

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

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HTML GUI

DSP

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 الكهر وميكانيكية في الجامعة التكنولوجية. التجارب المختبرية المنفذة ستنظمن أنواع الاشارات ، نظرية النمذجة ، متسلسلة فورير ، متسلسلة فورير المركبة، محول فورير، معكوس محول فورير، محول فورير المتقطع، محول فورير السريع (FFT) ، الألتفاف ، محول-Z ، المرشحات الرقمية . واجهة المستخدم الرسومية (GUI) المميزة لبرنامج (MATLAB) تم استخدامها لاعطاء الطالب طريقة سهلة ومرئية في الديانات بينما تم استخدام لغة ترميز النصوص التشعبية (HTML) في توضيح الأسس النظرية. لقد تم أستخدام الاستفتاء ومرئية في الديان البيانات بينما تم أجراء عملية التقييم . أظهرت نتائج التقويم أن محتبر (DSP) معاد الطالب طريقة سهلة ومرئية في الدينات المستخدام أجراء عملية التقييم . أظهرت نتائج التقويم أن محتبر (DSP) معان النظرية النمزية النفري الموير الموتات الرقمية . واجهة أجراء عملية التقييم . أظهرت نتائج التقويم أن محتبر (DSP) من الفتر حساعد الطالب طريقة سهلة ومرئية في الحاس المال فرا أجراء عملية التقييم . أظهرت نتائج التقويم أن مختبر (DSP) الافتراضي المقترح ساعد الطالب في فهم مباديء (DSP) ، كما أضاف تأثيرات

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 web server [Nedic. 2003: а Balamuralithara,2008]. Third. recorded experiments allow users to view actual experiments and work with data real [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 an instructional tool the authors as 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 implements GUI through paper. MATLAB Interface Development Graphica1 User 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

Transform (FFT) The Fast Fourier is a mathematical to reduce approach aims 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 convolution detailed information on 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

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 Ztransform 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.

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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 Splane 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.

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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 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

slightly higher mean scores relative to the highest

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.

GUIDE Quick Start	
Create New GUI Open Existing GUIDE templates Blank GUI (Default) GUI with Uicontrols GUI with Axes and Menu Modal Question Dialog	BLANK
Save new figure as: C:\D	ocuments and Settings\pc\My Documents\M Browse
	OK Cancel Help





Fig.4 GUI layout editor.

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		Virtual DSP Laboratory		
	Objective	Experiment NO.1		
		Classification of signals		
	Theory	Signals can be broadly classified into the following categories		
	Example	1- Continuous and discrete time signals.		
	Exercise	2- Analog and digital signals.		
		3- Periodic and a periodic signals.		
	Equations	4- Energy and power signals.		
	Quastions	5- Deterministic and probabilistic signals.		







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



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

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1. A signal $g(t)$ is an energy signal if
1. A signal $\sigma(t)$ is an energy signal if
1-A signal g(t) is an energy signal in
$\int \sigma(t) ^2 dt < \infty$
$\int g(i) = a_i < \infty$
2-A signal g(t) is power signal if
. 7/2
$0 < \lim_{t \to \infty} \frac{1}{t} \int g(t) ^2 dt < \infty$
$T \rightarrow \infty$ $T - T/2$

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

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Question	
1- classify the signal	
f(t)=cos (3t)	
The signal is function	
the signal is periodic	
the server server server server server server server server ser	
2. periodic signal is a:	
A power signal	
B- energy signal	
3. The power of epergy signals is zero while the energy of power signals is infinite	
A yes	
B- no	
	~

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

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

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	Virtual DSP Laboratory
Objective	Experiment NO.2
Theory Example	Sampling Theorem
Equations Quastion	Periodic sampling, the process of representing a continuous signal with a sequence of discrete data values, pervades the field of digital signal processing.
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Fig.11 Web page of experiment (2).

