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A Remote Over-Internet Hands-on Laboratory

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Abstract - **Information technology over the last few years has made tremendous leaps, reaching out to every aspect of modern society mainly business, entertainment and education. At the core of this information technology revolution has been the Internet with its vast reach into homes, offices, and classrooms making it a ready, easy and reliable tool for self-learning and technical resources. This has helped students pursue their academic interests, honing their skills from basic to advanced levels in an efficient and concise manner. Traditionally, the standard procedure for electrical engineering students to strengthen their theoretical concepts has been to attend various lab classes to gain valuable experience in design and implementation of classroom theories. However, there may be unavoidable circumstances in any engineering student's life arising from social, professional or medical obligations that may prevent him from attending a theory or practical class. The idea of having a virtual laboratory that can be accessed over the Internet is a practical approach to solving this problem and help students to cope up and sharpen their practical skills. This paper throws light upon an on-going virtual laboratory program at the University of Texas at San Antonio that enables students to access and operate hardware and software based experiments physically connected to a web-server using remote desktop technologies conveniently from their PCs.**

Keywords— Client, Remote desktop, Server, Virtual laboratory and Distance learning.

I. INTRODUCTION

The academic field is undergoing significant changes corresponding to the revolutionary advances in technology. Nowadays, more and more students have full time jobs or family obligations, which negatively affect on the frequency of student visits to the classes or labs. One of the enormous opportunities the modern technology provides lies in the effective use of computers and the Internet as potent educational tools. In the last few years many universities have successfully used Internet based distance learning technologies [1]-[3]. While internet technologies drive virtualization of conventional laboratory offerings, another trend in education is to introduce hands-on training methods to help students in understanding engineering concepts. The Infinity project makes engineering and science more accessible to a wider audience by using hands-on modules to explain various advanced technology concepts. Examples are nationally recognized projects such as Infinity [13] and EPICS [14]. Using technology kits and tutorials, the Infinity project helps students to understand the basics of personal cell phones, musical instruments, special effects for movies, etc. In the EPICS program, teams of undergraduates are designing, building, and deploying real systems to solve engineering-based problems for local community service and educational organizations. Remote education has certain constraints in hands-on education as the students can experiment with already set-up equipment but it has many advantages such as potentially centralized hands-on library of software modules which is easy to upgrade and maintain. These concepts correlate with the trends in worldwide hosted virtual desktop (HVD) market which is estimated to expand to 40 percent of the worldwide professional PC market [15].

This article describes an on-going program at the University of Texas at San Antonio (UTSA) which is focused in two directions (1) designing a library of hands-on software and hardware modules to help in engineering education; (2) the possibility of establishing virtual laboratories. The rest of the article has been further organized as follows. Section 2 presents the UTSA EE Toolbox. A brief review of several remote desktop technologies has been done in Section 3. Section 4 explains the overall remote Over-Internet laboratory. Assessment results are summarized in Section 5 and the article is concluded in Section 6.

II. UTSA EE TOOLBOX

The use of mathematical concepts, particularly matrix algebra, in nowadays electrical engineering studies is critical and cannot be underestimated. Matrix algebra concepts are widely used in many advanced electrical engineering studies such as Signal and Systems, Discrete Signal Processing, Wireless Communications, Robotics and Controls. At many universities including UTSA the students start to get familiar with matrix algebra in "Applied Engineering Analysis (EA)" or similar classes. In an effort to help students better understand the relation of analytical concepts with technologies from their life experience we develop a library of illustrative hands-on projects which can be downloaded or remotely accessed. Remote access is preferable as it resolves software availability, compatibility and competency issues. In other words, hands-on projects can be launched and used for educational tasks without a need for students to install

