ENHANCING ON-LINE ELECTRICAL ENGINEERING UNDERGRADUATE EDUCATION THROUGH A VIRTUAL LABORATORY

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Abstract

On-line education is utilized extensively and has been found to be effective in a multitude of subject areas, including engineering education. However, for on-line education to be fully effective in engineering education, a means must be developed to provide on-line students with laboratory experiences that achieve the same learning outcomes as face-to-face laboratories. To address this need, a pilot computer program, Project VELVET (Virtual Electronics Laboratory for Visualized Education and Training), for a virtual electronics laboratory is being developed. VELVET operates on Windows-based computers in a real-time environment. It presents to its user a virtual breadboard into which components may be inserted. A dc power supply and a signal generator are available to supply energy and signals to circuits, and measurements may be made with a virtual millimeters and a virtual oscilloscope. The algorithm and sample screen images of the program are presented in this paper.

Keywords

Virtual Laboratories, Electronics Laboratories, Engineering Education, Learning Research, On-line Education, Distance Education

Introduction

On-line courses, hybrid courses, and massively open on-line courses (MOOCs) are becoming more common. Such courses offer advantages for students in that they do not necessarily need to come to campus to attend classes. This is particularly beneficial to students who cannot attend traditional classes due to inconvenient travel or conflicting work schedules. Such courses are easily implemented and are effective in replacing lectures in many fields of study. However, there are unique challenges for courses that involve a laboratory.

Many engineering courses fall into the latter category as they often contain a laboratory. Some of these laboratories may be suitable for implementation as software-based virtual laboratories while others may involve physical experiments that can be controlled remotely. Other laboratories require physical testing and experimentation methods that cannot be conducted remotely. The first type might include circuit laboratories like VELVET; materials laboratories would be examples of the third type. Mechatronics laboratories would be examples of second type(a physical laboratory suitable for remote manipulation). Laboratories which can be virtualized or made suitable for remote operation, allow more engineering courses to be offered through distance education, thereby increasing the availability of engineering education. The focus of this paper is a virtualized electronics laboratory aimed at undergraduate electrical engineering education.

Requirements of a virtual laboratory

To be effective in undergraduate education, a virtual laboratory must provide at least the same level of learning as does a physical laboratory. That raises a very important question: in engineering education, is the goal to teach design and applications, or is it to teach the techniques of physical construction such as soldering or welding? In the context of current engineering education, the answer appears to be the former: teaching design principles and application of those principles, including system

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analysis and diagnosis. If one accepts that premise, provided that the necessary learning outcomes can be achieved, some laboratories can be virtualized, and can be effective in undergraduate education.

To be effective, a virtual laboratory must:

a) Allow students to make measurements in the virtual environment utilizing the same kinds diagnostic tools found in a physical laboratory(e.g., digital multimeter, oscilloscope).
b) Provide realistic virtual representations of the same components used in the physical laboratory.
c) Have "manufacturing tolerances" in virtual components that are of the same order as their physical counterparts; and
d) Enable achievement of the necessary student learning outcomes.
Project VELVET aims to address all of these requirements.

The software developed for implementation of the virtual laboratory must have a graphical user interface that is intuitive to an undergraduate engineering student. The learning curve must be minimal so that students spend their time in learning concepts rather than tools. The virtual breadboard circuit needs to resemble an actual breadboard with realistic components. The software must also be robust so that errors which may occur are trapped and feedback is provided to the student in much the same manner as a physical laboratory, for example, a component that is subjected to excessive power dissipation may burn out. Errors that may occur when solving a system of equations (such may occur when the values of matrix elements span many orders of magnitude) need to be dealt with in a rational manner.

Previous works

Many papers have been published related to the subject of virtual laboratories, applicable to diverse areas such as process engineering, electrical machinery, physics, and chemistry. For instance, Shaheen et al[1] describe a remote laboratory for the process control and automation. Tanyildizi and Orhan[2] describe a virtual laboratory for electrical machines and have developed a virtual laboratory for synchronous machinery, using Hyper Text Markup Language (HTML), Active Server pages (ASP) and Borland C++ Builder.

Ben et al[4] detail other virtual laboratory applications such as a web-based virtual oscilloscope laboratory experiment. Basher et al[3] outline a virtual laboratory for an introductory course on circuit analysis in an Electrical Engineering Technology program. They discuss the integration of LabVIEW with a PC laboratory, in which users are able to enter the parameters to be processed by means of a LabVIEW program, and data are taken with myDAQ (National Instruments, Austin TX).

