Namal University, Mianwali

Department of Electrical Engineering

EE 345 (L) – Digital Signal Processing (Lab)

Lab – 3

Convolution and Correlation using MATLAB

Student Name	Student ID
Fahim Ur Rehma Shah	NIM-BSEE-2021-24

Instructor: Zulaikha Kiran

Lab Engineer: Faizan Ahmad

Version 1.0 – Muhammad Usman – 15/04/2021
Version 1.1 – Zulaikha Kiran – 05/04/2022
Version 1.2 – Husnain, Saiqa Dilawaiz – 06/04/2023
Version 1.3 – Faizan Ahmad – 26/02/2024

Introduction

The purpose of this lab is to revise some MATLAB concepts and implementations including convolution, verify convolution properties, and find correlation.

Course Learning Outcomes

CLO1: Develop algorithms to perform signal processing techniques on digital signals using MATLAB and DSP Kit DSK6713

CLO3: Deliver a report/lab notes/presentation/viva, effectively communicating the design and analysis of the given problem

Equipment

- Software
  - MATLAB

Instructions

1. This is an individual lab. You will perform the tasks individually and submit a report.
2. Some of these tasks are for practice purposes only while others (marked as ‘Exercise’) have to be answered in the report.
3. When asked to display an image/ graph in the exercise either save it as jpeg or take a screenshot, in order to insert it in the report.
4. The report should be submitted on the given template, including:
   a. Code (copy and pasted, NOT a screenshot)
   b. Output values (from command window, can be a screenshot)
   c. Output figure/graph (as instructed in 3)
   d. Explanation where required
5. The report should be properly formatted, with easy to read code and easy to see figures.
6. Plagiarism or any hint thereof will be dealt with strictly. Any incident where plagiarism is caught, both (or all) students involved will be given zero marks, regardless of who copied whom. Multiple such incidents will result in disciplinary action being taken.

Background

Convolution

Convolution is an operation between the input signal to a system, and its impulse response, resulting in the output signal.
In discrete time, convolution of two signals involves summing the product of the two signals, where one of the signals is "flipped and shifted". It doesn't matter which signal is flipped and shifted. In other words, convolution is used to modify or transform a signal. Have to take care to get limits of sum correct. Convolution sum of signal x[n] with system impulse response h[n] is given by:

$$y[n] = \sum_{k=-\infty}^{k=+\infty} x[k]h[n-k]$$

Correlation

Correlation, on the other hand, involves measuring the similarity between two signals or images. It is a measure of how much two signals are related or how similar they are. Correlation is used to detect patterns, identify objects, and track motion.
Cross Correlation between two discrete time real signals x[n] and y[n] is given by:

$$R_{XY}[n] = \sum_{m=-\infty}^{+\infty} x[m]y[m+n]$$

As you can see from the above equations, the calculation of both convolution and cross correlation sum of two signals is similar, except for a sign difference. This means that for computational purposes, same algorithm can be used to calculate both, except for flipping of one of the signals in the former, compared with lack of flipping in the latter.

MATLAB Commands

The *conv* Command

conv(a,b) performs a convolution of vectors **a** and **b**. The result is a vector with

length = length(a) + length(b) - 1.

Imagine vector **a** as being stationary and the flipped version of **b** is slid from left to right. Note that

conv(a,b) = conv(b,a).

```
x = [0.5 0.5 0.5];          %define input signal x[n]
h = [3.0 2.0 1.0];          %unit-pulse response h[n]
y = conv(x,h);              %compute output y[n] via convolution
n = 0:(length(y)-1); %for plotting y[n]
stem(n,y); % plot y[n]
grid;
xlabel('n');
ylabel('y[n]');
title('Output of System via Convolution');
```