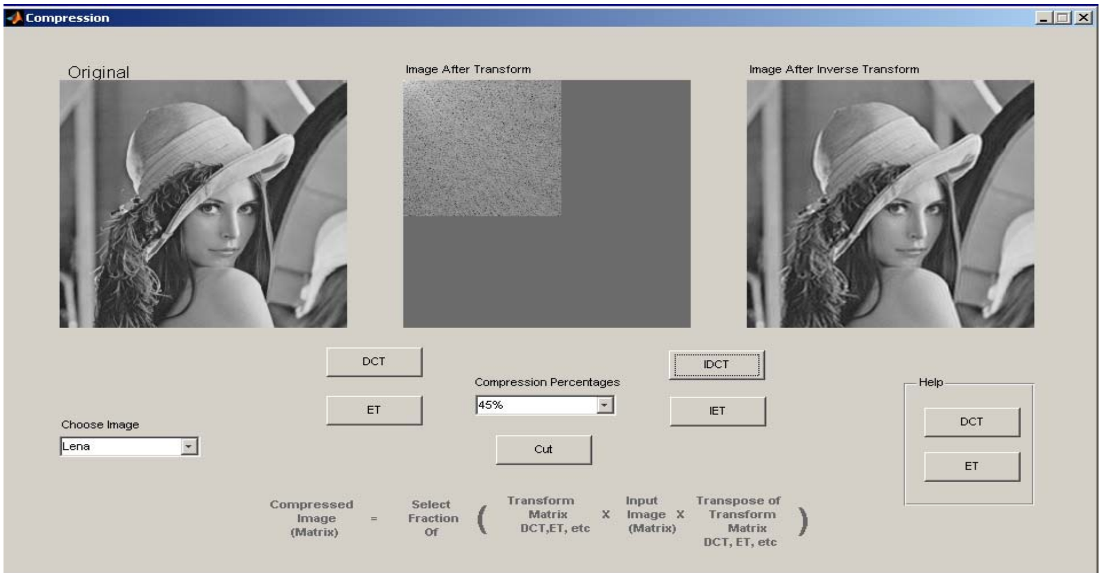

Figure 1. Interactive module explaining application of matrix algebra for image compression.

and run specific software. At the moment we developed a basic hands-on library using Matlab software from Mathworks [16] and a remote access to this library and to a conventional hands-on Datex experimentation station from Emona. The current version of hands-on Matlab-based toolbox has been specifically designed for the electrical engineering students to help them better understand the concepts covered by EA courses. This courses typically cover such topics as linear differential equations; linear algebra including matrices, vectors, determinants, linear systems of equations, matrix inverse, matrix eigenvalue problems, etc. The toolbox is an interactive software which does not require from students the Matlab programming proficiency. It includes both basic and advanced topics and relates them to real-world technologies.

For example basic modules help to understand complex numbers and sinusoids by plotting them using a handy user interface, understand the meaning of real and imaginary components for complex numbers, and amplitude, frequency and phase for the sinusoids.

The advanced labs cover topics as understanding applications of matrix algebra concepts (multiplication, inversion, transposition, eigenvalue decomposition, etc) for modern concepts such as "Spectra Estimation", "Compression", "Equalization" modules etc.

- **Spectra Estimation:** This module illustrates the usage of matrix multiplication for spectra estimation used in many engineering problems for frequency domain analysis of a signal. The signal can be transformed to the frequency domain by performing Discrete Fourier Transform (DFT). The N-point DFT can be defined through matrix multiplications. DFT transform matrix elements of size N is defined as follows

$$\left\|\mathbf{W}_N\right\|^{nk} = \frac{1}{\sqrt{N}} e^{-2j\pi nk/N} \tag{1}$$

For one dimension DFT the input signal $\mathbf{X} = (x_0, x_1, \ldots, x_{N-1})$ is multiplied to the transform matrix to obtain the transformed (output) signal $\mathbf{Y} = (y_0, y_1, \ldots, y_{N-1})$ in the frequency domain as shown in equations (2) and (3).

$$\mathbf{Y}{=}\mathbf{W}_{\mathrm{N}} \cdot \mathbf{X} \tag{2}$$

or

$$\begin{bmatrix} y_0 \\ y_1 \\ y_2 \\ \vdots \\ y_{N-1} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & w & w_N^2 & \cdots & w_N^{N-1} \\ 1 & w_N^2 & w_N^4 & \cdots & w_N^{2(N-1)} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & w_N^{N-1} & w_N^{2(N-1)} & \cdots & w_N^{(N-1)(N-1)} \end{bmatrix} \cdot \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ \vdots \\ x_{N-1} \end{bmatrix} \tag{3}$$

