Signals and Systems Laboratory (EC2P002)

EXPERIMENT-2

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Aim of the experiment:

To identify the five different systems given on the basis of their characteristics:

- Linearity/Non-Linearity
- Time Variance/Time Invariance
- Causality/Non-Causality

Theory: -

Linear System:

A linear system is one that satisfies the "superposition principle"

$$\tau\left(a_1x_1(n)+a_2x_2(n)\right)=\tau\left[a_1x_1(n)\right]+\tau\left[a_2x_2(n)\right]$$

Above equation says "response to weighted sum of all inputs" is equal to "sum of response to the weighted individual inputs"

Time invariant System:

Delay produced in input which will be reflected same amount of delay in the output response

$$x\left(n\right)\rightarrow system\rightarrow y\left(n\right)$$
$$x\left(n-k\right)\rightarrow syetem\rightarrow y\left(n-k\right)$$

Causal System:

If a system is said to be causal means if output of a system at any time depends only present and past input.

$$y(n)=F\left[x(n),x(n-1),x(n-2),x(n-3),x(n-4),x(n-5),.....\right]$$

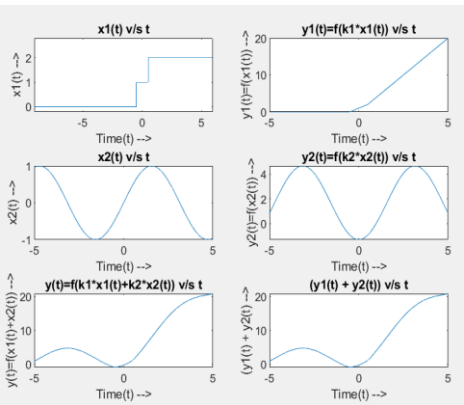
Results:

Signals taken: X1(t) = u(t+1/2) +u(t-1/2)

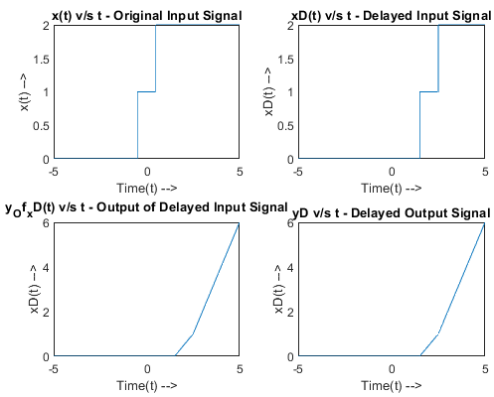
X2(t)=u(t)

$$1.y(t)=\int_{-\infty}^{t}x(t)$$

Linear



Time Invariance



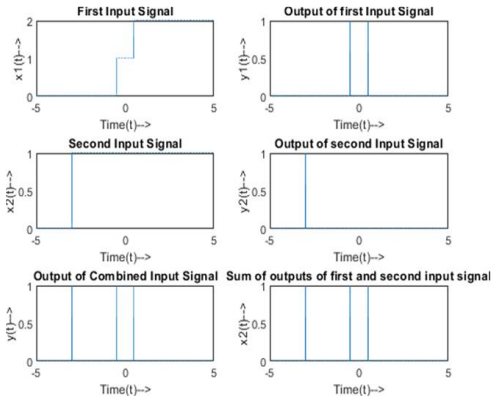
Causality

```
COMMAND WINDOW
>> system1
The system is causal
>>
```