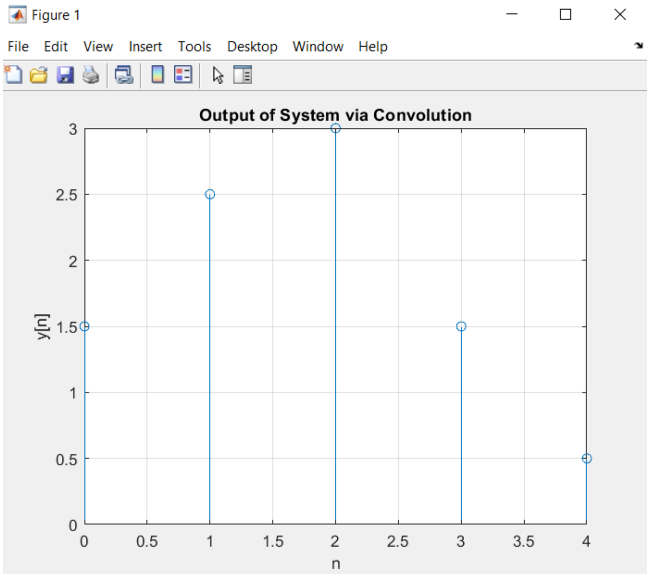


Figure 1: Convolution Result

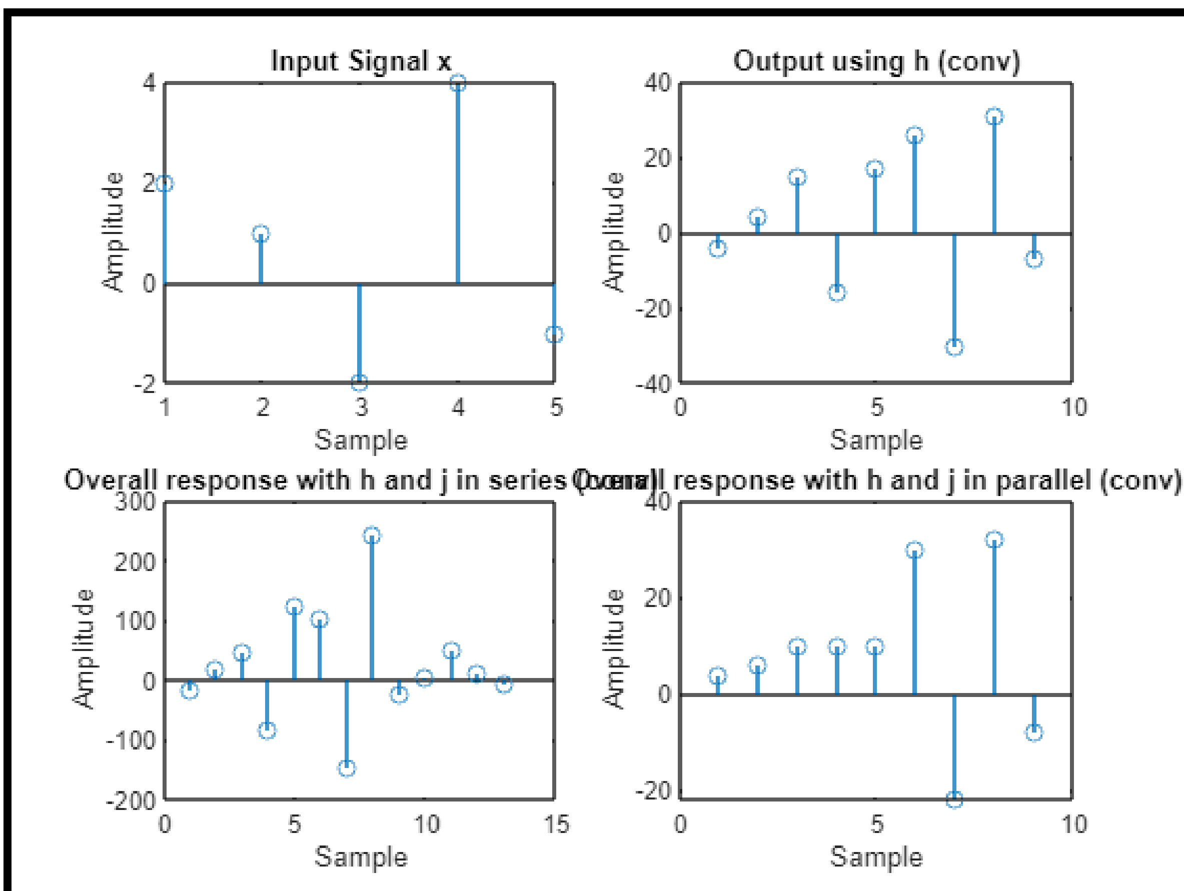
EXERCISE:

TASK 1:

