Signal Analysis using MATLAB

1) Introduction

MATLAB is a numerical computing environment developed by MathWorks. MATLAB stands for "**MATRIX LABORATORY**", and is a powerful computing environment for numerical calculations and multidimensional visualization.

MATLAB is popular for developing engineering applications because:

a) It reduces programming to data processing abstraction. Instead of focusing on intricate programming, it allows the user to focus on the theoretical concepts.
b) Developing code in MATLAB takes less time as compared to other programming languages.
c) It has a rich collection of library functions, called toolboxes, in almost every field of engineering. Users can access the library functions to build required applications.
d) It supports multidimensional visualization that allows experimental data to be rendered graphically in a comprehensible format.
e) MATLAB allows matrix manipulations, plotting of functions and data and implementation of algorithms.

2) Getting Help in MATLAB

MATLAB provides a user built-in help facility.

A user can access help either from the command line or by clicking on the graphical "Help" menu.

On the command line, the format for obtaining help on a particular MATLAB function is to type "help" followed by the name of the function.

Example: To learn more about the plot function, type the following instruction in the MATLAB command window:

```
>> help plot
```

If the name of the function is not known beforehand, you can use the "lookfor" command followed by a keyword that identifies the function being searched, to enlist the available MATLAB functions with the specified keyword.

Example: All MATLAB functions with the keyword "Fourier" can be listed by typing the following command:

```
>> lookfor Fourier
```

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3) M-files in MATLAB

M-files are macros of MATLAB commands that are stored as ordinary text files with the extension ".m" and can be executed over and over again. An M-file can be either a function with input and output variables or a list of commands. MATLAB requires that the M-file be stored either in the working directory or in a directory that is specified in the MATLAB path list.

Example: Consider using MATLAB on a PC with a user-defined M-file stored in a directory called "\MATLAB\MFiles". Then to access that M-file, either change the working directory by typing cd\matlab\mfiles from within the MATLAB command window, or by adding the directory to the path. Permanent addition to the path is accomplished by editing the \MATLAB\matlabrc.m file, while temporary modification to the path is accomplished by typing path(path,'\matlab\mfiles') from within MATLAB.

Note: MATLAB M-files are most efficient when written in a way that utilizes matrix or vector operations. Loops and "if" statements should not be used, because they are computationally inefficient.

4) Entering Data into MATLAB

Data can be inputted in MATLAB either in an M-file or directly in the command window. Data can be entered in MATLAB as a scalar quantity, a row or column vector, and a multidimensional array. In each case, both real and complex numbers can be entered. There is no need to declare the type of a variable before assigning data to it.

Example: Variable (a) can be assigned the value (6 + j8) by typing the following command:

```
a = 6 + 8j;
```

Example: Vector (d) containing the values 1 through 9 can be entered by typing the following command:

```
d = [1 2 3 4 5 6 7 8 9];
```

Example: Vector (g) containing values 0 to 10 in increments of 2 can be entered by typing the following command:

```
g = 0:2:10;
```

Example: A 3 x 3 matrix (A) can be entered by typing the following command:

```
A = [1 2 3; 4 5 6; 7 8 9];
```

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5) Control Statements

MATLAB supports several loop statement (for, while, switch, etc.) as well as the if-else statement. Functionally, these statements are similar to their counterparts in C but the syntax is slightly different.

A) Consider the following set of instructions in C:

```
int x[2][2] = {{2, 5},{4, 6}};
int y[2] [2] = {{1, 5},{6, -2}};
int z[2] [2];

for (m = 1; m <= 2; m++)
{
        for (n = 1; n<= 2; n++)
        {
                z[m] [n] = x[m] [n] + y[m] [n];
        }
}
```

a) Write down the equivalent MATLAB code for the above instructions using "for" loop and print the output.

b) Write down the equivalent MATLAB code for the above instructions using "while" loop and print the output.

c) Write down a MATLAB code without using loops by performing a direct sum of matrices X and Y and print the output.

B) Consider the following set of instructions in C:

```
int a = 15;
int x;
if (a > 0)
{
        x = 5;
}
else
{
        x = 100;
}
```

a) Write down the equivalent MATLAB code and print the output.

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6) Mathematical Operations using MATLAB

A) Consider the following function:

$$f[k] = e^{0.05k} \qquad for\ 1 \le k \le 30$$

Note: K can only be an integer value

Write down MATLAB code and print the result for the following operations:

a) Calculate the maximum value in (f)
b) Calculate the minimum value in (f)
c) Sum all the entries in (f)
d) Find the product of all the entries in (f)
e) Find the mean of all the entries in (f)
f) Find the variance of all the entries in (f)
g) Find the dimension of (f)
h) Find the length of (f)

B) Consider two matrices X and Y as given below:

$$X = \begin{bmatrix} 2 & 5 \\ 4 & 6 \end{bmatrix}$$

$$Y = \begin{bmatrix} 1 & 5 \\ 6 & -2 \end{bmatrix}$$

Write down MATLAB code and print the result for the following operations:

(a) Find the sum of X and Y
(b) Find the difference between X and Y
(c) Find the product between X and Y
(d) Calculate the transpose of X
(e) Calculate the inverse of X
(f) Perform an element by element multiplication between X and Y
(g) Perform an element by element division between X and Y
(h) Square each element of X.
(i) Raise each element in X to the power by its corresponding element in Y.

