DESIGN AND EVALUATION OF A WEB BASED VIRTUAL DSP LABORATORY USING GUI AND HTML

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تصميم وتقويم لمختبر DSP أفتراضي باستخدام صفحات الويب عن طريق GUI و HTML

الخلاصة :
التعليم الهندسي يجب ان يشترك فيه المختبر العملي وذلك لأسناد الجانب النظري وتطوير مهارات الطالب .ان لهذه المختبرات بعض المشاكل مثل الكلفة العالية جدا كما أنها تتطلب أشراف بالاضافة الى المحددات الزمنية والمكانية. يقدم البحث الحالي تصميم وتقويم لمختبر افتراضي تم بناءه باستخدام صفحات الويب لتدريس مادة معالجة الاشارة الرقمية (DSP) لطلبة الدراسات الاولية في قسم الهندسة الكهروميكانيكية في الجامعة التكنولوجية. التجارب المختبرية المنفذة ستتظمن أنواع الاشارات ، نظرية النمذجة ، متسلسلة فورير ، متسلسلة فورير المركبة، محول فورير، معكوس محول فورير، محول فوريرالمتقطع، محول فورير السريع (FFT) ، الألتفاف ، محول-Z ، المرشحات الرقمية . واجهة المستخدم الرسومية (GUI) المميزة لبرنامج (MATLAB) تم استخدامها لاعطاء الطالب طريقة سهلة ومرئية في ادخال البيانات بينما تم استخدام لغة ترميز النصوص التشعبية (HTML) في توضيح الأسس النظرية. لقد تم أستخدام الاستفتاء ومقياس ليكرت ذي الخمس نقاط في أجراء عملية التقييم . أظهرت نتائج التقويم أن مختبر (DSP) الافتراضي المقترح ساعد الطلبة في فهم مباديء (DSP) ، كما أضاف تأثيرات أيجابية في أداء ورغبات الطلبة بالمقارنة مع طرق التعليم التقليدية.

ABSTRACT:
Engineering education should involve practical laboratory to support theoretical foundation and develop student skills. These hands on laboratories have some disadvantages such as expensive, supervision required, time and place restrictions. This paper presents design and evaluation of a web based virtual laboratory for teaching Digital Signal Processing (DSP) to undergraduate students in Electromechanical Engineering Department at the University of Technology. The laboratory experiments includes classification of signals, sampling theorem, Fourier series, complex Fourier series, Fourier transform, inverse Fourier transform, discrete Fourier transform, Fast Fourier Transform (FFT),convolution , Z-transform, and digital filters. Graphical User Interface (GUI) feature of MATLAB have been used to provide students with a friendly and visual approach in specifying input parameters while Hyper Text Markup Language (HTML) was used to illustrate theoretical foundations. The questionnaire survey and five point Likert scale are utilized in performing evaluation. Results of this evaluation showed that the proposed virtual DSP laboratory was helped students in DSP concepts, made positive effects on students' achievements and attitudes when compared to traditional teaching methods.

KEYWORDS: Engineering Education, Virtual laboratory, DSP, Internet, GUI, HTML

I.INTRODUCTION

Digital Signal Processing (DSP) course have been taught at Electromechanical Engineering Department, University of Technology. This course involves a large number of complicated mathematical equations that need some explanation to appreciate underlying concepts. The hands on laboratory can be used to help students in illustrating these conceptual concepts and developing their practical skills [Feisel, 2005]. However, these hands on laboratories have some drawbacks such as expensive, supervision required, time and place restrictions [Nedic, 2003; Balamuralithara,2008].

In the last decade, there has been a growing trend in the utilization of simulation-based virtual laboratories for undergraduate students in the engineering and science colleges. However, these modern laboratories are cost effective [Wolf,2009], increase the student performance [Macias,2001;Campbell,2004], encourage self learning by providing hands on activities [Chu,1999], and suitable for use in distance learning when the World Wide Web (WWW) access is available [Agrawal,2008]. Several authors have presented researches in engineering education covered a wide range of disciplines, such as electrical engineering [Tanyildizi, 2009], mechanical engineering [Gil, 2000], control engineering [Uran, 2008], chemical engineering [Murphy,2002] , and civil engineering [Budhu,2002], while other authors were introduced researches in science education [Stone,2007; Jimenez,2003].

Nowadays, virtual laboratory is used as prevalent alternative to the traditional hands on laboratory and must be performed the same learning outcomes. However, some universities already have been started to utilize virtual laboratories in the engineering colleges such as John Hopkins University in USA [Karweit], Polytechnic University of Valencia in Spain [Tejedor,2008], Warsaw University of Technology in Poland [Sobczuk,2007], University of Pisa in Italy [D'andrea,2008], and many others.

Virtual laboratories can be broadly classified into three types: **First**, simulation laboratories that use software and web server to emulate the physical laboratory [Nedic, 2003; Balamuralithara,2008] . In these laboratories, the users can modify the parameters of the simulation and observe the changes in the system. **Second**, remote laboratories allow users to view, control and acquire data from a physical experiment through a web server [Nedic, 2003; Balamuralithara,2008]. **Third**, recorded experiments allow users to view actual experiments and work with real data [Sidhu,2010;Chan,1998].

Virtual laboratory has been assessed by several researchers and they have concluded that there is no significant difference in student learning results from using virtual learning laboratory versus physical laboratory [Campbell, 2002]. However, complete removal of physical laboratory from the syllabus would not be accepted by students according to their feedback [Wiesner,2004].

This paper presents design and evaluation of web-based virtual DSP laboratory developed by the authors as an instructional tool for undergraduate students at the Electromechanical Engineering Department /University of Technology [Burak ,2008]. The developed virtual laboratory has been evaluated by (30) undergraduate students and (5) lecturers from the Electromechanical Engineering Department / University of Technology.

II. LABORATORY IMPLEMENTATION

The implementation of the virtual DSP laboratory required a variety of tools to facilitate the use of different presentation methods. Two important software programs in the development of the virtual DSP laboratory included Hyper Text Markup Language (HTML) and MATLAB Graphical User Interface (GUI).

1) Hyper Text Markup Language (HTML)

The HTML version 4 has been used to demonstrate theory information of DSP in a web page form. The main web page of the developed virtual DSP laboratory will begins with the presentation screen shown in Fig. 1. As can be seen from this main web page, the student can study and perform required experiments in any of the following topics by clicking on the button **1)** Classification of signals, **2)** Sampling theorem, **3)** Fourier series, **4)** Complex Fourier series, 5) Fourier transform, **6)** Inverse Fourier transform,**7)** Discrete Fourier transform, **8)** Fast Fourier Transform (FFT), **9)** Convolution,**10)** Z-transform, and **11)** Digital filters. These topics constitute the core structure of DSP course that is presently introduced to the undergraduate students in Electromechanical Engineering Department.

The HTML code for the main web page is generated dynamically through the Hypertext Preprocessor (PHP) as shown in Fig.2. The PHP code is interpreted by a web server to generate the web page of virtual DSP laboratory. The PHP is available as a processor for most modern web servers and as a standalone interpreter on most operating systems and computing platforms.

2) Graphical User Interface

The Graphical User Interface (GUI) is a MATLAB based toolbox with the following features: **1)** User friendly environment, (drag and drop) approach, **2)** Developing a model needs short time **3)** No knowledge in computer programming required to perform an experiment, **4)** The student can set the desired parameters in any experiment and plot result using mouse clicks. Therefore, GUI has been utilized to perform mathematical calculation for any DSP model used herein in this paper. MATLAB implements GUI through Graphica1 User Interface Development Environment (GUIDE) which allows the user to create figure windows containing graphical objects. In order to start create models in GUI type GUIDE in the MATLAB prompt window that will cause appearing GUIDE program as shown in Fig.3. This window is separated equally into right side window which is called (open existing GUI) used to open an already exist model in the workspace while the left side window is called (create new GUI) which is used to build new GUI model with the help of four GUIDE templates; blank GUI, GUI with uicontrols, GUI with axes and menu, and modal question dialog.

By clicking on the blank GUI in GUI beginning window and clicking on save new figure to save model with name SIGNALS_GUI as shown in Fig.4. The component palette at the left side of the GUI layout editor contains the pushbuttons, toggle buttons, lists, menus, text boxes, and so forth components that will be used to build simulation program for stepper motor. This component palette can display with its names.

Note that due to space limitation the authors cannot presents all programming steps, for further details see [Burak]. The following are experiments of the developed virtual DSP laboratory.

Experiment (1): Classification of signals

In this experiment, the student can conducts experiment on five types of signals as shown in Fig.5. Each experiment has a menu on the left hand side includes objective, theory, example, exercise, equation, and question. The objectives of the experiment can be obtained by pressing on the objective button. The necessary information and theory bases for this experiment will displayed after pressing on the theory button as shown in Fig.6. Example button can be used to present solved example as shown in Fig.7. The exercise button is intended for conducting the required experiment on continuous, discrete time, and digital signal using GUI. The last two buttons are used for mathematical description of the experiment and to perform self test after complete experiment as shown in Fig.8 and Fig.9 respectively.

The exercise of experiment (1) shown in Fig.10 was designed in MATLAB GUI. The student can perform experiment on three different types of signals, sine, triangle and square wave. The frequency, sampling rates, and the number of bits per sample of the selected signal can be changed through using slider menu .After selection of input signal parameters, one can plot experiment results by pressing on display button.

Experiment (2): Sampling Theory

The experiment of sampling theory is shown in Fig.11. This experiment can be accessed through clicking on the sampling theory button in the main web page. The student can explore this experiment with the help of the menu on the left hand side which has six different buttons. When the student clicks on the first button, this will cause in viewing of experiment objectives while clicking on the second button will cause to display experiment theory as shown in Fig.12.

It is possible to view a number of solved examples in sampling theory through clicking on the third button as shown in Fig.13. These examples can help students to understand basic principles of sampling theorem and prepare them to practical exercise. Fig.14 shows an interactive exercise which has been developed in MATLAB GUI to deal with continuous and discrete time domain signals. Furthermore, the effects of signal aliasing can also be studied. The student can change the frequency as well as the phase for the aforementioned signals either by using slider or by entering required value in appropriate box and then observe the frequency spectrum of the signal in a three displays. A web page containing all the necessary equations for this experiment can be reached by clicking on the equation button in the left menu of experiment (2) as shown in Fig.15.Finally, in order to complete this experiment, the student should be able to correctly answer on a number of questions as shown in Fig.16.

Experiment (3): Fourier series

This experiment starts with reviewing some historical background for the famous Fourier paper as shown in Fig.17. The basic principles for representing any periodic signal by means of Fourier series were illustrated in a web page as shown in Fig. 18. It is possible to demonstrate solved examples that can be helpful to explain how to obtain coefficients in Fourier series as shown in Fig.19. From the excise menu of this experiment, the student can choose from the GUI menu one of the following signals: **1)** Square wave, **2)** Triangle wave, **3)** Ramp and Saw tooth waves, **4)** Full wave rectified sine, **5)** Full wave rectified cosine, **6)** Half wave rectified sine, **7)** Half wave rectified cosine to perform exercise in Fourier series as depicted in Fig.20. This exercise has been designed to be flexible enough in changing frequency of the selected signal by placing mouse on the slider. All the necessary equations for this experiment were prepared in web page as shown in Fig.21. For evaluation purpose the student should be passed a self test as shown in Fig.22.

Experiment (4): Complex Fourier series

In preceding experiment we have learned representation of signals by using Fourier series. Now, the advantageous to use complex representation of the sine and cosine signals we will be discussed in this experiment as shown in Fig.23.

The theory behind using complex Fourier series in the analysis of signals as a superposition of complex exponentials was introduced in a web page as shown in Fig.24. Normally, the principles of complex Fourier series rely on sophisticated equations that cannot be understood by student without solved examples as shown in Fig.25.

The exercise for this experiment has been developed in MATLAB GUI as shown in Fig.26, with the following features: **1)** There are so many built in wave forms which can be obtained by clicking on the slider to perform required experiment. **2)** Changing the amplitude, period and width of any desired signal is quite simple by using slider. **3)** There are three display windows used to observe and plot results.

All the necessary equations were given in Fig.27 while the self test was prepared using multiple choose as shown in Fig.28.

Experiment (5): Fourier Transform

This experiment addresses the use of Fourier transform in converting signals from time domain to frequency domain. The Fourier transform of continuous and discrete signals will be discussed in details. It can access this experiment by clicking on the Fourier transform button in main web page as shown in Fig.29.

A brief description of the basic ideas and theorems of Fourier transform can be obtained after clicking on the theory button as shown in Fig.30.A solved example that illustrates the power of this technique in handling signals will be available by clicking on the example button of the experiment as shown in Fig.31.

The exercise of this experiment has been developed in MATLAB GUI for use in conducting Fourier transform experiments in time domain as well as frequency domain. This exercise will be ready to start performing certain experiments after clicking on the exercise button as shown in Fig.32.

The are many features has been added to facilitate perform this exercise such as variety of signals, change of signal magnitude and phase in time domain as well as frequency domain is very simple because it is based on slider, has four display to monitor results uses two for time domain and the rest for frequency domain.

The derivations of Fourier transform equations and some explanation can be found by clicking on the theory button as shown in Fig.33. The student should perform multiple-choice self-test as shown in Fig.34. The grading of this test appears after complete test.

Experiment (6): Inverse Fourier Transform

The inverse Fourier transforms used to convert frequency series of complex values into the original time series. We have been developed an experiment to study this conversion and it can be get access to this experiment by clicking on inverse Fourier transform button as shown in Fig.35.In order to get more information on the theory basis of inverse Fourier transforms press on the theory button as shown in Fig.36.

There is a solved example which may increase student perception can be viewed by clicking on the example button as shown in Fig.37.

The MATLAB GUI has been used to develop inverse Fourier transform exercise in such away the student can perform experiment in short time with clear steps. To start this exercise you should press on the exercise button as shown in Fig.38.The essential equations and derivation for inverse Fourier transform could be very helpful in underline some basic concepts. Therefore, these equations can be obtained if we clicking on the equation button as shown in Fig.39.

Evaluating what students have learned throughout this exercise can be accomplished in multiples choose test which can be accessed by clicking on the question button as shown in Fig.40.

Experiment (7): Discrete Fourier Transform

There are many applications that use Discrete Fourier Transform (DFT) to perform a specific task. Generally, the DFT is difficult topic due to their inherent mathematical equations. Therefore, we have been developed this experiment to help student in understanding basic concepts of DFT. To start this experiment, click on the DFT button in the main web page as shown in Fig.41.We have been designed a series of options on the left hand side of this experiment which give access to the different sections, for example to get information on theory basis, click on the theory button as shown in Fig.42.

It is possible after complete reading theory basis to view some solved example on DFT concepts by clicking on the example button as shown in Fig.43. The exercise for this experiment has been developed in MATLAB GUI to give students more insight into DFT and remove any confusion might be happen due to their misunderstanding of complicated mathematical equations.

The exercise can launch by clicking on the exercise button as shown in Fig.44. There are four types of signals could be used to perform experiments such as sine wave, square wave, triangle wave, and saw tooth wave. These signals can be selected by placing cursor at the signals menu. Also, the number of cycles in the selected signal can be changed similarly. To get detailed mathematical equations and derivation of DFT press on the equations button as shown in Fig.45. The end of this experiment include multiple choose test that should be performed by any participated student and this test could be launched by clicking on the question button as shown in Fig.46. If the students did not get good score in this test, they should repeat experiment again.

Experiment (8): Fast Fourier Transform

The Fast Fourier Transform (FFT) is a mathematical approach aims to reduce computational power of DFT. The FFT have a wide range of applications in communication, biomedical engineering, and radar systems. Therefore, the FFT has become an invaluable analysis tool and every enrolled student in this course should have good expertise to use this tool. Fig.47 shows FFT experiment which can be launched to perform experiments by clicking

The student can obtain more information on basic concepts of FFT to increase intuitive development by clicking on the theory button as shown in Fig.48. An 8-points solved example was used to intuitively justify the FFT algorithm. This example will be launched by pressing on the example button as shown in Fig.49. From this example one should be note that the FFT owes its success to the fact that the algorithm reduces the number of multiplications and additions in the computation. By clicking on the exercise button the student can start performing experiments on FFT as shown in Fig.50. The graph of FFT spectrum can be displayed on the three small windows. Fig.51 shows part of the FFT equations which can be browsed by clicking on the equation button. As with the preceding experiments, the student should answer on a number of questions in order to complete this experiment and this test could be started by clicking on the question button as depicted in Fig.52. The minimum score to pass this experiment is 50 percent.