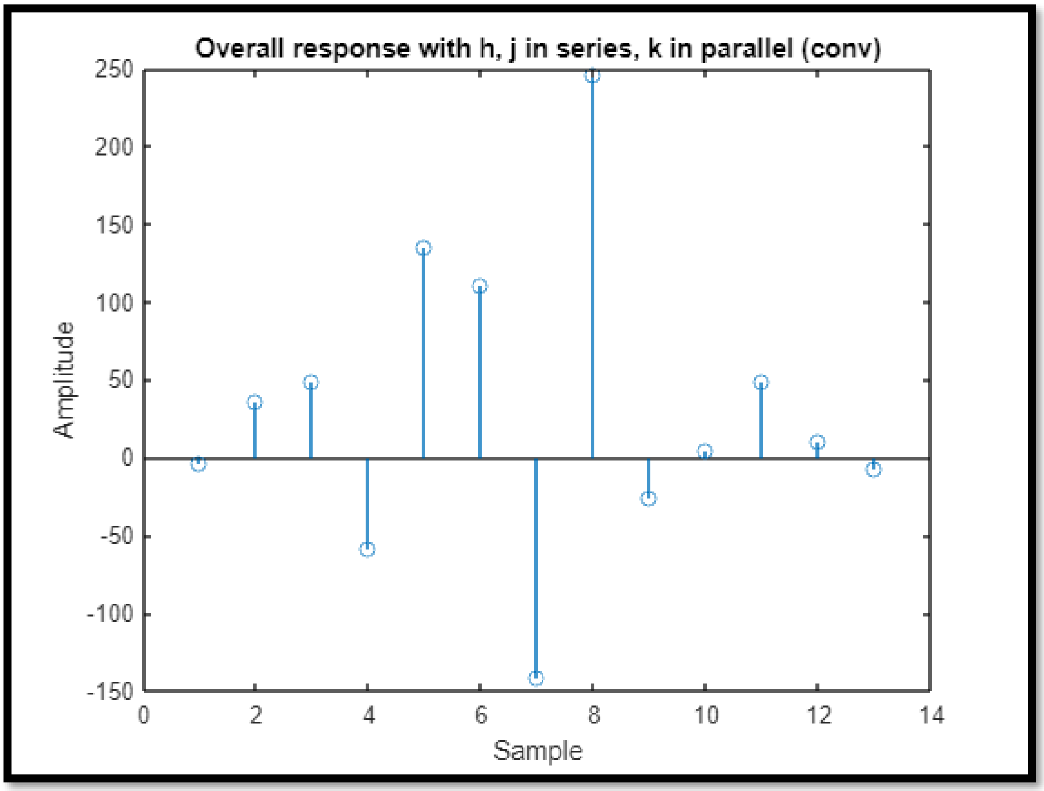
1. Let input signal x be [2, 1, –2, 4, -1] and the system h be [-2, 3, 4, –3, 7]. Find the output of the system y by
   - using the conv command
2. Now suppose we add another system j = [4, –1, 2, 3, 1] in series with the above system. Now find the overall response and output y of the above system using the conv command.
3. Again suppose now j is attached in parallel to h and the result is series with x. Plot the resultant signal.
4. Now suppose the two systems h and j are in series and a third system k = [6, 5, 4, 3, 2] has been attached with them in parallel and the result is series with x. Plot the overall signal y.

```
% Input signal
x = [2, 1, -2, 4, -1];

% System h
h = [-2, 3, 4, -3, 7];

% System j
j = [4, -1, 2, 3, 1];

% System k
k = [6, 5, 4, 3, 2];

% Convolution with h using conv command
y1 = conv(x, h);

% Overall response with h and j in series (conv)
hj = conv(h, j);
y2 = conv(x, hj);

% j in parallel with h, then series with x (conv)
hj_parallel = h + j;
y3 = conv(x, hj_parallel);

% h and j in series
hj_series = conv(h,j);

% Zero-pad the shorter vector (k) to match hj_series length
k_padded = [k, zeros(1, length(hj_series) - length(k))];

% Combine hj_series and k_padded (effectively parallel connection)
result = hj_series + k_padded;

% Series with x (conv)
y4 = conv(x, result);
```

```matlab
% Plot results separately
figure;
subplot(221);
stem(x);
title('Input Signal x');
xlabel('Sample');
ylabel('Amplitude');

subplot(222);
stem(y1);
title('Output using h (conv)');
xlabel('Sample');
ylabel('Amplitude');

subplot(223);
stem(y2);
title('Overall response with h and j in series (conv)');
xlabel('Sample');
ylabel('Amplitude');

subplot(224);
stem(y3);
title('Overall response with h and j in parallel (conv)');
xlabel('Sample');
ylabel('Amplitude');
```



```
figure;
stem(y4);
title('Overall response with h, j in series, k in parallel (conv)');
xlabel('Sample');
ylabel('Amplitude');
```



Explanation :

This code simulates a signal processing system using different sets of values (h, j, k) and performs operations like convolution and parallel connections. It convolves the input signal x with h to get y1, then combines h and j in series to get y2. It also shows the output when h and j are in parallel and then series with x (y3). It further combines h and j in series, pads k with zeros to match the length, and adds them in parallel to get a result. Finally, it convolves the result with x to get y4. The code then plots the input signal x, and the different output signals obtained from the operations for visualization.