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The provent of the process of the stand and by the stand and by the frequency ($z_{1} + z_{1}$) $z_{2} + z_{2}$ $z_{1} = z_{1}(m_{2}) = 4\cos((m_{1}^{2} + \phi)) \dots (2\pi)$	😋 Back - 🐑 - 💌 🛋 🏫 🔎 Search 🔆 Pavorites 🌚 🕻	🗢 · 🚵 🐵 · 🔜 🕙 🗱 🚩 🥸
Theory Common Direct Time Conversion (Common Common C	Address http://www.EMECH-VDSPL.com	Select - Discourse
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The new point spins the converted of the formula of the spin the		Theory
The of the balk we be based on the second we can be a second with the second we based of t		
where, we is the reduit for discrete fine stand and to be the type for the former of the stand. The stand and to be the stand and to be the type for the stand and to be type for the stand and to be type former of the stand and the stan	Most of the real world signals that we encounter are c	continuous time signals. It is difficult and costly to process signals in continuous time. If the continuous time
where, we is the radius frequency (rad) of the signal and to is the cycle frequency (25, $\delta_{I}\pi_{I}^{*} = 4\cos(2\pi_{I}\pi_{I}^{*} + \phi)$)(27)	signals can be converted to discrete time signals (sam)	ple values at discrete points) by some reliable method, then computers can be used to do the processing in
Therefore domain takes A sampling in the process that can be used to solve the commonly the signal of discrete time signal. If a few conclusions are used, there is a solve the	discrete time. In most cases, processing discrete tim	ie signals is flexible and preferable, compared to that of continuous time signals. The conversion process
representing and receivering a confinitour time signal from its samples. Will be reliable and the Kampling. The area specifies these conditions. An ideal system that covere control of the form: $\frac{SO}{T_{i}-T_{i}}$ Fig. (1) continuous time sinusoidal signal $x(t) = 4\cos(c_{0}t + \phi) \dots (2\sigma)$ where, we is the radius frequency (ad) of the signal and to be the optimized form: $x(t) = 4\cos(c_{0}t + \phi) \dots (2\sigma)$ where, we is the radius frequency (ad) of the signal and to be the optimized form: $x(t) = 1 + \cos(c_{0}t - \phi) \dots (2\sigma)$ $x[t] = x(t) = x($	discrete domain value. Sampling is the process that	can be used to convert the continuous time signal to discrete time signal. If a few conditions are met, then
converts Continuous-time signal is as shown in the figure. Consider a continuous-time signal of the form. $\begin{array}{c} & & & \\ \hline \hline & & \\ \hline & & \\ \hline & & \\ \hline & & \\ \hline \hline & & \\ \hline & & \\ \hline & & \\ \hline \hline & & \\ \hline \hline & & \\ \hline \hline $	representing and recovering a continuous time signal for	rom its samples will be reliable and the Sampling Theorem specifies these conditions. An ideal system that
$\frac{x(t) + \frac{x(t) + x(t)}{t}}{t}$ Fig. (1) continuous time sinusoidal signal $x(t) - 4\cos(\alpha_0 t + \phi) \dots 0 \alpha_0$ where, we is the radius frequency (rad) of the signal and for its the cost ($\alpha_0 t + \phi$) 0 α_0 where, we is the radius frequency (rad) of the signal and for its the cost ($\alpha_0 t - t + \phi$) 0 α_0 where, we is the radius frequency (rad) of the signal and for its the cost ($\alpha_0 t - t + \phi$) 0 α_0 $x(t) = 4\cos(\alpha_0 t - t + \phi) \dots 0 \alpha_0$ $x(t) = 4\cos(\alpha_0 t - t + \phi) \dots 0 \alpha_0$ $x(t) = 4\cos(\alpha_0 t - t + \phi) \dots 0 \alpha_0$	converts Continuous-time signal to discrete-time signal	is as shown in the figure. Consider a continuous time sinusoidal signal of the form,
$\frac{\text{sco} - \frac{1}{C \cdot \text{top}} x[n] = x(nT_i)}{T_i - 1.t_i}$ Fig. (1) continues ($n_0 t_i + \phi$) $(d\sigma)$ $x(t) = A \cos(2\sigma_t f_i + \phi) \dots (d\sigma)$ where, we is the ration frequency (rat) of the signal and for is the cyclic frequency (fiz) of the signal. The corresponding discrete time signal $x[n]$ can be obtained by sampling XO, using the ideal system show above. Hence, $x[n]$ is of the form: $x[t] = x(mT_i) = A \cos(2\sigma_t f_i + \phi) \dots (2\sigma)$ $x[t] = x(mT_i) = A \cos(2\sigma_t f_i \pi f_i + \phi) \dots (2\sigma)$		
$\sum_{i=1}^{n} \frac{1}{T_i - 1 d_i}$ Fig. (1) continuous time sinusoidal signal $\sum_{i=1}^{n} \frac{1}{T_i - 1 d_i}$ Fig. (1) continuous time sinusoidal signal $\sum_{i=1}^{n} \frac{1}{T_i - 1 d_i}$ where, we is the radius frequency (ad) of the signal and 0 is the cyclic frequency (dz) of the signal. The corresponding discrete line signal x[0] can be obtained by sampling x(0), using the ideal system show about 2 is (1) is of the frequency (dz) of the signal. The corresponding discrete line signal x[0] can be obtained $\sum_{i=1}^{n} \frac{1}{T_i - 1 d_i} = x(\alpha x_i) =$		$\mathbf{x}(\mathbf{t}) = \mathbf{x}(\mathbf{n}) = \mathbf{x}(\mathbf{n}T_s)$
$\begin{bmatrix} T_{a-1}T_{a} \\ T_{a-1}T_{a} \end{bmatrix}$ Fig. (1) continuous time sinusoidal signal $x(t) = 4\cos(2\pi f_{a}t + \phi) dx)$ $x(t) = 4\cos(2\pi f_{a}t + \phi) dx)$ where, we is the radius frequency (rad) of the signal and to be the equation (2\pi f_{a}t + \phi) dx) where, we is the radius frequency (rad) of the signal and to be the equation (2\pi f_{a}t + \phi) dx) $x[t] = x(t) $		
