2006-774: INTEGRATING MATLAB GRAPHICAL USER INTERFACE IN STATICS COURSE

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Abstract

In this paper a Graphical User Interface (GUI) platform to supplement teaching and learning in Engineering Mechanics–Statics course is developed. The package encompasses several interrelated modules of the concepts introduced in a typical Statics class. The GUI provides a user-friendly interactive approach to solving problems and displaying the results both numerically and graphically in two- and three-dimensional spaces. In addition to visualization, GUI approach allows users to modify input data and observe the effect on the solution, thus providing students with additional insight to predict the behavior of structures under different loading scenarios.

Introduction

Statics is a branch of mechanics which deals with the study of forces on objects at rest. It is a core course and the foundation for many subsequent courses in mechanical and civil engineering curriculum such as strength of materials, dynamics, fluid mechanics, machine design and structural design courses. This group of courses forms the basis of engineering design and practice. In many engineering courses, students have difficulty visualizing some of the theoretical concepts presented. especially in the real-world 3-dimensional problems. Due to a variety of reasons, students usually have difficulty in solving this class of problems.

Another observation from the numerous times I taught this course is that students tend to be mainly focused on arriving at the final numerical solution paying no or little attention to think on the influence and the significance of each force on the structure. For example, the influence of the angle of application of the force on the magnitude of the moment, and how it varies to reach a maximum when the angle sine is at its largest value.

A third observation is the weakness in algebraic manipulation abilities. After setting up the equilibrium equations, many students spend a great deal of time working on the algebraic manipulation rather trying to solve them. Their objective is usually to match the right answer. They often leave them unsolved or use the back substitution of the answers at the end of the text. Naturally, this will let them loose focus on understanding the subject matter and defies the purpose of learning something new. Although it is essential to get the right answer, however, we should usually expect more than that. Integrating the GUIs with the course couples both graphical and analytical approaches to solving problems and adds a variety of ways to reach students of different learning styles and analytical abilities.

In practice, the loading may change in magnitude and direction due to some functional or operational requirements, and unexpected loading condition. Therefore, students should be able to answer the “what if?” question, which will broaden their horizons and instill an inquisitive mind, stimulate independent way of thinking, encourage exploration of different ideas/solutions, and develop perseverance to overcome obstacles. Thus, there is a need for an easy-to-use analytical and graphical platform that enhances students' comprehension of some abstract concepts by presenting the material in an appealing fashion.

GUI provides the user with intuitive windows-like tools such as pushbuttons, pull-down menus, sliders, and editable textboxes as shown in the subsequent sections. When pushbutton is clicked, the GUI invokes the action described on the label of that button in conjunction with the textbox input, slider input, pull-down menu, or toggle button requirements. One of the best advantages of the using GUI verses traditional programming is that in GUI it is not necessary to be knowledgeable in programming. Eliminating this requirement forces students to focus on the subject matter, rather than on debugging and editing programs or learning how to program. The application can also be compiled into a window-based executable format or integrated into JAVA applets [1].

MATLAB is a widely easy-to-use technical computing language that integrates computation, visualization, and programming. More than 800 MatLab-based books are available for educators, students, and professionals, which is a clear evidence of the popularity of this language in academia and industry. Many textbooks have a companion CD and or MATLAB based exercises. The graphics component facilitates displaying and animating vectors and matrices in two-dimensional and three-dimensional graphs. It has a built in graphical user interface tool that can be customized and integrated in many courses such as signal processing [2,3], control systems [4,5], machine design [6], electromagnetic [7], and thermodynamics [8].

Graphical user interface desirable features

One of the main advantages of adopting GUI over the traditional script language is the elimination of the requirement of the programming language. However, there are many other desirable features in a successful GUI.

Firstly, GUIs must be simple, intuitive and self explanatory. The interface should be based on familiar terms, graphics and concepts rather than programming jargon. Another desirable feature is the resilience and robustness to user input error; this can be accomplished using error dialogue boxes, and warning messages [9]. Error dialogue boxes must suspend the program until corrective actions are taken, for instance, in case entering a non-numeric character in the input vector, the GUI should prompt the user that the input must be numeric In addition, the recovery mechanism might include options like delete undo or use of some help file.

A third feature is user guidance and help [9], which can be achieved by providing theoretical background of all the GUI tasks, step-by-step illustrative examples showing how to input the variables and the expected outcomes once the task is executed.

A fourth feature is diversity [9], the GUI should account for the needs of different users especially those with some physical or writing disabilities. That can be achieved by minimizing required typing of the GUI inputs, using numerical input pads, pull-down menus. Finally, instructional

GUIs are not supposed to replace the traditional pencil-paper approach in solving problems; nor it is supposed to replace the textbook; rather it must supplement them.