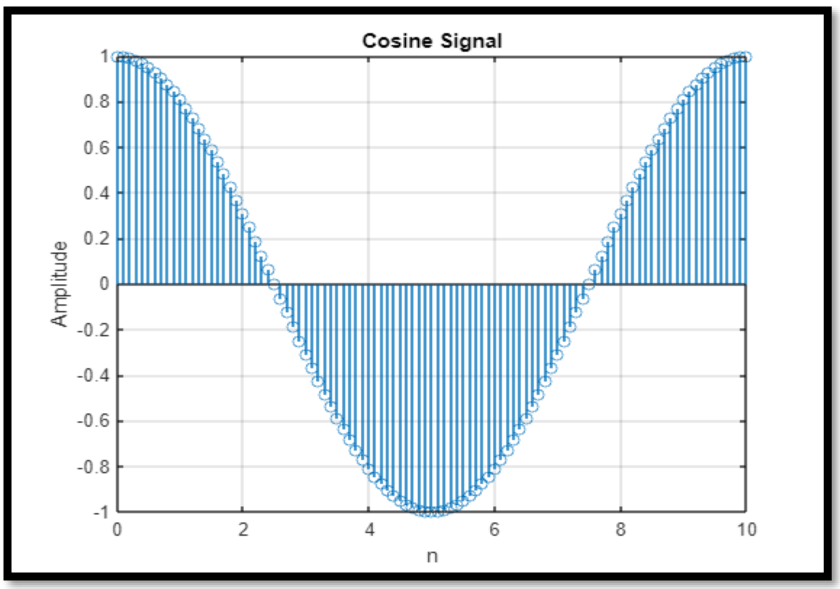
TASK 2:

Write a MATLAB code to:

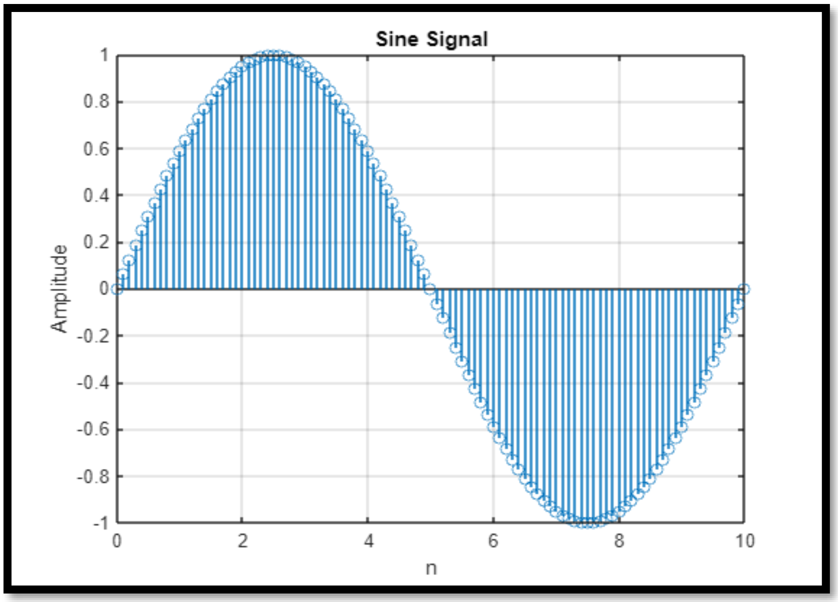
1. Generate a discrete time sinusoidal signal cos(2πf0n) with any frequency of your choice and using a predefined time axis. The time axis should be defined so that the signal exists for 10 time periods.
2. Generate another discrete time sinusoidal signal sin(2πf0n) with the same frequency and time axis.
3. Find the cross correlation of the two signals using the predefined MATLAB function.

