MODELING A SPIDER WEB AS AN ELECTRICAL NETWORK

Eric A. Cheek *, Sonya Ricks ** and Corey Graves*

*Department of Electrical & Computer Engineering, **Department of Curriculum and Instruction
North Carolina Agricultural & Technical State University
Greensboro, NC 27411

Introducation

Project work continues to be one of the best ways to get students to employ higher order thinking skills and assist them in understanding the use of basic techniques and concepts. Modeling real life systems allows students to see how relevant their skills are and how computers can be used to implement their models. This project demonstrates how the process of learning and transfer learning can be included in curriculums such as engineering to help ensure that students can apply what they have been taught in the classroom to seemingly foreign situations.[1]

In developing a good project the author must consider the project content, its ties to the course learning objectives; the pedagogy employed and desired outcomes. This paper presents how a spider web is used in a circuit analysis course to enhance the understanding of mesh and nodal analysis. In addition it shows how to use MATLAB and/or computer programming to conduct simple simulations.

The Project

For the last 15 years, the project has been presented to Circuits I students shortly after covering nodal and mesh analysis as follows:

Surfing the WEB?

Group Project - Due in two weeks

Quite often engineers are called upon to model systems to get a better understanding of their behavior. One such set of systems of interest is spider webs. Some believe that spiders have lousy sight and rely heavily on their sense of touch to alert them when prey has been caught in their web. Once an insect is caught in the web the spider moves quickly towards it and covers it with additional webbing to insure the prey does not get away.

We are interested in modeling the web as a resistive network where the prey lands on the web will be represented as an energy source (voltage or current source) of your choice. The spider should detect a change in the network and move to the energy source.

Your job is to model the web and answer the following questions:

1. What measurement should the spider make, current or voltage?

2. How does the spider find its prey?

3. Where should the spider wait on the web?

Suggestions:

Write a program to generate the mesh or nodal equations of the web. Use a program such as MATLAB to solve the matrix equations. Be sure to justify any assumptions about the model of the web, spider or prey. (e.g. Justify the determination of the resistance in each thread of the web as a function of its length.)

The project may require that you run several simulations, before you come up with useful generalizations. I suggest you start with a small unrealistic web and work your way up. Take good notes at your group discussions, it will help in writing the final formal report. I strongly encourage graphic outputs to illustrate important points.

Project Content

The project requires Critical Thinking, Decision Making, Modeling (Computer Simulation) and Synthesis & Evaluation (the highest levels of Bloom's Taxonomy). The open-endedness requires the students to think critically on how to model the web. Derivation and justification of the resistance contained in a thread of web, as well as the best method of analysis (nodal or mesh), require collaboration among the group and decision making. After modeling and synthesizing the web on the computer students are required to evaluate the data to determine where the spider should wait on the web and the path it would take to get to the prey.

Learning Objective

Two course learning objectives are addressed by this project: 1) applying nodal and mesh analysis techniques and 2) using matrix algebra to solve simultaneous equations. Once the group has agreed on the model for the prey (voltage or current source) and the type of measurement the spider will make, they proceed to write the nodal or mesh equations in matrix form. These matrix equations have ranged from 4X4 to 100 X 100. Mesh generally was the preferred analysis method; most groups simply used the computer to calculate the mesh currents, while a few groups extended their programs to calculate the current through each thread.

Pedagogy

Transfer learning is defined as the ability to extend what has been learned in one context to new contexts (Ibid). Contemporary research on this subject matter posit that the focus for learning and transfer be in the actual practice or performance. However, advocates of this theory highlight particular types of practice that should be emphasized, along with the relevance of the fundamental abilities of the learner. Transfer learning maintains four key characteristics that are necessary to produce transfer learning in pedagogical activities: 1) initial learning, which requires a certain level of expertise in the subject matter is required for transfer 2) abstract representations of knowledge, which can help promote transfer 3) an active, dynamic process rather than a passive end-product of a learning experiences. Brings about transfer 4) design of instruction that helps students learn is important because all new learning involves transfer based on previous learning (Ibid). This project contains these elements to ensure that transferring occurs, for instance, it includes instruction and strategy provided by professor and student observations and data collection. This is one of the essential characteristics in the success of the process. The project requires the students to work collaboratively throughout the learning process. Teams discuss all aspects of the problem and often bring questions such as: When the prey lands on the web, does the source replace the resistor or is it in parallel or series with the resistor? The teaching assistants and instructors simply ask: "What does your group think and can you justify your assumption?"