The Inverse DFT (IDFT) is computed using inverse DFT matrix which is transposed and conjugated DFT matrix due to orthogonality (4).

$$\mathbf{X}{=}\mathbf{W}_N^{-1} \cdot \mathbf{Y} = \mathbf{W}_N^{*T} \cdot \mathbf{Y} \tag{4}$$

Using "Spectra Estimation" module users are able to choose signal, such as sinusoid, sinc, rectangular or other typical signal, from the signal list, perform DFT and visualize the signal in the frequency domain.

- **Compression Module (Figure 1).** This application shows the usage of matrix multiplication, transposition, inversion and eigen decomposition for compression of images similar to JPEG compression format. Compression can be performed by transforming signal (image) to the

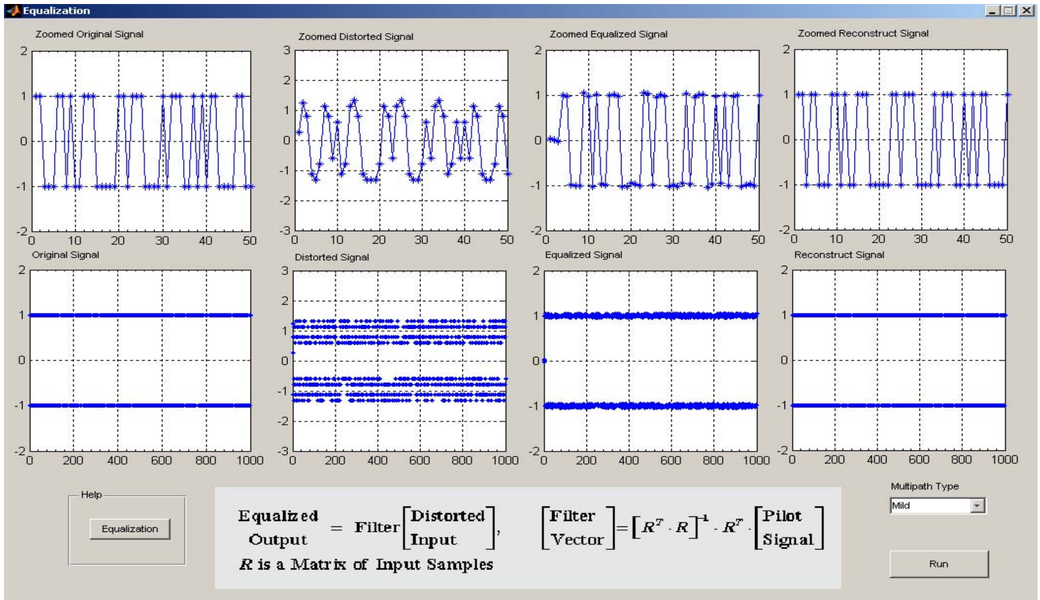

Figure 2. Equalization module explains the matrix algebra application for wireless communications.

frequency domain, using Discrete Cosine Transform (DCT) or a transform based on eigen decomposition (ET) and transform back to the time domain after cutting down the fraction of the low-energy signal in the frequency domain. The N-point DCT transform can be defined through matrix multiplications as follows:

$$\|\mathbf{C}_N\|^{nk} = \begin{cases} \dfrac{1}{\sqrt{N}} & k=0, 0\le n\le N-1 \\ \sqrt{\dfrac{2}{N}}\cos\left(n+\dfrac{1}{2}\right)\dfrac{\pi k}{N} & 1\le k\le N-1, 0\le n\le N-1 \end{cases} \quad (5)$$

For one dimension DCT the input signal $\mathbf{X}=(x_0,x_1,\ldots,x_{N-1})$ is multiplied to the transform matrix to obtain the transformed (output) signal $\mathbf{Y}=(y_0,y_1,\ldots,y_{N-1})$ in the frequency domain. One and two dimension DCTs are shown in equations 6 and 7 respectively.