Description and Methodology

The main thrust of this project is to provide students with an additional tool to understand and visualize mathematically complex concepts covered in a typical engineering mechanics-Statics course, which will enhance their learning and understanding of this subject. This tool will also be available for all subsequent courses that need Statics background. Inadequate knowledge of Statics, negatively influence the learning and teaching of these subjects as considerable time must be devoted to review the Statics part. Courses like Strength of Materials, Machine Design, and structural design are examples of subjects that depend primarily in excelling Statics.

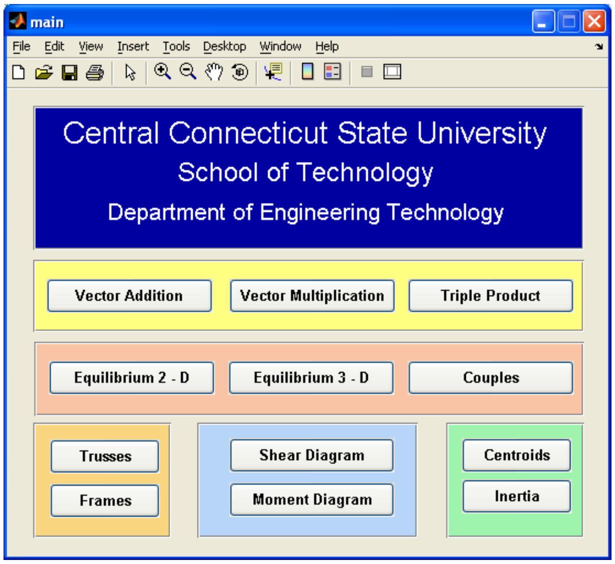
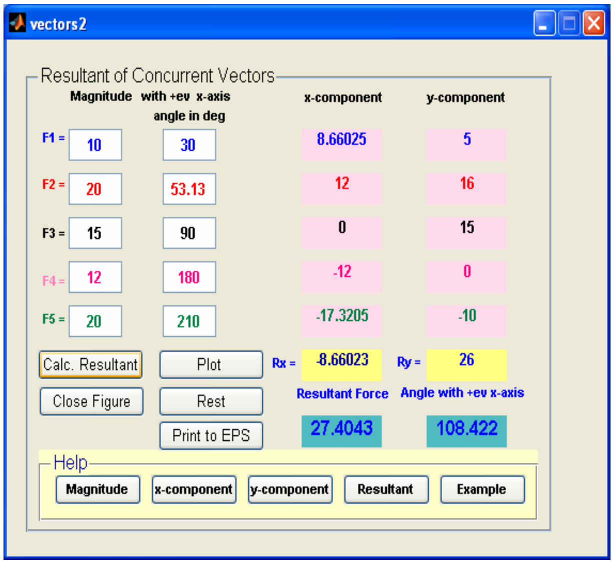


Figure 1: Main Module



	Magnitude	with +ev x-axis angle in deg	x-component	y-component
F1 =	10	30	8.66025	5
F2 =	20	53.13	12	16
F3 =	15	90	0	15
F4 =	12	180	-12	0
F5 =	20	210	-17.3205	-10

Rx = -8.66023 Ry = 26

Resultant Force	Angle with +ev x-axis
27.4043	108.422

Figure 2: Vector addition GUI

The package consists of several interrelated modules arranged in the same order of the most commonly used engineering mechanics-Statics textbook as shown in Figure 1. Students can navigate through the whole package using the appropriate button on this GUI.

Vector addition module

The first module in the package is the vector algebra module which divided into three sub-modules as shown in Figure 1. The first part of this module covers the basic vector addition operations using both graphical tip-to-tail method and analytical component approaches as shown in Figure 2. The default values of the editable textboxes are all set to zero. The user enters each vector magnitude and its angle with the positive x-axis, as shown below. The text color in each box matches the line color in the graphical approach.

When the user clicks the "Calc. Resultant" button, the GUI decomposes each vector into its components, and then calculates and displays the sum of the x- and y-components. After finding the components, the GUI sums them to find the components of the resultant vector R, the result can be expressed in polar form using the Pythagorean Theorem as illustrated. The user can change the magnitude and/or the direction of any vector and the new resultant are updated accordingly simply by invoke the "Calc. Resultant" button.

The plot button invokes the graphical tip-to-tail method that is based on parallelogram rule which states that the sum of two concurrent vectors is equal in magnitude and in direction to the diagonal of the parallelogram formed by the two vectors being added.

In the case of two vectors the paper-pencil procedure involves drawing each vector to scale with the proper orientation. The length of the diagonal is the vector sum of the two original vectors. The process can be successively applied to adding three or more vectors. The process is fairly accurate in case of two vectors, but it is time consuming and imprecise in case of multiple vectors case.

