2006-1696: USING MATLAB TO SOLVE ENGINEERING PROBLEMS FOR UNDERGRADUATES

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ABSTRACT

The purpose of this paper is to present the experience to teach sophomore and senior students on the application of MATLAB in numerical analysis of engineering problems. MATLAB is a professional engineering and scientific software package developed and marketed by MathWorks, Inc. Many engineering schools now require and /or use MATLAB as one of their primary computing tools. The author taught MATLAB in course MEEN 1320 (Computer Based Graphics/Design II) in Texas A&M University –Kingsville in Fall 2005. The main objective of the course MEEN 1320 is to help sophomore students to solve basic engineering numerical problems and generate charts and graphs using MATLAB. This course is designed to give students opportunities for hands-on practice through the lab work and project studies. The author also instructed senior students to use MATLAB for experimental data analysis in course MEEN 4131 (Mechanical Engineering Laboratory). In this paper, these successful teaching experiences are summarized and some additional suggestion is also addressed.

Introduction

MATLAB has been largely used in many engineering schools, because it provides a friendly interactive system that incorporates numeric computation, symbolic computation, and scientific visualization [1-2, 4-10]. Authors taught a sophomore course to help the students apply the MALAB tool for engineering problem solving in mechanical design and analysis [3]. Also in a senior course: mechanical engineering laboratory, the students employed this software for experimental data analysis. First, this paper organizes the useful teaching experience, and shows how the classes are designed to improve the student problem-solving ability by using MATLAB. Several student's semester projects and analysis results are presented in the second part. For a senior course, the students applied MATLAB tool for experiment data analysis. The examples and benefits by using MATLAB for data analysis are concluded in the third part. Finally, the summaries of teaching experience and suggestions are also given in the conclusions.

Contents

1. MATLAB tool for an undergraduate course to solve engineering problem

MATLAB is a very powerful tool for engineering problem solving. It has interactive computation and visualization interface. Therefore it is comparatively easy for undergraduates to study. MATLAB is introduced in a sophomore course: Computer-aided design and analysis in department of mechanical and industrial engineering at Texas A&M University-Kingsville (TAMUK) in fall 2005. The purpose of this course to help student know computation and visualization capabilities of MATLAB, understand numerical methodology for popular engineering problem solving, and learn the problem-solving process through the example studies, practical lab work, and semester projects. After finishing this course, students should be able to independently use MATLAB to solve engineering problems encountered in their future study and work.

This course includes the introduction of MATLAB environment, computation and graphics functions, basic knowledge of linear algebra and matrices, numerical techniques of popular engineering problems, and special topics in mechanical design and control. This course has lecture and laboratory session, and mechanical department of TAMUK provides students enough time and space for hand-on practice. In the lecture, the instructor follows the class syllabus and delivers the MATLAB function, method and application of each topic of numerical analysis. In the weekly Lab, the students are required to practice the MATLAB functions covered in the lectures of the same week, and program short MATLAB codes to solve the typical problems in each numerical analysis topic. In the Lab, instructor and teaching assistants check and help each individual student in their code programming and function, stay with them to go though the codes and solve their problems in the assignment and lab work, enhance their understanding of each specific topic. Weekly assignment and lab work are designed to follow the lecture, and help students practice numerical skills and apply MATLAB functions for each special application. In the end of the semester, students are involved in team project with different topics: statistically analyzing experimental data, practicing plotting skills, solving linear equations, generating fitting curve and interpolation from collected test data, conducting numerical integration and differentiation, and solving of ordinary differentiation equation. Team projects are required to make group presentations in front of the class, and questions can be asked to any person in this group. Also project reports are needed to explain advantage and limitation of their engineering analysis in different topics.

2. Presentation of students projects by using MATLAB tool

Students are excited to apply MATLAB tool to solve some engineering problems through group projects. Each group works on different topic and makes presentation, so the students have the chance to understand other groups work. In the following, several group projects are briefly introduced and their analysis results are also presented.