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C) Consider the two row vectors:

$$f = [1, 4, -2, (4 - 2i)]$$

$$g = [-3, (5 + 7i), 6, 2]$$

Write down MATLAB code to perform the following mathematical operations on vectors (f) and (g) and print the output.

a) Addition $r_1 = f + g$

b) Dot product $r_2 = f \cdot g$

c) Mean $r_3 = \frac{1}{4}\sum_{k=1}^{4} f(k)$

d) Average energy $r_4 = \frac{1}{4}\sum_{k=1}^{4} |f(k)|^2$

7) Plotting Figures in MATLAB

A) Generate and plot the following Continuous Time (CT) signals, using MATLAB. **Do not use any loops in your code**. The horizontal axis should extend only for the range over which the signal is defined. Label your figures with the appropriate title, x-axis units, and y-axis units.

$$x(t) = 5\sin(2\pi t)\cos(\pi t - 8) \qquad for -5 \le t \le 5$$

$$x(t) = 5e^{-0.2t}\sin(2\pi t) \qquad for -10 \le t \le 10$$

B) Generate and plot the following Discrete Time (DT) signals, using MATLAB. **Do not use any loops in your code**. The horizontal axis should extend only for the range over which the signal is defined. Label your figure with the appropriate title, x-axis units, and y-axis units. (**Note: K can only be an integer value**)

$$f[k] = -0.92\sin\left(0.1\pi k - \frac{3\pi}{4}\right) \qquad for -10 \le k \le 20$$

$$f[k] = (-0.93)^k e^{\frac{j\pi k}{\sqrt{350}}} \qquad for\ 0 \le k \le 50$$

Use the command "stem" to plot the DT functions.

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8) Solving Differential Equations using MATLAB

A) Compute the graphical solution for the following differential equation using MATLAB and the "ode23" function found in MATLAB. Label your figure with the appropriate title, x-axis units, and y-axis units.

$$\frac{dy}{dt} + 4y(t) = 2\cos(2t)$$

The initial condition y (0) = 2 and the time interval is 0 ≤ t ≤ 15 seconds. Compare your answer with analytical solution (i.e. solution performed by hand).

9) Fourier Series using MATLAB

A) Write MATLAB code to generate and plot a square wave g (t) having the following characteristics:

Frequency = 1 Hz
Amplitude = 5 Volts
DC-bias = -3 Volts
Time Interval = -3 ≤ t ≤ 3 Seconds

Label your figure with the appropriate title, x-axis units, and y-axis units.

Now, write MATLAB code to approximate the square wave as a Fourier series and plot it using m = 1, 5, 10, and 20.

$$S(t) = \frac{a_0}{2} + \sum_{m=1}^{\infty} [a_m \cos(m2\pi ft) + b_k \sin(m2\pi ft)]$$

The Fourier coefficients are given by:

$$a_0 = \frac{2}{T}\int_0^T g(t)\,dt$$

$$a_m = \frac{2}{T}\int_0^T g(t)\cos(m2\pi ft)dt$$

$$b_m = \frac{2}{T}\int_0^T g(t)\sin(m2\pi ft)dt$$

Label your figure with the appropriate title, x-axis units, and y-axis units.

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B) Write MATLAB code to generate and plot the following function in the time interval -L ≤ t ≤ L seconds, where L = 5.

$$g(t) = -t^4 + 17t^3 - t^2 - 47$$

Label your figure with the appropriate title, x-axis units, and y-axis units.

Now, write MATLAB code to approximate the above function as a Fourier series and plot it using m = 1, 5, 10, and 20.

$$S(t) = \frac{a_0}{2} + \sum_{m=1}^{\infty}\left[a_m\cos\left(\frac{m\pi t}{L}\right) + b_k\sin\left(\frac{m\pi t}{L}\right)\right]$$

The Fourier coefficients are given by:

$$a_0 = \frac{1}{L}\int_{-L}^{L} g(t)\,dt$$

$$a_m = \frac{1}{L}\int_{-L}^{L} g(t)\cos\left(\frac{m\pi t}{L}\right)dt$$

$$b_m = \frac{1}{L}\int_{-L}^{L} g(t)\sin\left(\frac{m\pi t}{L}\right)dt$$

Label your figure with the appropriate title, x-axis units, and y-axis units.

10) Fourier Transform and Inverse Fourier Transform using MATLAB

A) Write MATLAB code to generate and plot a Cosine wave g (t) having the following characteristics:

Frequency = 5 Hz
Amplitude = 19 Volts
Time Interval = 0 ≤ t ≤ 3 Seconds

Label your figure with the appropriate title, x-axis units, and y-axis units.

a) Perform a Fourier Transform on the above signal using the command (FFT) and plot the result in the frequency domain.

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Label your figure with the appropriate title, x-axis units, and y-axis units.

b) Write MATLAB code to perform an inverse Fourier Transform of the signal obtained in part (a) using the command (IFFT) and plot the result in the time domain.

Label your figure with the appropriate title, x-axis units, and y-axis units.

B) Write MATLAB code to generate and plot a Square wave g (t) having the following characteristics:

Frequency = 5 Hz
Amplitude = 19 Volts
Time Interval = $0 \le t \le 3$ Seconds

Label your figure with the appropriate title, x-axis units, and y-axis units.

a) Perform a Fourier Transform on the above signal using the command (FFT) and plot the result in the frequency domain.

Label your figure with the appropriate title, x-axis units, and y-axis units.

b) Write MATLAB code to perform an inverse Fourier Transform of the signal obtained in part (a) using the command (IFFT) and plot the result in the time domain.

Label your figure with the appropriate title, x-axis units, and y-axis units.