Through experimental learning and reflection, many students have an "Aha" experience when they notice the symmetry in their matrices or that the prey only affects one or two mesh equations. Even though the symmetry of matrices is discussed in every circuit's book, this "Aha" experience seems to register with the students better. This demonstrates the transfer learning of previous knowledge or "initial learning" that students received regarding the study of model system behaviors to new knowledge and learning experience [2], which is the observation and model systems practice they employ with the spider web.

Expected Outcomes

Upon completion of this project students will be able to:

1.) Use the computer to model a large network;

2.) Define and justify assumptions; and

3.) Apply nodal or mesh analysis techniques.

Sample Model

Consider the spider web model in Figure 1 where T1 through T16 represent sixteen threads of web. The points A through D will be possible initial locations of the spider in this investigation. For simplicity, assume the prey lands on a single thread of the web and not the intersections.

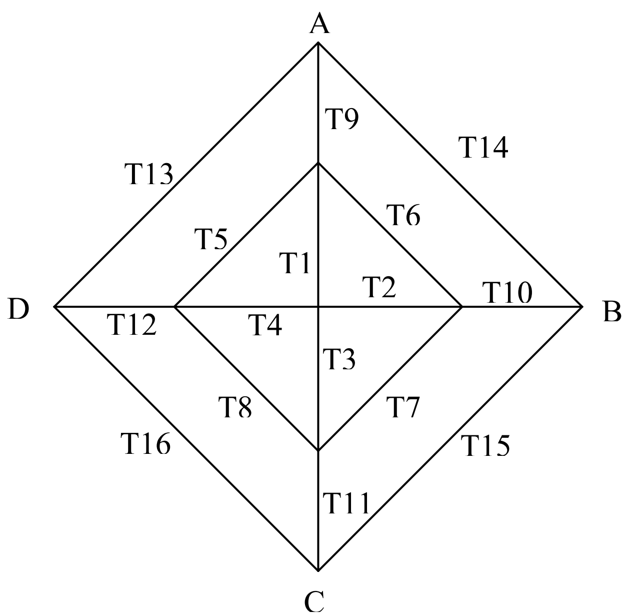

Figure 1

The circuit in Figure 2 represents a spider web at rest (no prey). 1Ω resistors represent the shorter threads of web while the longer (perimeter) threads are 2Ω resistors. This is justified by assuming each thread has the same cross sectional area and resistive material, thus the resistance is proportional to the length. The matrix Equation 1 represents the mesh-equations for the circuit. Without any energy sources, the input vector and all mesh currents are zero.

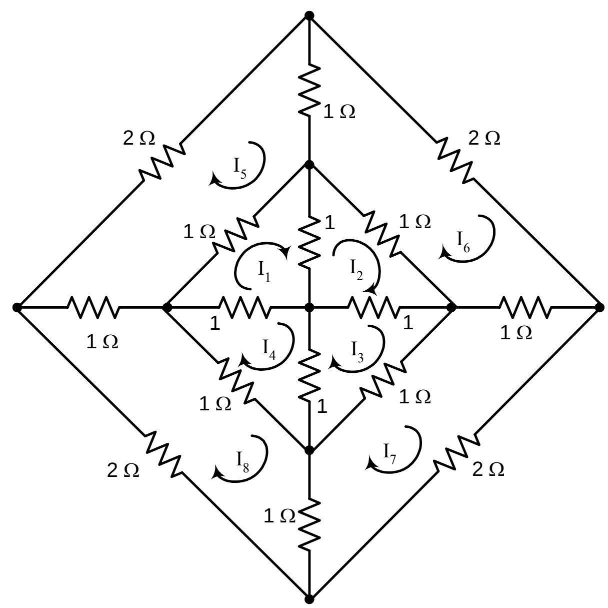

Figure 2

$$\begin{bmatrix} 3 & -1 & 0 & -1 & -1 & 0 & 0 & 0 \\ -1 & 3 & -1 & 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 3 & -1 & 0 & 0 & -1 & 0 \\ -1 & 0 & -1 & 3 & 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 & 5 & -1 & 0 & -1 \\ 0 & -1 & 0 & 0 & -1 & 5 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 & -1 & 5 & -1 \\ 0 & 0 & 0 & -1 & -1 & 0 & -1 & 5 \end{bmatrix} * \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \\ I_7 \\ I_8 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Equation 1