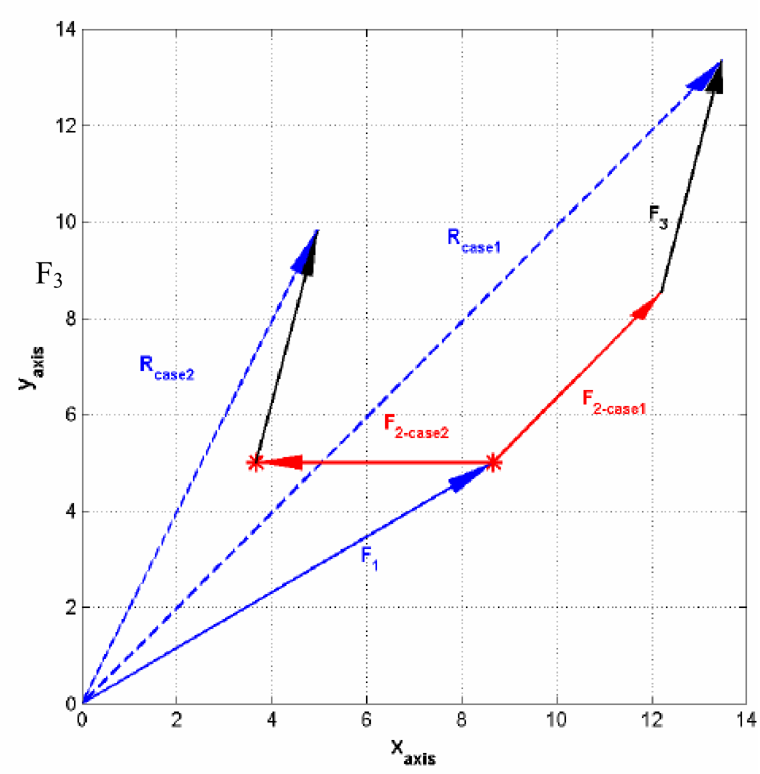


Figure 3: Vector addition GUI output

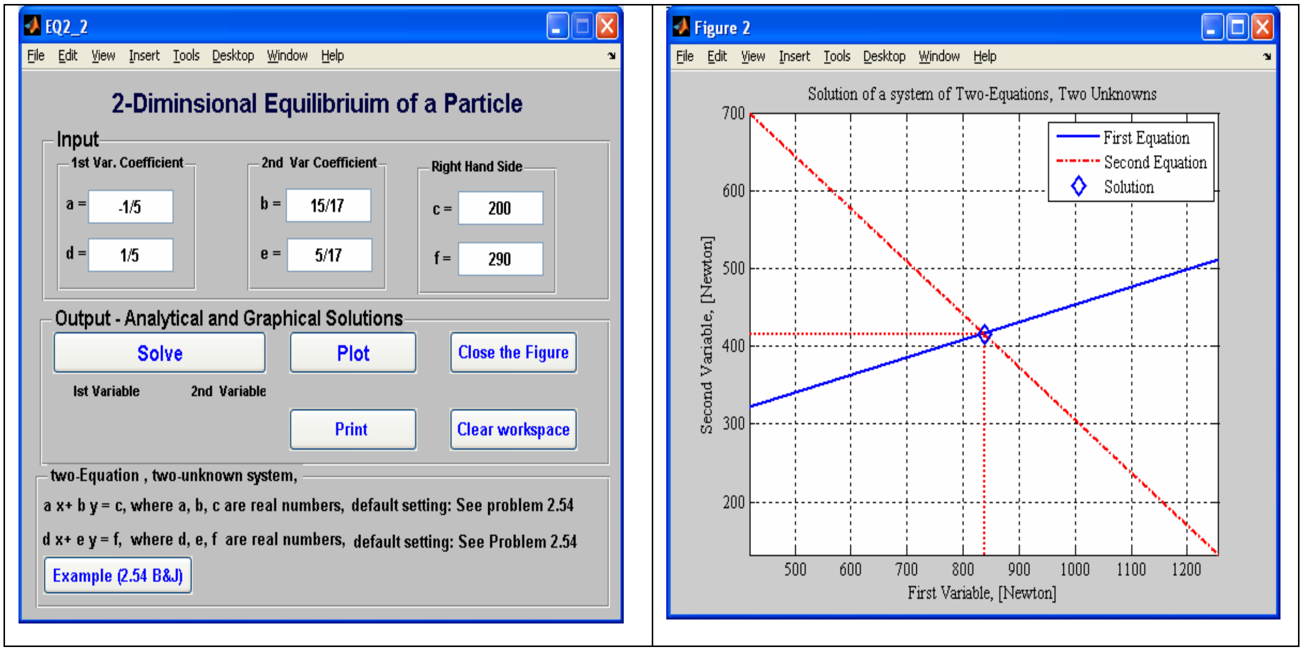
The GUI employs the same principles, however, in a more efficient and accurate fashion. By representing forces as lines of different lengths and orientations on the screen, students are forced to think of them as physical objects with real magnitude and direction, not just as numerical abstractions.