$\frac{T_{c}-1T_{c}}{Fig. (1) continuous issue is subsolid a signal is \frac{x(t) - 4\cos(c_{0}t + \phi), 0.0}{x(t) - 4\cos(c_{0}t + \phi), 0.0)} where, we is the radius frequency (rad) of the signal and D is the cyclic frequency (fiz) of the signal. The corresponding discrete time signal x[n] can be obtained by sampling x(b, using the ideal system shown above. Hence, x[n] is of the form:x[n] = x(nT_{c}) = 4\cos(c_{0}nT_{c} + \phi)(2\sigma) x[n] = x(nT_{c}) = 4\cos(c_{0}nT_{c} + \phi)(2\sigma)$		
Fig. (1) continuous time sinusoidal signal $x(t) = 4\cos(\alpha_0 t + \phi)$ $(0, \sigma)$ where, we is the radius frequency (rad) of the signal and to is the cycle frequency ($2\pi_0 t + \phi$) $(0, \sigma)$ where, we is the radius frequency (rad) of the signal and to be the signal and the		$T_s = 1/f_s$
Fig. (1) continuous time sinusoidal signal $x(t) = 4\cos(\cos(t + \phi)(2\pi)$ where, we is the radius frequency (rad) of the signal and D is the cyclic frequency (Ez) of the signal. The corresponding discrete time signal N[n] can be obtained by sampling x(0, using the ideal system show above. Hence, x[n] is of the form: $x[n] = x(nx_{1}^{2}) = 4\cos(\cos(nx_{1}^{2} + \phi)(2\pi)$ $x[n] = x(nx_{1}^{2}) = 4\cos(\cos(nx_{1}^{2} + \phi)(2\pi)$		
$\frac{x(r) - 4\cos(ny_i r + \phi) \dots dm}{x(r) - 4\cos(ny_i r + \phi) \dots dm}$ where, we is the radius frequency (rad) of the signal and D is the cyclic frequency (Hz) of the signal. The corresponding discrete time signal x[n] can be obtained by sampling x(f), using the ideal system show the effect of the form: $x[n] = x(nx_i^2) = 4\cos(ny_i nx_i^2 + \phi) \dots(2m)$ $x[n] = x(nx_i^2) = 4\cos(ny_i nx_i^2 + \phi) \dots(2m)$		Fig. (1) continuous time sinusoidal signal
$x(t) = A \cos(2\pi f_0^2 t + \phi) (2n)$ where, we is the radius frequency (rad) of the signal and for is the cyclic frequency (Rz) of the signal. The corresponding discrete time signal x[n] can be obtained by sampling x(0), using the ideal system show above. Hence, x[n] is of the form. $x[n] = x(nT_1) = A \cos(2\pi f_0 nT_1 + \phi) \qquad(2n)$ $x[n] = x(nT_1) = A \cos(2\pi f_0 nT_1 + \phi) \qquad(2n)$		$\mathbf{x}(t) = 1 \cos(\alpha t + \alpha) \qquad 0 \cos(\alpha t + \alpha) = 0 \cos(\alpha t + \alpha)$
$x(t) = A\cos(2\pi J_0 t + \phi) \dots (d\sigma)$ where, we is the radian frequency (rad) of the signal and 0 is the cyclic frequency (H2) of the signal. The corresponding discrete time signal x[n] can be obtained by sampling x(t), using the ideal system shown above. Hence, x[n] is of the form, $x[n] = x(nT_s) = A\cos(\alpha_b nT_s + \phi) \dots (2\alpha)$ $x[n] = x(nT_s) = A\cos(2\pi J_0 nT_s + \phi) \dots (2\alpha)$		$x(r) = x \cos(m_r r + p)$ (iii)
where, we is the radius frequency (rad) of the signal and 0 is the cyclic frequency (Rz) of the signal. The corresponding discrete fine signal s[n] can be obtained by sampling x(0, using the ideal system shows above. Hence, x[n] is of the form: $x[n] = x(nx_n) = A\cos(\alpha_n nx_n^2 + \phi) \qquad(2\pi)$ $x[n] = x(nx_n) = x(nx_$		$x(t) = A\cos\left(2\pi f_0 t + \phi\right) \dots (db)$
by sampling x(f), using the ideal system shown above. Hence, x[n] is of the form, $x[n] = x(nT_s) = A \cos(\alpha_b nT_s + \phi) \dots (2\alpha)$ $x[n] = x(nT_s) = A \cos(2\pi_b nT_s + \phi) \dots (2\alpha)$	where, wo is the radian frequency (rad) of the signal a	nd f0 is the cyclic frequency (Hz) of the signal. The corresponding discrete time signal sful can be obtained
$x[n] = x(nT_s) = A\cos(\omega_0 nT_s + \phi) \qquad \dots (2a)$ $x[n] = x(nT_s) = A\cos(2\pi f_0 nT_s + \phi) \qquad \dots (2b)$	by sampling x(t), using the ideal system shown above.	Hence, x[n] is of the form.
$x[n] = x(nT_i) = A\cos(\alpha_b nT_i + \phi) \qquad \dots (2\sigma)$ $x[n] = x(nT_i) = A\cos(2\pi f_i nT_i + \phi) \qquad \dots (2b)$		
$x[n] = x(nT_t) = A\cos\left(2\pi f_0 nT_t + \phi\right) \dots (2b)$		$x[n] = x(nT_s) = A\cos(\omega_0 nT_s + \phi) \qquad \dots (2a)$
		$x[n] = x(nT_{4}) = A\cos\left(2\pi f_{0}nT_{4} + \phi\right) \dots (2b)$
Thus the sampling operation can be seen as a transformation from Continuous-time to discrete-time. The system used here is only a mathematical idealization. In real-world, this needs to be implemented using an AD converter that has quantization and jitter problems.	Thus the sampling operation can be seen as a transfor real-world, this needs to be implemented using an A/D	mation from Continuous-time to discrete-time. The system used here is only a mathematical idealization. In converter that has quantization and jutter problems.
The obtained samples, by themselves cannot be used to reliably reconstruct the original signal. This is because, more than one continuous-time signal can have the	The obtained samples, by themselves cannot be used	to reliably reconstruct the original signal. This is because, more than one continuous-time signal can have the
same discrete-time samples, depending on their own frequency and sampling frequency. So, in order to reconstruct the signal, we need to know the sampling rate	same discrete-time samples, depending on their own fi	requency and sampling frequency. So, in order to reconstruct the signal, we need to know the sampling rate
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Fig.12 Web page of theory bases for experiment (2).