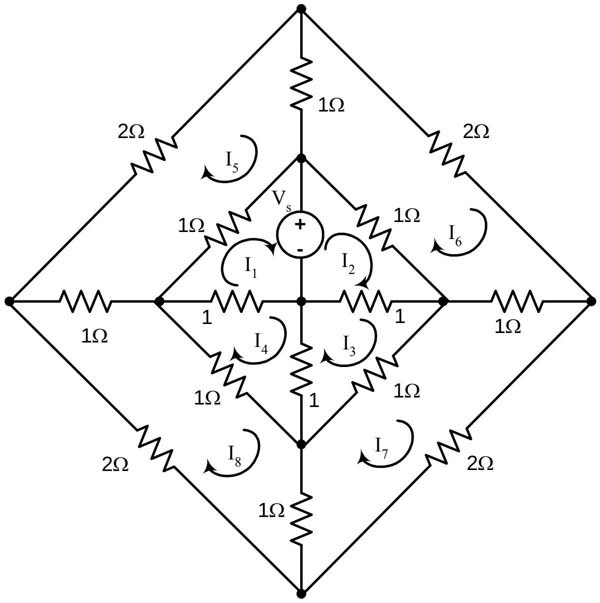

Figure 3

$$\begin{bmatrix} 2 & 0 & 0 & -1 & -1 & 0 & 0 & 0 \\ 0 & 2 & -1 & 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 3 & -1 & 0 & 0 & -1 & 0 \\ -1 & 0 & -1 & 3 & 0 & 0 & 0 & -1 \\ -1 & 0 & 0 & 0 & 5 & -1 & 0 & -1 \\ 0 & -1 & 0 & 0 & -1 & 5 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 & -1 & 5 & -1 \\ 0 & 0 & 0 & -1 & -1 & 0 & -1 & 5 \end{bmatrix} * \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \\ I_7 \\ I_8 \end{bmatrix} = \begin{bmatrix} -2 \\ 2 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Equation 2

The circuit in Figure 3 represents a case where a bug lands on the web between meshes I1 and I2, thread 1, (T1). The bug is represented by a voltage source, which replaces the thread resistance. Replacing the resistor by a source is the option chosen by most students, other options would place sources in series or parallel with the resistor. The change in the system only affects the first two mesh equations (see Equations 2).

MATLAB is used to solve the matrix equations and determine the current in each thread. A is the 8x8 coefficient matrix, B the 8x1 input column vector and I is defined as A/B which is the inverse of A times B in MATLAB. "Threadcurrent" is a routine written in MATLAB to calculate the current through each thread.

```
A =
     2   0   0  -1  -1   0   0   0
     0   2  -1   0   0  -1   0   0
     0  -1   3  -1   0   0  -1   0
    -1   0  -1   3   0   0   0  -1
    -1   0   0   0   5  -1   0  -1
     0  -1   0   0  -1   5  -1   0
     0   0  -1   0   0  -1   5  -1
     0   0   0  -1  -1   0  -1   5

>B= [-2 2 0 0 0 0 0 0]';
>I=A\B
I =
   -1.2885
    1.2885
    0.3462
   -0.3462
   -0.2308
    0.2308
    0.0962
   -0.0962

>Threadcurrent
The current in thread  1 is:  -2.5769  amps.
The current in thread  2 is:   0.9423  amps.
The current in thread  3 is:   0.6923  amps.
The current in thread  4 is:  -0.9423  amps.
The current in thread  5 is:  -1.0577  amps.
The current in thread  6 is:   1.0577  amps.
The current in thread  7 is:   0.2500  amps.
The current in thread  8 is:  -0.2500  amps.
The current in thread  9 is:  -0.4615  amps.
The current in thread 10 is:   0.1346  amps.
The current in thread 11 is:   0.1923  amps.
The current in thread 12 is:  -0.1346  amps.
The current in thread 13 is:  -0.2308  amps.
The current in thread 14 is:   0.2308  amps.
The current in thread 15 is:   0.0962  amps.
The current in thread 16 is:  -0.0962  amps.
```