Experiment (9): Convolution

The convolution can be defined as a mathematical operation on two functions f and h, producing a third function that is viewed as a modified version of one of the original functions. The convolution is of great importance due to its wide range of applications from signal and image processing to acoustics and probability theory. Fig. 53, shows the convolution experiment which can be launched by pressing on the convolution button. When the student pressing on the theory button a web page as shown in Fig.54 which gives detailed information on convolution fundamentals.

A solve example can be accessed by clicking on the example button as shown in Fig.55. The purpose of this example is for assistance in learning convolution. Now, the student can perform experiment on convolution by pressing on the exercise button as shown in Fig.56. It is possible to choose the desired signal to conduct convolution from a button called get x(t). Three displays were used to monitor two input signals, multiplication and convolution results, respectively. The equations of convolution theorem are shown in Fig.57. The self test question of this exercise is shown in Fig.58.

Experiment (10): Z-Transform

The Z-transform is very powerful mathematical tool used in design, analysis and monitoring of systems. The importance of this experiment comes from the fact that knowledge of Z-transform is essential to design of digital filters. This experiment will be started by clicking on the Z-transform button as shown in Fig.59. In this experiment, the definition of the Z-transform from the Laplace transform of a discrete-time signal as well as the properties of Z-transform is presented.

A useful aspect of the Z-transforms is the representation of a system in terms of the locations of the poles and the zeros of the system transfer function in a complex plane can be found by clicking on the theory button as shown in Fig.60. Several examples illustrating the physical significance of Z-transform and their effect on the frequency response of a system is available by clicking on the examples button as depicted in Fig.61.

An interactive and user friendly software program has been developed in MATLAB GUI to conduct experiments in z-transform. This exercise can be accessed by pressing on the exercise button as depicted in Fig. 62. The developed Z-transform exercise has the following features: **1)** Students can add poles and zeros by mouse click or by input required poles and zeros in box. **2)** Poles and zeros can be moved around the Z-plane by selecting them and pulling the mouse around, with the instant update of the system frequency impulse response. **3)** System transfer function or filter coefficients were used to indirectly specify poles and zeros. The derivation of the so-called Z-plane, and its associated unit circle, from sampling the S-plane of the Laplace transform can be accessed by pressing on the equations button as shown in Fig.63. A multiple choose test should be performed by students to measure learning at the various cognitive levels. This test can be started by clicking on the question button as shown in Fig.64.

Experiment (11): Digital Filter

This is the last experiment in the developed virtual DSP laboratory. In this experiment, the students can conduct experiments on the digital filters for both Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) by clicking on the digital filter button as shown in Fig.65.

A digital filter is an electronic filter usually linear used in removing undesirable elements of a signal or compensating for some frequency dependent distortion within the signal. For more information on these filters as well as advantageous and disadvantageous can be reached by clicking on the theory button as depicted in Fig.66. Numerous numbers of solved examples in digital filters have been added into this experiment to help students in understanding theoretical concepts. These examples will be viewed by pressing on the example button as shown in Fig.67.

The exercise of this experiment will be started after pressing on the exercise button as shown in Fig.68. From this figure, it is clear that, the upper GUI model can be used to perform FIR filter experiments while the middle GUI model used to conduct IIR filter experiments. The features of the developed exercise can be summarized as: **1)** Students easily can select filter type to conduct experiment such as a low pass, high pass, band pass, and band stop filter from the popup menu. **2)** Allow to change filter order, frequency (1) and frequency (2) using the silder. **3)** Options, such as rectangular, bartlett, hamming, hanning, and blackman windowing functions are also available to applied using slider. **4)** The pole- zero placements and the magnitude of the filter can be observed by using two display screens (see lower figure in Fig.68).The mathematical equations of FIR and IIR filters can be obtained by clicking on the equations button as shown in Fig.69. The student should be exposed to a test consists of multiple choice questions each question has two answers. This test could be started by pressing on the question button as shown in Fig.70.

III-Evaluation

The developed Virtual DSP Laboratory has been evaluated by fifteen final year students (10 males and 5 females). All the participants in the survey were from Electromechanical Engineering Department, University of Technology. The Likert scale will be used to analyze the results of the questionnaire survey. This scale measure either positive or negative response to a statement. The responding to a Likert questionnaire item, respondents specify their level of agreement to a statement. A recent empirical study found that a five point or seven point scale may produce slightly higher mean scores relative to the highest possible attainable score, compared to those produced from a ten point scale, and this difference was statistically significant [Dawes,2008]. Therefore, in this paper, the students were asked in questionnaire survey to provide their degree of agreement using five-point Likert scale (strongly disagree **1**, disagree **2**, neither agree nor disagree **3**, agree **4**, and strongly agree **5**).

The evaluation statements were designed to assess the students' attitudes toward using the developed virtual DSP laboratory in the course, make sure that it's achieve course objectives, and to determine if the students would find the presentation and the contents of the developed virtual DSP laboratory beneficial to their performance, learning, and understanding in the laboratory course.

Means and standard deviations of the survey results are presented in Table 1. As indicated in Table (1) the students generally agreed that the developed virtual DSP laboratory provides a convenient environment for learning. It was also confirmed that developed virtual DSP laboratory is fairly easy to use in the sense of moving around different menus rapidly. Furthermore, they were able to take as much time as they wished to review the material. The best part of developed virtual DSP laboratory turned out to be, as intended, its user-friendly environment and easy accessibility. Majority of students thought that the virtual laboratory was helped them to get a better understanding of signal processing and that they were able to visualize some of the concepts.

Conclusions

In this paper, a web based virtual DSP laboratory has been developed in MATLAB GUI and HTML to enhance the understanding of concepts taught in the undergraduate DSP course. The proposed virtual laboratory is affordable, interactive, and can be used in distance learning via using World Wide Web (WWW). Furthermore, offers an excellent and suitable platform to prepare undergraduate students before they are going into the actual laboratory.

There are 11 experiments have been performed using the developed virtual DSP laboratory and all of these experiments were selected from the curriculum of the Electromechanical Engineering Department /University of Technology. A methodology for evaluation of developed virtual DSP laboratory based on five point Likert scale was outlined. The results of questionnaire survey indicate that the majority of the students felt that the developed virtual DSP laboratory was beneficial in understanding of DSP algorithms, make learning an enjoyable experience and it had further aroused their interests. It is expected that the virtual laboratories as promising technology will increasingly use in engineering and sciences colleges to complement hands on laboratories but not to substitute them.

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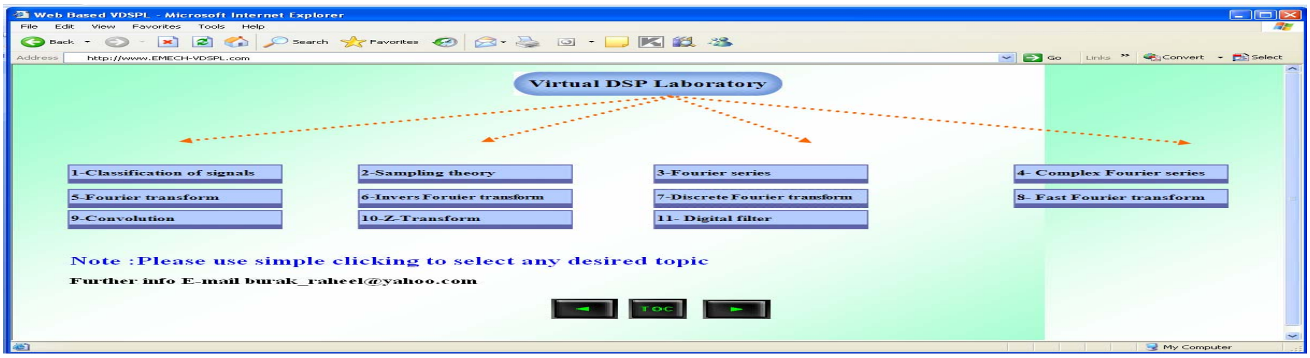

Fig.1 Main web page of virtual DSP laboratory.

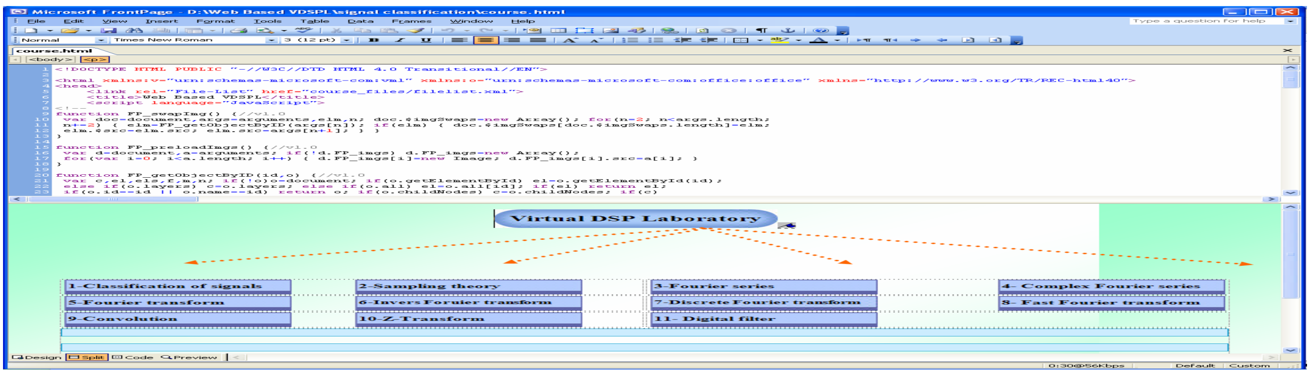

Fig.2 HTML code of the main web page.

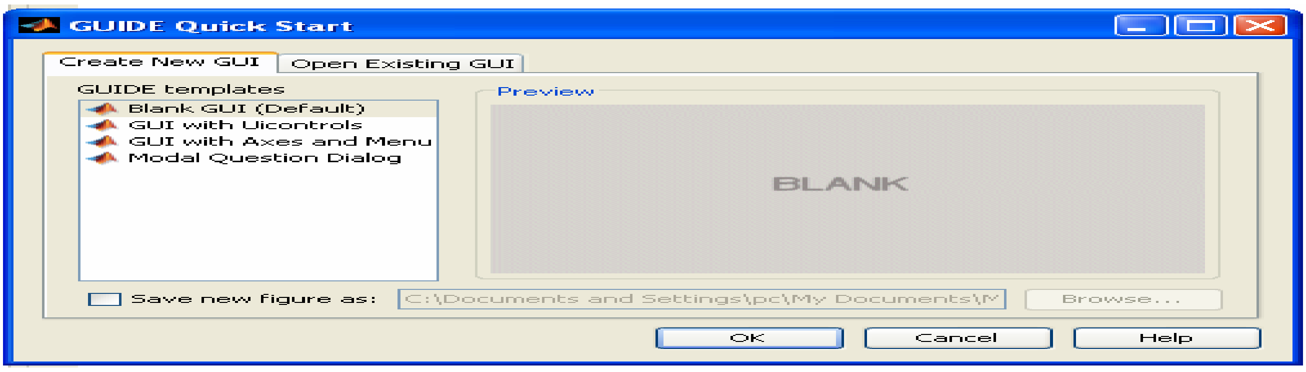

Fig.3 GUIDE quick start dialog box.

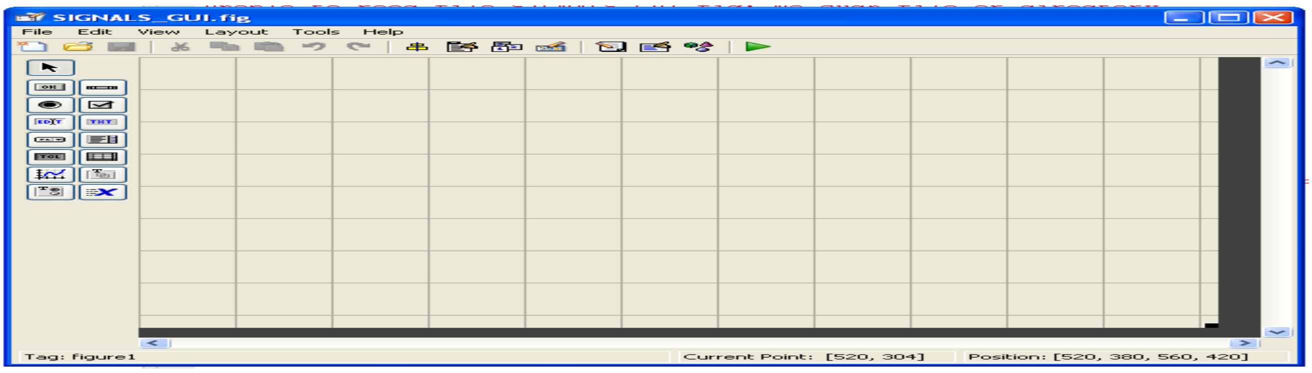

Fig.4 GUI layout editor.

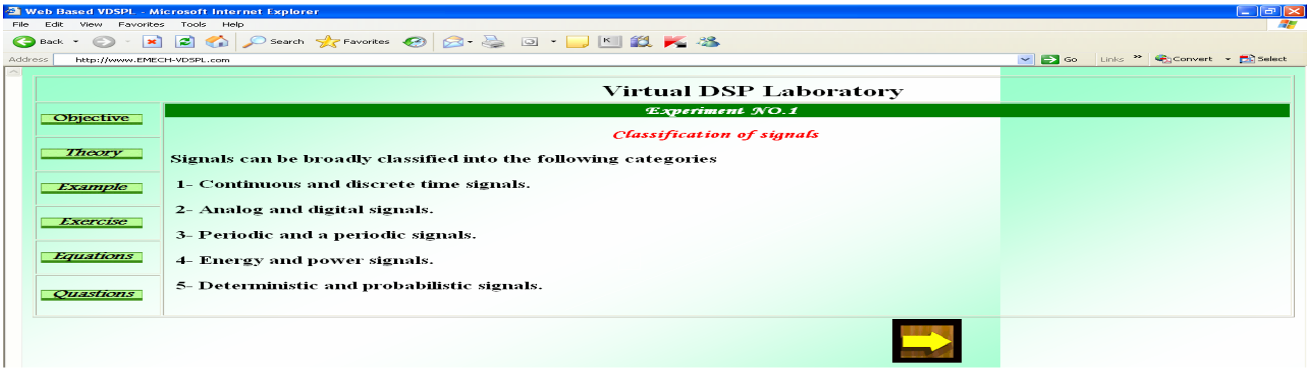

Fig.5 Web page of experiment (1).

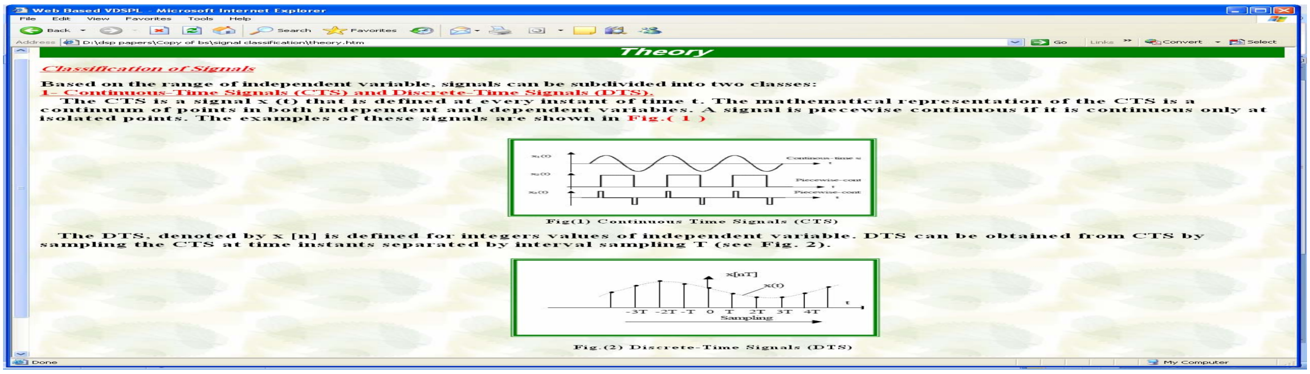

Fig.6 Web page of theory bases for experiment (1).