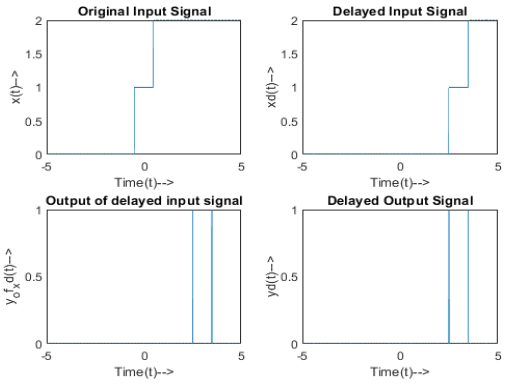
- Time-Invariant
- Casual
- Linear

$$2.y(t) = \frac{\mathrm{d}}{\mathrm{d}t}(x(t))$$

Linearity



Time-Invariance



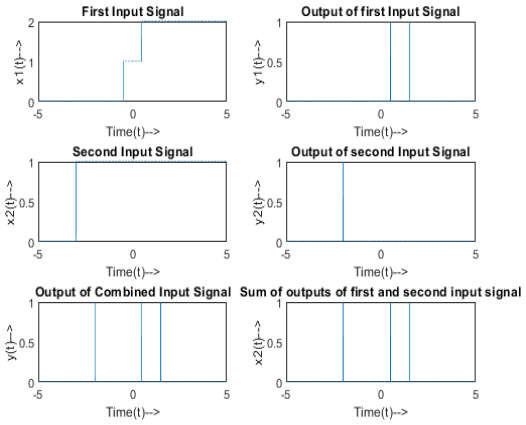
Causality

```
COMMAND WINDOW
>> system2
The system is causal
>>
```

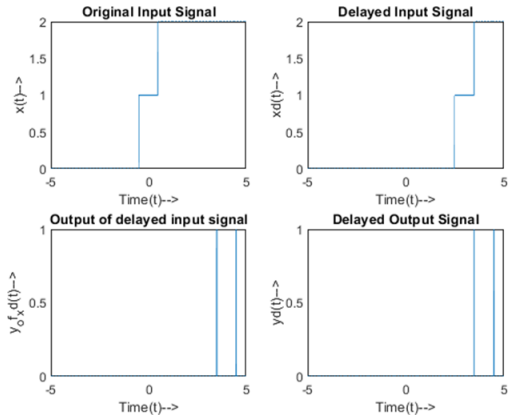
- Linear
- Time-Invariant
- Casual

$$3.(t) = \frac{\mathrm{d}}{\mathrm{d}t}(x(t-1))$$

Linearity



Time-Invariance



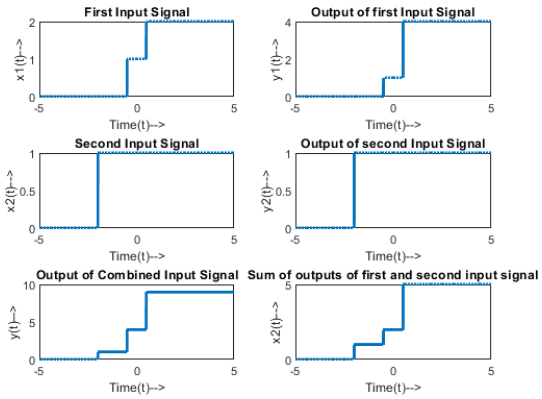
Causality

```
COMMAND WINDOW
>> system3
The system is causal
>>
```