Development of VELVET mathematical model

Figure 1 depicts of virtual breadboard and connection of resistors. This example virtual breadboard has eight connection strips for leads of components. In the left-hand of figure 1 resistor R5 has been connected between breadboard connection 1 and breadboard connection 5.The First insertion is made to breadboard connection 1;electrical node 1(represented by the circle number1) is assigned to this connection. The second lead insertion is made to breadboard connection 5,which is assigned to electrical node 2.The current in this component is designated i_1,flowing into R5 at the first lead(node 1) and leaving R5 at the second lead(node2).Similarly the next component R1 is connected between breadboard connections 5 and 8.The connection of R1 to breadboard connection 5 does not require designation of an electrical node since connection 5 is already associated with electrical node2.The connection of the second lead of R1 to breadboard connection 8 causes connection 8 to be mapped to electrical node 3.The current i_2 in R1 flows from node2 to node3.
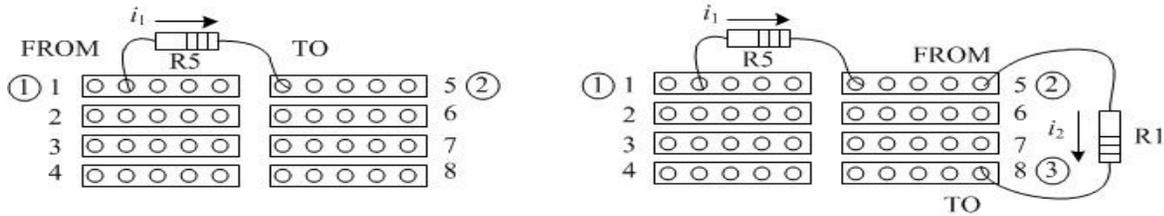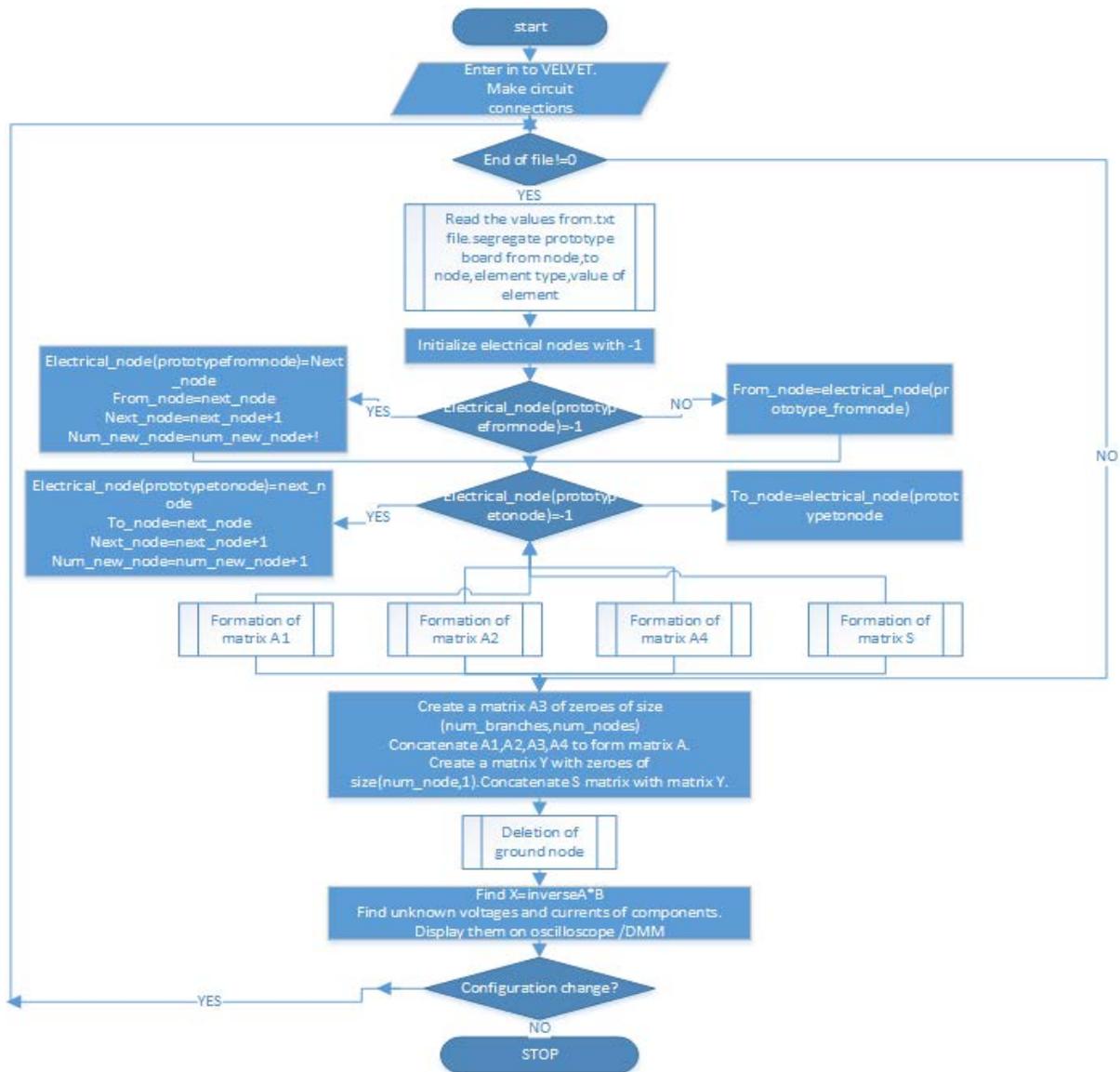
Fig 1: Depiction of virtual breadboard