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Example	
example:- Find a signal g(t) that is band - limited to B Hz and whose samples are	
$g(0)=1$ and $g(\pm T_{g}) = g(\pm 2T_{g}) = g(\pm 3T_{g}) = \dots = 0$	
where the sampling interval $T_{\rm g}$ is the Nyquist interval for g(t), that is, $T_{\rm g}$ = 1 / 2B	
Solution :	
We use the interpolation formula	
$g(t) = \sum_{k} g(kT_{k}) \operatorname{sm} c(2\pi B t - k\pi) g(t) = \sum_{k} g(kT_{k}) \operatorname{sm} c(2\pi B t - k\pi)$	

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



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The Continuous-Discrete Sampling is a program that have been	Plot Galleria Evil Hole		
leveloped in MATLAB GUI to perform exercise for continuous	Input: cos(2x 14.01)	$x[n] = \cos(2\pi 1.17 n)$	Output: cos(2x 2.0 t)
and discrete signals in time domain and and frequency domain		Chick on this plot to one above	
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Features:			
See's can change the input frequency and sampling rate.	Time (see)	Three (complete)	Time (see)
Reconstruction through D/A is also shown.		1 1	
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Fig.14 Web page of exercise for experiment (2).

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	Equations	
	$\overline{g}(t) = g(t)\delta_{T_x}(t) = \sum_n g(nT_x)\delta(t - nT_x)$	
	$\delta_{T_s}(t) = \frac{1}{T_s} [1 + 2\cos\omega_s t + 2\cos2\omega_s t + 2\cos3\omega_s t + \dots]$	
	$\overline{g}(t) = g(t) \delta_{T_{t}}(t)$	
	$= \frac{1}{T_a} [g(t) + 2g(t)\cos \omega_a t + 2g(t)\cos 2\omega_a t + 2g(t)\cos 3\omega_a t + \dots]$]
	$ \frac{\mathcal{G}(\omega) = \frac{1}{T_{j}} \sum_{\alpha = -\infty} \mathcal{G}(\omega - n\alpha_{j}) \\ \mathbf{F}_{\alpha} \ge \mathbf{E}^{T_{j}} \xrightarrow{\alpha = -\infty} \mathcal{G}(\omega - n\alpha_{j}) $	
	$T_s < \frac{1}{2B}$	

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

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Question	
1. Say 12 samples of one time period of a discretized sine wave are given. How to determine	he the absolute time period of the sine wave
(if $T_s = 0.05 \text{ ms/sample}$)	
A- = 0.05 ms	
B- 0.6 ms	
2. In discrete systems absolute frequency determination in Hz is dependent upon the	
sample frequency fs =	
B- f_=T_	
3- we must the fs > 2B	
A yes	
D no	

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

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Theory	<u>Fourier Series And</u>	alyses
Example	 Joseph Fourier submitted a paper in 1807 to the Academy of Sci description of problems involving heat conduction, and was at fin However, it contained ideas which have developed into an import 	ences of Paris. The paper was a mathematical rst rejected for lack of mathematical rigour. tant area of mathematics named in his honour,
Exercise	Fourier analysis. According to the theory developed by Fourier, any periodic funct	tion $f(t)$, with period T, may be represented by an
Equations	infinite series of the form	
Quastion	where the coefficients $a_{\mathcal{O}}, a_n$, and b_n for a given periodic function	$\inf f(t)$



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Theory
Fourier series
What is Fourier series representation and why do we need it ? The analysis of LTI (Linear Time Invariant) systems can be made easier if we can represent different signals using some basic set of signals. Fourier Series is one kind of representation of signals, where we use complex exponentials. These basic signals can be used to construct more useful class of signals using Fourier Series representation. Fourier Series can be used to represent both continuous and discrete Periodic signals.
Fourier Series representation of Continuous time periodic signal
There are two well known basic periodic signals, the sinusoidal signal
$x(t) = \cos \omega_0 t$
and complex exponential signal given as,
$x(t) = e^{jxyt}$
These are periodic with fundamental frequency w0 and fundamental period $T = 2p/w0$. These signals are called periodic since $x(t) = x(t+T)$ Associated with this signal are other harmonic complex exponentials, given as

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

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Example	
example (1)	
1. Show that the Fourier Series coefficients for the square wave studied earlier are:	
solution:-	$a_0 = 0$
a_0 and a_n were found in the notes. To find b_n we use	$b_n = \begin{cases} a_n = 0 \\ 0, & \text{if } n \text{ is even} \\ \frac{4}{n\pi}, & \text{if } n \text{ is odd} \end{cases}$
$b_n = \frac{2}{2t} \int_{1}^{\frac{1}{2}} \frac{1}{\tau^2} x(t) \sin (g \omega_1 t) dt$ and	
$\mathbf{v}(\boldsymbol{p}) = \left\{ \begin{array}{cc} 1, & 0 < \boldsymbol{r} < \frac{\boldsymbol{T}^{T}}{2} \\ -\boldsymbol{T} \end{array} \right\}$	
to find that $\frac{-1}{2} < t < 0$]	Querra Quer
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Fig.19 Web page of solved example used in experiment (3).







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

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Question	n		
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A odd			
B- even			
2- Fourier series in trigonometric sine			
o=0 For (x t) is			
A odd B even			

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



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

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Theory	
Complex Fourier Series	
By using the Euler formula $e^{i\theta} = \cos \theta + i \sin \theta \sin \theta$ and $e^{i\theta}$ can be expressed as complex exponential terms	
$\cos\theta = \frac{e^{i\theta} + e^{-i\theta}}{2}$ and $\sin\theta = \frac{e^{i\theta} - e^{-i\theta}}{2i}$	
Therefore the Fourier coefficients of a Fourier series can be rewritten by using the complex exponential terms as follows	
$\cos \frac{i\pi \pi t}{p} = \frac{1}{2} \left[\exp\left(\frac{i\pi t}{p}\right) + \exp\left(-\frac{i\pi t}{p}\right) \right]$	
$\sin\frac{\imath \imath \varkappa t}{\wp} = \frac{1}{2\imath} \left[\exp\left(\frac{\imath \imath \imath \varkappa t}{\wp}\right) - \exp\left(-\frac{\imath \imath \imath \varkappa t}{\wp}\right) \right]$	
The standard Fourier series can be converted into a complex exponential form by substituting their exponential equivalents for the cosine and sine terms:	
$\mathcal{J}(z) = \frac{\sigma_n}{2} + \sum_{n=1}^{\infty} \left(\frac{\sigma_n}{2} \left[\exp\left(\frac{2i\pi\pi t}{p}\right) + \exp\left[-\frac{2i\pi\pi t}{p}\right) \right] + \frac{\delta_n}{2i} \left[\exp\left(\frac{2i\pi\pi t}{p}\right) - \exp\left[-\frac{2i\pi\pi t}{p}\right) \right] \right] (19.18)$	
Collecting terms on the various exponentials and noting that $1/i = -i$, we obtain	
$\mathcal{J}(t) = \frac{\alpha_n}{2} + \frac{\alpha_n}{n\pi t} \left[\frac{\alpha_n - i b_n}{2} \exp\left(\frac{m \pi t}{p}\right) + \frac{\alpha_n + i b_n}{2} \exp\left(-\frac{m \pi t}{p}\right) \right]$	
If we now define	
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Fig.24 Web page of theory bases for experiment (4). $\$



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



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

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Equation	
$C_n = \frac{1}{T} \int_0^T f(t) e^{-jn\omega_0 t}$	
$f(t) = \sum_{\eta = -\infty}^{\infty} C_{\eta} e^{j\eta \omega_0 t}$	
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Fig.27 Web page of equations used in experiment (4).





