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In the framework of the Greek Operational Programme for Education and Initial Vocational Training (O.P. "Education") a significant number of actions were co-financed by the European Social Fund, the European Regional Development Fund and National resources. The TECHNOLOGICAL EDUCATIONAL INSTITUTE OF ATHENS (T.E.I. of Athens), as a key supporting activity of its educational framework under the Actions Category 2.2.2.a. «Reformation of Undergraduate Studies Programs» and the TECHNOLOGICAL EDUCATIONAL INSTITUTE OF CRETE (T.E.I. of Crete), in the framework of its Institutional Project under the Actions Category 2.6.1.e «Reformation of Undergraduate Studies Programs & Environment», have jointly undertaken the initiative to actively contribute and participate in the organization of the «2005 WSEAS International Conference on ENGINEERING EDUCATION»

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Combining traditional electronics laboratory teaching methodology with ECAD Simulation Software for Biomedical Engineering Undergraduates

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Abstract: - This paper presents the implementation of a laboratory classroom for teaching medical electronics technology by introducing computer-based electronics simulation combined with traditional laboratory methods. A survey of Electronic CAD (ECAD) tools, both in terms of literature and software benchmarking, has been carried out prior to the selection concerning the appropriate software tool used in the present implementation. The electronics simulation focuses on educating biomedical engineering undergraduate students in medical electronics principles, by providing additional in-depth training, combined with the classical electronics laboratory training. Traditional "hands-on" training methodology is not discarded, since experience gained in the laboratory environment cannot be substituted by virtual environments. The structure of the laboratory gives emphasis on student-centered learning.

Key Words: - Electronic CAD, electronics simulation, biomedical engineering education, student-centered learning

1 Introduction *

Electronic engineering has been traditionally taught as a combination of theoretical lectures and laboratory exercises. Laboratory setting is considered efficient for the familiarization of University students with electronic components, measurement and troubleshooting techniques, and design principles.

Although laboratory experiments are the standard for student training, several factors are obstructing their in-depth education. Implementation of complicated electronics designs on "breadboards" is a time-consuming procedure, and troubleshooting of implementation is acknowledged to be complicated both for students and professors. While measurements made on real electronic modules are reflecting real-life situations, it is often the case that results are not in line with the theoretical model of the design due to exogenous factors (ICs failures & tolerances, electromagnetic noise etc), thus students are deviating from their training target. Above all, laboratories utilize expensive equipment which is not ordinarily available to individual students, which makes very difficult the implementation and verification of designs at "remote" settings. Difficulties of the laboratory environment could demotivate students and disorient them from the laboratory's training targets.

Simulation of electronics' design has become a part of teaching procedure throughout the world since the 70s [1,2]. Electronic Computer Aided Design (ECAD) tools, are design platforms originally designed for industrial development process. Currently different vendors have developed software that incorporates Graphical User Interfaces (GUIs), permitting developers to virtually test and measure the design performance. GUIs have evolved, and "mimic" the laboratory environment, including virtual components (apart from actual manufacturers' component libraries) and virtual instruments (Voltmeters, Oscilloscopes etc.). Evidence exist [3,4], that the implementation of such simulation software, increases students motivation and enhances student-centered learning [5,6].

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2 Electronics Simulation Software Tools

Since the design of electronics with software was first introduced in 1963 in MIT by I. Shutherland [7], software tools have evolved sufficiently to accommodate educational characteristics. The main characteristics of electronics' simulation software are the ease of design modification, the reuse of components, the measurement and verification of the design (real-time simulation), the modular design of complicated circuits, the development without the utilization of a prototype, the embedded manufacturers component libraries and documentation, the output capabilities to manufacturers formats and, last but not least for educational purposes, the integration of virtual laboratory equipment.

Universities throughout the world are using simulation software for teaching purposes [2], not only for electronic principles but in all engineering fields. Universities are motivated to use ECAD tools as part of their laboratory structure due to the enhancement of students' interest and motivation in the learning process [3,4,8,9], reduced cost of laboratories [10] and benefits derived from remote teaching, either in the form of distance education [11], or in the form of additional University training in individuals' location.

Many vendors have developed software tools that fit the educational curriculum. OrCAD® (Cadence Design Systems Inc., San Jose, California, USA), Multisim® (Electronics Workbench, Toronto, Canada), Proteus® (Labcenter Electronics Inc., Grassington, England), Protel® (Altium Inc., Sydney, Australia), Pspice® (MicroSim Inc., Irvine, California, U.S.A.), to name a few, are products available that could fulfill both industry and education purposes.