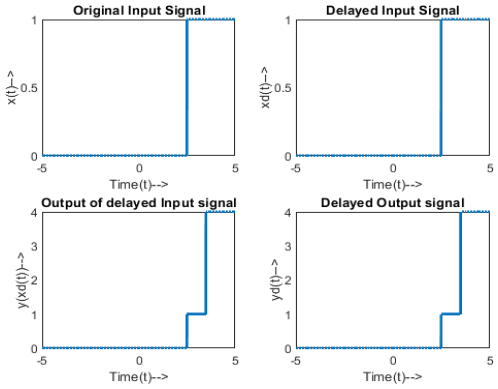
- Linear
- Time-Invariant
- Casual

$$4. y(t) = x(t)^2$$

Linearity



Time-Invariance



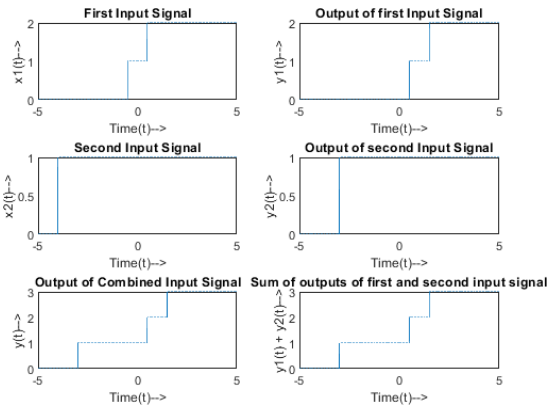
Causality

```
COMMAND WINDOW
>> clear
>> system4
The system is causal
>>
```

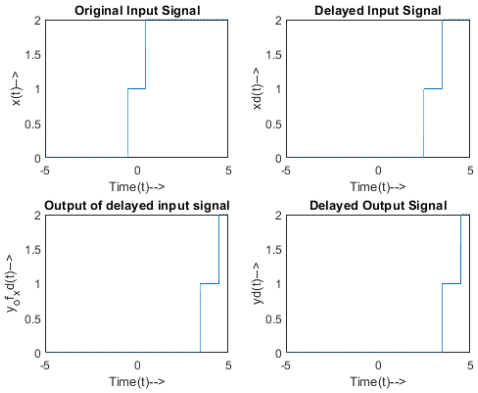
- Non-Linear
- Time-Invariant
- Casual

$$5. y(t) = x(t-1)$$

Linearity



Time-Invariance



Causality

```
COMMAND WINDOW
>> system5
The system is causal
>>
```

- Linear
- Time-Invariant
- Casual

Discussion:

The system is linear if it holds superposition theorem as we verified. We shifted input and output signal to check if the input is equal to output and hence if the system is time invariant. Lastly, we checked for causality if the output depends upon only on past or present values. We saw that our practical results followed the theoretical ones. MATLAB is a powerful tool to form systems and plot input and output signals.

Conclusion:

Our experiment was completed as we formed each system equation and observed the input and output signals to draw conclusions about the nature of the system. All the given systems were time-invariant and causal. Except system 4, all systems were linear.

Appendix

1) **System-1**

```
syms t;
x1=heaviside(t-0.5)+heaviside(t+0.5);
subplot(3,2,1);
fplot(x1);
title("x1(t) v/s t");
xlabel("Time(t) -->");
ylabel("x1(t) -->");
k1=input("Enter first contant ");
y1=int((k1*x1),-1000,t);
subplot(3,2,2);
fplot(y1);
title("y1(t)=f(k1*x1(t)) v/s t");
xlabel("Time(t) -->");
ylabel("y1(t)=f(x1(t)) -->");
x2=sin(t);
subplot(3,2,3);
fplot(x2);
title("x2(t) v/s t");
xlabel("Time(t) -->");

ylabel("x2(t) -->");