Users can change the magnitude and/or direction of any vector and the see how this change influences the resultant magnitude and direction as shown in Figure 3. To make tracking the changes easier, each vector color matches the text color in the input box as shown in Figure 2 This is a very important feature that helps in instilling an inquisitive mentality in engineering students early in their scholastic lives. It helps them to answer the "what if" question, which is very common in any engineering design process and is an essential skill for engineers to develop. If desired, the user has the option to start a new figure.

The file can be exported to encapsulated postscript colored format to be used as a homework attachment or other purposes. Help files provide the theoretical background behind the concept of vector addition, as well as a step-by-step worked example illustrating how to input variables and the expected output. In case an invalid entry, like a non-numerical value in the editable textbox, the GUI suspends the program and prompts the user to take the proper corrective action.

Equilibrium of a Particle

This module provides numerical and graphical solutions for 2- and 3- dimensional equilibrium of a particle. Before using this module, the user has to formulate the problem and obtain the necessary equations; hence, the pencil-paper approach is preserved. The user can change any parameter and observe the changes both numerically and graphically as shown in Figure 4. Due to the inherited difficulties in dealing forces in space, the 2-dimensional module is extended to cover the 3-dimensional equilibrium problems as shown in Figure 5. As a further enhancement of the 3-dimensional module, additional tool will be incorporated to provide force decomposition in space, determining the moments of the force system about a given point. The solutions will be displayed both numerically and graphically.