Fig 2: Flowchart of proposed algorithm

Network equations are assembled as the circuit is built. Figure 2 shows the flowchart of proposed algorithm. Matrices A1, A2,A4 and S are explained in detail in below given example.

5. Validation of the Algorithm

The above algorithm is validated with the help of the following example. By following the procedure given in the mathematical model, network equations are assembled from circuit topology, and the unknown values (node voltages and branch currents)are computed.

5.1Circuit diagram

Figure3 is a simple example circuit consisting of three meshes involving six resistors and a dc voltage source. Numbers adjacent to the schematic indicate the assumed node numbers. There is no ground node shown in the circuit diagram; VELVET develops the network equations for all nodes and then modifies those equations after one of the nodes is selected as the reference (ground) node. Arrows indicate flow of currents in respective branches.
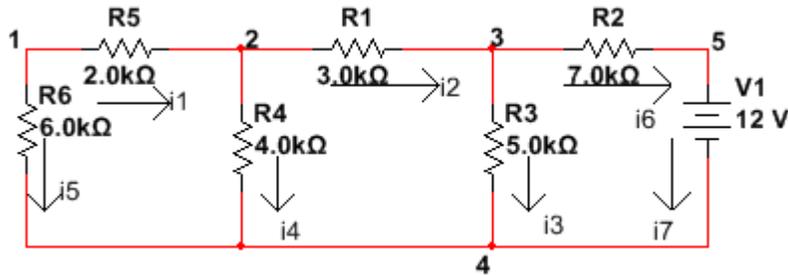

Fig 3: Circuit diagram of example circuit

From the circuit, based on Kirchhoff's current law (KCL), node equations are formulated as:

At node 1: $\quad i_1 - i_5 = 0$

At node 2: $\quad -i_1 + i_2 + i_4 = 0$

At node 3: $\quad -i_2 + i_3 + i_6 = 0$

At node 4: $-i_5 - i_4 - i_3 - i_7 = 0$

At node 5: $-i_6 + i_7 = 0$

From the circuit constitutive equations are formulated as follows:

For branch with R5: $\quad \dfrac{v_1 - v_2}{R5} - i_1 = 0$

For branch with R1: $\quad \dfrac{v_2 - v_3}{R1} - i_2 = 0$

For branch with R3: $\quad \dfrac{v_3 - v_4}{R3} - i_3 = 0$

For branch with R4: $\quad \dfrac{v_2 - v_4}{R4} - i_4 = 0$

For branch with R6: $\quad \dfrac{v_1 - v_4}{R6} - i_5 = 0$

For branch with R2 resistor: $\quad \dfrac{v_3 - v_5}{R2} - i_6 = 0$

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For branch with voltage source: $v_5 - v_4 = potential\ of\ source\ V1$ (12V in Fig.3)