Example 1: Compute the new velocity and acceleration of the aircraft after a change in power level. During a test flight, the test pilot has set the engine power at 50,000 Newtons, which causes the 20,000 Kg aircraft to attend a cruise speed of 250 m/s. The engine throttles are then set to a power level at 80,000 Newtons, and then the aircraft begins to accelerate. The differential equation that determines the acceleration of the aircraft is

$$\frac{dv}{dt} = a(v,t) = \frac{T}{m} - 0.00005v^2$$

T = thrust level in Newtons (80,000 Newtons)
m = mass in Kg (20,000 Kg)
Write a MATLAB program to determine the new cruise speed after the change in power level of the engines by plotting the solution to the differential equation.
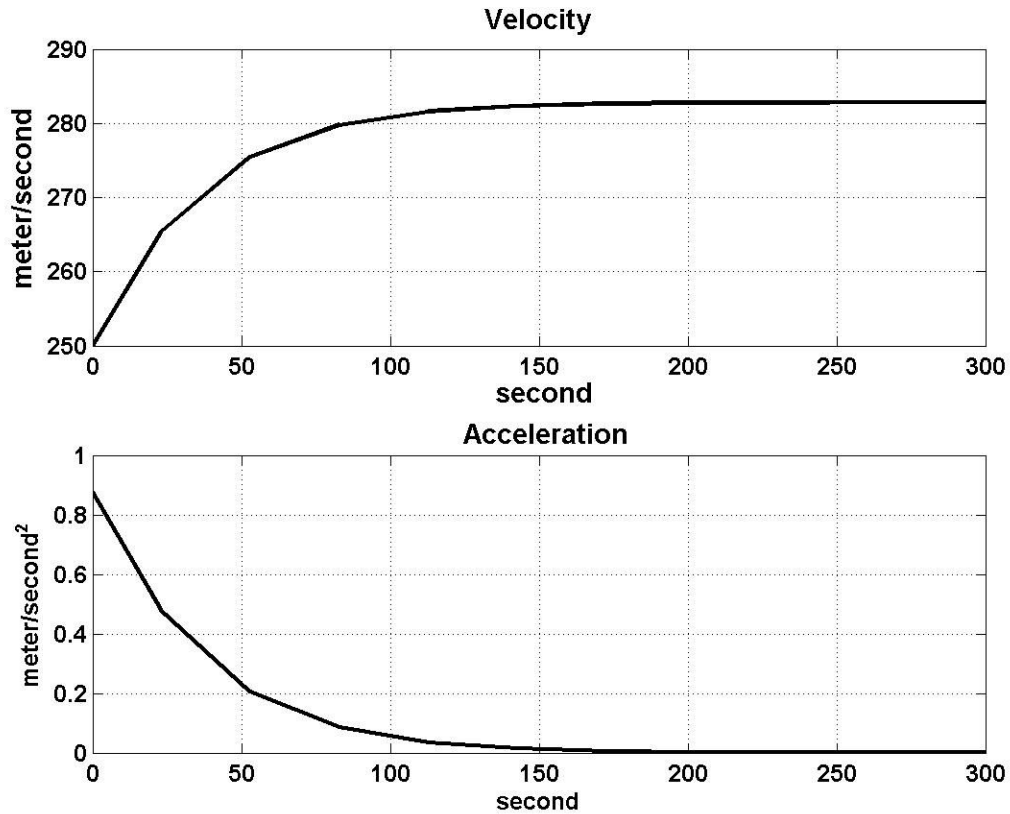
Figure 1. Velocity and Acceleration Solution to The Differential Equation