4. Plot all of the above as discrete time signals, with proper independent axis, and label all plots

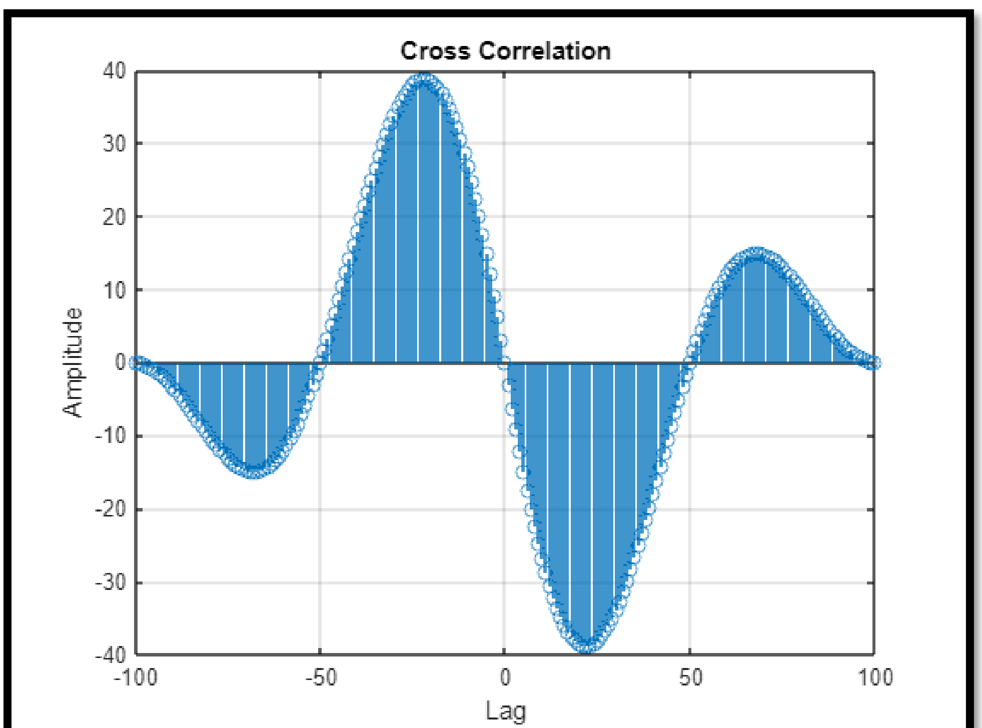
```
% Generate a discrete time sinusoidal signal cos(2πf0n) with any frequency
f0 =  0.1; % Frequency of the sinusoidal signal
n = 0:0.1:10; % Predefined time axis for 10 time periods
x1 = cos(2*pi*f0*n); % Generate the cosine signal
% Generate another discrete time sinusoidal signal sin(2πf0n) with the same frequency
and time axis
x2 = sin(2*pi*f0*n); % Generate the sine signal
% Find the cross correlation of the two signals
cross_corr = xcorr(x1, x2);

% Plot all of the signals with proper labeling
figure;
% Plot the first sinusoidal signal
stem(n, x1);
xlabel('n');
ylabel('Amplitude');
title('Cosine Signal');
grid on;
```