Using both Kirchhoff and constitutive equations we form both a square coefficient matrix A representing the left-hand sides of the equations and a column vector of known values representing the right-hand sides. The dimensions of matrix A are ($N_{nodes} + N_{branches}$) by ($N_{nodes} + N_{branches}$) where N_{nodes} is the number of nodes and $N_{branches}$ is total number of branches. The matrix A is subdivided into four sub matrices (designated as A_1, A_2, A_3 and A_4 for the purpose of construction. A column vector of sources (S) and a column vector of zeroes(Y) are also formed and concatenated to form column vector of known values with ($N_{nodes} + N_{branches}$) elements. From the above equations, sub-matrices, A_1, A_2, A_3 and A_4 and vectors S and Y can be formed as:

$$A1 = \begin{bmatrix} 1/2K & -1/2K & 0 & 0 & 0 \\ 0 & 1/3K & -1/3K & 0 & 0 \\ 0 & 0 & 1/5K & -1/5K & 0 \\ 0 & 1/4K & 0 & -1/4K & 0 \\ 1/6K & 0 & 0 & -1/6K & 0 \\ 0 & 0 & 1/7K & 0 & -1/7K \\ 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$
(Nodes, Branches)

$$A2 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$
(Branches, Branches)

$$A3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$
(Nodes, Nodes)

$$A4 = \begin{bmatrix} 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ -1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & -1 & -1 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$
(Branches, Nodes)

$$S = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 12 \end{bmatrix} \qquad Y = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$A = \begin{bmatrix} A1 & A2 \\ A3 & A4 \end{bmatrix}$$

The combined matrix formulation can be represented as:

$$\begin{bmatrix} A1 & A2 \\ A3 & A4 \end{bmatrix} \begin{bmatrix} S \\ Y \end{bmatrix} = \begin{bmatrix} V \\ I \end{bmatrix} \qquad\qquad S1 = \begin{bmatrix} S \\ Y \end{bmatrix}$$

When these equations are solved, vector V contains node voltages and vector I contains branch currents. Matrices A_3, A_4 and Y represent KCL and matrices A_1, A_2 and S are derived from constitutive relations.

Once the network equations are formulated, VELVET chooses a ground node based upon the circuit topology. The rules are selecting ground node follow a hierarchy. If a dc power supply is connected to the circuit, the node connected to the common terminal power supply is designated as ground. If no dc power supply is present, VELVET checks for the presence of the signal generator. If the signal generator is present, the node connected to generator reference terminal is designated as ground. If neither the power supply nor the signal generator are present, VELVET checks for the presence of the

oscilloscope and/or the digital multimeter (DMM).If one of these test instruments is present, ground is assigned to the node connected to the reference lead of the instrument.(If both are present, ground is determined by the reference lead of the oscilloscope probe).

Once the ground node is determined,, the column of coefficients in Matrix *A* corresponding to voltage at the ground node is deleted and the row representing the KCL equation at the ground node is also deleted. In the circuit of figure 3, the common lead of the dc power supply is connected to node 4,and node 4 is thus designated as ground. This designation causes the modification of matrices A and Y to form new matrices *A* and *Y* .These new matrices are given below with deleted elements of the original matrices shown in cyan.

$$
A' = \begin{bmatrix}
1/2K & -1/2K & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1/3K & -1/3K & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1/5K & -1/5K & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\
0 & 1/4K & 0 & -1/4K & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\
1/6K & 0 & 0 & -1/6K & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 1/7K & 0 & -1/7K & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & -1 & 0 & -1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1
\end{bmatrix}
\qquad
Y' = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}
$$

Nodes + Branches -1

The values of branch currents and non-ground node voltages are computed as:

$$\begin{bmatrix} V' \\ I \end{bmatrix} = A^{-1} \begin{bmatrix} S \\ Y' \end{bmatrix}$$

Where V' represents node voltages except the reference node and I represent branch currents. For the circuit of Figure 3, the computed node voltages and branch currents are:

$$
\begin{bmatrix} V' \\ I \end{bmatrix} = = \begin{bmatrix} v1 \\ v2 \\ v3 \\ v5 \\ i1 \\ i2 \\ i3 \\ i4 \\ i5 \\ i6 \\ i7 \end{bmatrix} = \begin{bmatrix} 1.165 \\ 1.5534 \\ 3.30 \\ 12 \\ -0.00019 \\ -0.00058 \\ 0.00066 \\ 0.00038 \\ 0.00019 \\ -0.00124 \\ -0.00124 \end{bmatrix}
$$

The network equations are re-formulated whenever there is a change in the circuit topology. This allows students to re-configure their circuits "on the fly" as occurs when a circuit element is added to or removed.