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

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	Virtual DSP Laboratory	
Objective	Experiment NO.5	
Theory	Fourier Transform	
Example	The Fourier transform defines a relationship between a signal in t	ae time domain and
Exercise	its representation in the frequency domain. Being a transform,	no information is
Equations	the Fourier transform, and vice versa.	ered from knowing
Question		
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Fig.29 Web page of experiment (5).

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		Theory	
Fourier Tran 1- If on every $\int_{-1}^{-1} \mathcal{F}(x) _{dt} = \infty$ ist	finite interval, f satisfies the Diris, the following integral	chlet conditions and if the improper integral	
P(w)	$= \int_{-\infty}^{\infty} \mathcal{J}(x) \exp(-x \omega x) dx$		
is known as th transformation	e Fourier transform, whose valu by F. we write	e at $f(t)$ is the function $F(w)$. Denoting this	
$\mathbb{P}(\infty)$	- F [/(0)]		
The function f	can be recovered by using the Fo	urier integral	
£ (0) -	$= \frac{1}{2\pi} \int_{-\infty}^{\infty} P(\omega) \exp(i \omega t) d\omega$		
The function f denoted by	(t) is in turn referred to as the inv	erse Fourier transform of F(w) and is	
J (2) -	- F ⁻¹ [ℓ ² (∞)]		
Several in	nportant transforms are listed in t	he following table:	
	f(t)	F(w)	
	$\mathbf{a} \cdot \mathcal{J}(a) = \begin{cases} 0 & z < 0 \\ a - az & 0 < z \\ a > 0 \end{cases}$	$F(\infty) = \frac{1}{\alpha + i \infty}$	
	$\mathbf{b} \cdot \mathcal{J}(t) = \begin{cases} e^{at} & t \leq 0 \\ e^{-at} & 0 \leq t \leq 0 \end{cases}$	$P(\omega) = \frac{2\alpha}{\alpha^2 + \omega^2}$	

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

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Ryample			~
Example 1: Find the Fourier transform of the following function			Charles and the second se
$J'(t) = \begin{cases} e^{at} & t \leq 0 \\ e^{-at} & t \geq 0 \end{cases} a > 0$			
Solution			
The Fourier transform is given by Eq. (20.13)			
$P(\omega) = \begin{bmatrix} u \\ - x \end{bmatrix} f(t) \exp(-t\omega t) dt = \begin{bmatrix} u \\ - x \end{bmatrix} e^{-st} \exp(-t\omega t) dt + \begin{bmatrix} u \\ - x \end{bmatrix} e^{-st} \exp(-t\omega t) dt$			
$=\left[\frac{\exp\left(-(\alpha+i\alpha)\lambda\right)}{(\alpha-i\alpha)\lambda}\right]^{\alpha} + \left[\frac{\exp\left((\alpha-i\alpha)\lambda\right)}{(\alpha-i\alpha)\lambda}\right]^{\alpha}$			
$=\frac{1}{2}\frac{1}{2$			
Example 21 Find the Fourier Transform of the following signal, Sketch a graph of the signal and one of			
the magnitude of its frequency spectrum.			
$x(t) = \{e^{-2t}, 0 \le t \ge 0\}$			
The Fourier Transform is defined as			
$\mathcal{X}(tr) = \int_{-\infty}^{\infty} A(t) e^{-ht} dt$			
so the FT of this signal is			
$X(tar) = \int_{0}^{t} e^{-2t} e^{-\lambda t} dt$			
$T_{\alpha} = \frac{1}{2} \int dx $			

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

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Exercise	
	Overview This applet allows a user to view and manipulate a signal and the fourier transform in a way that makes apparent some of the basic properties of the Fourier transform. The signal is represented internally in a symbolic manner so that the signal and its transform are accurate representations of the continuous Fourier transform and not a discrete approximation

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



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

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	77	ecory						In	verse Four	ier Tran	sforms				
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	Equ Qu	ations astion							Spatial Frequency . Domain	[Inverse Fourier		Spatia Domai	1 11	
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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).

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Equation		
Inverse Fourier Transform of f (t) is		
$\mathcal{F}^{-1}(g(\omega)) = \frac{1}{2\pi} \int_{-\infty}^{\infty} g(\omega) e^{-i\omega t} d\omega = O(t)$		
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Fig.39 Web page of equations used in experiment (6).

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the inverse Fourier Transform $f(t)$ can be obtained by substituting the known function $G(\infty)$ into the second	id equation opposite and integrating.
Yes	

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

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F					
		Virtual DSP Laboratory			
	Objective	Experiment NO.7			
	Theory Example	Discrete Fourier Transforms_			
	Exercise Equations	The Discrete Fourier Transform (D.F.T) is an invertible transform widely employed in signal processing and computed using stable efficient algorithms known as Fast Fourier Transform (F.F.T) algorithms.	analysis. It can be		
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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.45 Web page of equations used in experiment (7).