2-Diminsional Equilibriuim of a Particle

Input

1st Var. Coefficient: a = -1/5, d = 1/5

2nd Var Coefficient: b = 15/17, e = 5/17

Right Hand Side: c = 200, f = 290

Output - Analytical and Graphical Solutions

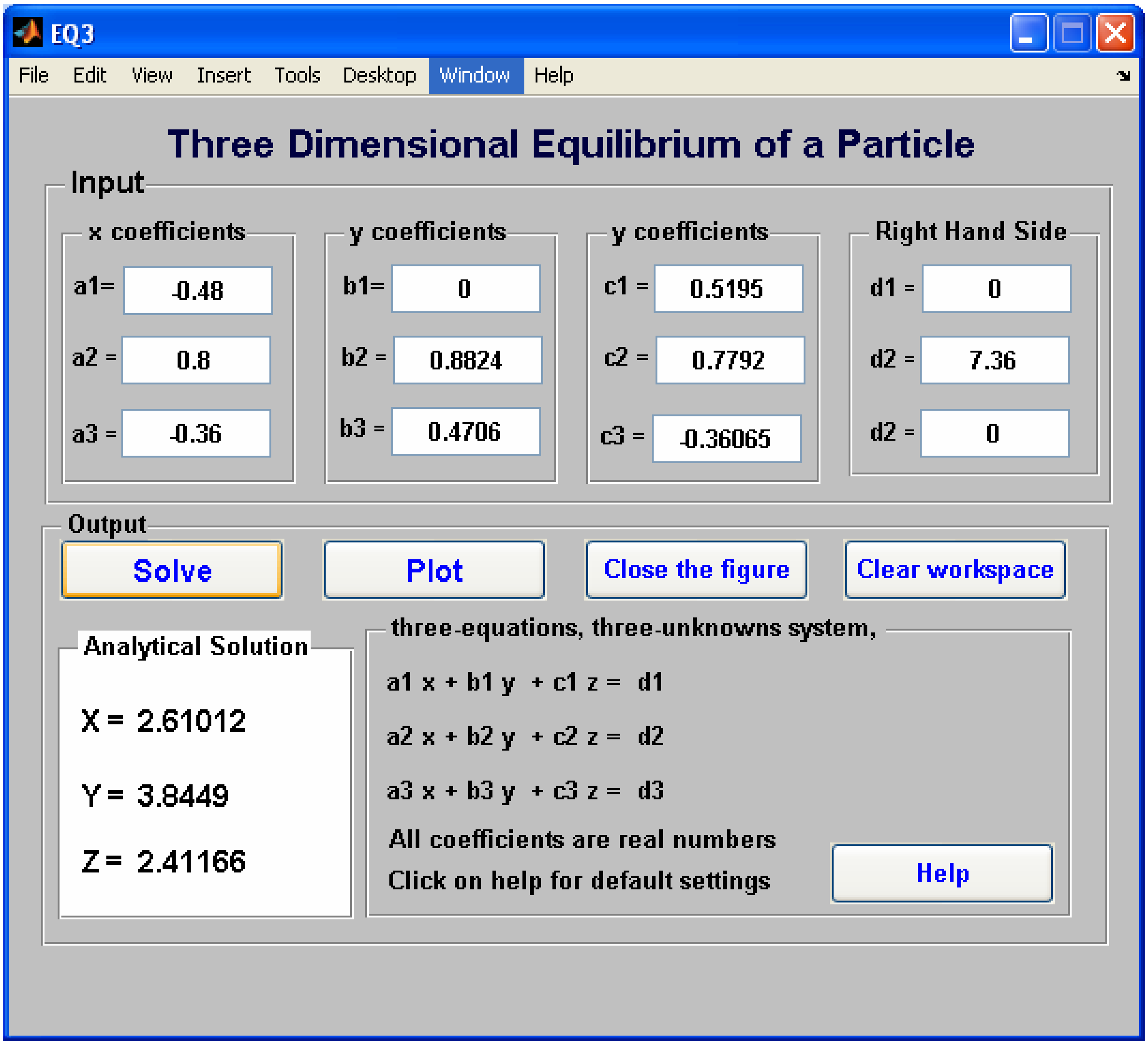
Ist Variable   2nd Variable

two-Equation , two-unknown system,

a x+ b y = c, where a, b, c are real numbers, default setting: See problem 2.54

d x+ e y = f, where d, e, f are real numbers, default setting: See Problem 2.54

Figure 4: 2-Dimensional Equilibrium of a Particle



Three Dimensional Equilibrium of a Particle

Input

x coefficients	y coefficients	y coefficients	Right Hand Side
a1= -0.48	b1= 0	c1 = 0.5195	d1 = 0
a2 = 0.8	b2 = 0.8824	c2 = 0.7792	d2 = 7.36
a3 = -0.36	b3 = 0.4706	c3 = -0.36065	d2 = 0