k2=input("Enter second constant ");
y2=int((k2*x2),-1000,t);
subplot(3,2,4);
fplot(y2);
title("y2(t)=f(k2*x2(t)) v/s t");
xlabel("Time(t) -->");
ylabel("y2(t)=f(x2(t)) -->");
x=k1*x1+k2*x2;
y=int(x,-1000,t);
subplot(3,2,5);
fplot(y);
title("y(t)=f(k1*x1(t)+k2*x2(t)) v/s t");
xlabel("Time(t) -->");
ylabel("y(t)=f(x1(t)+x2(t)) -->");
Y=y1+y2;
subplot(3,2,6);
fplot(Y);
title("(y1(t) + y2(t)) v/s t");
xlabel("Time(t) -->");
ylabel("(y1(t) + y2(t) -->");
err=y-Y;
fprintf("the error is %.4f",err);
if(err==0)
 disp("The function is linear");
else
 disp("The function is not linear");
end

x=@(t)dirac(t);
y=int(x(t),t,-1000,t);
c=0;
for t=-50:0.1:-0.1
 if y(t)~=0
 c=1;
 break;
 elseif y(t)==0
 c=0;
 end
end
if(c==0)
 disp("The system is causal");
else
 disp("The system is not causal");
end
```

```
syms t;
x1=heaviside(t-0.5)+heaviside(t+0.5);
d=input("Enter delay time to check for time-invariance ");
subplot(2,2,1);
fplot(x1);
title("x(t) v/s t - Original Input Signal");
xlabel("Time(t) -->");
ylabel("x(t) -->");
xD = heaviside((t-d)-0.5)+heaviside((t-d)+0.5);
subplot(2,2,2);
fplot(xD);
title("xD(t) v/s t - Delayed Input Signal");
xlabel("Time(t) -->");
ylabel("xD(t) -->");
y_Of_xD=int(xD,-1000,t);
subplot(2,2,3);
fplot(y_Of_xD);
title("y_Of_xD(t) v/s t - Output of Delayed Input Signal");
xlabel("Time(t) -->");
ylabel("xD(t) -->");
yD=int(x1,-1000,(t-d));
subplot(2,2,4);
fplot(yD);
title("yD v/s t - Delayed Output Signal");
xlabel("Time(t) -->");
ylabel("xD(t) -->");
error=yD-y_Of_xD;
fprintf("The error is %.4f",error);
if(error == 0)
 disp("The system is time-invariant");
else
 disp("The system is time-variant");
end
```