$$\mathbf{Y}=\mathbf{C}_\mathrm{N}\cdot\mathbf{X} \quad (6)$$

$$\mathbf{Y}=\mathbf{C}_\mathrm{N}\cdot\mathbf{X}\cdot\mathbf{C}_\mathrm{N}^\mathrm{T} \quad (7)$$

The Inverse DCT (IDCT) is computed using inverse DCT matrix which is transposed DCT matrix due to orthogonality. One and two dimension IDCTs are shown in equations (8) and (9) respectively.

$$\mathbf{X}=\mathbf{C}_N^{-1}\cdot\mathbf{Y}=\mathbf{C}_N^T\cdot\mathbf{Y} \quad (8)$$

$$\mathbf{X}=\mathbf{C}_N^T\cdot\mathbf{Y}\cdot\mathbf{C} \quad (9)$$

Eigenvalue Transform matrix is composed of eigenvalue vectors and is obtained from eigenvalue decomposition of certain (autocorrelation) matrices. An example eigenvalue transform is the one obtained from the following matrix (autocorrelation matrix of first order Markov process)

$$\mathbf{R}_N = \begin{bmatrix} \rho^0 & \rho^1 & \rho^2 & \cdots & \rho^{N-1} \\ \rho^1 & \rho^0 & \rho^1 & \cdots & \rho^{N-2} \\ \rho^2 & \rho^1 & \rho^0 & \cdots & \rho^{N-3} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \rho^{N-1} & \rho^{N-2} & \rho^{N-3} & \cdots & \rho^0 \end{bmatrix} \quad (10)$$

where ρ is a constant, and $0<\rho<1$. A matrix $\mathbf{V}_N$ composed of eigen vectors obtained from the eigenvalue decomposition can be used as an orthogonal transformation similar to DCT matrix described earlier. This transform is also called Karhunen-Loeve transform (KLT). For eigenvalue decomposition matrices $\mathbf{R}_N, \mathbf{V}_N$ are related as shown in equation (11).

$$\mathbf{R}_N=\mathbf{V}_N\cdot\mathbf{\Lambda}_N\cdot\mathbf{V}_N^T \quad (11)$$

Where $\mathbf{\Lambda}_N$ is a diagonal matrix with eigenvalues on the diagonal and $\mathbf{V}_N$ is matrix composed of eigenvecors. For one dimension ET the input signal $\mathbf{X}=(x_0,x_1,\ldots,x_{N-1})$ is multiplied to the transform matrix to obtain the transformed (output) signal $\mathbf{Y}=(y_0,y_1,\ldots,y_{N-1})$ in the frequency domain. One and two dimensional transformations are shown in equations (12) and (13) respectively.

$$\mathbf{Y}=\mathbf{V}_\mathrm{N}\cdot\mathbf{X} \quad (12)$$

$$\mathbf{Y}=\mathbf{V}_\mathrm{N}\cdot\mathbf{X}\cdot\mathbf{V}_\mathrm{N}^\mathrm{T} \quad (13)$$

The Inverse ET (IET) is computed using inverse ET matrix which is transposed ET matrix due to

TABLE 1
REMOTE DESKTOP SYSTEMS

Products	File Transfer	Chat	Compatibility	Security Level	Software Installation for Client	Multi-User Support	Response Delay	Prices
Remote Desktop Connection	Yes	No	Win/Mac (Viewer only)/ Linux (Viewer only)	High	Yes	No	Medium	Free
TeamViewer	Yes	Yes	Win/Mac	High	No	Partially Yes	Medium	Medium
GoToMyPc	Yes	Yes	Win/Mac/Linux/Unix	High	Yes	No	High	High
LogMeIn Free	No	No	Win/Mac	High	No	No	High	Free
LogMeIn Pro	Yes	Yes	Win/Mac	High	No	No	High	High

orthogonality. One and two dimension IETs are shown in equations (14) and (15) respectively.

$$\mathbf{X}=\mathbf{V}_N^{-1}\cdot\mathbf{Y}=\mathbf{V}_N^{T}\cdot\mathbf{Y} \tag{14}$$

$$\mathbf{X}=\mathbf{V}_N^{T}\cdot\mathbf{Y}\cdot\mathbf{V} \tag{15}$$

Using the user interface students can apply these transformations to real images and compress them in a concept which is basic for many compression standards such as JPEG, MPEG, etc.