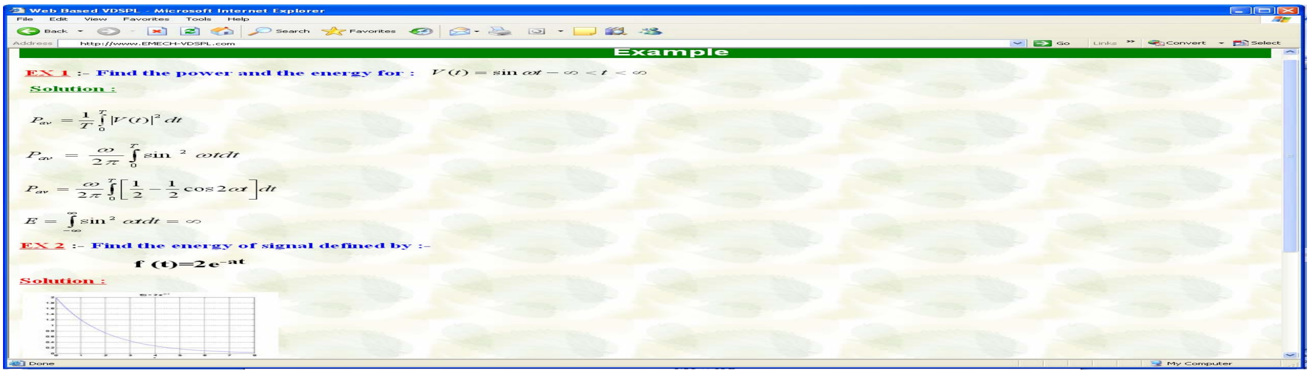

Fig.7 Web page of solved example introduced in experiment (1).

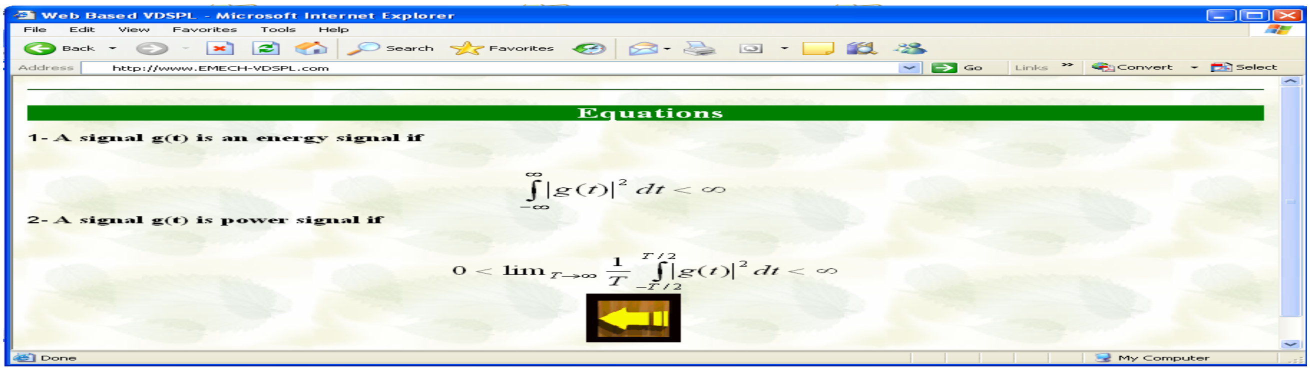

Fig.8 Web page of equations used in experiment (1).

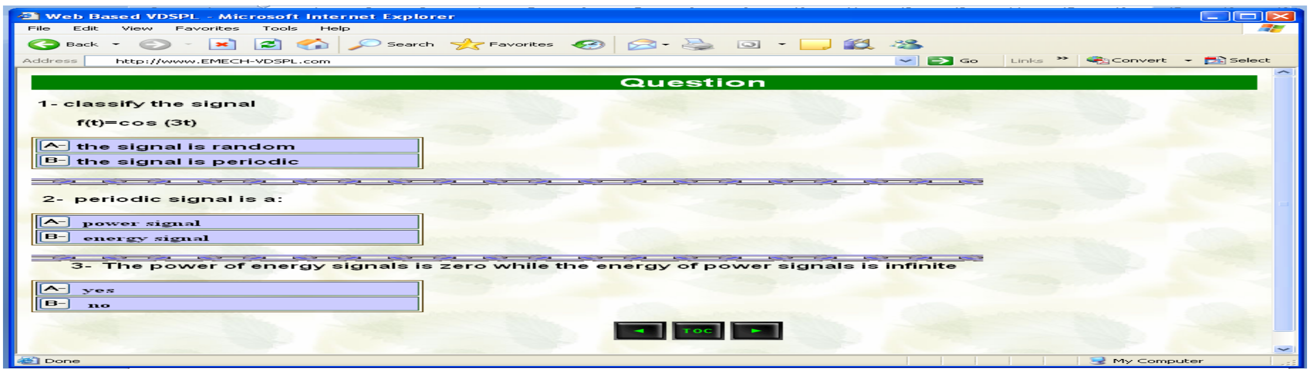

Fig.9 Web page of self test questions applied to experiment (1).

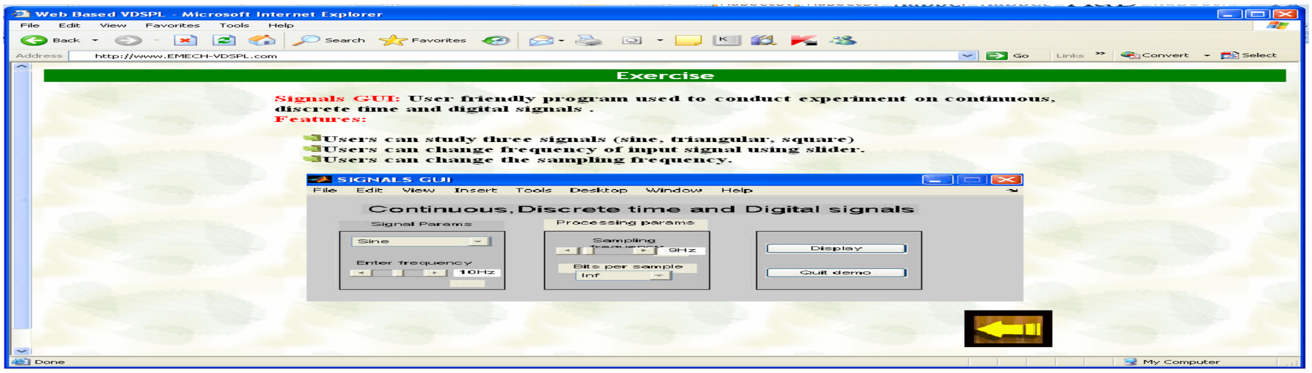

Fig.10 Web page of exercise for experiment (1).

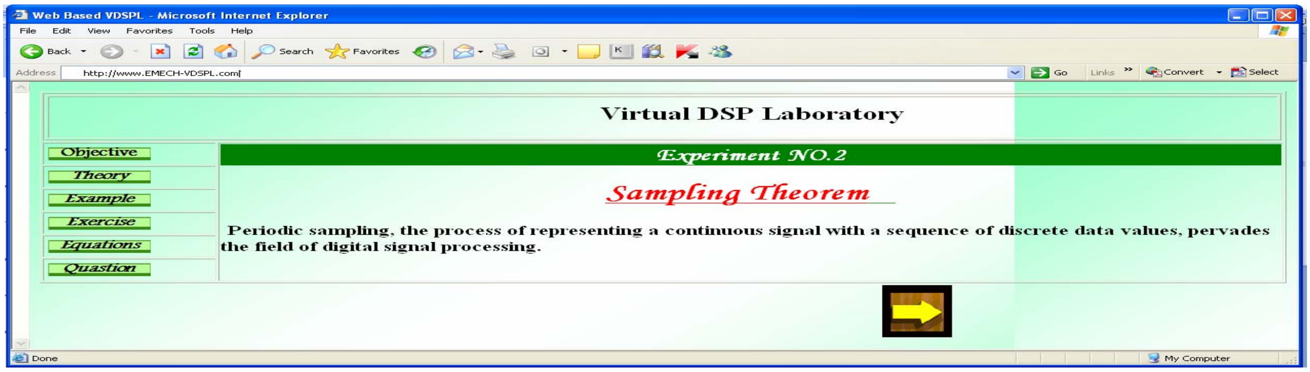

Fig.11 Web page of experiment (2).

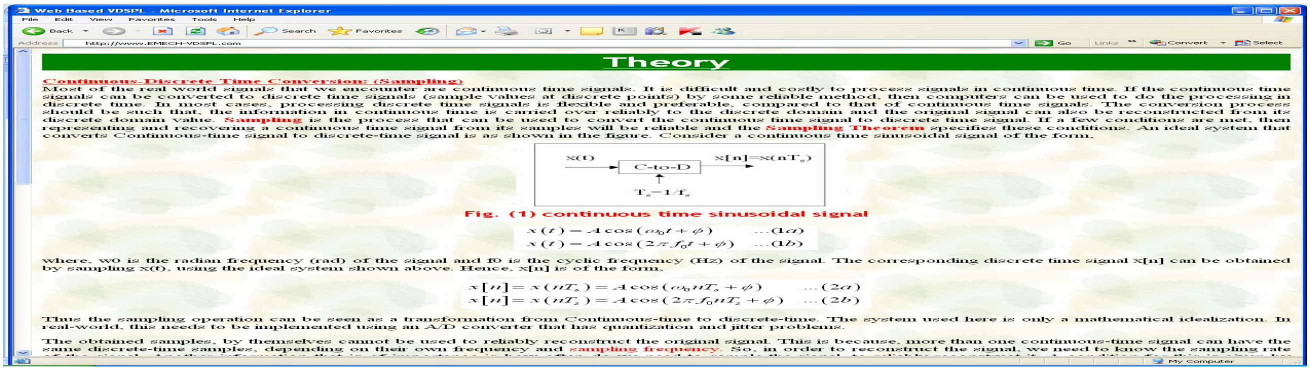

Fig.12 Web page of theory bases for experiment (2).

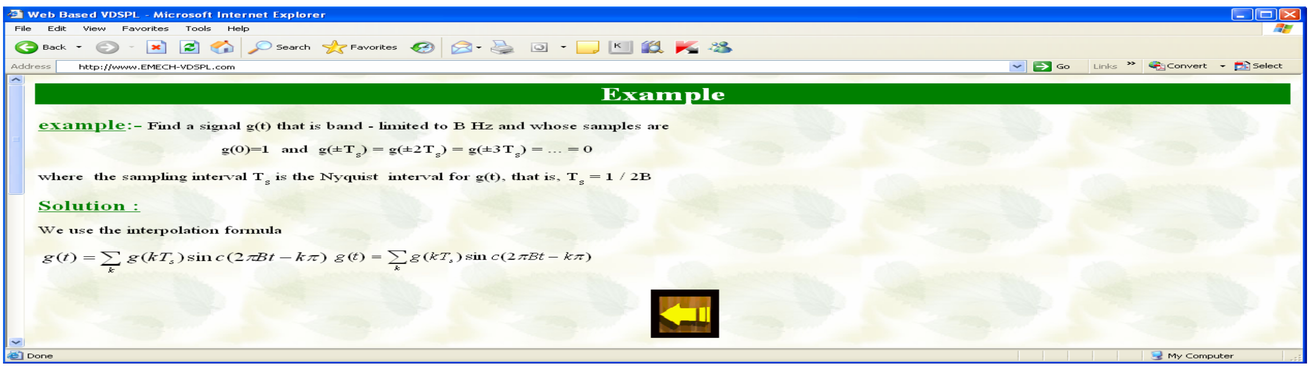

Fig.13 Web page of solved example used in experiment (2).

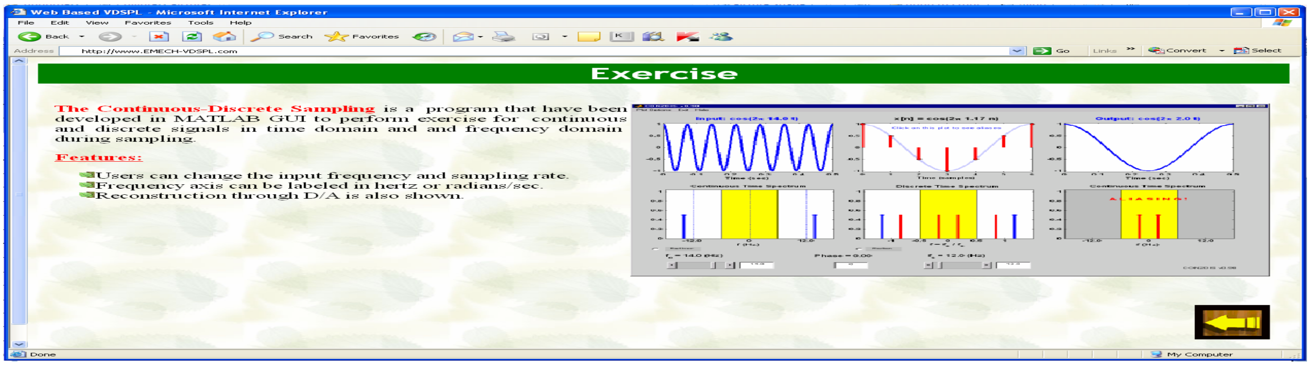

Fig.14 Web page of exercise for experiment (2).

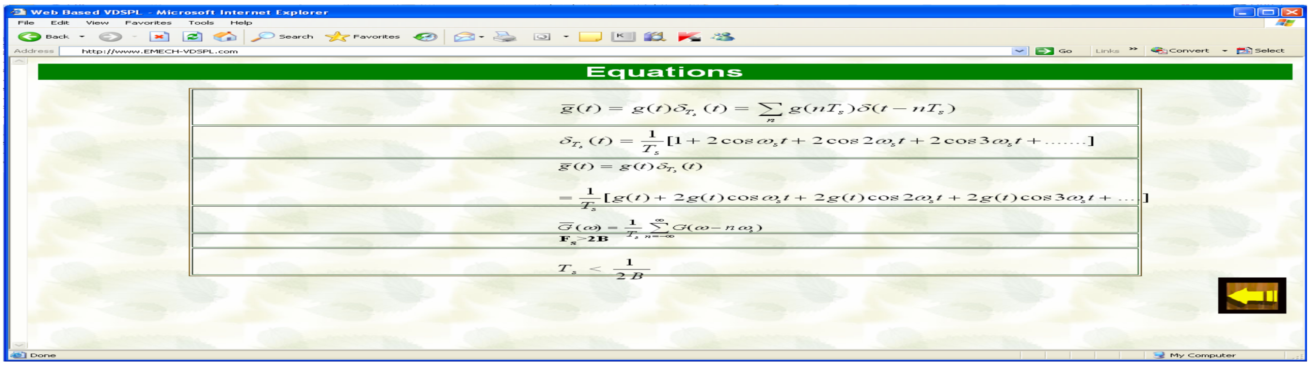

Fig.15 Web page of equations used in experiment (2).

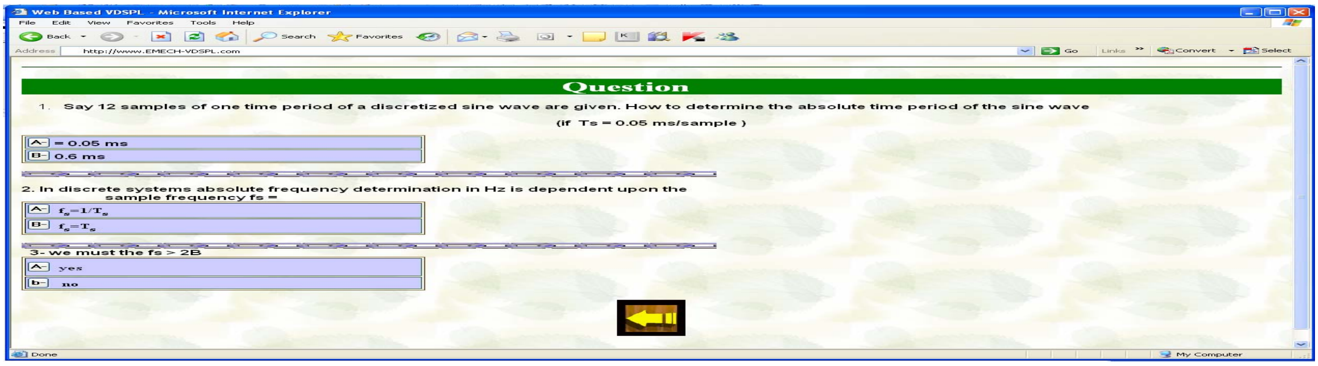

Fig.16 Web page of self test questions applied to experiment (2).