Output

Analytical Solution

X = 2.61012

Y = 3.8449

Z = 2.41166

three-equations, three-unknowns system,

a1 x + b1 y + c1 z = d1

a2 x + b2 y + c2 z = d2

a3 x + b3 y + c3 z = d3

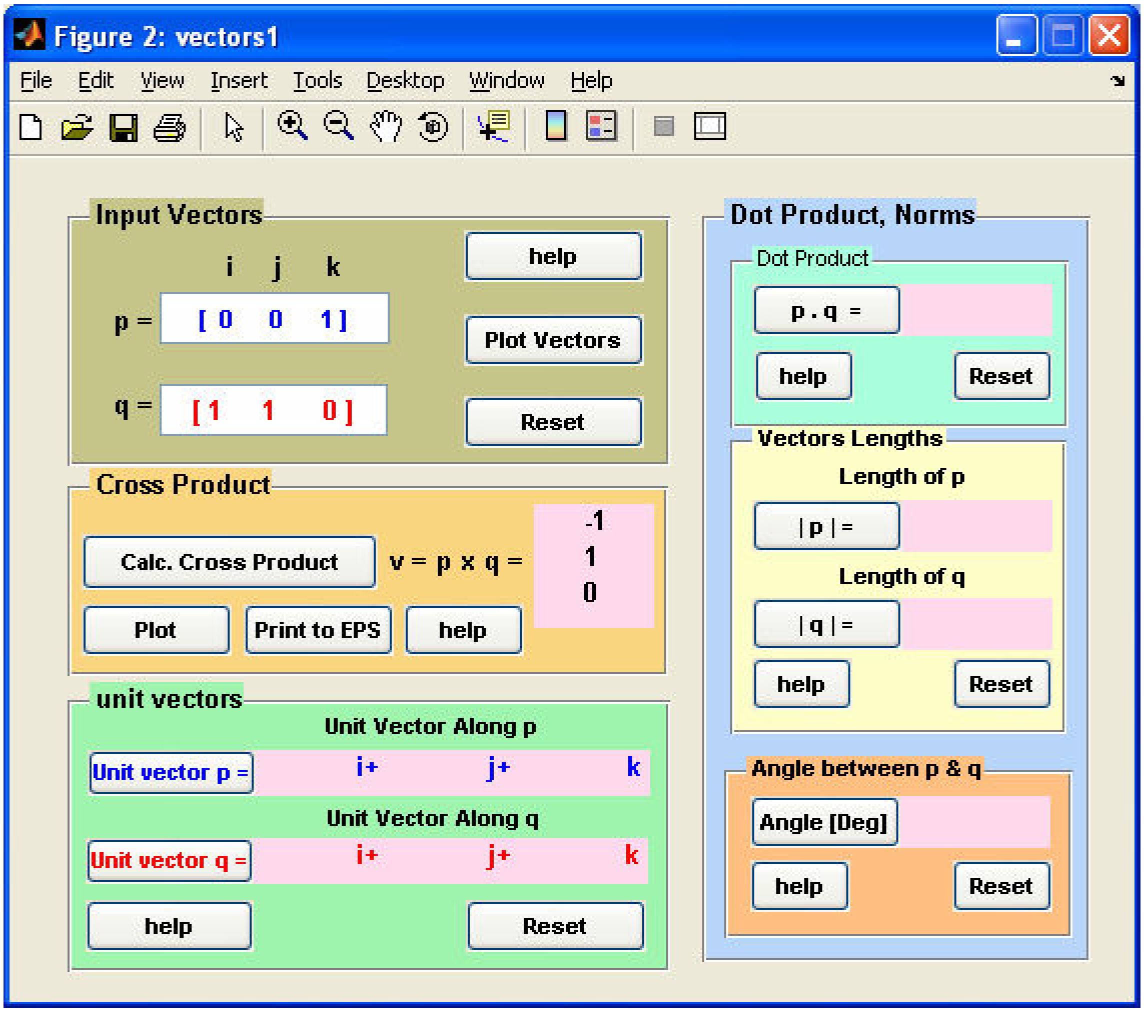
All coefficients are real numbers

Click on help for default settings

Figure 5: 3-Dimensional Equilibrium of a Particle

Basic vector operations module

This panel provides a comprehensive tool for the basic vector operations such as cross product, scalar product, unit vectors, and dot product. Figure 6 illustrates the structure of this module.



p = [0 0 1]

q = [1 1 0]

v = p x q = -1 1 0

Figure 6: Vector product module

The cross product, also known as vector product, is an operation on coplanar vectors P and Q is defined as [10]:

$$\vec{V} = \vec{P} \times \vec{Q} =$$

$$\vec{V} = \left(P_x \vec{i} + P_y \vec{j} + P_z \vec{k} \right) \times \left(Q_x \vec{i} + Q_y \vec{j} + Q_z \vec{k} \right)$$

$$\vec{V} = \left(P_y Q_z - P_z Q_y \right) \vec{i} + \left(P_z Q_x - P_x Q_z \right) \vec{j} + \left(P_x Q_y - P_y Q_x \right) \vec{k}$$

where $\vec{V}$ is perpendicular to the plane formed by $\vec{P}$ and $\vec{Q}$, the sense of $\vec{V}$ is in or out of this plane which is determined using the right-hand rule. To help students understand and visualize these concepts, the vectors are plotted on 3-d graph in which each vector matches the corresponding text color used in the GUI as shown in Figure 7.

The user can also dynamically spin the figure any desired direction to accommodate a better perspective to see that vector $\vec{V}$ is perpendicular to the plane composed by $\vec{P}$ and $\vec{Q}$. Upon changing the inputs, the user has the option to hold the current figure and observe the changes in the results both numerically and graphically, or using the reset button to start a new figure. The numerical values of the vectors can also be viewed in the figure using the data cursor provided in latest MatLab versions. Figures can be saved in many different formats or printed. If desired, the numerical output is saved to a text file.

The help buttons provide a detailed discussion of the concept under consideration similar to the class notes. A detailed sample problem is worked in the help file showing all the steps required to get the numerical answer. To safeguard against invalid inputs in the textboxes, like entering any non-numeric character in the editable text fields, the user will be prompted to change the inputs. The other vector operations on the right panel of the GUI are the dot product, norms or magnitudes and the angle between the vectors. Help files are also provided for all of these operations.