2) **System-2**

```
t=-5:0.005:5;
l=length(t);
x1=zeros(1,l);y1=zeros(1,l);
%Let x2=u(t+3) then y2=diff(x2)=k2 * del(t+3)
x2=zeros(1,l); y2=zeros(1,l);
k1=input("Enter constant 1 ");
k2=input("Enter constant 2 ");
x=k1*x2; %Combined input i.e, x=k1*(u(t-0.5)+u(t+0.5))+k2*u(t+3)
y=zeros(1,l); %Output of combined input i.e., y=diff(x)=k1*(del(t0.5)+del(t+0.5))+k2*del(t+3)
for i=1:l
 if(t(i)>=0.5)
 x1(i)=2;
 elseif(t(i)>=-0.5 && t(i)<=0.5)
 x1(i)=1;
 end
 if(t(i)==0.5 || t(i)==-0.5)
 y1(i)=k1*1;
 y(i)=k1*1;
 end

 if(t(i)>=-3)
 x2(i)=1;
 end
 if(t(i)==-3)
 y2(i)=k2*1;
 y(i)=k2*1;
 end
end
subplot(3,2,1);
plot(t,x1);
xlabel("Time(t)-->");
ylabel("x1(t)-->");
title("First Input Signal");
subplot(3,2,2);
plot(t,y1);
xlabel("Time(t)-->");
ylabel("y1(t)-->");
title("Output of first Input Signal");
subplot(3,2,3);
plot(t,x2);
xlabel("Time(t)-->");
ylabel("x2(t)-->");
title("Second Input Signal");
subplot(3,2,4);
plot(t,y2);
xlabel("Time(t)-->");
ylabel("y2(t)-->");
title("Output of second Input Signal");
subplot(3,2,5);
plot(t,y);
xlabel("Time(t)-->");
ylabel("y(t)-->");
title("Output of Combined Input Signal");
subplot(3,2,6);
plot(t,(y1+y2));
xlabel("Time(t)-->");
ylabel("x2(t)-->");
```

```
title("Sum of outputs of first and second input signal");
err=immse(y,(y1+y2));
fprintf("the error is %.4f",err);
if(err==0)
 disp("The function is linear");
else
 disp("The function is not linear");
end

%Causality check
c=causal(x1,y1,t);
disp(c);

t=-5:0.005:5;
l=length(t);
x=zeros(1,l);y=zeros(1,l);
%Given, x(t)=u(t-0.5)+u(t+0.5) we can write y(t)=del(t-0.5)+del(t+0.5)
for i=1:l
 if(t(i)>=0.5)
 x(i)=2;
 elseif(t(i)>=-0.5 && t(i)<=0.5)
 x(i)=1;
 end
 if(t(i)==0.5 || t(i)==-0.5)
 y(i)=1;
 end
end
d=input("Enter delay time");
xd=zeros(1,l);y_of_xd=zeros(1,l);
% =>xd(t)=x(t-d)=u(t-d-0.5)+u(t-d+0.5) and y_of_xd=diff(xd)=diff(x1(td))=del(t-d-0.5)+del(t-d+0.5)
for i=1:l
 if(t(i)>=(0.5+d))
 xd(i)=2;
 elseif(t(i)>=(-0.5+d) && t(i)<=(d+0.5))
 xd(i)=1;
 end
 if(t(i)==(d+0.5) || t(i)==(d-0.5))
 y_of_xd(i)=1;
 end
end
yd=zeros(1,l); %Also, yd(t)=y(t-d)
for i=1:l
 if((t(i)-d)==0.5 || (t(i)-d)==-0.5)
 yd(i)=1;
 end
end
subplot(2,2,1);
plot(t,x);
xlabel("Time(t)-->");
ylabel("xd(t)-->");
title("Original Input Signal");
subplot(2,2,2);
plot(t,xd);
xlabel("Time(t)-->");
ylabel("xd(t)-->");
title("Delayed Input Signal");
subplot(2,2,3);
plot(t,y_of_xd);
xlabel("Time(t)-->");
ylabel("y_of_xd(t)-->");
title("Output of delayed input signal");
subplot(2,2,4);
plot(t,yd);
xlabel("Time(t)-->");
ylabel("yd(t)-->");
title("Delayed Output Signal");
err2=immse(yd,y_of_xd);
%Calculating root mean square error between "Output of delayed input signal"
and "Delayed output signal"
fprintf("The error is %.4f",err2);
if(err2==0)
 disp("The signal is time-invariant");
else
 disp("The signal is time-variant");
end
```