Example 2: 3-D plots of functions with two variables. The graphics tool is very helpful for the students to understand the functions and collected experimental data such as sensor measured temperature though different times and duplicate tests. For example, generate the 2-D mesh within the range x = [-3, 3] and y = [-2, 2]. Develop surface and contour plots for the function f(x,y) = 4/(2+x^2+y^2).
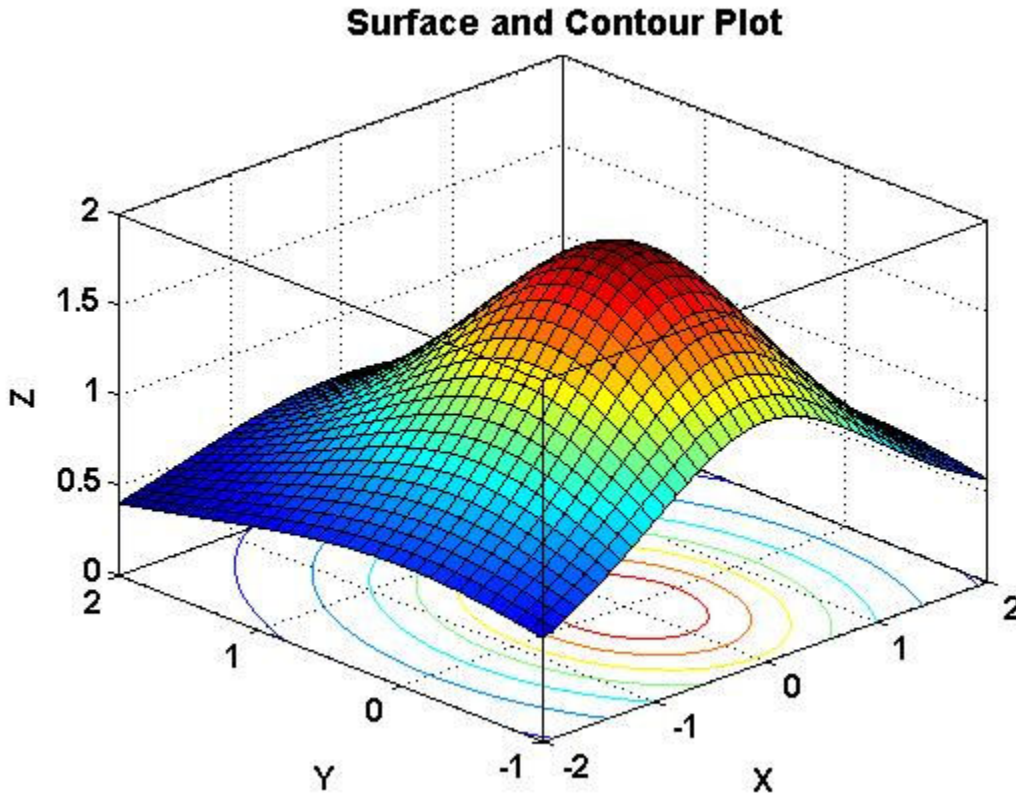
Figure 2. Surface and Contour Plots of a Two-Variable Function

Example 3: Statistical analysis of the output signal of a dynamic system. The statistics analysis of a output signal is helpful to characterize the dynamic system. Although this statistics analysis work can be done with Excel Worksheet, MATLAB will make the computation much easier with built-in MATLAB functions and also provide better graphics features. Write a MATLAB program to read and plot an ASCII data file signal.dat that contains the ouput of a dynamic signal over a period time. The program should also computer the following information: mean, standard deviation, variance, average power, average magnitude, and number of a zero crossings.
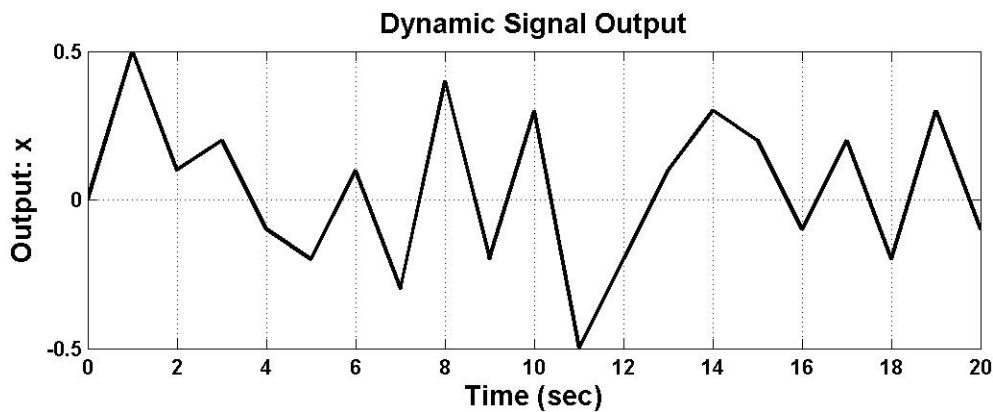

Figure 3. Output Signal of a Dynamic System

Statistics of a dynamic signal: x
Mean: 0.0381
Standard deviation: 0.258
Variance:0.0665
Average Power:0.0648
Average Manitude:0.219
Zero Crossings:13.0