- **Equalization:** This application demonstrates an example of using matrix multiplication, transposition, and inversion for improving the quality of signal reception by compensating signal propagation distortions in wireless communication. A prearranged training sequence $\mathbf{S}$ is assumed to be known at the receiver. The received signal is a distorted version of $\mathbf{S}$ due to channel errors. The goal of the equalizer is to find a finite impulse response filter (FIR), $\mathbf{F}$, such that the output of the equalizer is approximately equal to the known source, though possibly delayed in time. $\mathbf{S}$ is shown in equation (16).

$$\mathbf{S}=\begin{bmatrix} s[n+1] \\ s[n+2] \\ s[n+3] \\ \vdots \\ s[p] \end{bmatrix} \tag{16}$$

Received signal samples $r[n]$ are collected in a matrix $\mathbf{R}$ as follows

$$\mathbf{R}_N=\begin{bmatrix} r[n+1] & r[n] & \cdots & r[1] \\ r[n+2] & r[n+1] & \cdots & r[2] \\ r[n+3] & r[n+2] & \cdots & r[3] \\ \vdots & \vdots & \ddots & \vdots \\ r[p] & r[p-1] & \cdots & r[p-n] \end{bmatrix} \tag{17}$$

$\mathbf{R}$ has a special structure, that the entries along each diagonal are the same. It is known as a Toeplitz matrix. The Least-Squares optimal solution for the equalizer coefficients is shown in (18).

$$\mathbf{F}=\left(\mathbf{R}^T\cdot\mathbf{R}\right)^{-1}\cdot\mathbf{R}^T\cdot\mathbf{S} \tag{18}$$

The matrix form of the equalizer's output is shown in (19) and (20).

$$\mathbf{Y}=\mathbf{R}\cdot\mathbf{F} \tag{19}$$

or

$$\begin{bmatrix} y[n+1] \\ y[n+2] \\ y[n+3] \\ \vdots \\ y[n] \end{bmatrix}=\begin{bmatrix} r[n+1] & r[n] & \cdots & r[1] \\ r[n+2] & r[n+1] & \cdots & r[2] \\ r[n+3] & r[n+2] & \cdots & r[3] \\ \vdots & \vdots & \ddots & \vdots \\ r[p] & r[p-1] & \cdots & r[p-n] \end{bmatrix}\cdot\begin{bmatrix} f_0 \\ f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} \tag{20}$$

With the "Equalization" application users are able to choose the multipath distortion type from the multipath list, perform equalization by explained algorithm and visualize the original, the distorted, the equalized and the reconstruct signals. The "Equalization" module is shown in Figure 2.

III. REMOTE DESKTOPE TECHNOLOGIES

With the continued expansion of The Internet and Web technologies Remote Desktop (RD) became a widely used tool in modern academic work. Instructors explain class topics and help students on specifically equipped computers which are accessed remotely. Nowadays it is widely used in distance learning classes [4]-[8].

Early RD technologies were designed for remote computer management, which involved command line interfaces and access through web pages without seeing the same desktop view as a local user. Along with the system development the networked computers' capabilities increased and it became feasible to use Graphical User Interfaces (GUI) in remote desktop technologies. In the beginning Microsoft Corporation introduced remote desktop access only for their servers in Windows NT 4.0 Terminal Server Edition. Terminal Server was then refined in the Windows 2000 Server Series. Finally, Remote Desktop was expanded in Windows XP for Remote Assistance where a user can invite any other user to assume complete control over his/her system through Internet [10]. The RD system from Microsoft is available on all machines with Windows XP and newer Windows versions, and is also available in Microsoft web page for free download. It is compatible only with Microsoft Windows operation systems. Besides Windows RD there are many RD systems present in the market with different capabilities. The Table 1 shows the general descriptions of some of them.