3) System-3

```
t=-5:0.005:5;
l=length(t);
x1=zeros(1,l);y1=zeros(1,l);
%Let x2=u(t+3) then y2=diff(k2*x2(t-1))=k2*del(t+2)
x2=zeros(1,l); y2=zeros(1,l);
k1=input("Enter constant 1 ");
k2=input("Enter constant 2 ");
x=x1+x2; %Combined input i.e, x=k1*(u(t-1-0.5)+u(t-1+0.5))+k2*u(t+2)
y=zeros(1,l);
for i=1:l
 if(t(i)>=0.5)
 x1(i)=2;
 elseif(t(i)>=-0.5 && t(i)<=0.5)
 x1(i)=1;
 end
 if(t(i)==1.5 || t(i)==0.5)
 y1(i)=k1*1;
 y(i)=k1*1;
 end
 if(t(i)>=-3)
 x2(i)=1;
 end
 if(t(i)==-2)
 y2(i)=k2*1;
 y(i)=k2*1;
 end
end
subplot(3,2,1);
plot(t,x1);
xlabel("Time(t)-->");
ylabel("x1(t)-->");
title("First Input Signal");
subplot(3,2,2);
plot(t,y1);
xlabel("Time(t)-->");
ylabel("y1(t)-->");
title("Output of first Input Signal");
subplot(3,2,3);
plot(t,x2);
xlabel("Time(t)-->");
ylabel("x2(t)-->");
title("Second Input Signal");
subplot(3,2,4);
plot(t,y2);
xlabel("Time(t)-->");
ylabel("y2(t)-->");
title("Output of second Input Signal");
subplot(3,2,5);
plot(t,y);
xlabel("Time(t)-->");
ylabel("y(t)-->");
title("Output of Combined Input Signal");
subplot(3,2,6);
plot(t,(y1+y2));
xlabel("Time(t)-->");
ylabel("x2(t)-->");
title("Sum of outputs of first and second input signal");
err=immse(y,(y1+y2));
fprintf("The error is %.4f",err);
if(err==0)
 disp("The function is linear");
else
 disp("The function is not linear");
end

%Causality check
c=causal(x1,y1,t);
disp(c);

%Time-invariance check
t=-5:0.005:5;
x=zeros(1,l); y=zeros(1,l);
for i=1:l
 if(t(i)>=0.5)
 x(i)=2;
 elseif(t(i)>=-0.5 && t(i)<=0.5)
 x(i)=1;
 end
 if(t(i)==1.5 || t(i)==0.5)
 y(i)=k1*1;
 end
end
%Given, x1(t-1)=u(t-1-0.5)+u(t-1+0.5) we can write y1(t)=diff(x(t-1))=del(t1-0.5)+del(t-1+0.5)

d=input("Enter delay time");
xd=zeros(1,l);y_of_xd=zeros(1,l);

for i=1:l
 if(t(i)>=(0.5+d))
 xd(i)=2;
 elseif(t(i)>=(-0.5+d) && t(i)<=(d+0.5))
 xd(i)=1;
 end
 if(t(i)==(d+1.5) || t(i)==(d+0.5))
 y_of_xd(i)=1;
 end
end
yd=zeros(1,l); %Also, yd(t)=y1(t-d)=diff(x1(t-1-d))
for i=1:l
 if((t(i)-d-1)==0.5 || (t(i)-d-1)==-0.5)
 yd(i)=1;
 end
end
subplot(2,2,1);
plot(t,x);
xlabel("Time(t)-->");
ylabel("x(t)-->");
```

```
title("Original Input Signal");
subplot(2,2,2);
plot(t,xd);
xlabel("Time(t)-->");
ylabel("xd(t)-->");
title("Delayed Input Signal");
subplot(2,2,3);
plot(t,y_of_xd);
xlabel("Time(t)-->");
ylabel("y_of_xd(t)-->");
title("Output of delayed input signal");
subplot(2,2,4);
plot(t,yd);
xlabel("Time(t)-->");
ylabel("yd(t)-->");
title("Delayed Output Signal");
err2=immse(yd,y_of_xd);
%Calculating root mean square error between "Output of delayed input signal"
and "Delayed output signal"
fprintf("The error is %.4f",err2);
if(err2==0)
 disp("The signal is time-invariant");
else
 disp("The signal is time-variant");
end
```