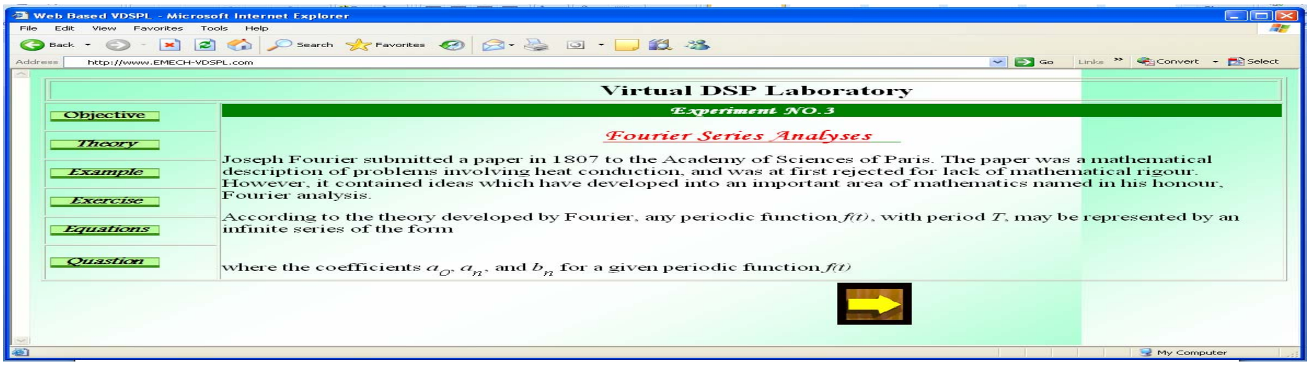

Fig.17 Web page of experiment (3).

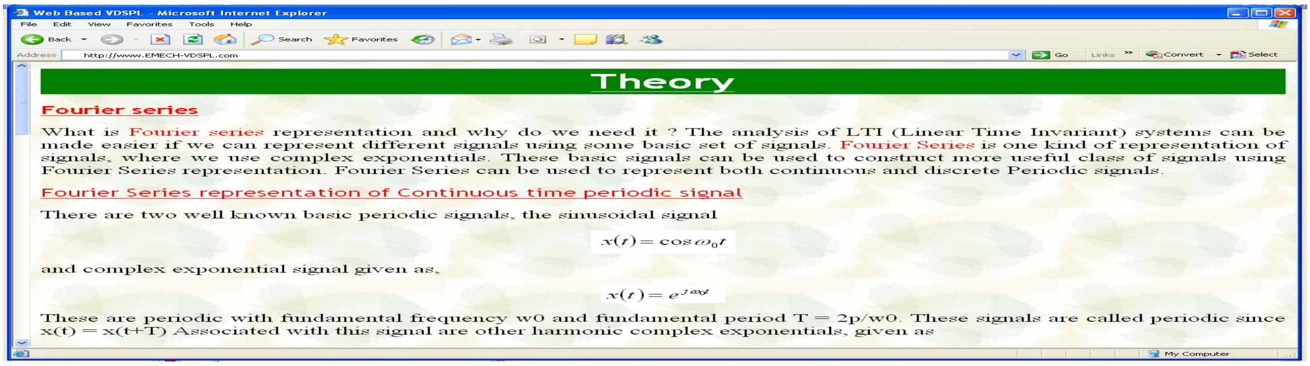

Fig.18 Web page of theory bases for experiment (3).

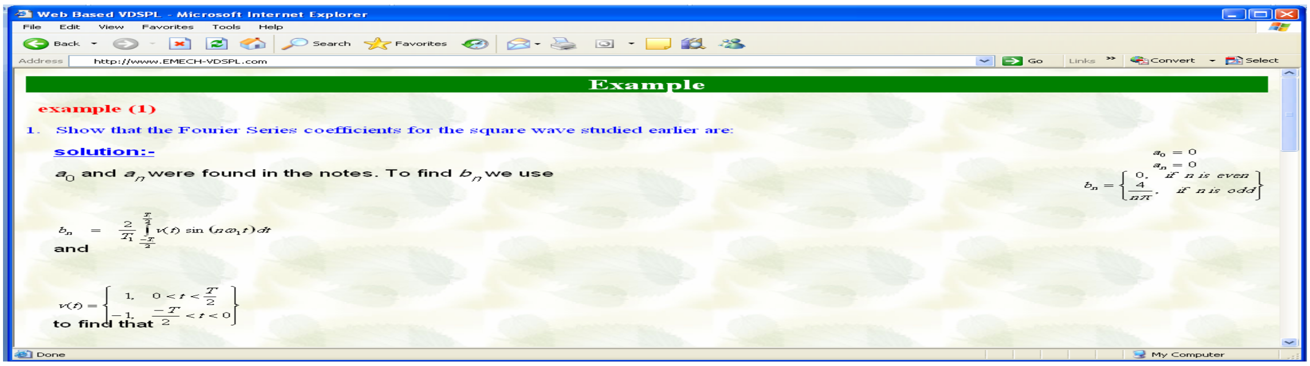

Fig.19 Web page of solved example used in experiment (3).

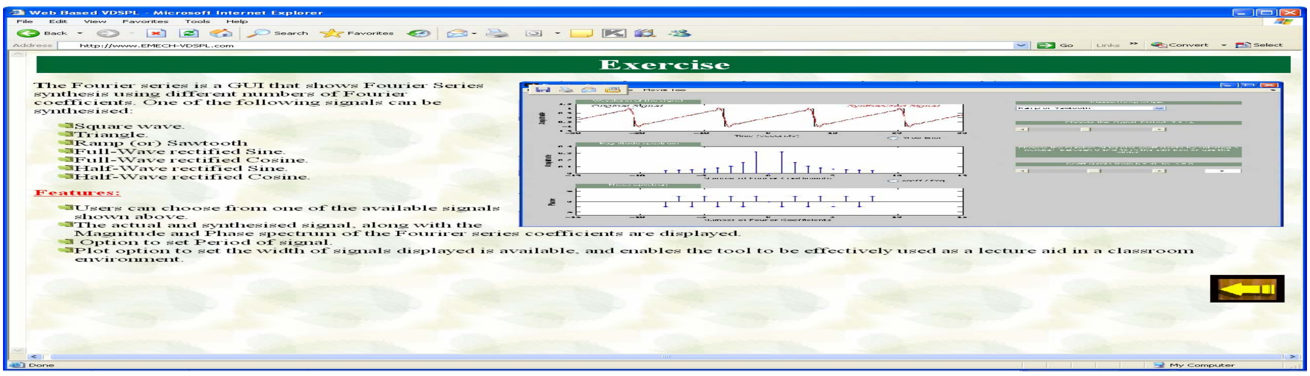

Fig.20 Web page of exercise for experiment (3)

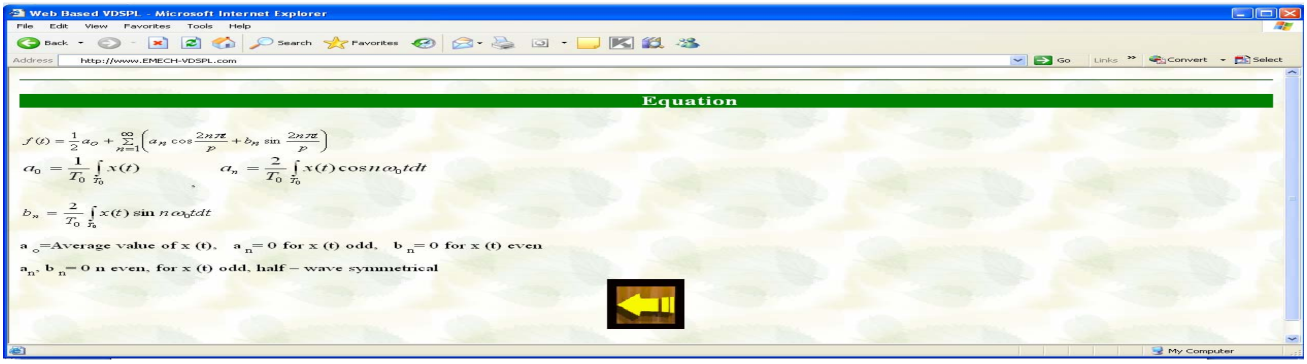

Fig.21 Web page of equations used in experiment (3)

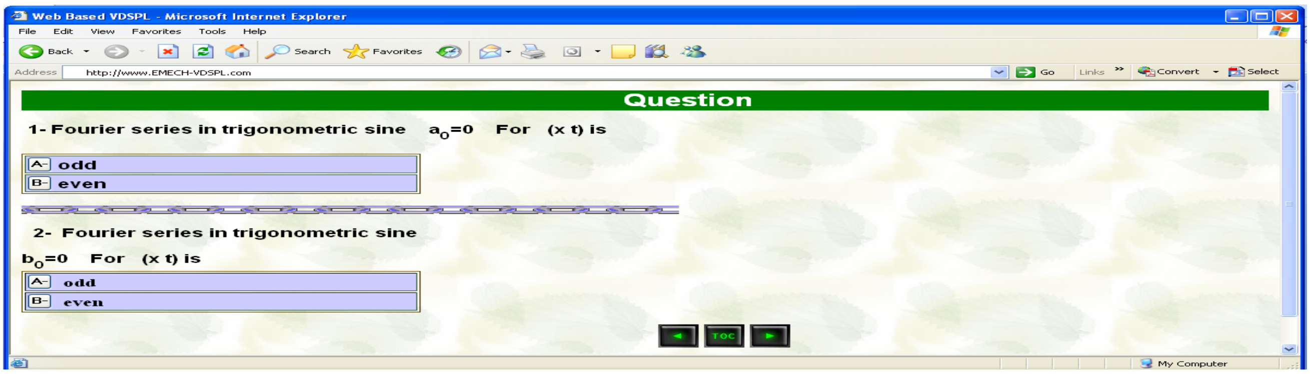

Fig.22 Web page of self test questions applied to experiment (3).

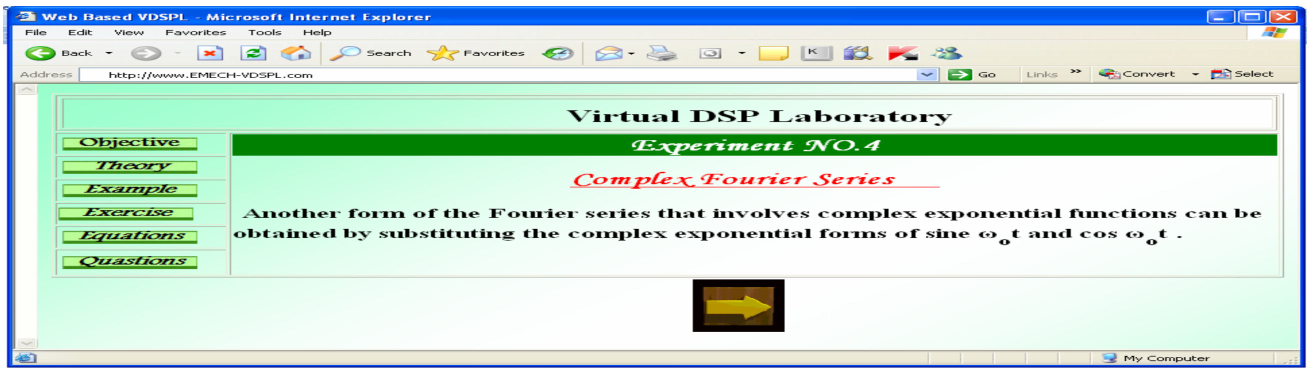

Fig.23. Web page of experiment (4).

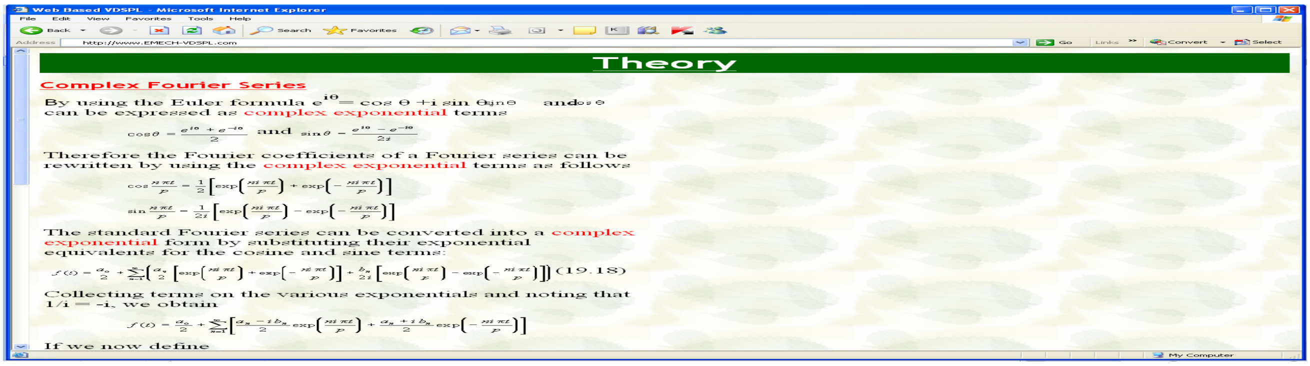

Fig.24 Web page of theory bases for experiment (4).

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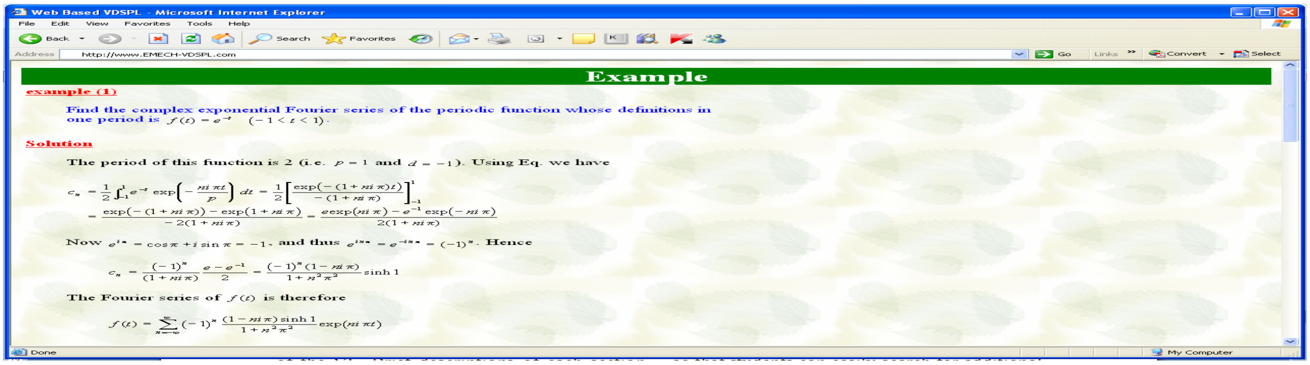

Fig.25 Web page of solved example used in experiment (4).

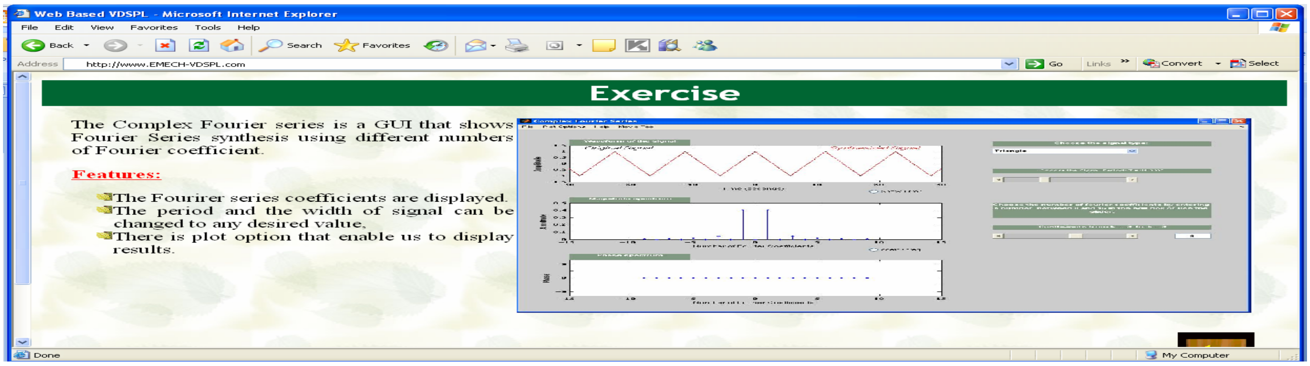

Fig.26 Web page of exercise for experiment (4).

