattern is

It illustrates clearly that there are two other interferences at the angle of 30 and 35 degrees.

*Code*:

%% task 6

Sd=spv(array,[90,0]);

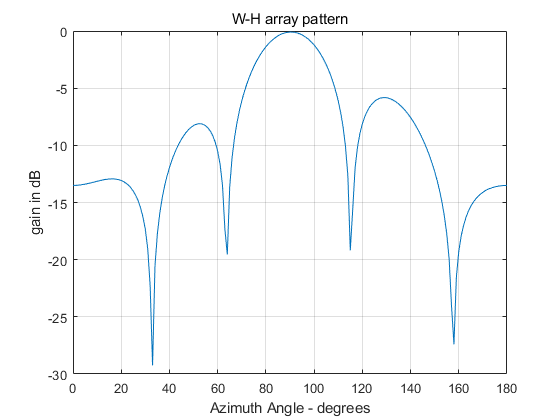
a=1;

wopt=a\*Rxx\_theoretical\Sd;%inv(Rxx\_theoretical)\*Sd

Z=pattern1(array, wopt);

plot2d3d(Z, 0:180,0,'gain in dB','W-H array pattern');

**Task 7**

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描述已自动生成

When changing the noise to 10dB (sigma2=0.1), interferences could not be distinguished. The shape is likely to be the initial pattern.

*Code*:

%% task 7

%theoreical cal

array=[-2 0 0; -1 0 0; 0 0 0; 1 0 0; 2 0 0];

directions=[30,0; 35,0; 90,0];

%task 2

S=spv(array,directions);

Rmm=eye(3,3); % (A,A) (B,B) (C,C) are 1, others are 0

sigma2=0.1;

Rxx\_theoretical=S\*Rmm\*S'+sigma2\*eye(5,5);

%task3

load Xaudio.mat;

load Ximage.mat;

soundsc(real(X\_au(2,:)),11025);

displayimage(X\_im(2,:),image\_size,201,'The received signal at 2nd antenna');

Rxx\_au=X\_au\*X\_au'/length(X\_au(1,:));

Rxx\_im=X\_im\*X\_im'/length(X\_im(1,:));

%task4

Rmm=[];

S=[];

directions=[];

sigma2=[];

%task5

val\_theo=eig(Rxx\_theoretical);

val\_au=eig(Rxx\_au); val\_im=eig(Rxx\_im);

[E,D]=eig(Rxx\_au);

%task6

Sd=spv(array,[90,0]);

a=1;

wopt=a\*Rxx\_theoretical\Sd;%inv(Rxx\_theoretical)\*Sd

Z=pattern1(array, wopt);

plot2d3d(Z, 0:180,0,'gain in dB','W-H array pattern');

**Task 8**

When only one direction of the signal is sure, the Wiener-Hopf array pattern is affected greatly by the power of the noise. If the noise is smaller than -40dB, the interferences could be distinguished easily and clearly.

**Task 9&10**

1. **Algorithm**

According to the algorithm introduced in [2], the MATLAB function music could be written as:

function [Pmu\_lg,P]=music(array,Rxx,M)

%algorism of Multiple Signal Classification (MUSIC)

%calculate covariance Rxx using practical method

%% main function

[E,D]=eig(Rxx); %E:eigenvectors, D: eigenvalues

%sort eigenvectors according to diagram of eigenvalues from large to small

[d,idx]=sort(diag(D),'descend');

% Ds=D(idx,idx);

E=E(:,idx);

[N,N1]=size(Rxx);

%get noise subspace

% En=E(:,M+1:N);

%fpoc:complement projection operator of A(Pn)

%P\_n =I\_N-P\_Es, P\_Es=Es\*inv(Es'\*Es)\*Es';(Es: sorted eigenvectors)

En=E(:,M+1:N);

Es=E(:,1:M);

Pn=fpoc(Es); % Pn=eig(N)-PEs;

for angle=1:181

direction=[angle-1,0];

S=spv(array,direction);

Pmu(angle)=1/(S'\*Pn\*S);

% Pmu(angle)=1/(S'\*En\*(En')\*S);

end

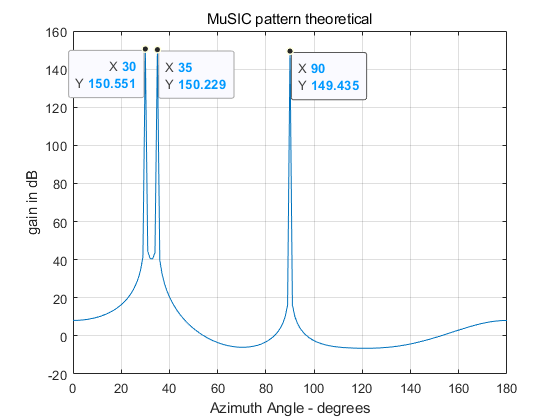
Pmu=abs(Pmu);