Example 4: Least-square linear regression and curve fitting is very useful for analysis of discrete test data, and help to find a normalized trend to represent the discrete data. Develop MATLAB program to do the linear and polynomial regression analysis. And generate your plots of least-square linear regression, and second-degree, third-degree and fourth–degree polynomial fit in a 2*2 graphic window.
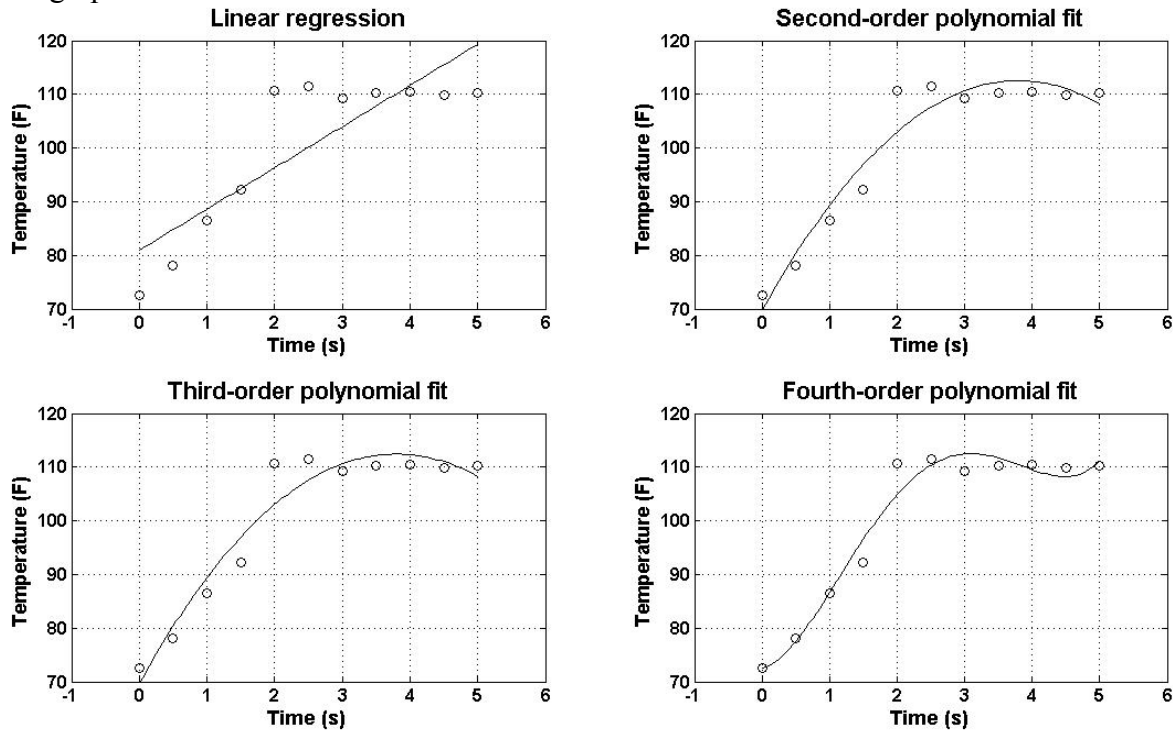

Figure 4. Least-Square Linear Regression and Curve Fitting

Example 5: This example is design to help students to understand the three popular methods of numerical differentiation. Create a data file contains time and altitudes for a sounding rocket that is performing high-altitude atmospheric research on the ionosphere. Using a backward difference, a forward difference and a central difference, compute the velocities of the altitude and plot these velocity data on the same plot.
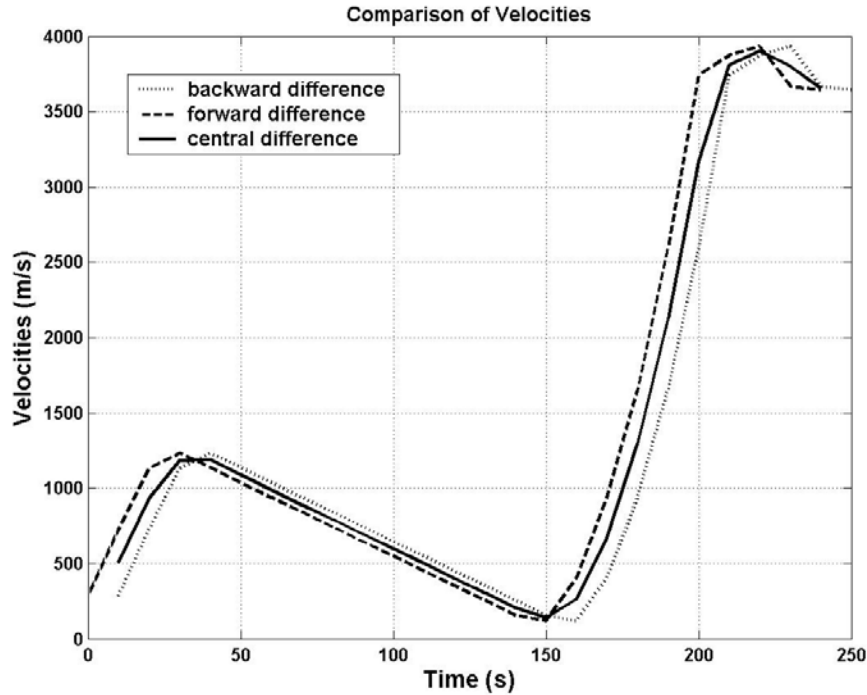
Figure 5. Velocities Analysis with Different Approaches