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	Question	
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	VBScript	
A- Yes		
B- No		
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2- The D.F.T to continuous function		
A Yes		
II- No	OK	
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Fig.46 Web page of self test questions applied in experiment (7).

on the FFT button.				
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Virtual DSP Laboratory				
Objective Experiment NO.8				
Theory Fast Fourier Transform				
Example 1-The FFI provides a means to reduce the computational complexity of the DFT by takes arithmetical operational complexity operational com	tions from			
Exercise order (\mathbb{N}^2) to order (\mathbb{N}^1)				
Equations				
2-The FFI algorithm is usually implemented by using DSP chips such as Texas instruments and analogue de	Nices.			
3. The computational cost of doing both FFT and IFFT may be less than conventional methods.				
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$\mathbf{F} = \mathbf{A}^{T} \mathbf{W} + \mathbf{A}^$				

Fig.47 Web page of experiment (8).

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Theory(
meary	
Fast Fourier Transform	
Why the F.F.T ?	
The Past Fourier Transform is a simply a method of laying out the computation, which is much faster for large values of N, where N is the number of the sequence.	f samples in
The Fast Fourier Transform FFT	
The DFT requires the calculation of the sums	
$H(f) = \int_{-\infty}^{+\infty} h(t) e^{2\pi i f t} dt$	
whenk' = $\exp(3\pi i/N)$. At first sight, this requires at least N ² analight for a second state all N of the coefficients H_{μ} . But this is not the case. As ""Numerical Bespies", the animation may be broken into two parts one over the even-numbered elements $(h = 1, 2, 5,)$. In turn, each one of these parts can be broken into the even-numbered and odd-numbered parts, and the process can be consistent of $(h = 1, 2, 5,)$. In turn, each one of these parts can be broken into the even-numbered and odd-numbered parts, and the process can be consistent of the even-numbered and odd-numbered parts, and the process can be consistent of the even-numbered and odd-numbered parts, and the process can be consistent of the even-numbered in the state of the even-numbered in the state of the even-numbered in the state of the event of the even of the even-numbered in the state of the event event of the event of the event of the event event event of the event event event of the event event event event of the event event event event event of the event	explained in d-numbered atimued, with ection of the After this is
done, the required N values of H, can be generated by making a sequence of 2,4,8,point summations. The total time for the operation scales not	as N ² but as
N logN, so that for large transforms there is a enormous saving in time.	
As a consequence of the bit-reversal process, the application of the F.F.T to a vector of data in a computer leaves the resulting components of the tr rather mixed-up state. For the programs you will use in this course, this mixed-up state has been sorted out for you, so that the vector available aft consists of values at the following frequency components in increasing order:	ansform in a er the <mark>F.F.T</mark>
$\int (\pi - NU^2), f(\pi - NU^2 + 1), f(\pi - NU^2 + 2),, f(0), f(1),, f(NU^2 - 2), f(NU^2 - 1)$	
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Fig.48 Web page of theory bases for experiment (8).	

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Example	
$x[0] \simeq \qquad $	
A[1]	
* point * point	
a(3)	
$x[5] = \frac{y_{11}}{y_{12}} + \frac{y_{12}}{y_{22}} + \frac{y_{22}}{y_{22}} - point = -\infty X[3]$	
Alor Alar	
x[7] - x[7]	
Recursively, we can further decompose the (N/2)-point DFT into smaller substructures:	
$\times 101$ \rightarrow	
AUTO TOTAL AND ADDET TO X[4]	
x [N] with the point of the poi	
$x[n] \circ$ $x_{w_2} = w_2 = maint = o x[3]$	
$x[7] = \frac{x}{-1}$ $x = \frac{1}{-1}$ $x = \frac{1}{-1}$ $x = x[7]$	
Winneller and heres	
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Fig.49 Web page of solved example used in experiment (8).

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

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Equation		
$X(k) = G(k) + W_n^k H(k)$		
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Fig.51 Web page of equations used in experiment (8).

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Question	<u> </u>
1.	
The F.F.T is a faster version of the Discrete Fourier Transform (DFT).	
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Fig.52 Web page of self test questions applied in experiment (8).



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		Virtual DSP Laboratory		
		Experiment NO.9		
	Objective	Convolution		
	Theory	Convolution is the term given to the mathematical technique for determining a system output given an input signal and the system inputs response. It is written as		
	Example	$s(t) = \int_{0}^{t} s(t - s) h(s) ds$ Discrete Convolution Convolution as interfaces by a discrete time parallel which is more appropriate to digital signal		
	Exercise	processing systems. For the mathematics, the integration is replaced by a summation, hence convolution may be re-expressed as $r(t) = \sqrt[5]{2}r(t) - r(t)r(t)$		
	Equations	Correlation is a technique that is very similar in mechanism to convolution, with one subtle difference. The correlation integral is given by		
	Quastions	$k_{\pi}(A) = \int_{-\infty}^{\infty} y(x) x(x + A) dx$ While this may appear to be similar to equation (1) with some changes of variable, unlike convolution where is time reversed, in correlation this is not the case. The integral thus no longer represents the output of a filter driven by an input signal.		
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Fig.53 Web page of experiment (9).

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Theory	
Convolution	
Convolution is an operation by which the output of an linear time-invariant (LTD system	with
a known response can be determined, given an arbitrary input signal. Observe the system	to
the left with continuous-time input v(2) and output v(2) Convolution is simply the process	
that determines the output given the lipto.	
	$x(q) = \mathcal{S}(q),$
	$y(\tau) = \int_{-\infty}^{\tau} x(\tau) d\tau$
\rightarrow LTI \rightarrow	
	$=\int_{-\infty}^{\infty} \delta(\tau) d\tau$
	- 400
The that inputse is used as an example input for the system shows above. When the response and is denoted by $h(t)$. So, in this example $h(t) = u(t)$ The system in this particular	a mput to any LTI system is a unit inputse, the output is called the imputse of the completion of the second state of the second state of the second state of the second state of the second
the output, according to the system's corresponding mathematical relationship shown to	the right of it. In general, however, any relationship which is linear and time
invariant, with that impulse as input quantes as a valid impulse response for an L11 syst	211.
shifted version of the imput	he nearbant, if the impulse is shifted to a new location, the output is simplified to a new location, the output is simplified to a very helpful and important property
· LII · · · · · · · · · · · · · · · · ·	. In the case of the integrator, the output of a shifted unit impulse is a shift
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The standard second sec	
obtained from the individual components that make up the input signal. If both in	a many and time-invariance hold, the output of the system can be found through
relation known as the Convolution Integral:	
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Fig.55 Web page of solved example used in experiment (9).