- **TeamVeiwer** [11]: It provides the client instant control of the computer or server desktop over Internet. It is available either for Microsoft or Mac platforms. Furthermore it fully supports the connectivity between different platforms. It includes full encryption based on the https/SSL standard for enhanced security. TeamViewer has the capability to define the level of user access to the computer. It is usually installed software on the server side. Clients are able to connect to the server from any computer running the software without permanent installation. Other attractive TeamViewer's features are file transfer, chat, the ability to define access levels and multi-user screen view. One of the bottlenecks of the software is the multi-user access scheduling. The system gives complete access to the client, i.e. all the clients can have complete control of the mouse and keyboard at the same time, which makes the system partially unsuitable for multi-user use. TeamViwer software is currently available in the market for free, but only for private use. As of today it costs $699 for lifetime commercial use [10].
- **GoToMyPc** [11]: This application was developed by Citrix Corporation. It provides a connection between client and server by using the Internet through the intermediate GoToMyPc server, which causes additional delays during client-server connection. GoToMyPc software needs to be installed on the server side. The client once installs a small program on his computer, and connects to the server by visiting the webpage and entering a previously specified username and password using any web browser. It is available for Windows, Mac, Unix and Linux. GoToMyPc secures communicated data using Advanced Encryption Standard (AES) encryption. It gives the client either full access to the server or screen view ability. Guests are given determined levels of access by invitation emails sent from remote desktop session organizer. GoToMyPc has file transfer, chat, remote sound, files printing and drawing abilities. However the lack of multi-user ability and the software installation on the client side is a bottleneck for academic use. As of today GoToMyPc costs $179/year [11].
- **LogMeIn** [12]**:** This free RD software connects the client to the server directly through the Internet. LogMeIn software needs to be properly installed on the server. The client directly connects to the server by visiting the LogMeIn webpage and entering a previously specified username and password using any web browser. LogMeIn is compatible with Windows or Mac platforms and uses a high level SSL end-to-end 128 to 256-bit encryption. LogMeIn gives the client full access to the server. "LogMeIn Free" software has chat, remote control and desktop viewing abilities. "LogMeIn Pro" version has additional capabilities of remote sound, file transfer, drag and drop files, sharing and the capability to organize meetings where the guests, invited to the meeting by receiving a special link from the meeting organizer, can obtain complete access over the server or just screen view abilities. As of today LogMeIn Pro has a monthly charge of $19.75 [12].

IV. REMOTE INTERNET-BASED LABARATORY

The laboratories provide valuable experience in engineering and technology education. However, such laboratories are not always necessarily available to students. Virtual laboratories are a possible alternative to traditional laboratories, and they are already used in distance learning education in several universities.

Remote Desktop technologies were chosen as a solution. Using Remote Desktop (RD) technologies the students can directly access the server which connected to the bundle and controls its operation. As a case study the TeamViewer is used as RD software.

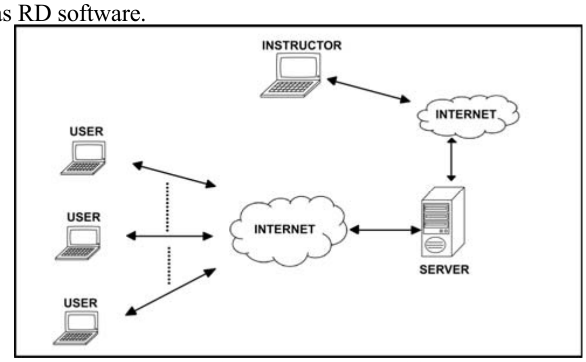

Figure 3. Block diagram of the remote over-internet lab setup.

The TeamViewer software gives the client access to all programs on the server. The Windows XP professional edition is used as the operation system on the server. The security policy tool from Windows is used to control access to the operating system and the programs, such as MATLAB. All the experiments can be done remotely through Internet. It also can provide connectivity between students and instructor during the online experiments by using the TeamViewer's software chat functionality. The block diagram of the system is shown in Figure 3.