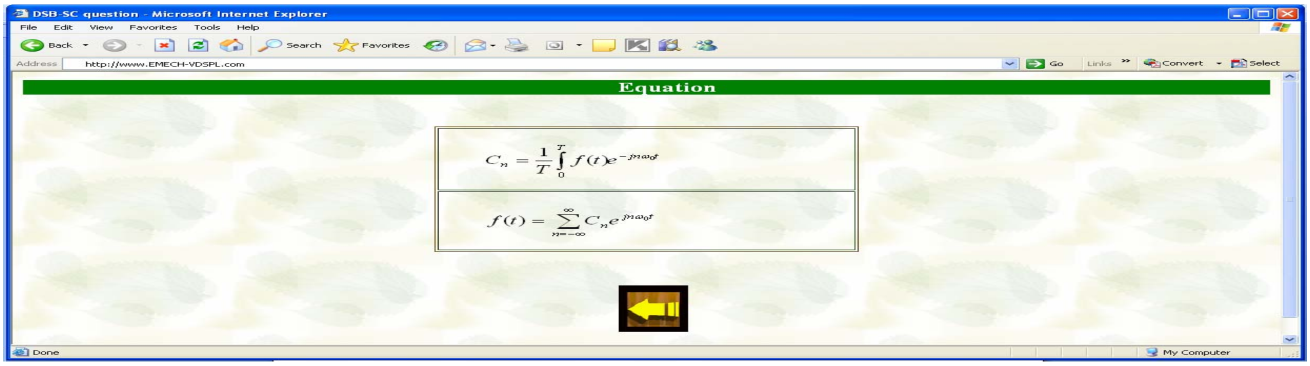

Fig.27 Web page of equations used in experiment (4).

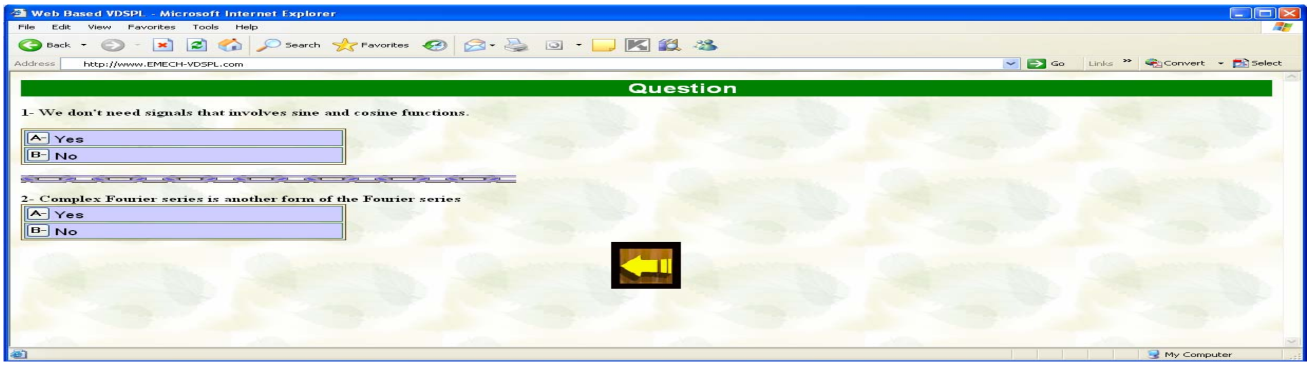

Fig.28 Web page of self test questions applied in experiment (4).

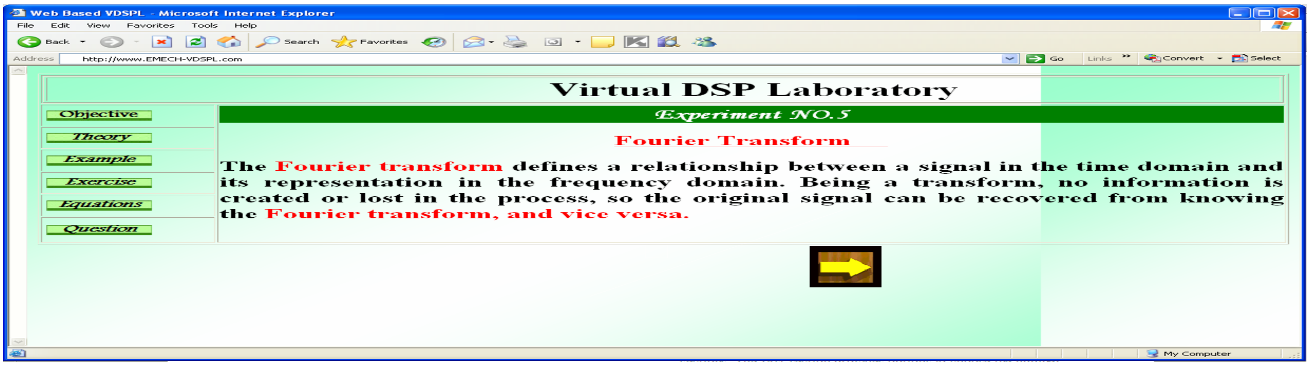

Fig.29 Web page of experiment (5).

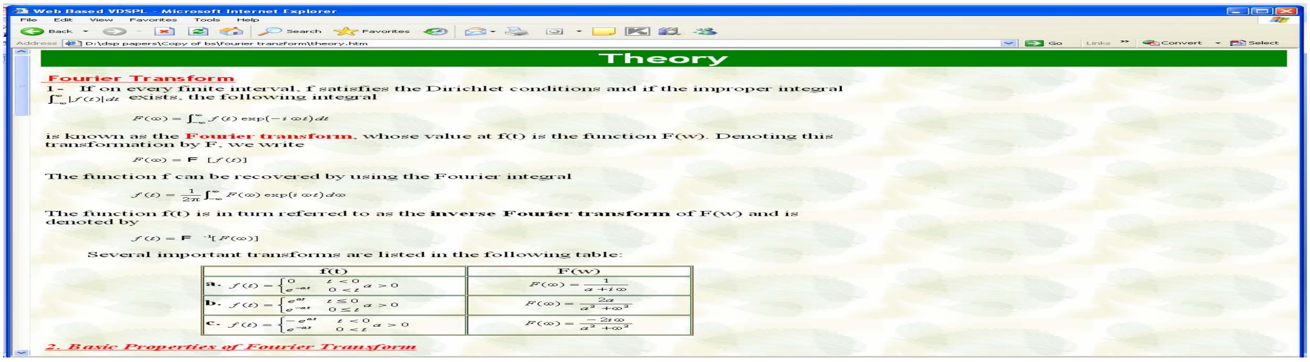

Fig.30 Web page of theory bases for experiment (5).

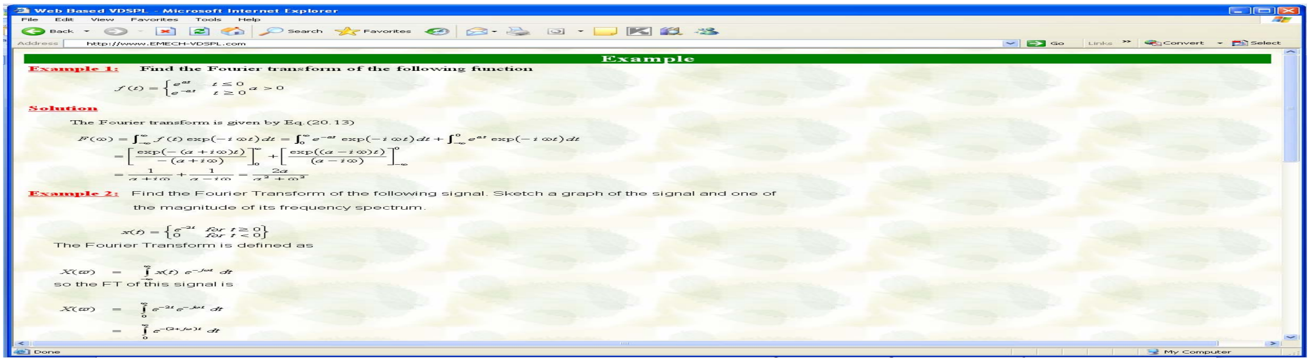

Fig.31 Web page of solved example used in experiment (5).

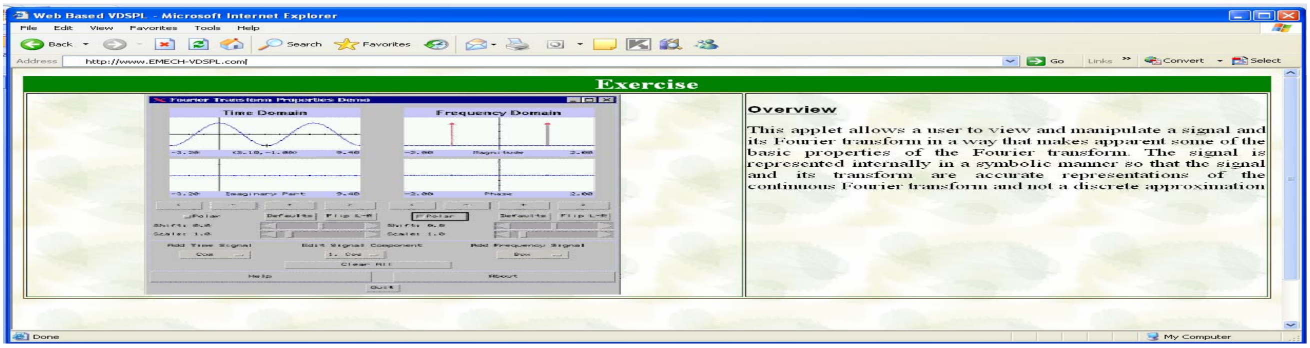

Fig.32. Web page of exercise for experiment (5).

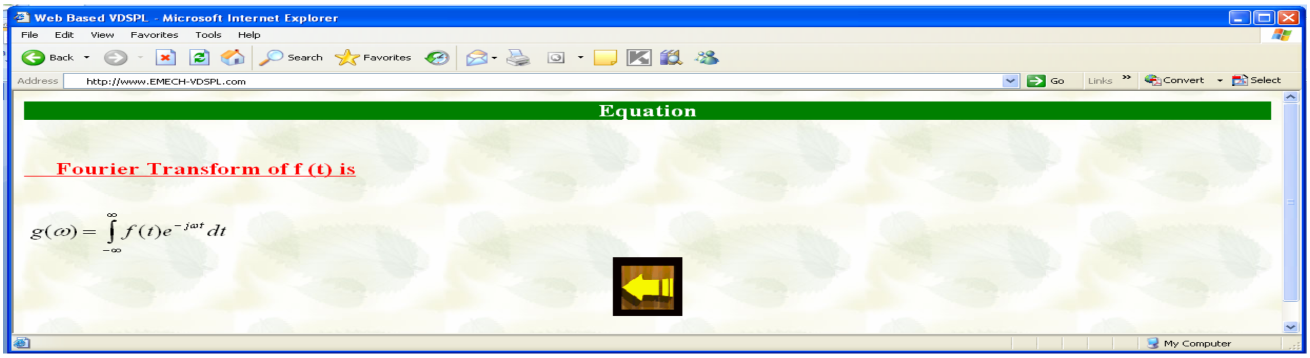

Fig.33 Web page of equations used in experiment (5).

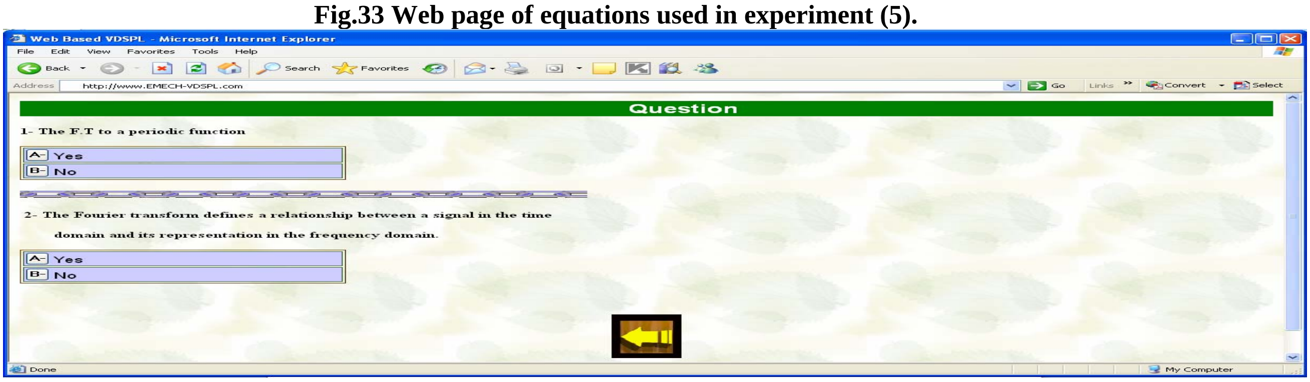

Fig.34 Web page of self test questions applied in experiment (5).

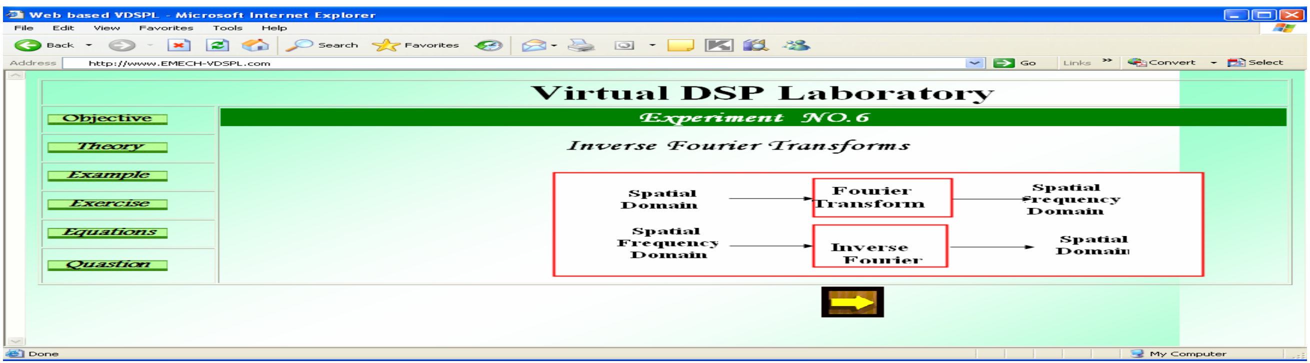

Fig.35 Web page of experiment (6).

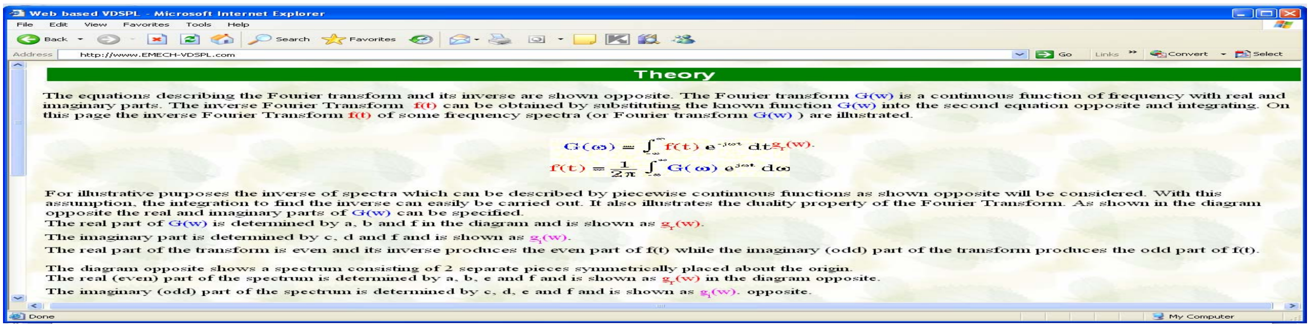

Fig.36 Web page of theory bases for experiment (6).

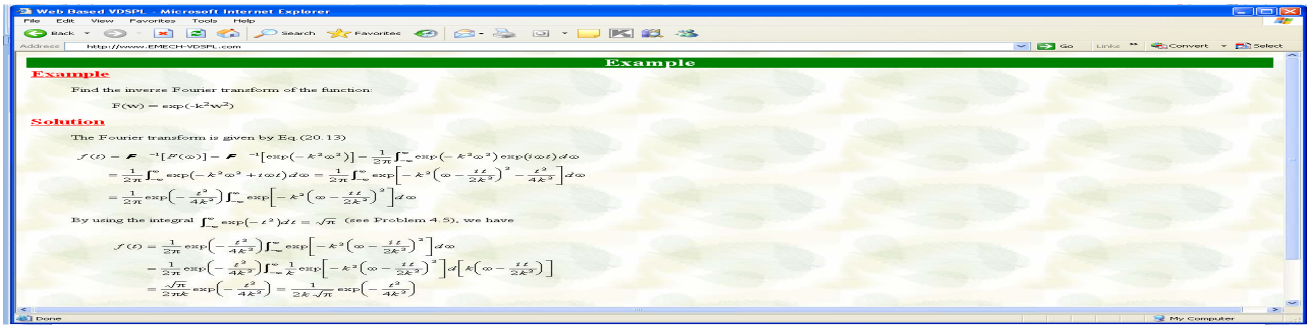

Fig.37 Web page of solved example used in experiment (6).