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Exercise	
A Got x(t)	
Figned Signal Right Puter	
	Annual and a t
T t = 1.34 Givt v(t) Givt h(t)	
Distance of the bits	
2.0 C.0	
Signal Axis:	
\mathbf{x}_{i} $\mathbf{b}(\mathbf{t} \cdot \mathbf{y}) = \mathbf{r} \cdot \mathbf{c} \mathbf{d}$	
4 t = 1.34 Multiplication Axis: c.2	00000 5 1
Convolution Axis:	
$\mathbf{y}(\mathbf{i}) = \mathbf{j}_{\mathbf{x}}(\mathbf{c}) \mathbf{b}_{\mathbf{i}}(\mathbf{c}_{\mathbf{v}}) \mathbf{d}_{\mathbf{v}}$	
Close Halp Click inside plot area to respate age	OK Concel
2°0 -6 J 6 10	
Description	
D The purpose of this program is to conduct experiments on continuous convolution and visualize the results	
2) There are different types of signal which can be obtained by pressing on get x(t) button , see figure on the right hand side.	
3) The upper left window shows the square waveform x(t) and inpulse waveform h(t).	
4) The middle left window shows the multiplication of two functions s() and h(t-) as a function of).	
b) The lower left while with the convention of two waveforms, xit) and nit.	
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Fig.56 Web page of exercise for experiment (9).





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Question	
1- The Auto correlation between two similar function	
R ha	
2- The Cross correlation between two similar function	
A Yes	

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

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1		Virtual DSP Laboratory								
		Experiment No.11								
	objective	Distant Effort								
		Digital Filter								
		Input System Output								
	Theory	Signal + Filter Filtered								
		Noise								
	Example									
		Advantages of Digital Filters								
		The following list gives some of the main advantages of digital over analog lifers.								
		1-A digital filter is programmable, i.e. its operation is determined by a program stored in the processor's memory. This means the digital filter over a satist be channed without affecting the disputition of the available of the disputition								
	L. XCFC.LSC	and the state of t								
		2-1) grai hiters are easily designed, tested and implemented on a general-purpose computer or workstation.								
1		3-The characteristics of analog filter circuits (particularly those containing active components) are subject to drift and are dependent on temperature. Disital filters do not suffer from these problems, and so are extremely stable with respect both to time and temperature.								
	Equations	A Table during any language district films and handle (any ferror any start of second she had a film and a films any handle second she had been any								
		increase, digital filters are being applied to high frequency signals in the RF (radio frequency) domain, which in the past was the exclusive								
		preserve of analog technology.								
	Quastions	5-Digital filters are very much more very attle in their ability to process signals in a variety of ways; this includes the ability of some types of diside filters are very much more very attle in their ability to process signals.								
1		digital inter to adapt to changes in the characteristics of the signal								
1										

Fig.59 Web page of experiment (11).

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Theory	
1- IIR Infinite impulse response	
The side formations for TTT	
Basic surface for the	
IIR filter Infinite impulse response (III) filters are an alternative to finite impulse response (TEI) filters. Offer TPE implementation, but III filters induce another phase and are more sensitive to numerical problems to use the sensitive to numerical problems to use the sensitive to the s	m, an IR implementation can meet a given filter specification with less computation than an sign of digital IR filters is heavily dependent on that of their analog counterparts because because and the second se
Properties of an IIR Filter	
The general equation of an UR filter can be expressed as follows:	
$rr(x) = \frac{b_{0,1} + b_{1,2} \pi^{-1} + \ldots + b_{2,2} \pi^{-N}}{1 + a_{1,2} \pi^{-1} + \ldots + a_{2,4} \pi^{-N}}$ $\sum_{k=0}^{N} b_{k} \pi^{-k}$	
$-\frac{1}{1+\sum_{k=1}^{M}a_{k}z^{-k}}$ ak and bk are the filter coefficients.	
The transfer function can be factorized to give:	
$H(z) = k \frac{(z-z_1)(z-z_2)\cdots(z-z_N)}{(z-p_1)(z-p_2)\cdots(z-p_N)} = \frac{Y(z)}{X'(z)}$	
Where: x_1, x_2, \dots, x_N are the zeros.	
P1. P2, PN are the poles.	
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Fig60 Web page of theory bases for experiment (11).





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

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Example	
Example 1 :	
We want to low pass filter a signal that contains a sinuscid and a significant amount of noise. Figure 1 shows a portion of this signal's sinusoid, discerning the sine wave in the signal is virtually impossible. One of the primary applications of linear filters is noise remova pass band with the signal's spectrum and greatly reduce all other frequency components that may be present in the noisy signal.	s waveform. If it weren't for the overlaid al: preserve the signal by matching filter's
Iffered using the quency-domain techniques. Each filtered section is added to other outputs that overlap to create the signal order input. The sinusoidal component of the signal is shown as the red deshed inter order of the signal and the signal is shown as the red deshed inter order of the signal is a solution of the signal is a solution of the signal is a solution of the signal	equivalent to having filtered the
$1 - 17$, $n \in \{0,, 16\}$, which makes $q=16$. Its frequency response (determined by computing the discrete Fourier transform) is shown to each sectivity of the frequency-domain filtering approach is maximally efficient Choose the section length N_1 , so that N_1 is a power of two. To use	a Figure 2. To apply, we can select the length of a length-64 FFT, each section must be 48
samples long Filtering with the difference equation would require 33 computations per output while the frequency domain requires a little over 16; this finant filtering works.	frequency-domain implementation is over twice as
Trans	Commentary