V. ASSESSMENT RESULTS

The survey about distance learning systems in education has been conducted in classroom setting before using the remote Internet-based laboratory. The responses from the students have been collected and analyzed. The poll results are graphically shown in Figure 4. All students use the Internet regularly (100%) and most of them (92.3%) have access to it at home. Less than the half of the class (38.5%) used distance learning systems in their education before, but most of the class (84.6%) would like to use it in future education.

The remote Internet-based laboratory sessions are offered in applied engineering 1 class which is a catalog Collage of Engineering department's course at the University of Texas at San Antonio. The applied engineering analysis I course covers aspects of basic topics, such as Laplace transform, transform derivatives and integrals, matrices and vectors, matrix multiplication, solution of the linear systems, inverse of

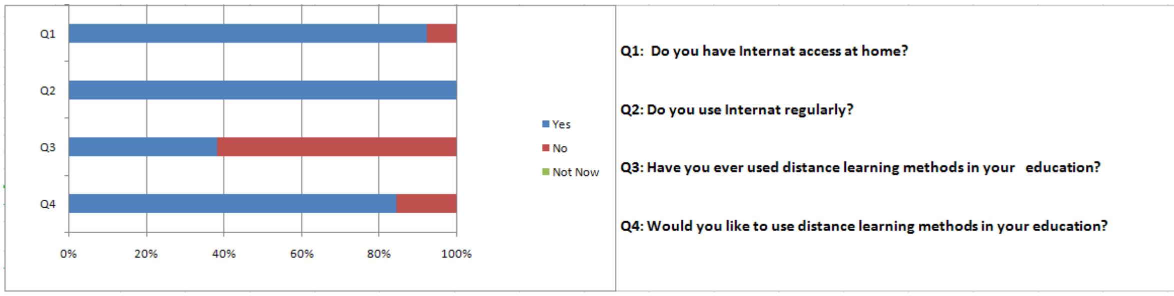

Figure 4. Questions related to distance learning systems

matrix, eigenvalues and eigenvectors and diagonalization The UTSA toolbox was presented during the class and the reviews from the students were collected before using the system. The labs were successfully completed by the student as lab assailments by using the remote Internet-based laboratory. The results from the reviews are shown in Figures 4 and 5.

As shown in Figure 5, the responses from the students were mostly positive. The majority (56.6 %) expected that the virtual lab would be related to class topics. The majority of the class (71.1%) concluded that it helped them to better understand the topics discussed in the class. Also majority consensus was that the virtual lab helped the students to get applied knowledge (89.4%), and that it improved their motivation (89.4%). The large percentage of the students (63.9%) also expected after using the system to have more virtual lab experiments in their future education. The impression of the students regarding on the usability of the system was 42.3%, 43.6%, 10.1% and 4% respectively "Excellent", "Good", "Fair" and "Bad". The overall virtual lab tutorial and virtual lab are assessed respectively as "Excellent" by 38.9% and 40.2% of students, "Good" by 48.9% and 52.3% and "Fair" by 12.2% and 7.5% of users. The results of the polls are shown in Figures 5 and 6.

VI. Conclusion

In this paper a remote laboratory design concept for studies in engineering classes is studied. The available remote desktop (RD) software is reviewed. As a case study RD software Teamviewer is used for virtual experiments. The system has been used in classroom setting; the user assessment data are collected and analyzed showing a strong interest and potential in experimentation. This is especially valuable for those students who cannot physically attend lab sessions to obtain hands-on experience.

Despite of the fact that the majority of the students had not used distance learning systems before, they certainly would like to use them in the future. Most of the class, after using the system, opined that it helped them to better understand syllabus topics and gain more applied knowledge. Similar to the described remote toolbox setup a remote over-internet lab is established using Datex module from Emona [17], see Figure 7. Assessment results are similar to data obtained for the Matlab toolbox.