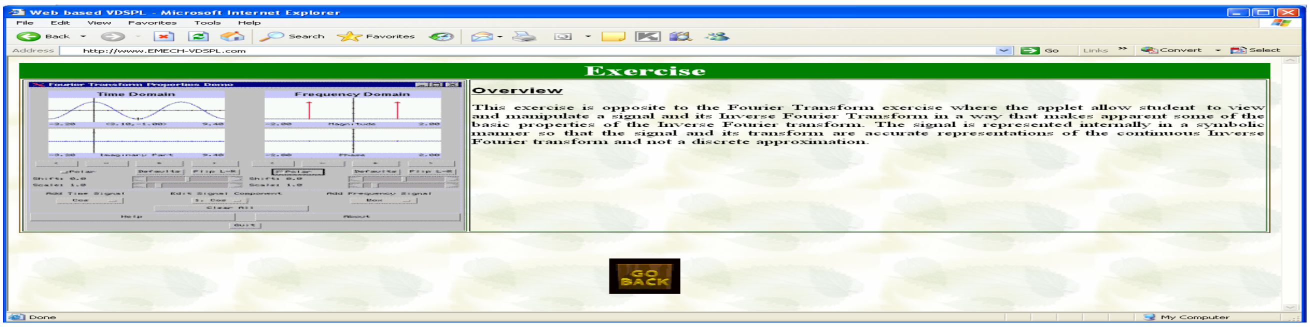

Fig.38 Web page of exercise for experiment (6).

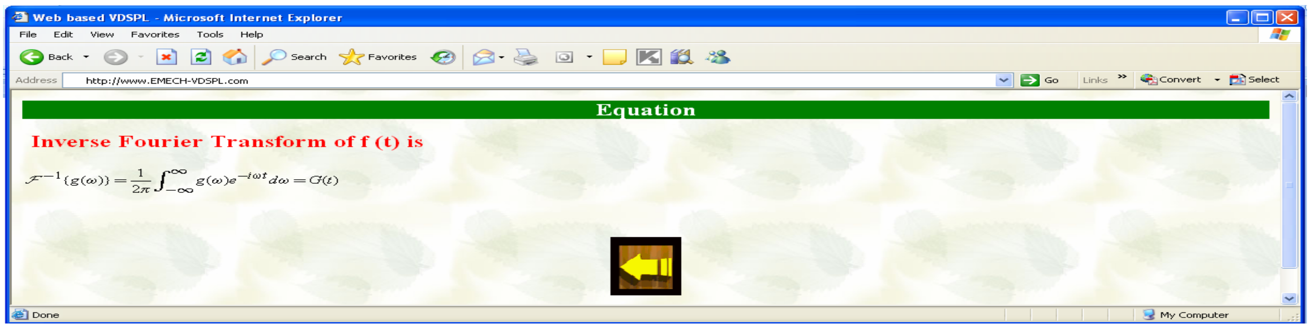

Fig.39 Web page of equations used in experiment (6).

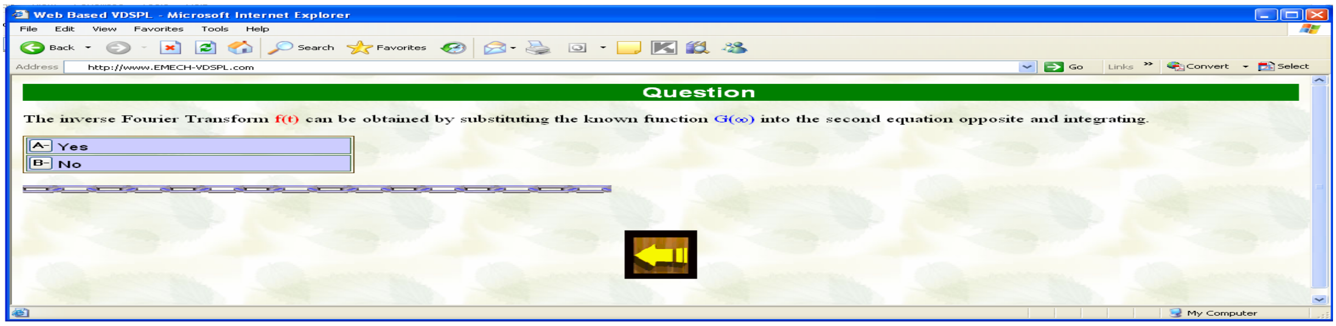

Fig.40 Web page of self test questions applied in experiment (6).

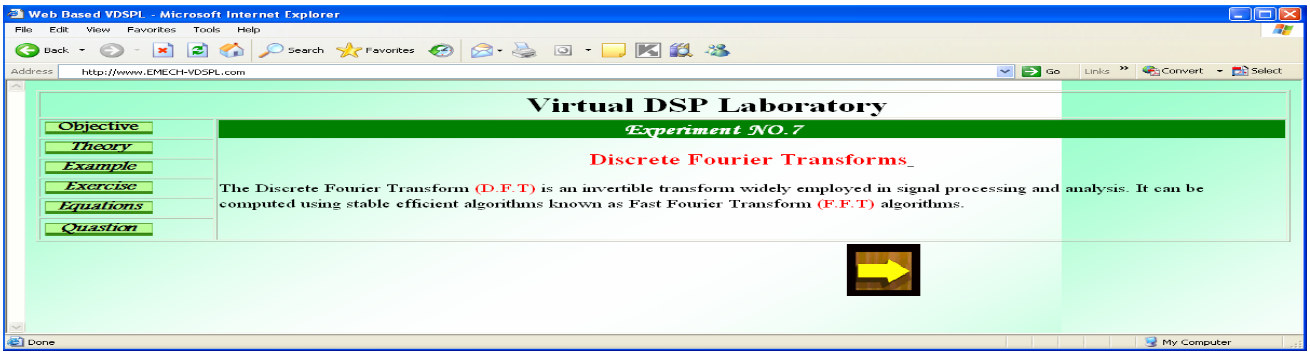

Fig.41 Web page of experiment (7).

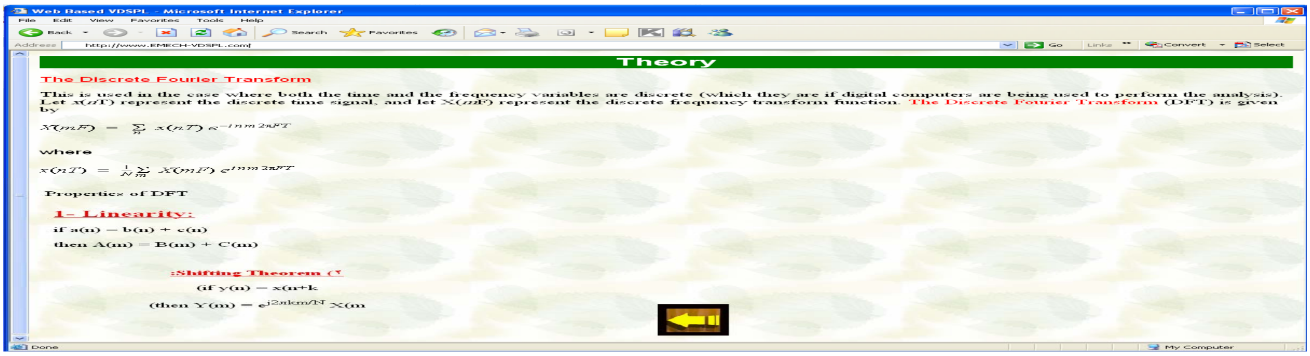

Fig.42 Web page of theory bases for experiment (7).

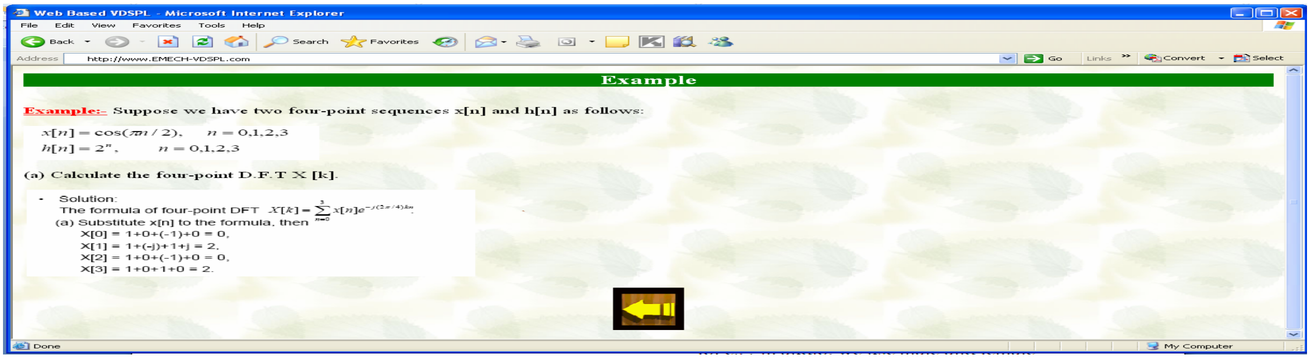

Fig.43 Web page of solved example used in experiment (7).

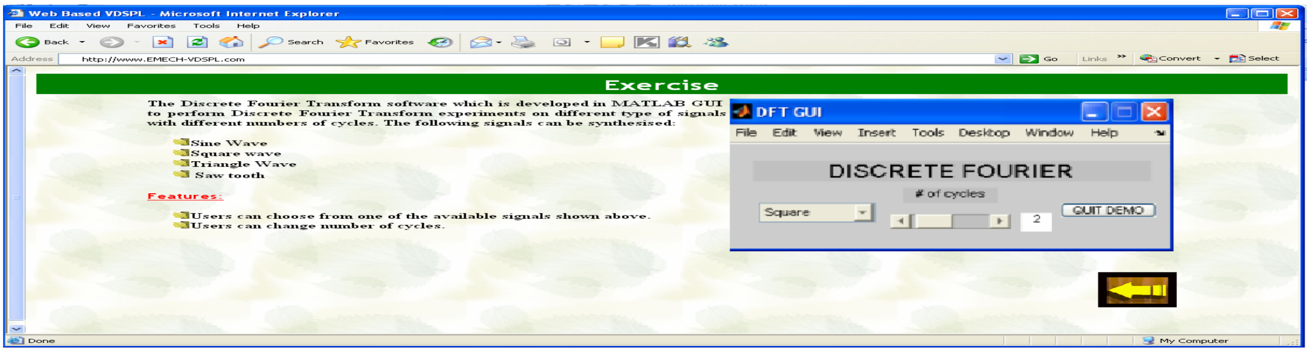

Fig.44 Web page of exercise for experiment (7).

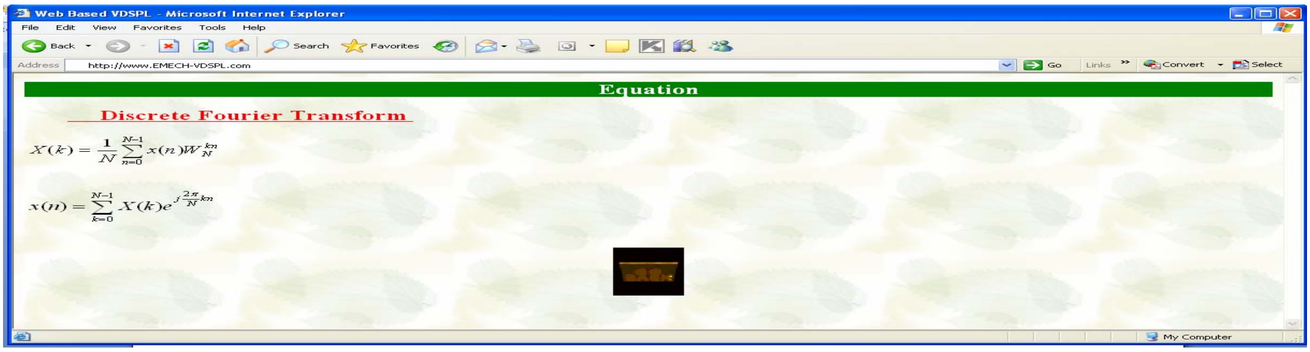

Fig.45 Web page of equations used in experiment (7).

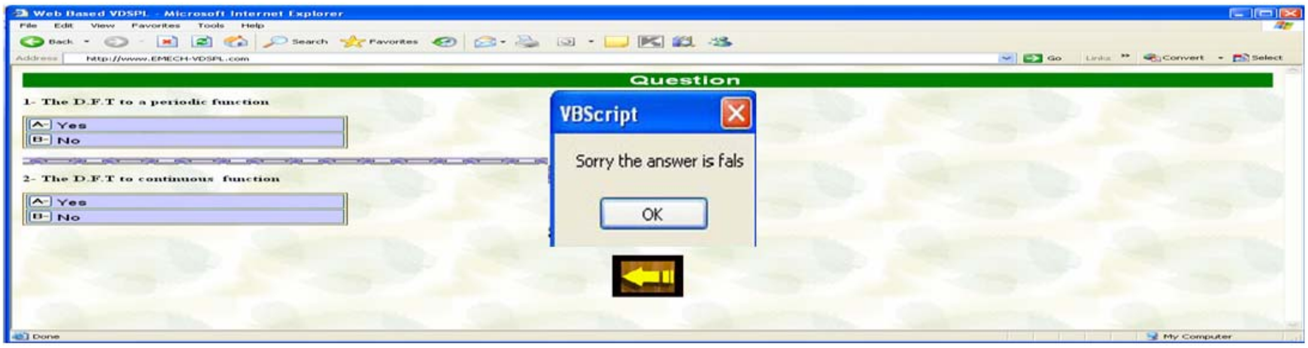

Fig.46 Web page of self test questions applied in experiment (7).

on the FFT button.

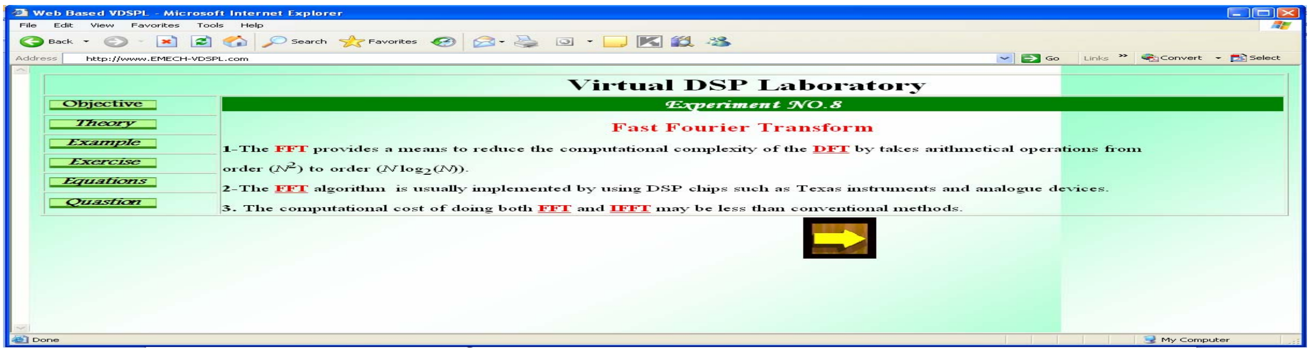

Fig.47 Web page of experiment (8).

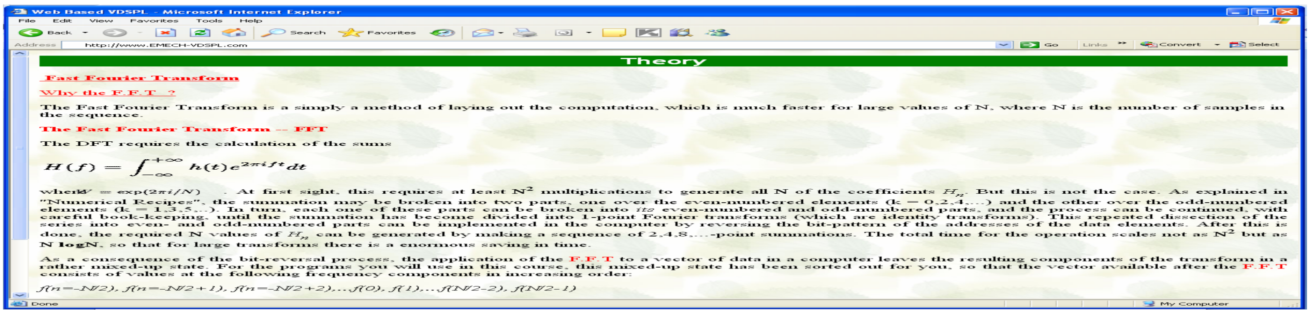

Fig.48 Web page of theory bases for experiment (8).