Pmu\_max=max(Pmu);%arg\_M\_min;

Pmu\_lg=10\*log10(Pmu);

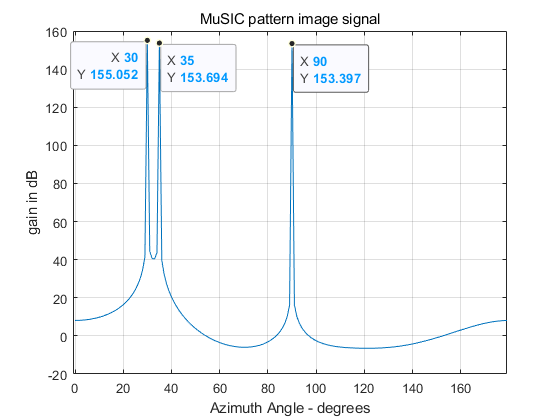
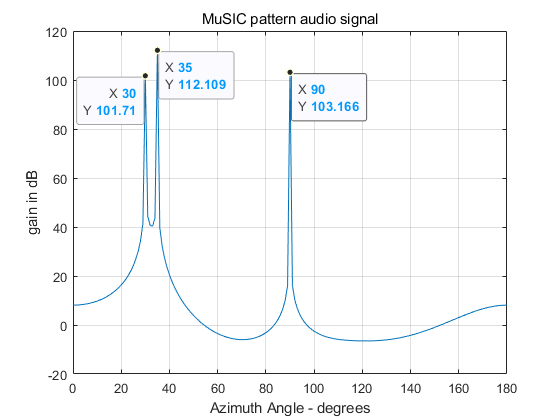
P=10\*log10(Pmu/Pmu\_max);

1. **Task9:**



There are 3 sources at directions 30, 35 and 90 degrees.

1. Task 10



From the figures above, 3 interferences(sources) at directions 30,35 and 90 degrees are clearly illustrated.

*Code:*

%% task 9&10&11

%basic parameters

array=[-2 0 0; -1 0 0; 0 0 0; 1 0 0; 2 0 0];

M=3; %number of signal (known)

%% task9 music\_theoretical

directions=[30,0; 35,0; 90,0];

S=spv(array,directions);

Rmm=eye(3,3); % (A,A) (B,B) (C,C) are 1, others are 0

sigma2=0.0001;

Rxx\_theoretical=S\*Rmm\*S'+sigma2\*eye(5,5);

[Pmusic\_theo,Ptheo]=music(array, Rxx\_theoretical,M);

plot2d3d(Pmusic\_theo,0:180,0,'gain in dB','MuSIC pattern theoretical');

%% task10 music\_audio

load Xaudio.mat;

load Ximage.mat;

% soundsc(real(X\_au(2,:)),11025);

% displayimage(X\_im(2,:),image\_size,201,'The received signal at 2nd antenna');

Rxx\_au=X\_au\*X\_au'/length(X\_au(1,:));

[Pmusic\_au,Pau]=music(array,Rxx\_au,M);

plot2d3d(Pmusic\_au,0:180,0,'gain in dB','MuSIC pattern audio signal');

%% task10 music\_image

Rxx\_im=X\_im\*X\_im'/length(X\_im(1,:));

[Pmusic\_im,Pim]=music(array,Rxx\_im,M);

plot2d3d(Pmusic\_im,0:180,0,'gain in dB','MuSIC pattern image signal');

%% task11\_part1 1&2 signals are fully correlated

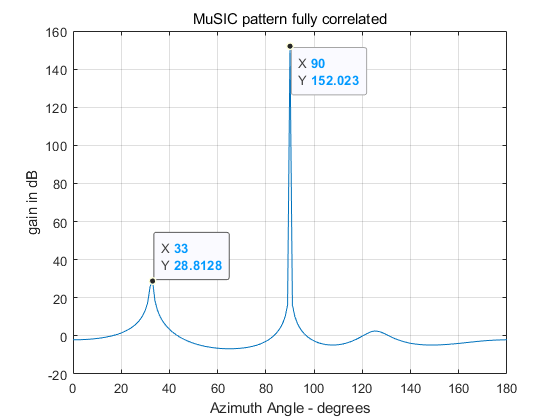
Rmm=[1,1,0;1,1,0;0,0,1]; %sources from 30 and 35 degrees fully correlated