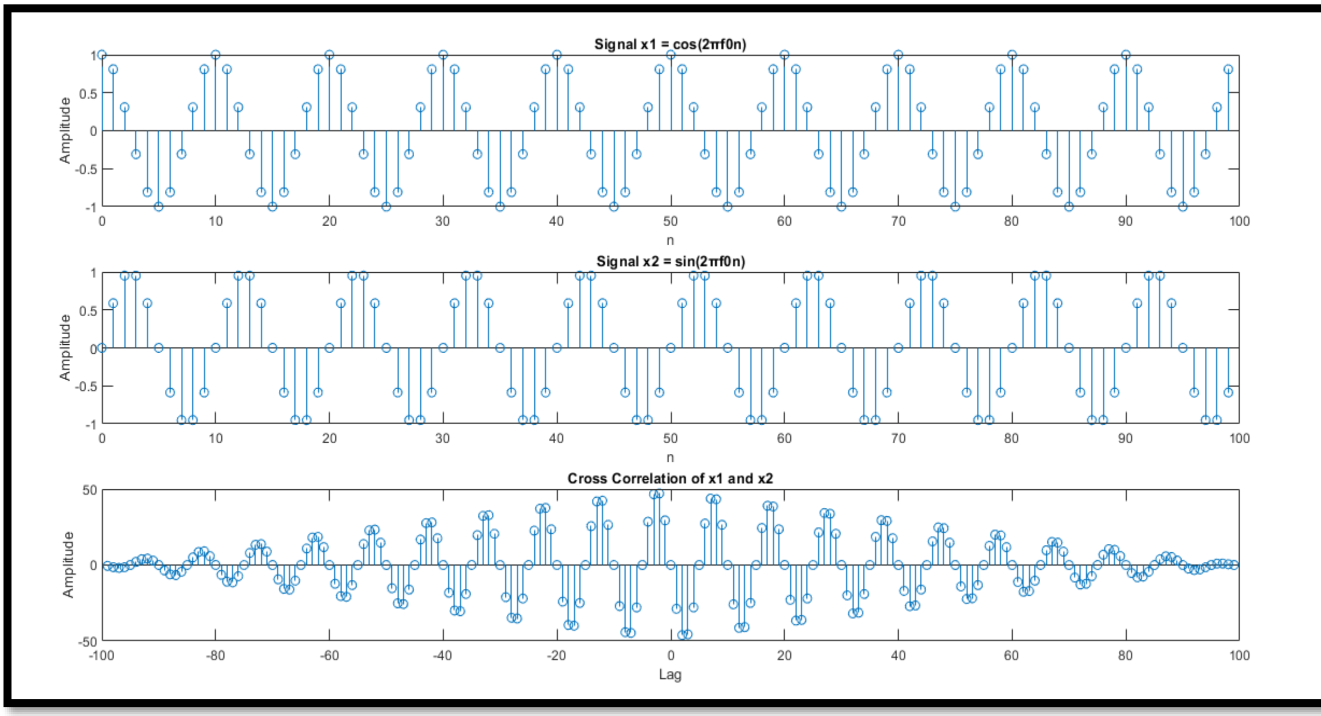

```
% Plot the second sinusoidal signal
stem(n, x2);
xlabel('n');
ylabel('Amplitude');
title('Sine Signal');
grid on;
```




```
% Plot the cross correlation of the two signals
L = length(cross_corr);
lag = -(L-1)/2:(L-1)/2;

stem(lag, cross_corr);
xlabel('Lag');
ylabel('Amplitude');
title('Cross Correlation');
grid on;
```



With 10 waveforms output:



Explanation:

This code creates two simple wave patterns, a cosine wave, and a sine wave, with the same frequency. Then it checks how similar these waves are by sliding one on top of the other and seeing how much their peaks and dips line up. The more they line up, the higher the value at that position in the "cross correlation" graph. Finally, it plots all three graphs: the original cosine wave, the original sine wave, and the "cross correlation" which shows how similar they are.

Conclusion:

In this lab, we explored the concepts of convolution and correlation in MATLAB by performing calculations on signals and visualizing the results. We first investigated how similar two sine waves were using cross-correlation. Then, we built a signal processing system that manipulated a signal using convolution and experimented with different configurations. By examining the resulting graphs, we gained insight into how these mathematical operations affect signals.

Evaluation Rubric

- **Method of Evaluation**: In-lab marking by instructors, Report submitted by students
- **Measured Learning Outcomes**:

CLO1: Develop algorithms to perform signal processing techniques on digital signals using MATLAB and DSP Kit DSK6713
CLO3: Deliver a report/lab notes/presentation/viva, effectively communicating the design and analysis of the given problem

	Excellent 10	Good 9-7	Satisfactory 6-4	Unsatisfactory 3-1	Poor 0	Marks Obtained
Tasks (CLO1)	All tasks completed correctly. Correct code with proper comments.	Most tasks completed correctly.	Some tasks completed correctly.	Most tasks incomplete or incorrect.	All tasks incomplete or incorrect.	
Output (CLO1)	Output correctly shown with all Figures/Plots displayed as required and properly labelled	Most Output/Figures/Plots displayed with proper labels	Some Output/Figures/Plots displayed with proper labels OR Most Output/Figures/Plots displayed but without proper labels	Most of the required Output/Figures/Plots not displayed	Output/Figures/Plots not displayed	
Answers (CLO1)	Meaningful answers to all questions. Answers show the understanding of the student.	Meaningful answers to most questions.	Some correct/ meaningful answers with some irrelevant ones	Answers not understandable/ not relevant to questions	Not Written any Answer	
Report (CLO3)	Report submitted with proper grammar and punctuation with proper conclusions drawn and good formatting	Report submitted with proper conclusions drawn with good formatting but some grammar mistakes OR proper grammar but not very good formatting	Some correct/ meaningful conclusions. Some parts of the document not properly formatted or some grammar mistakes	Conclusions not based on results. Bad formatting with no proper grammar/punctuation	Report not submitted	
Total						