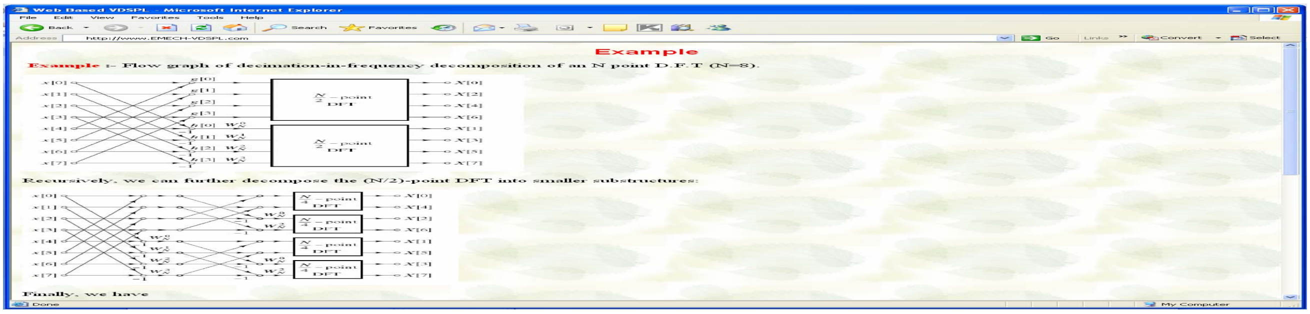

Fig.49 Web page of solved example used in experiment (8).

Fig.50 Web page of exercise for experiment (8).

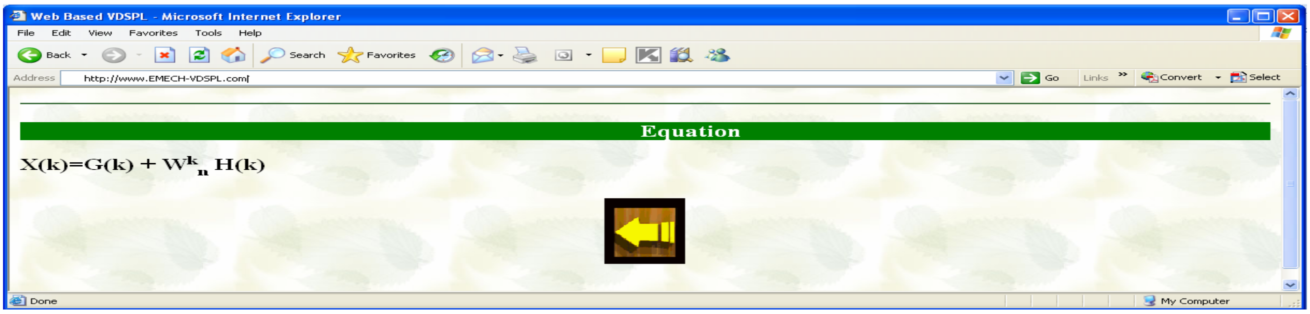

Fig.51 Web page of equations used in experiment (8).

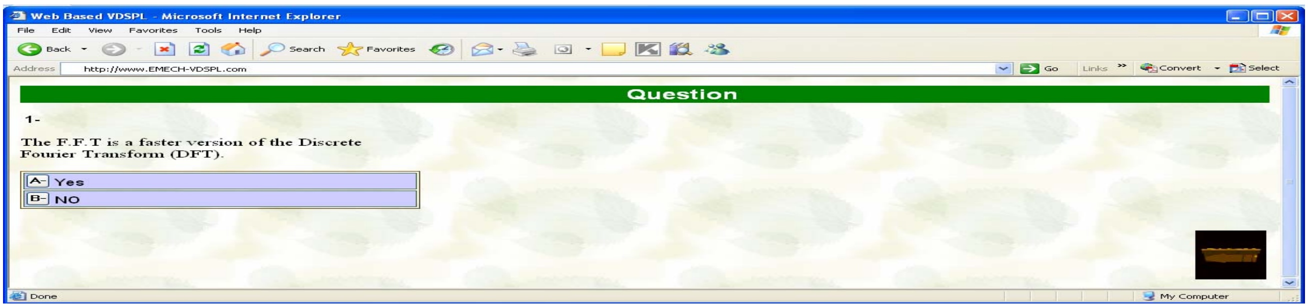

Fig.52 Web page of self test questions applied in experiment (8).

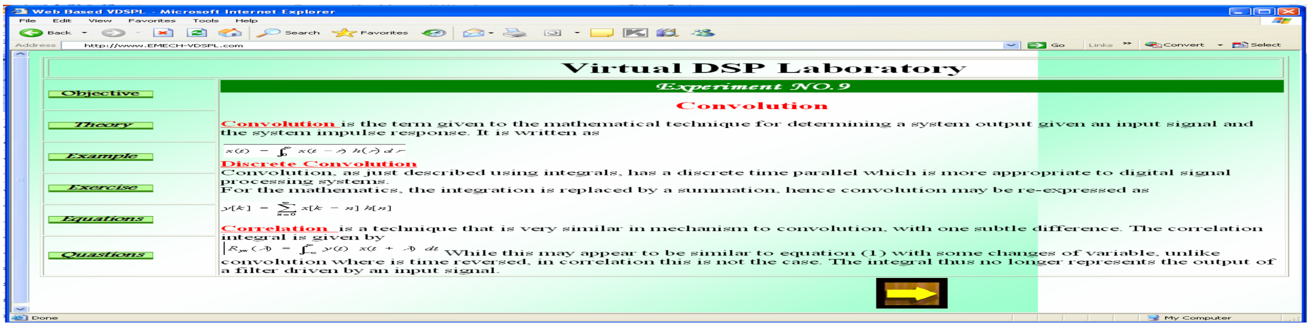

Fig.53 Web page of experiment (9).

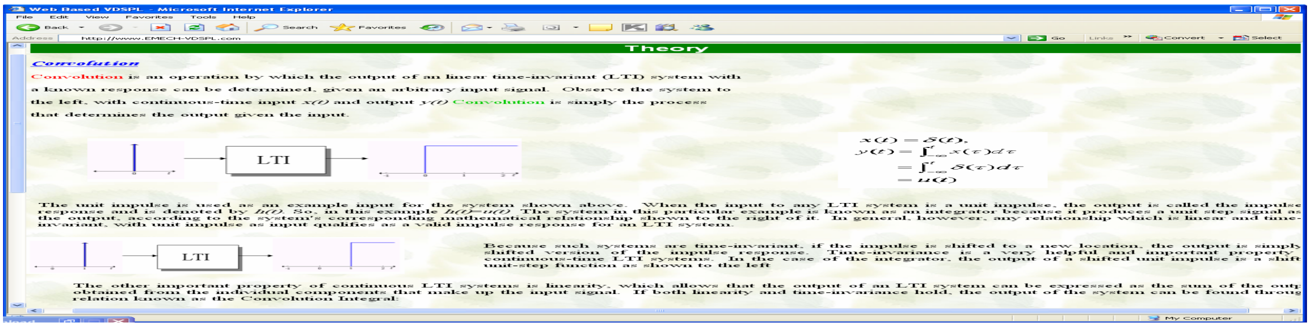

Fig.54 Web page of theory bases for experiment (9).

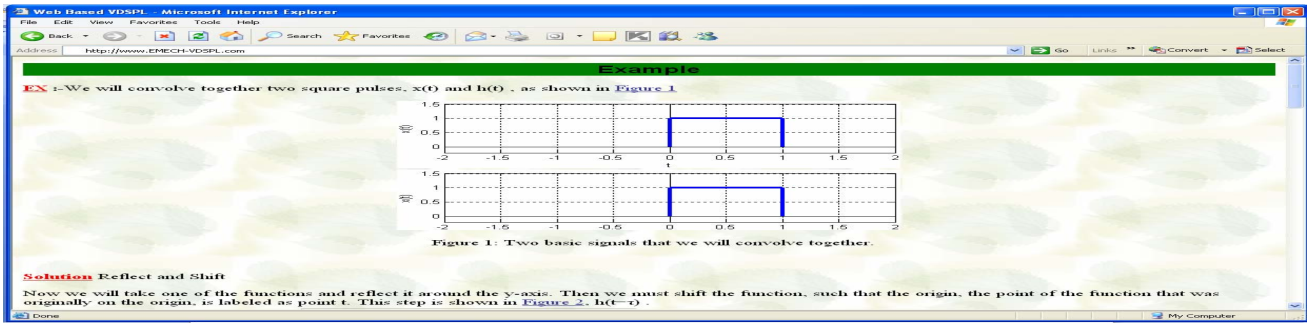

Fig.55 Web page of solved example used in experiment (9).

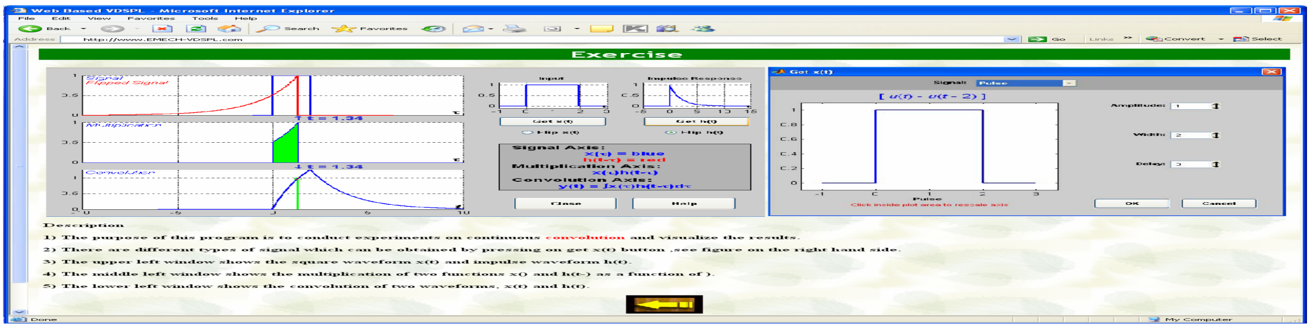

Fig.56 Web page of exercise for experiment (9).

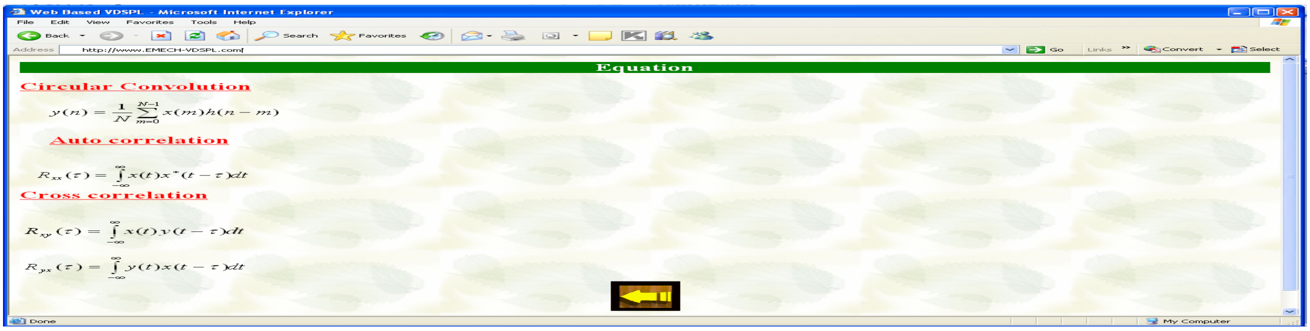

Fig.57 Web page of equations used in experiment (9).

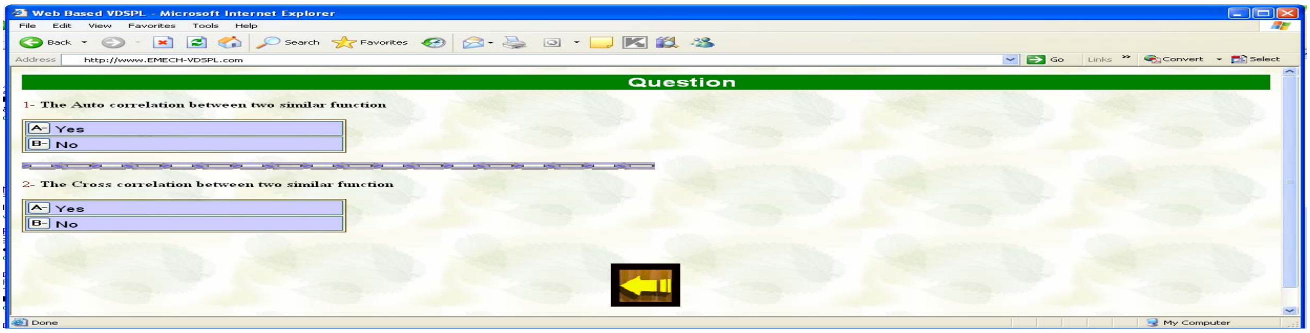

Fig.58 Web page of self test questions applied in experiment (9).

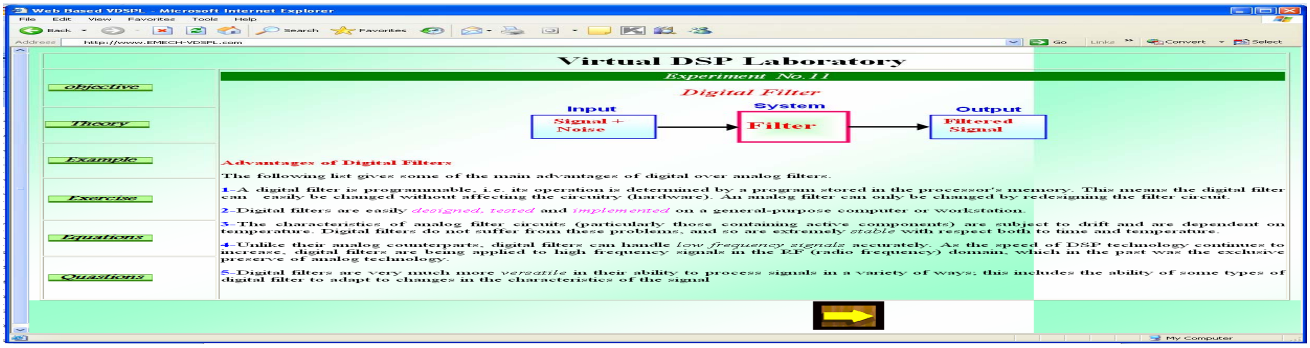

Fig.59 Web page of experiment (11).

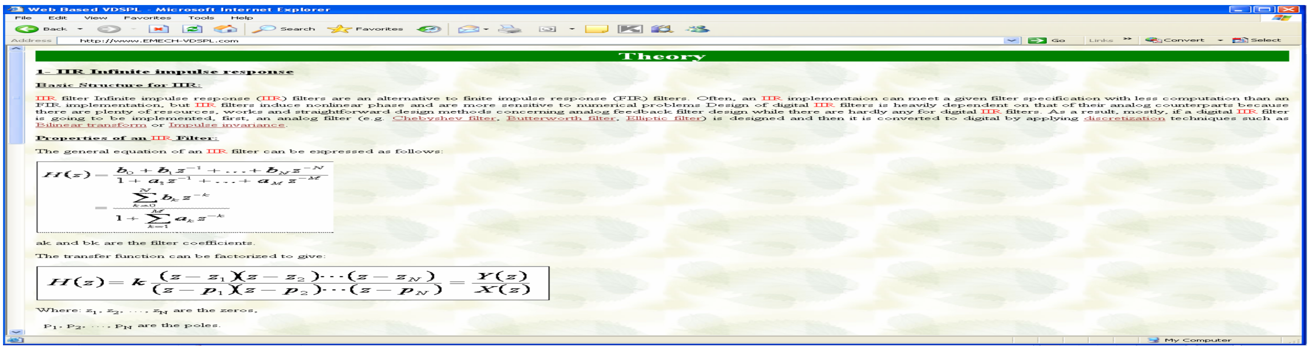

Fig60 Web page of theory bases for experiment (11).