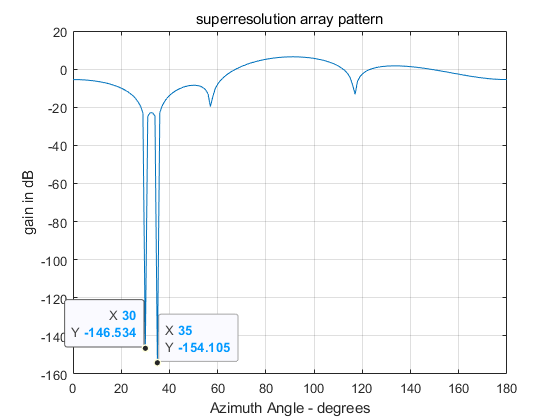
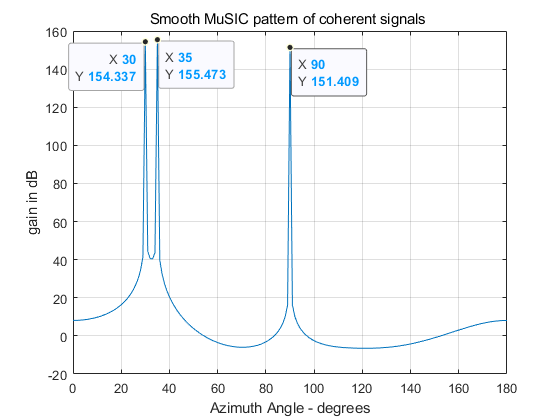
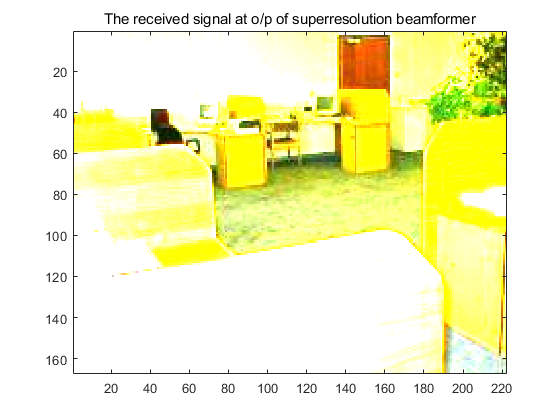
Rxx\_coherent=S\*Rmm\*S'+sigma2\*eye(5,5);

[Pmusic\_coherent,Pcoh]=music(array, Rxx\_coherent,M);

plot2d3d(Pmusic\_coherent,0:180,0,'gain in dB','MuSIC pattern fully correlated');

Task 11





%% task11\_part1 1&2 signals are fully correlated

Rmm=[1,1,0;1,1,0;0,0,1]; %sources from 30 and 35 degrees fully correlated

Rxx\_coherent=S\*Rmm\*S'+sigma2\*eye(5,5);

[Pmusic\_coherent,Pcoh]=music(array, Rxx\_coherent,M);

plot2d3d(Pmusic\_coherent,0:180,0,'gain in dB','MuSIC pattern fully correlated');

%% task11\_part2 smooth

Rbar=smooth(array,Rmm,S);

Rxx\_smooth=S\*Rbar\*S'+sigma2\*eye(5,5);

[Psmooth,Pcoh]=music(array, Rxx\_smooth,3);

plot2d3d(Psmooth,0:180,0,'gain in dB','Smooth MuSIC pattern of coherent signals ');

%% task12 superresolution beamformer

%part1 au

Sd=spv(array,[90,0]); %Sdisire

wopt1=Rxx\_au\Sd;

yt1=wopt'\*X\_au;

soundsc(real(yt1),11025);

%task2

wopt2=Rxx\_im\Sd;

yt2=wopt2'\*X\_im;

displayimage(yt2, image\_size, 202,'The received signal at o/p of W-Hbeamformer');

%task3

Sj=S(:,1:2); %

% Sj=spv(array,[30,0;35,0]);

wopt3=fpoc(Sj)\*Sd;

yt3=wopt3'\*X\_im;

displayimage(yt3, image\_size, 202,'The received signal at o/p of superresolution beamformer');

Z=pattern1(array, wopt3);

plot2d3d(Z, 0:180,0,'gain in dB','superresolution array pattern');

**References:**

1. 4\_ACT\_Array Receivers\_SIMO\_MIMO\_2019, A. Manikas
2. Schmidt R.O., "Multiple Emitter Location and Signal Parameter Estimation", IEEE Transactions on Antennas and Propagation, Vol. AP-34, No.3, pp 276-280, March 1986
3. Shan T., Wax M., Kailath T., "On Spatial Smoothing for Direction-of-Arrival Estimation of Coherent Signals", IEEE Transactions on Acoustics, Speech and Signal Processing, Vol. ASSP-33, No.4, pp 806-811, August 1985.