For the purpose of the laboratory course of Biomedical Technology I, which will evolve into the Biosignal Acquisition laboratory, Multisim v.7.0® was chosen as the appropriate software tool for educating undergraduate students on medical electronics technology. The choice of the specific software was based on benchmarking of three different ECAD simulation tools (OrCAD v.9.0®, PROTEL®, Multisim v.7.0®), and assignment of relevant scores by the department staff. Scores were assigned based on suitability of the product, for the educational purposes of the laboratory. The choice was also supported by relevant literature [4], in which students recommended the above product in terms of preference among two software tools.

3. Educational Benefits

3.1 Laboratory Structure

The laboratory aims to provide in-depth training of biomedical engineering undergraduate students on medical electronics. The laboratory uses a methodology blending traditional "hands-on" electronic training with virtual simulation of electronics designs. The course structure covers the following medical electronic areas:

- Operational Amplifiers – Non-inverting.
- Operational Amplifiers – Adding & Difference amplifiers.
- Operational Amplifiers – Comparators, hysterisis & simple analog-to-digital (ADC) circuits.
- Operational Amplifiers - Peak detectors.
- Operational Amplifiers – Active filters (low-pass, high-pass, notch filters).
- Operational Amplifiers – Instrumentation amplifiers, common-mode rejection ratio (CMRR) measurements.
- Electrocardiograph (ECG) acquisition modules.
- Temperature monitoring and signal conditioning techniques.
- Light detection circuits and principles of absorbance oximetry.
- Operational Amplifiers – Multivibrator design.

Theoretical background on the above subjects is provided by the relative theory course. Students during laboratory training are following extensive documented instructions to perform an electronic design (Fig. 1). The traditional methodology is the utilization of breadboard techniques and measurement equipment for the design verification. Following the completion of the hands-on design, students are called to test and troubleshoot a simulated electronic circuit identical to their implementation laboratory. Students simulate and compare measurements between virtual and practical design (Fig. 2).

3.2 Advantages gained through the student-centered approach

The philosophy of our Department's approach is to train undergraduate students in medical technology instrumentation principles in combination with advanced technologies available to the industry, but it is also driven by the learner–centered approach [6, 12]. It encourages students to solve problems they will face in real life as Biomedical Engineers. The actual implementation of hardware design, testing design

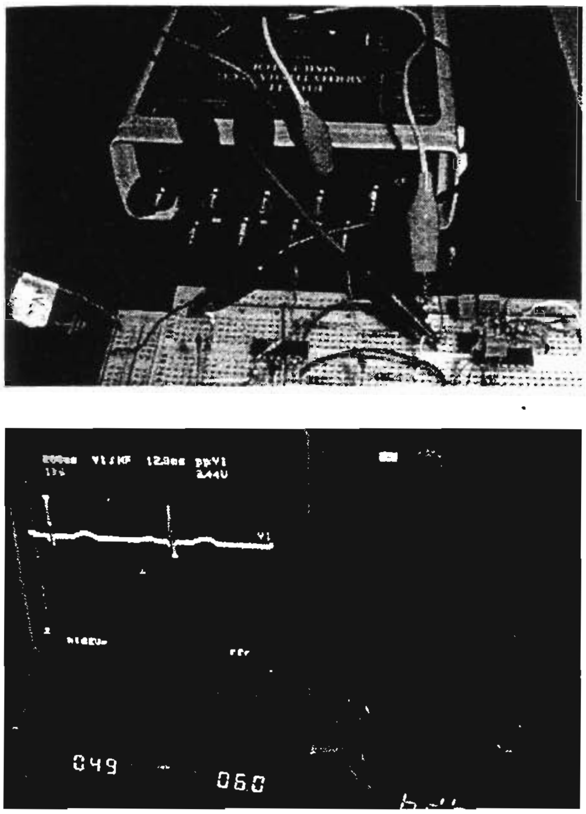

Fig. 1: ECG amplifier circuit: hands-on measurements.

