Department of Electrical & Computer Engineering

Course No: ECE 4124

Course Title: Digital Signal Processing Sessional

Experiment No: 04

Experiment Name: Detecting Signal Delay Using Cross-correlation and the Z Transform

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Experiment Name: Detecting Signal Delay Using Cross-correlation and the Z Transform

Theory: Cross-correlation is a mathematical process that determines how similar two signals are as they are shifted relative to each other. It is often used to find patterns, align signals, and perform other analyses in signal processing, image analysis, and other domains. Cross-correlation is similar to linear convolution in that it compares two signals directly rather than convolving one signal with the time-reversed version of the other.

The cross-correlation at time index n of two discrete signals x[n] and y[m], where n and m are integer indices indicating time steps, is defined as:

$r[n] = \sum(m = -\infty \text{ to } \infty) [x[n + m] * y[m]]$

The cross-correlation result at time index n is represented by r[n]. The correlation is computed at each shift as the reference signal y[m] is shifted over the main signal x[n].

In practice, cross-correlation can be computed using a variety of algorithms, including the direct computation demonstrated above, as well as fast Fourier transforms (FFT) for increased efficiency. When dealing with huge datasets, FFT-based approaches come in handy.

The Z-transform is a mathematical transformation that is often used to analyze discrete-time signals and systems. It is similar to the Laplace transform, which is used for continuous-time signals and systems. The Z-transform represents discrete signals and systems in a complex frequency domain, which is important for understanding their behavior, stability, and response to different inputs.

The Z-transform of a discrete-time signal x[n] is denoted as X(z) and is defined as a power series:

$X(z) = \sum(n = -\infty \text{ to } \infty) [x[n] * z^{(-n)}]$

Here, z is a complex variable. The Z-transform essentially converts a discrete signal from the time domain (n) to the Z-domain (z).

The Z-transform is very useful for studying difference equations describing discrete-time linear systems. It's commonly utilized in signal processing, control systems, digital filter design, and communication systems, among other things.

Required Software: MATLAB

Code:

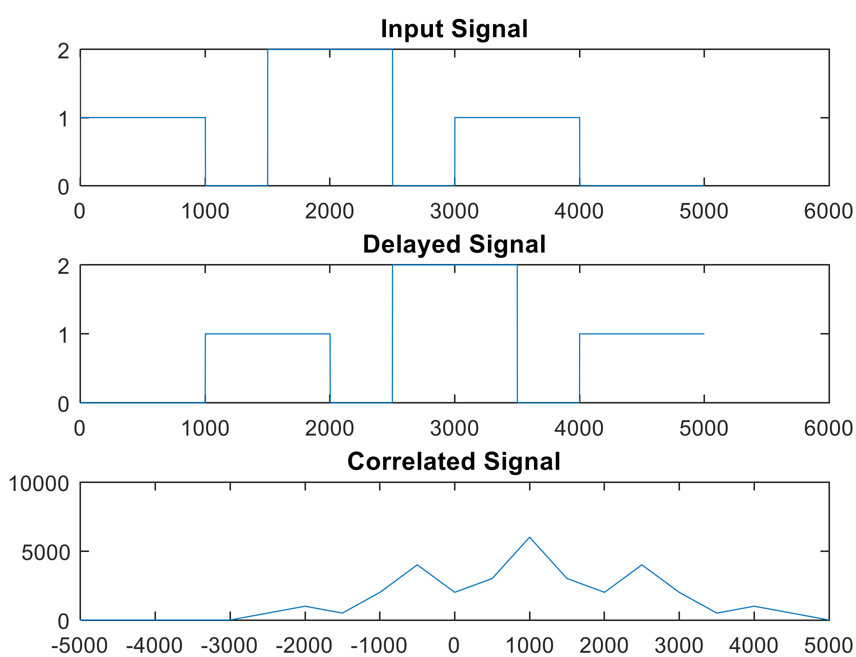
Signal Delay (Continuous):

```
clc;
clear all;
t=0:0.001:5;

x1= t>=0 & t<=1;
x2= t>=1.5 & t<=2.5;
x3= t>=3 & t<=4;
x=x1+2*x2+x3;
d1= t>=1 & t<=2;
d2= t>=2.5 & t<=3.5;
d3= t>=4 & t<=5;
d=d1+2*d2+d3;
N= -(length(t)-1):(length(t)-1);
c= xcorr(d,x);

subplot(3,1,1);
plot(x);
title('Input Signal');
subplot(3,1,2);
plot(d);
title('Delayed Signal');
subplot(3,1,3);
plot(N,c);
title('Correlated Signal');
```