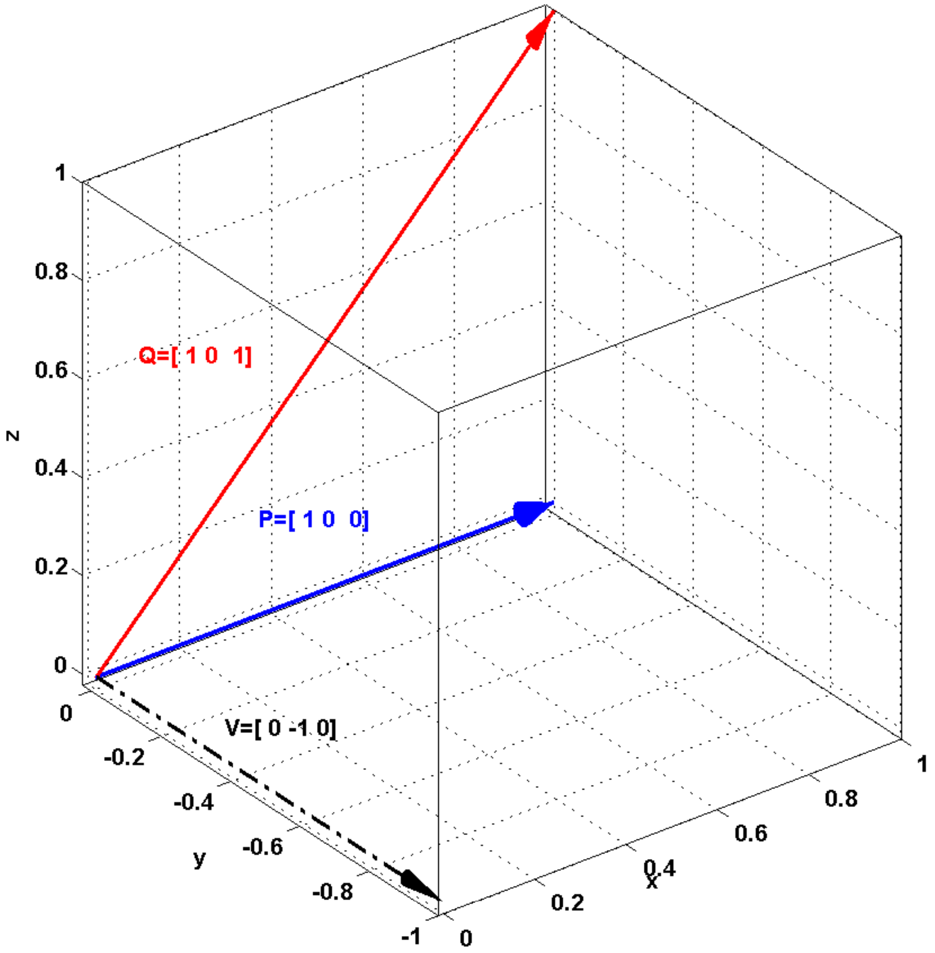
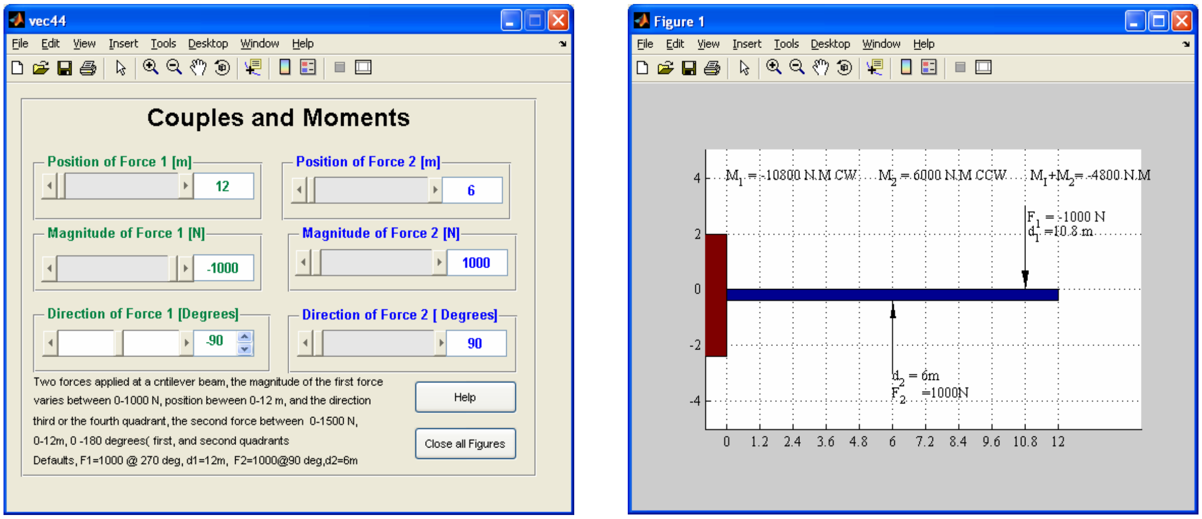


Figure 7: Cross product module output

Other Modules in the Package

The other modules cover vector triple product, equilibrium of a particle in two- and three-dimensions which involves finding the reaction forces and tension forces in cables that satisfy the equilibrium conditions. Figure 8 illustrates the couples and equivalent force system module, the version shown is for a cantilever beam, a simply supported beam option is also available.