4) System-4

```
t=-5:0.005:5;
l=length(t);
x1=zeros(1,l); y1=zeros(1,l);

x2=zeros(1,l); y2=zeros(1,l);
k1=input("Enter constant 1 ");
k2=input("Enter constant 2 ");
x=x1+x2; %Combined input i.e, x=k1*x1+k2*x2=k1*(u(t-0.5)+u(t+0.5))+k2*u(t+2)
y=zeros(1,l);

for i=1:l
 if(t(i)>=0.5)
 x1(i)=2;
 y1(i)=4*k1*k1;
 y(i)=4*(k1*k1)+(k2*k2)+4*(k1*k2);
 elseif(t(i)>=-0.5 && t(i)<=0.5)
 x1(i)=1;
 y1(i)=k1*k1;
 y(i)=k1*k1+k2*k2+2*k1*k2;
 elseif(t(i)>=-2 && t(i)<=-0.5)
 y(i)=k2*k2;
 end
 if(t(i)>=-2)
 x2(i)=1;
 y2(i)=k2*k2;
 end
end
subplot(3,2,1);
plot(t,x1,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("x1(t)-->");
title("First Input Signal");
subplot(3,2,2);
plot(t,y1,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("y1(t)-->");
title("Output of first Input Signal");
subplot(3,2,3);
plot(t,x2,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("x2(t)-->");
title("Second Input Signal");
subplot(3,2,4);
plot(t,y2,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("y2(t)-->");
title("Output of second Input Signal");
subplot(3,2,5);
plot(t,y,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("y(t)-->");
title("Output of Combined Input Signal");
subplot(3,2,6);
plot(t,(y1+y2),"LineWidth",2);
xlabel("Time(t)-->");
ylabel("x2(t)-->");
title("Sum of outputs of first and second input signal");
err=immse(y,(y1+y2));
fprintf("The error is %.4f",err);
if(err==0)
 disp("The function is linear");
else
 disp("The function is not linear");
end

%Causality check
c=causal(x1,y1,t);
disp(c);

d=input("Enter delay time for time invariance check");
x=zeros(1,l);y=zeros(1,l);
for i=1:l
 if(t(i)>=0.5)
 x(i)=2;
 y(i)=4;
 elseif(t(i)>=-0.5 && t(i)<=0.5)
 x(i)=1;
 y(i)=1;
 end
end
xd=zeros(1,l); %xd(t)=x(t-d)=u(t-d+0.5)+u(t-d-0.5) ---Input Side Delay
y_of_xd=zeros(1,l); %y_of_xd(t)=(xd(t))^2=(x1(t-d)^2=(u(t-d+0.5))^2+(u(t-d0.5))^2+2*u(t-d+0.5)*u(t-d-0.5)
for I=1:l
 if(t(i)>=(d+0.5))
 xd(i)=1;
 y_of_xd(i)=4;
 elseif(t(i)>=(d-0.5) && t(i)<=(d+0.5))
 xd(i)=1;
 y_of_xd(i)=1;
 end
end
%Output Side Delay --> yd(t)=y(t-d)
yd=zeros(1,l);
for i=1:l
 if((t(i)-d)>=0.5)
 yd(i)=4;
 elseif((t(i)-d)>=-0.5 && (t(i)-d)<=0.5)
 yd(i)=1;
 end
end
subplot(2,2,1);
plot(t,xd,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("x(t)-->");
title("Original Input Signal");
subplot(2,2,2);
plot(t,xd,"LineWidth",2);
xlabel("Time(t)-->");
ylabel("xd(t)-->");
title("Delayed Input Signal");
subplot(2,2,3);
plot(t,y_of_xd,"LineWidth",2); %Output of delayed Input signal
xlabel("Time(t)-->");
ylabel("y(xd(t))-->");
title("Output of delayed Input signal");
subplot(2,2,4);
plot(t,yd,"LineWidth",2); %Delayed Output signal
xlabel("Time(t)-->");
ylabel("yd(t)-->");
title("Delayed Output signal");
err=immse(yd,y_of_xd);
fprintf("The error is %.4f",err);
if(err==0)
 disp("The signal is Time-Invariant");
else
 disp("The signal is Time-Variant");
end
```