Acknowledgement

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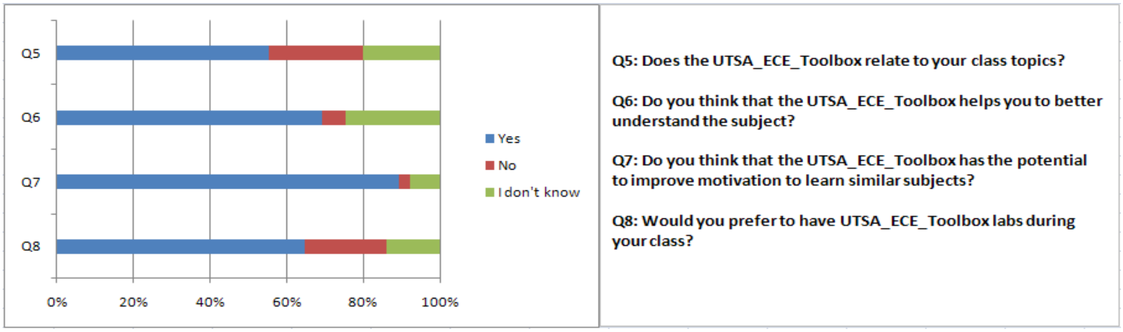

Figure 5. Questions related to Virtual Lab system.

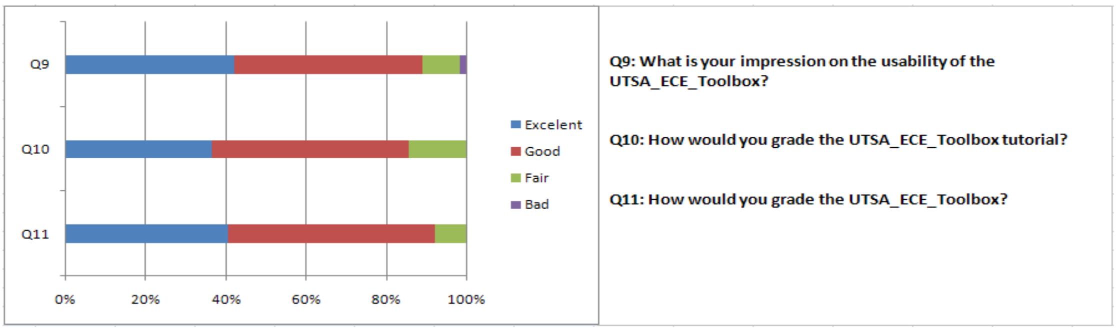

Figure 6. Questions related to Virtual Lab system.

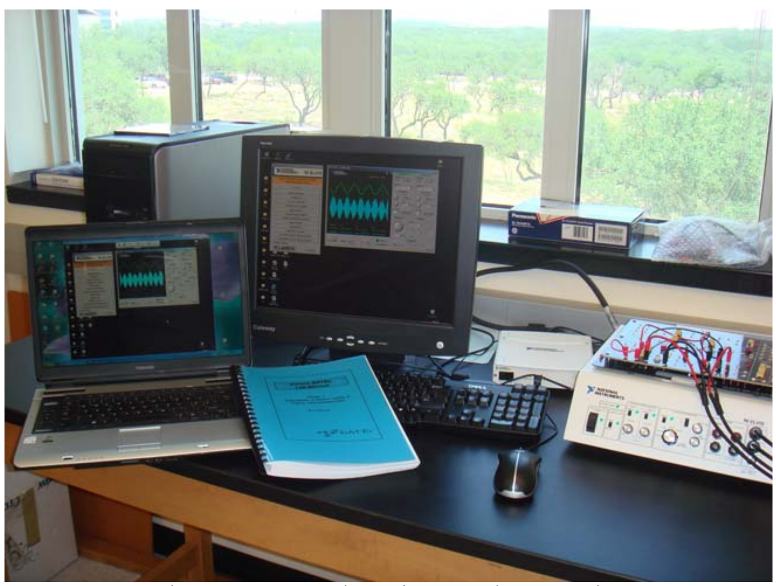
Figure 7. Remote experimentation setup using Datex units.