Couples and Moments

Position of Force 1 [m] 12

Position of Force 2 [m] 6

Magnitude of Force 1 [N] -1000

Magnitude of Force 2 [N] 1000

Direction of Force 1 [Degrees] -90

Direction of Force 2 [Degrees] 90

Two forces applied at a cntilever beam, the magnitude of the first force varies between 0-1000 N, position beween 0-12 m, and the direction third or the fourth quadrant, the second force between 0-1500 N, 0-12m, 0 -180 degrees(first, and second quadrants
Defaults, F1=1000 @ 270 deg, d1=12m, F2=1000@90 deg,d2=6m

Help

Close all Figures

Figure 8: Couples module

As shown in Figure 8, the user can change the point of application of each force as well as their magnitudes and/or direction using the proper slider or the editable textbox. The couple magnitude and direction are displayed as shown in Figure 8. The user can interactively observe the changes in magnitude and direction of each force. This module illustrates how the magnitude of moment varies as a function of the force direction with respect to the position vector.

The other modules are self explanatory and cover the application of the basic equilibrium equations on structures such as trusses, frames, beams. Typically, the analysis of this class of problems is lengthy and susceptible to error propagation, which makes it difficult for students to achieve conclusive results.

Figure 9 shows the truss module, the user will be able to change the magnitude, direction, node of application, and support location. Ideas like zero force member can be very well illustrated using this module. Both method of joints and sections will be used.

Shear and moment diagrams module addresses statically determinant problems with user defined loading. Both concentrated and distributed are considered. First and second moment of area module will have three options.

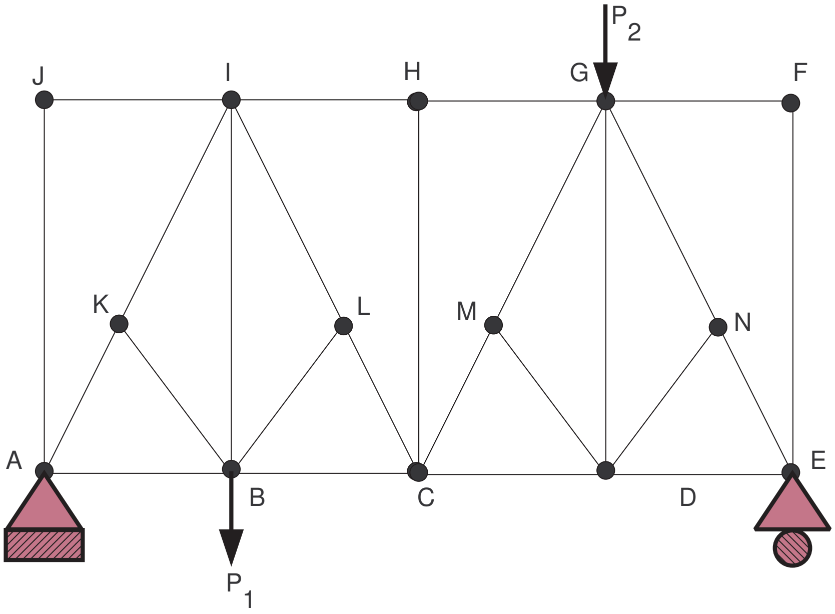


Figure 9: Trusses Module

The first is for areas prescribed by an explicit functional relation. The second option is for composite areas in which the user enters the required numerical values, the centroid with respect to the origin. A drop-down menu will enable the student to select from common engineering shapes; the GUI will calculate the area and the moment of inertia accordingly.

Assessment

To evaluate the effect of integrating GUI component into the course, the completed modules of the package are provided to the morning section of the class, the evening section students are not aware of this package availability or how to use it. Of course, the ultimate objective in introducing new tools in any course is enhancing students' learning. This goal represents the main metric of success. On the other hand, however, it is also imperative to enhance the package itself before formally adapting it as a teaching tool. Currently, students are asked to test each and every module and provide their feedback. Once all concerns and problems in the proposed package are addressed, the package will be formally introduced as an integral part of the course. The current qualitative verbal feedbacks are positive, and students seem to be in favor of this new tool.

Conclusion

The main objective of this project is to provide students with a supplementary tool unavailable in traditional lecture or textbook. The benefits of this package are not limited to Statics; however, it will help in many other courses such as FYE course, strength of materials, structural design, and machine elements.

This intuitive tool comes at no extra effort from the students since they will not be learning how to program or edit any script program. To use the package, students have to do the preliminary steps in setting up the problem, and then use appropriate module to reach the final solution and plot it. Therefore, the GUI will not replace the pencil-paper approach, nor sideline the text and lecture notes; rather it will supplement them. Student will be able to attempt more problems with dissipating his energy in manipulation, and algebra. Further, this will encourage them reattempt the problem again because they have the final result. Changing the inputs and monitoring their influence on the output will definitely help inspire students desire to answer the “what if” question, hence helping them to think out of the box and become a better designers who look at the problem from all perspectives analyzing all possible scenarios. The impact of using this tool will be monitored through regular surveys among the students, and through statistical analysis of student’s performance.

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