5) System-5

```
t=-5:0.005:5;
l=length(t);
k1=input("enter constant 1 ");
k2=input("enter constant 2 ");
%x1(t)=u(t+0.5)+u(t-0.5) => y1(t)=k1*x1(t-1)=k1*u(t-1+0.5)+k1*u(t-1-0.5)
x1=zeros(1,l); y1=zeros(1,l);
%x2(t)=u(t+4) => y2(t)=k2*x2(t-1)=k2*u(t-1+4);
x2=zeros(1,l); y2=zeros(1,l);
%x(t)=k1*x1(t)+ k2*x2(t) i.e, combined input signal
y=zeros(1,l);
for i=1:l
 if(t(i)>=0.5)
 x1(i)=2;
 elseif(t(i)>=-0.5 && t(i)<0.5)
 x1(i)=1;
 end
```

```
 if(t(i)>=1.5)
 y1(i)=2*k1;
 y(i)=2*k1+k2;

 elseif(t(i)>=0.5 && t(i)<1.5)
 y1(i)=1*k1;
 y(i)=k1+k2;
 end
 if(t(i)>=-4)
 x2(i)=1;
 end
 if(t(i)>=-3)
 y2(i)=1*k2;
 end
 if(t(i)>=-3 && t(i)<0.5)
 y(i)=1*k2;
 end
end
subplot(3,2,1);
plot(t,x1);
xlabel("Time(t)-->");
ylabel("x1(t)-->");
title("First Input Signal");
subplot(3,2,2);
plot(t,y1);
xlabel("Time(t)-->");
ylabel("y1(t)-->");
title("Output of first Input Signal");
subplot(3,2,3);
plot(t,x2);
xlabel("Time(t)-->");
ylabel("x2(t)-->");
title("Second Input Signal");
subplot(3,2,4);
plot(t,y2);
xlabel("Time(t)-->");
ylabel("y2(t)-->");
title("Output of second Input Signal");
subplot(3,2,5);
plot(t,y);
xlabel("Time(t)-->");
ylabel("y(t)-->");
title("Output of Combined Input Signal");
subplot(3,2,6);
plot(t,(y1+y2));
xlabel("Time(t)-->");
ylabel("y1(t) + y2(t)-->");
title("Sum of outputs of first and second input signal");
err=immse(y,(y1+y2));
fprintf("The error is %.4f",err);
if(err==0)
 disp("The function is linear");
else
 disp("The function is not linear");
end

c=causal(x1,y1,t);
disp(c);

t=-5:0.005:5;
x=zeros(1,1);y=zeros(1,1);
for i=1:1
 if(t(i)>=0.5)
 x(i)=2;
 elseif(t(i)>=-0.5 && t(i)<0.5)
 x(i)=1;
 end
 if(t(i)>=1.5)
 y(i)=2;
 elseif(t(i)>=0.5 && t(i)<1.5)
 y(i)=1;
 end
end
d=input("Enter delay time");
xd=zeros(1,1);y_of_xd=zeros(1,1);
for i=1:1
 if(t(i)>=(0.5+d))
 xd(i)=2;
 elseif(t(i)>=(-0.5+d) && t(i)<(d+0.5))
 xd(i)=1;
 end
 if(t(i)>=(d+1.5))
 y_of_xd(i)=2;
 elseif(t(i)>=(d+0.5) && t(i)<(d+1.5))
 y_of_xd(i)=1;
 end
end
yd=zeros(1,1); %Also, yd(t)=y(t-d)=x(t-d-1)
for i=1:1
 if((t(i)-d-1)>=0.5)
 yd(i)=2;
 elseif((t(i)-d-1)>=-0.5 && (t(i)-d-1)<0.5)
 yd(i)=1;
 end
end
subplot(2,2,1);
plot(t,x);
xlabel("Time(t)-->");
ylabel("x(t)-->");
title("Delayed Input Signal");
subplot(2,2,2);
plot(t,xd);
xlabel("Time(t)-->");
ylabel("xd(t)-->");
title("Delayed Input Signal");
subplot(2,2,3);
plot(t,y_of_xd);
xlabel("Time(t)-->");
ylabel("y_of_xd(t)-->");
title("Output of delayed input signal");
subplot(2,2,4);
plot(t,yd);
xlabel("Time(t)-->");
ylabel("yd(t)-->");
title("Delayed Output Signal");
err2=immse(yd,y_of_xd);
%Calculating root mean square error between "Output of delayed input signal"
and "Delayed output signal"
fprintf("The error is %.4f",err2);
if(err2==0)
 disp("The signal is time-invariant");
else
 disp("The signal is time-variant");
end
```

Causality Function

```
function c=causal(x,y,t)
t1=0;t2=0;
l=length(t);
for i=1:l
 if(x(i)>0)
 t1=t(i);
 break;
 end
end
for i=1:l
 if(y(i)>0)
 t2=t(i);
 break;
 end
end
if(t2<t1)
 c="The system is non-causal ";
elseif(t1>t2)
 c="The system is causal ";
else
 c="The system is causal ";
end
end
```