6. Sample Implementation Screens

Figure 4 shown below is the main screen of VELVET. It has breadboard and connections to a dual-output virtual power supply on the right of the screen; to the left are a virtual multimeter, an oscilloscope and the power supply. Figure 5 shows an example screen the user sees when selecting a resistor. In this case, the user has chosen a 20Ω resistor. The virtual component is shown, including a display of both its nominal and actual values.
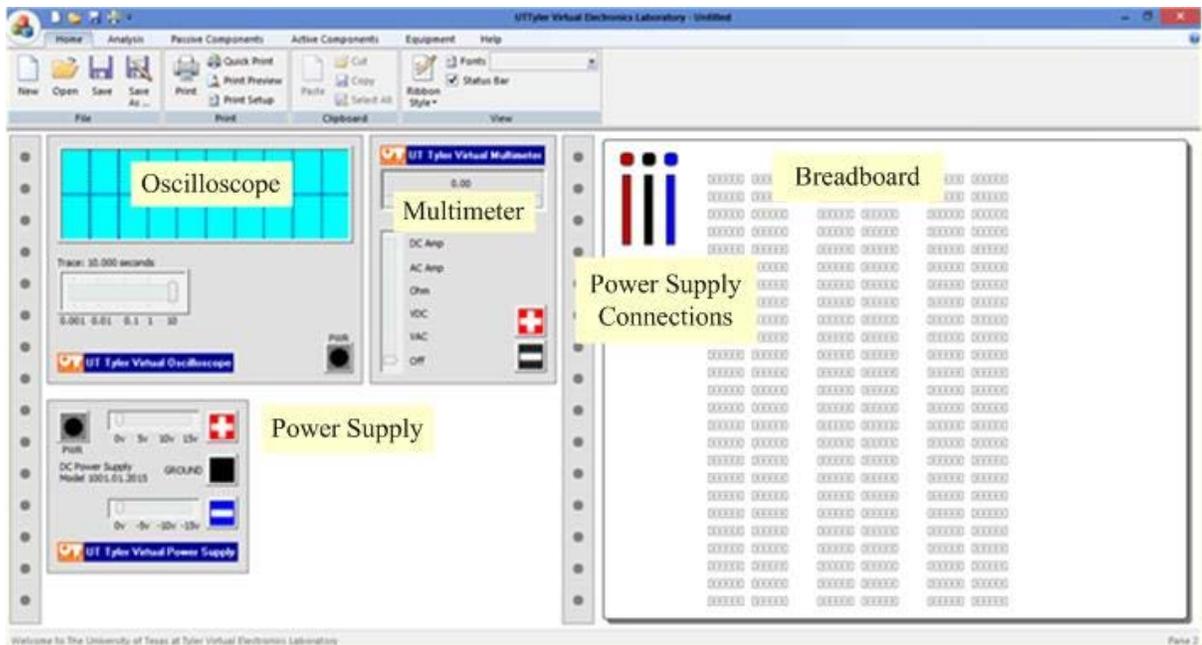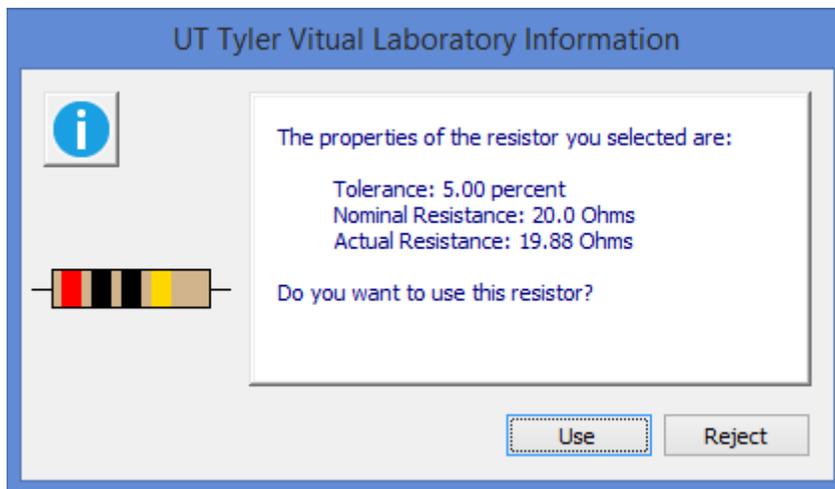

Fig 4: Main screen of VELVET

Fig 5: Resistor with actual resistance value similar to realistic resistor.

7. Conclusion

In this paper we have outlined the preliminary development of a virtual laboratory tool for introductory circuit analysis courses.Futher development is in progress; we are currently developing the methodology for incorporating reactive elements and controlled sources and activation of failure modes due to excessive power dissipation. We have included randomized component to component variability as encountered in realistic labs. We anticipate future reports as development proceeds.

Acknowledgements

8 References

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