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

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	Virtual DS	5P Laboratory					
	Texperim	ent NO.10					
Objective	Z-Tr	ansform					
Theory	The Z-banaform can be considered as a discrete equivalent of the Laplace transform . The Z-transform converts a discrete dime-domain signal into a complex frequency domain prepresentation.						
	Illustration	Property Name					
	$] + bf_2[k] \xleftarrow{\mathscr{P}} aF_1(z) + bF_2(z)$	Linearity					
Example	$\xrightarrow{\mathscr{D}} zF(z) - zf[0]$	Shift Left by 1					
	$-2] \stackrel{\mathcal{D}}{\longleftrightarrow} z^2 F(z) - z^2 f[0] - z f[1]$	Shift Left by 2					
Exercise	$ \begin{array}{c} \underbrace{\overset{g_{i}}{\longrightarrow}} x^{a} F(x) - x^{a} \underbrace{\overset{g_{i}}{\longmapsto}}_{i=a} f(k) x^{-b} \\ = x^{a} \left(F(x) - \underbrace{\overset{g_{i}}{\longmapsto}}_{i=a} f(k) x^{-b} \right) \end{array} $	Shift Left by n					
	t ⁻ⁿ F(z)	Shift Right by n					
Equations		Multiplication by time					
	$] \stackrel{\mathcal{P}}{\longrightarrow} F_1(\mathbb{Z}) F_2(\mathbb{Z})$	Convolution					
		Initial Value Theorem					
Quastions	$\lim_{z \to 1} (z - 1) F(z)$	Final Value Theorem					
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Fig.63 Web page of experiment (10).

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	Theory	
Pole-Zero plot and its relation to Frequency dou Pole-Zero plot is an important tool, which helps us interpreting results in either domain. It also helps in t	nature to relate the Frequency domain and Z-domain representation of determining stability of a system, given its transfer function H (s)	a system. Understanding this relation will help
	$\mathcal{K}(e^{-fm}) = \sum_{j=-m}^{\infty} \mathcal{K}[\mathcal{M}]e^{-fmm}$	
and Z-transform is given as		
	$X(z) = \sum x[\alpha] z^{-\alpha}$	
	Page - Frank	
There is a close relationship between these equation transform is simply $\mathcal{N}(\mathcal{A})$ with $z = e^{A \mathcal{A}}$, i.e for $ z = I$, t	$e^{-\mu \omega}$, then the z-transform reduces to 0 he z-transform corresponds to the Fourier transform. If instead v	he Pourier transform. When it exists, the Pour we express z in polar form as
There is a close relationship between these equation transform is simply $\mathcal{N}(2)$ with $z \to z^{\infty}$ i.e for $ z = 1$, if	The set of	he Pourier transform. When it exists, the Pour we express zin polar form as
There is a close relationship between these equation transform is simply XEP with $e^{-e^{-\lambda t}t}$ is for $ e = 7$, the Third is the Forkeric transform of the Product of the product of the second secon	In . If we replace x with $x^{n/2}$, then the x-transform reduces to 0 the stransform correspond to the Fourier transform. If instead x $x = x^{n/2}$ ordened sequence x [1] and the exponential sequence $x < x^n$. For $x < x$	he Pourier transform. When it exists, the Pour express = in polar form as
There is a close relationship between these equation transform is simply $N(2)$ with $z=e^{jM}$. Le for $ x =7$, if This is the Pourier transform of the product of the s for the z-bransform be Pourier transform and z-transformer.	In the set of the set	the Pourier transform. When it exists, the Pour we express # in polar form as
There is a close relationship between these equation transform is simply $N(x)$ with $x=x^{\mu\nu}$, e for $ x =1$, 0 This is the Fourier bransform of the product of the z On a similar line, the Fourier bransform and z-bransf	Interval Interval to the setting of the setting form reduces to the setting form correspond to the Fourier transform. If instead to $x = rer^{2/6}$ original sequence of all and the exponential sequence $r r^{2}$. For $r =$ original sequence of a given as $H(ror) = \frac{2}{4r^{2}} D_{\mu} e^{-rrat}$	he Pourier transform. When it exists, the Pou we express # in polar form as
There is a close relationship between these equation transform is simply $N(x)$ with $x=x^{\mu\nu}$, e for $ x =1$, 0 This is the Fourier bransform of the product of the z On a similar line, the Fourier bransform and z -bransf	The set of	he Pourier transform. When it exists, the Pou we express = in polar form as



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EN :- Find Z.T. of unit impulse signal?				
$\delta(k) = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$				Concernance of the second
$X(z) = \sum_{k=0}^{\infty} x(k) Z^{-k}$				
$= X1(0) Z - 0 + \dots = 1 * Z - 0 = 1$				
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Fig.65 Web page of solved example used in experiment (10).



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Equation	s	
Z-Transform Equation		
1-Bilateral Z-Transform.		
$Z\{x[n]\} = \sum_{n=-\infty}^{\infty} x[n] z^{-n} = X(z)$		
From DTFT viewpoint: $Z{x[n]} = F{r^nx[n]} _{n^m=n}$		
(Or, DTFT is a special case of z-T when $z = e^{j\omega}$, unit circle.)		
2- Inverse Z-Transform. $x[n] = \frac{1}{2\pi j} \oint_{\Gamma}^{T} X(z) z^{n-1} dz Z^{-1}[X(z)]$		
3-Single-sided - Transform (unilatoral) – for causal sequences $\mathcal{K}(z) = \sum_{\substack{n=0\\n=0}}^{\infty} x[n]z^{-n}$		
Region of Convergence (ROC): The set of values of a for which the a transform converges.	ALLA	

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



A yes B no



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



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

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		

Table 1 Survey results

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