Output:



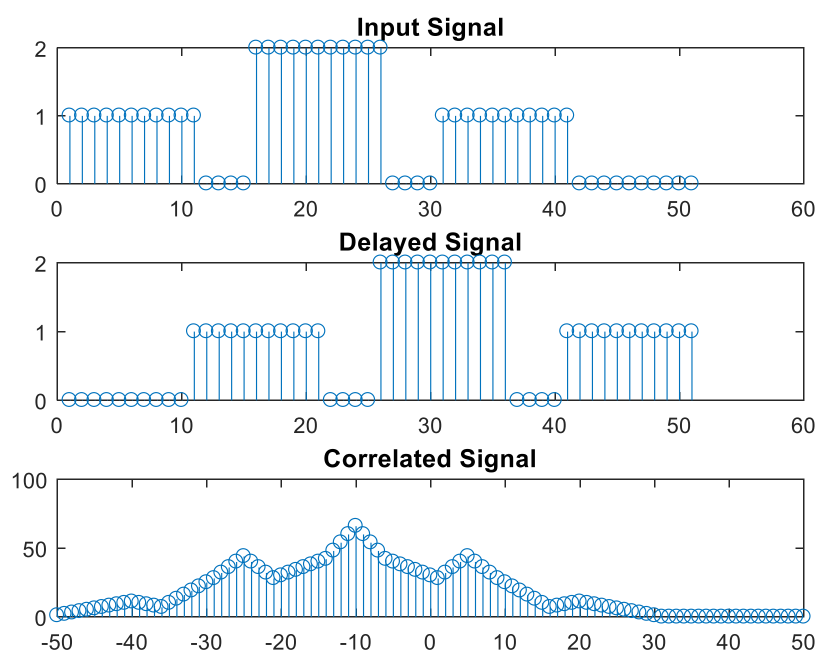
Signal Delay (Discrete):

```
clc;
clear all;
t=0:0.1:5;

x1= t>=0 & t<=1;
x2= t>=1.5 & t<=2.5;
x3= t>=3 & t<=4;
x=x1+2*x2+x3;
d1= t>=1 & t<=2;
d2= t>=2.5 & t<=3.5;
d3= t>=4 & t<=5;
d=d1+2*d2+d3;
N= -(length(t)-1):(length(t)-1);
c= xcorr(x,d);

subplot(3,1,1);
stem(x);
title('Input Signal');
subplot(3,1,2);
stem(d);
title('Delayed Signal');
subplot(3,1,3);
stem(N,c);
title('Correlated Signal');
```

Output:



Z-Transform:

```
clc;
clear all;

x = [1, 2, 4, 6, 8];
H=0;
N = length(x);
y= sym('Z');

for i=1:N
 H= H+x(i)*y^(1-i);
end
display(H);
```

Output:

```
H =

 2/Z + 4/Z^2 + 6/Z^3 + 8/Z^4 + 1
```

Discussion and Conclusion: In this experiment, we looked at signal delay detection in both continuous and discrete circumstances, as well as the use of the Z-transform. We used cross-correlation techniques to successfully locate signal delays, comparing an input signal with its delayed form. Notably, the peak index of the resulting cross-correlation provided us with critical timing information. The experiment gave the predicted results in both cases.