Thread currents are defined, in terms of mesh currents, as the lower mesh number through the thread minus the higher mesh number. Thus thread 1's current is I1 – I2. The spider uses these thread currents to find the prey. For example, if the spider follows the thread with the highest current magnitude from an initial point to the prey, the patterns will be as follows:

From A through T9 to T1
From B through T14 through T9 to T1
From C through T11 through T3 to T1
From D through T13 through T9 to T1

It is important to note the paths from points B and D to the prey at T1 are not the shortest paths. Thus, further research can be done to find better algorithms to determine the shortest path.

Similar scenarios are conducted with the prey landing on threads T5, T9 and T13, also with the spider starting at other intersections such as the center. The web symmetry allows one to eliminate 75% of the scenarios. Problems with multiple preys landing on the web have also been explored.

Outcomes

There were expected and unexpected outcomes. The expected included the students having an opportunity to apply mesh and nodal analysis to a large system using Matlab and other computer programs. The unexpected outcomes included research on spider webs. Some of the more interesting websites and quotes are:

http://www.wsu.edu/DrUniverse/spiders.html

"The spider intentionally makes part of its web sticky and part of it non-sticky. It knows how to avoid the sticky parts, and its prey does not."

"Spider webs are made of protein a sugar"

http://faculty.washington.edu/yagerp/silkprojecthome.html

"Spider Silk is a natural polymer that is far superior to synthetic polymer in terms of strength and production efficiency"

"Scientist study spider silk in an effort to improve the fabrication of synthetic polymers."

http://fluid.stanford.edu/~mbrennan/interests/insects/spider_silk.html

"Without hot temperatures, crushing pressure or harsh chemicals, spiders are able to produce a steady stream of silk, one of the toughest fibers known. Silk, while light and elastic, is stronger than steel yet easily recyclable, potentially replacing plastics for many uses."

Conclusions

Modeling a spider web as an electric circuit provides great opportunities for students to:

1. Think critically;
2. Work collaboratively;
3. Employ circuit analysis techniques;
4. Conduct empirical research and;
5. Transfer knowledge to new problems.

Acknowledgements

The collaboration between education and engineering faculty was initiated by a Retention grant from the Hewlett-Packard Foundation and Grant # EEC-0230645 from the National Science Foundation.

References

1. Bransford, J.D., Brown, A.L., and Cocking, R.R. (2000). How People Learn: Brain, Mind, Experience and Schools. Jossey-Bass, pp. 9-15.

2. Halpern, D. and Hakel, M. (2002). Applying the Science of Learning to University Teaching and Beyond. National Academy Press, 89, pp. 51-71.

Biographical Information

Eric A. Cheek is the Director of the Electrical & Computer Engineering CORE program at North Carolina A&T State University. He received B.S. degrees in Electrical Engineering and Mathematics from Carnegie-Mellon University, M.S. and Ph.D. degrees in Electrical Engineering from Howard University. He is active in student retention and effective teaching projects and a member of ASEE and NAMEPA.

Sonya Ricks is an instructor in the Curriculum and Instruction Department at North Carolina A&T State University. She received her B.A. degree in Political Science from North Carolina Central University and her M.S. degree from North Carolina A&T State University. She is currently involved in research that focuses on the impact of student learning and transfer learning on student retention in their major. She also has research interest in secondary social studies and literacy of minority students.

Dr. Corey Graves received his M.S. degree in Electrical Engineering (1994) and PhD degree in Computer Engineering (1999) from North Carolina A&T State University and North Carolina State University, respectively. Dr. Graves currently holds an Assistant Professor position at North Carolina A&T State University. His current research interests include the development and implementation of Digital Signal Processing and Communication algorithms, and technology-based educational enhancement.