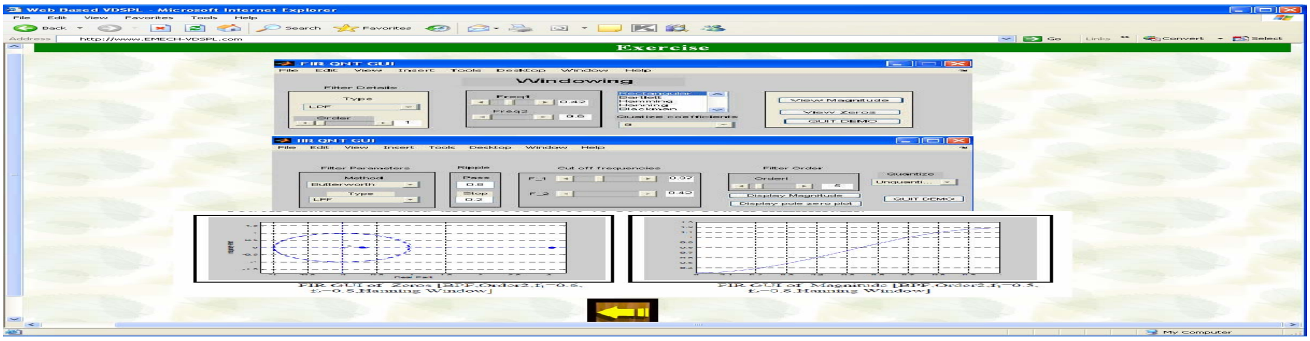

Fig.61 Web page of exercise for experiment (11).

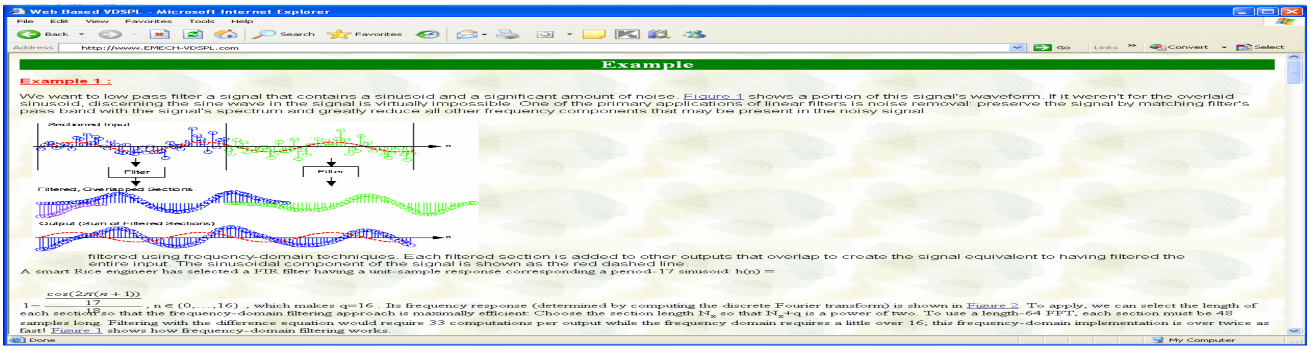

Fig.62Web page of solved example used in experiment (11).

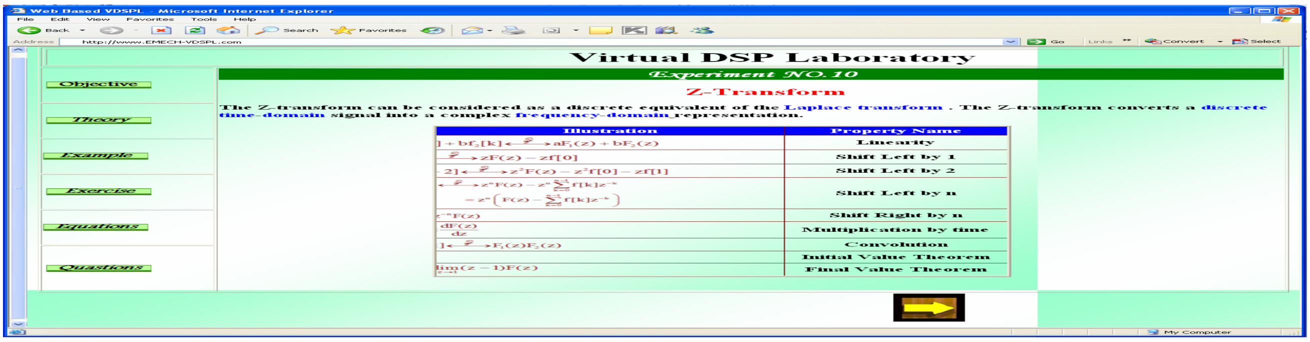

Fig.63 Web page of experiment (10).

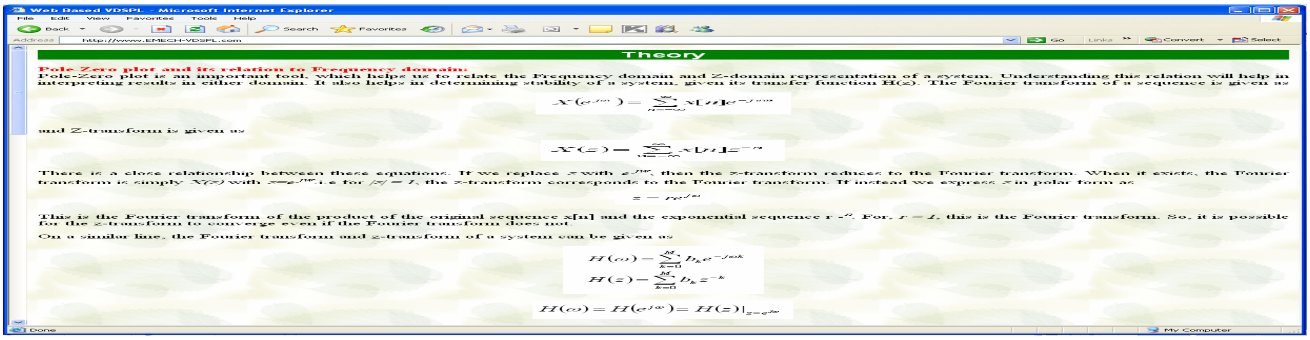
Fig.64 Web page of theory bases for experiment (10).

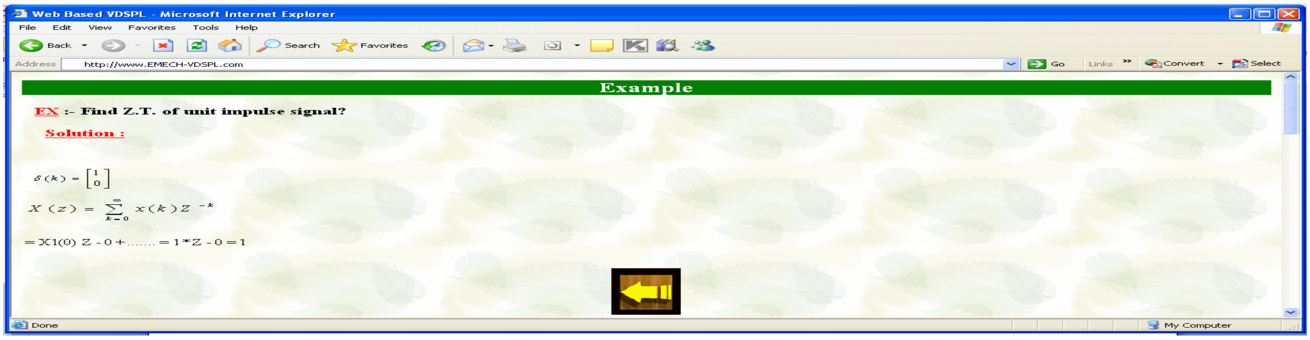
Fig.65 Web page of solved example used in experiment (10).

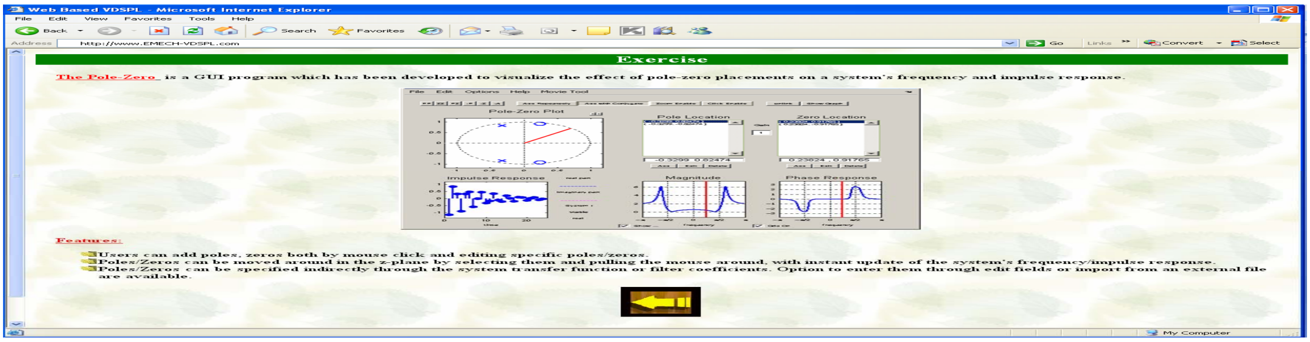
Fig.66 Web page of exercise for experiment (10).

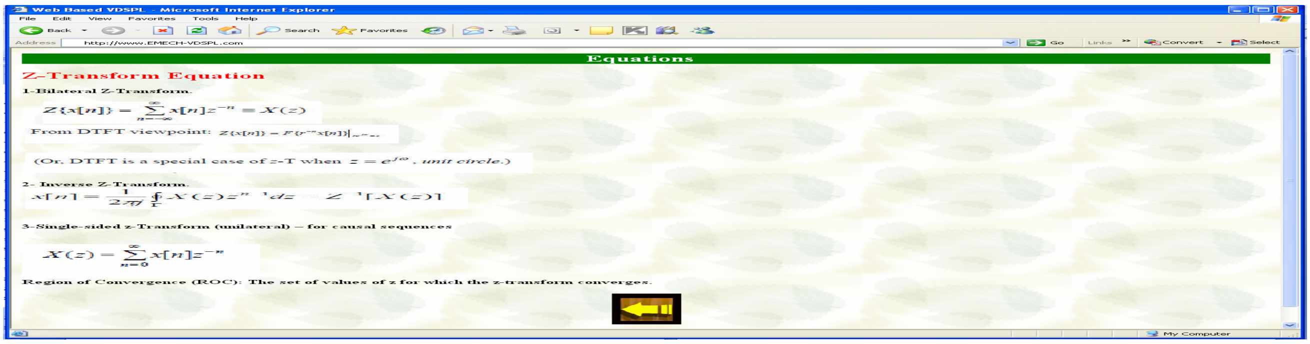
Fig.67 Web page of equations used in experiment (10).

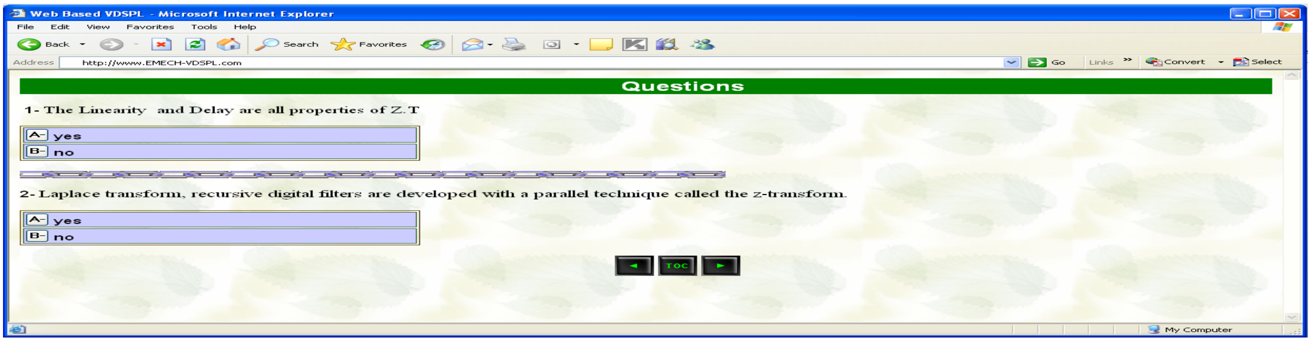

Fig.68 Web page of self test questions applied in experiment (10).

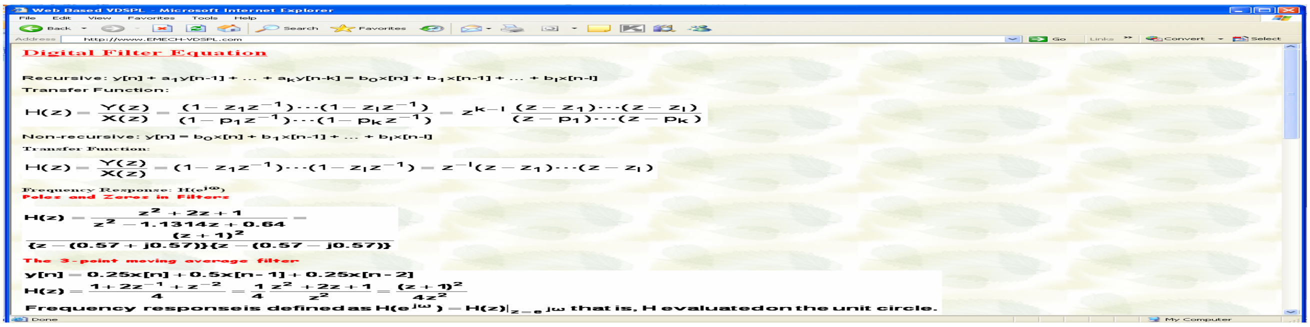

Fig.69 Web page of equations used in experiment (11).

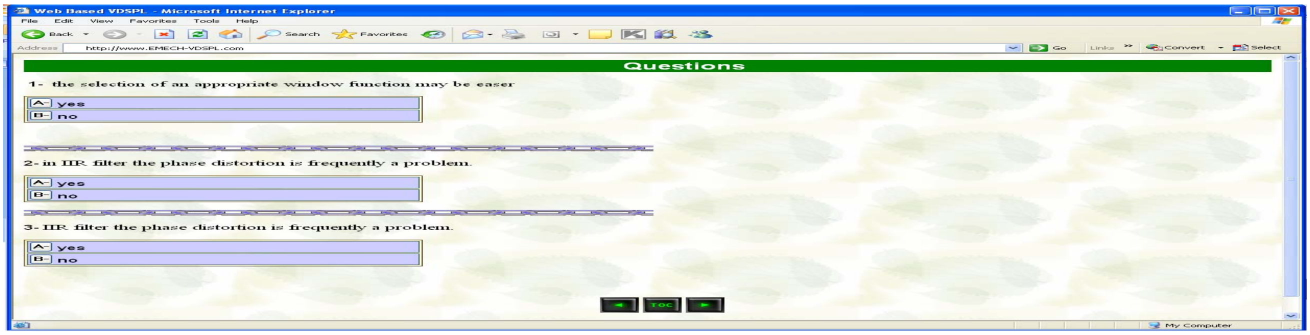

Fig.70 Web page of self test questions applied in experiment (11).

Table 1 Survey results

Survey Questions		Responses						
		1	2	3	4	5	Mean	Standard Deviations
Q1-	Was the virtual laboratory well organized?	0	0	0	2	13	4.86	2.22
Q2-	Were the learning outcomes clearly defined?	0	0	0	4	11	4.73	1.62
Q3-	Ran well on my computer?	0	0	0	1	14	4.93	2.99
Q4-	Loaded in a reasonable amount of time?	0	0	1	1	13	4.8	1.96
Q5-	Was virtual laboratory easy to navigate?	0	0	0	2	13	4.86	2.22

Q6-	There were enough figures and solved examples?	0	0	0	6	9	4.6	1.19
Q7-	Is the virtual laboratory material of high quality?	0	0	0	5	10	4.67	1.37
Q8-	There were enough exercises?	0	0	0	2	13	4.86	2.22
Q9-	Was virtual laboratory easy to understand?	0	0	0	4	11	4.73	1.62
Q10-	Would be helpful in preparing for the hands on laboratory?	0	0	0	7	8	4.53	1.33
Q11-	Have you learned with this virtual laboratory?	0	0	0	2	13	4.86	2.22
Q12-	Would you recommend this laboratory to other students?	0	0	0	5	10	4.67	1.37
Q13-	Overall, how would you rate this virtual laboratory?	0	0	0	1	14	4.93	2.99
Q14-	Should have more images/text demonstrations?	7	5	0	3	0	1.93	1.5
Q15-	Helped me to feel more confident about the procedures?	0	0	0	4	11	4.73	1.62