Through this course work, the students learned to user MATLAB tool for general engineering problem analysis. MATLAB has a comprehensive tutorial package and help documents. For each MATLAB function, the usage and example are included to explain how to use it. For example, Differences and approximate derivatives function: diff
Description: Y = diff(X) calculates differences between adjacent elements of X. If X is a vector, then diff(X) returns a vector, one element shorter than X, of differences between adjacent elements: [X(2)-X(1) X(3)-X(2) ... X(n)-X(n-1)]

Examples: The quantity diff(y)./diff(x) is an approximate derivative.
x = [1 2 3 4 5];
y = diff(x)
y =
   1   1   1   1

Students can learn each MATLAB function through the built-in help document and then build a solid basis for self-learning more advanced features of MATLAB.

3. MATLAB application in a senior laboratory course

MATLAB has very powerful and efficient features, so it can be easily applied in the other course study. For a senior course mechanical engineering laboratory, the students are encouraged to apply MATLAB tool for their lab data analysis. For example, on the experiment of heat convection investigation on the horizontal and vertical plates under free and forced loading,

students are required to calculate the convection parameters for different cases. Simple MATLAB codes are developed to do the complicate computation based on the correlations under different boundary conditions. Also this code provides an efficient way for experimental data analysis by avoiding duplicate work. Students feel much easier and quicker to finish their lab report.

Some experimental measurements can be easily checked by applying numerical analysis with MATLAB tool. For example, heat conduction experiments are conducted on the beam and plate under different boundary conditions. Temperatures are measured at grid points based on a regular geometry mesh. These measurements are required to compare with finite-difference numerical analysis. For the plate in the following figure, the entire inner surface is at the temperature of 300°C, and the entire outer surface is exposed to the convection environment at 100°C. Using MATLAB to calculate the temperatures for the nodes indicated and compare with measurements.

T_∞=100°C
h =30 W/ m²·°C

k = 10
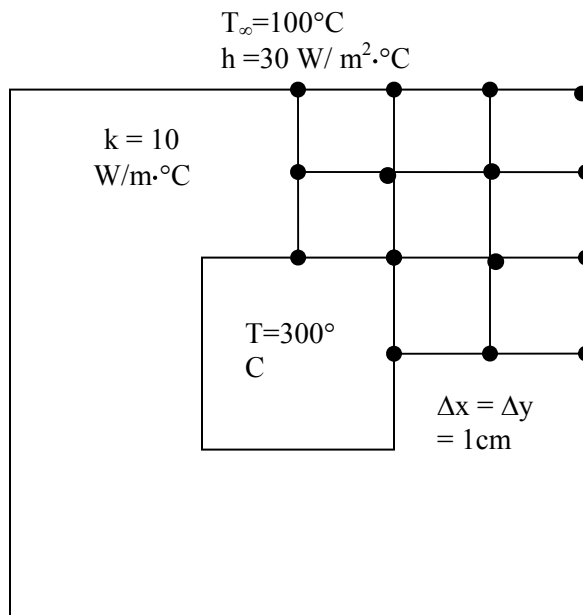W/m·°C

T=300°C

$\Delta x = \Delta y$
= 1cm

Figure 6. Numerical Analysis for Steady Conduction and Convection

Senior students are taught to generate a series linear equation based on the geometry mesh, governing equations and boundary conditions. MATLAB codes are generated to solve a series linear equation to obtain the temperature at different gird points. By doing this numerical analysis, students understand better of heat conduction principles and also show them a good way to check their test data.

Conclusions

During the sophomore year, the mechanical and civil engineering students are required to complete a course in computer systems, programming and engineering analysis. The selected software package for this course was MATLAB in TAMUK. It was found that MATLAB

packages could be learned quickly to tackle meaningful problems in undergraduate engineering within one semester. This package has its strengths and plays an important role in undergraduate engineering instruction. MATLAB can be applied to a variety of other engineering course for the problem solving for the future study. The students seemed to really enjoy these methods and were much more comfortable with the graphical results.

For the future teaching, projects and lab work designed toward improving problem solving abilities will be very helpful. Also it seems that student performance could be improved in programming courses through unlimited access to computer and software resources.

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