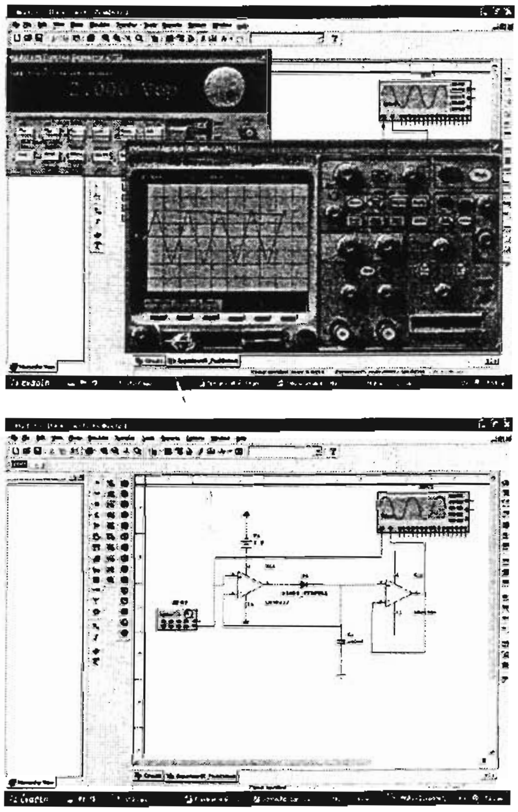

Fig.2: Peak detector circuit: simulated measurements.

performance and computer-aided simulation, aims to help students understand the necessity of having an appropriate theoretical background in the related topics of biomedical science, electronics and computer-aided design and simulation. Since collaboration and participation enhances the learning procedure, students are encouraged to do so, both with laboratory tutors and among them, using the network capabilities of the biomedical laboratory. Recommendation of Internet resources and access to the selected sites during laboratory hours is enhancing students' participation in their learning process. Technology-enhanced student-centered learning environments promote students' curiosity, by facilitating discovering and investigating, which is a very significant motivation to learn [5].

4 Conclusions

The proposed laboratory utilizes a teaching combining of medical electronics principle, based on traditional "hands-on" methodology and computer- aided simulation of electronic circuits. The simulation process overcomes the disadvantages of traditional breadboard techniques concerning troubleshooting and measurements accuracy. It also overcomes cost-related issues, directly involved with implementation and testing of electronic designs outside the laboratory.

The software tools are used in combination with the classical laboratory "hands-on" training method. Although software has evolved enough to "mimic" laboratory setting, it is not a substitute but rather a supplement for the educational curriculum. In the laboratory setting students are facing real-life problems and utilize professional equipment. As software is considered the virtual environment of a laboratory, the laboratory becomes the virtual environment of a professional setting.

The learning model used in the present application, which is also applied to the other laboratory courses involved in the framework of the project "Upgrading of Undergraduate Curricula of Technological Educational Institution of Athens" (APPS program - T.E.I. of Athens) [12,13], promotes the learning procedure by triggering students' self-activation, curiosity and participation. It does not intent to fully overshadow existing traditional teaching methods, but is considered a necessary supplement of these methods.

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Signal and Image Processing Application Development in the Biomedical Engineering Degree Program

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Abstract: - A different approach to the digital signal and image processing training is presented. The students are taught a) the theoretical background of signal and image processing, b) how to use it to implement the theoretical examples by developing program applications, and c) to integrate an autonomous application for signal or image processing. Throughout the whole process they obtain useful skills for their further career.

Key-Words: - Signal processing, Image processing, Biomedical engineering education

1 Introduction*

Digital Signal and Image Processing (DSIP) are at the forefront of information technology and they are used in a wide variety of modern electronic and information systems. They are the basis for a growing variety of applications including medical diagnosis, remote sensing, geophysical prospecting, space exploration, molecular biology, microscopy, and machine vision. For these reasons DSIP courses are now days included in the vast majority of the engineering training programs at different Universities and Institutions.

There is a tremendous number of excellent books analyzing the principles of DSIP [1-9] that assist the relevant trainers and help the students to understand the basic DSIP principles. However, DSIP applications on real signals and real images remain a difficult task.

This work presents a different approach to DSIP training of undergraduate students. It is designed to be applied in a Biomedical (BM) engineering degree program and besides the mathematical analysis of the DSIP principles it includes the development of two complete autonomous applications, one for signal and one for image processing in the MATLAB environment [10-13]. Throughout the whole training process, a deeper understanding of the mathematical and physical principles of different DSIP applications is achieved, which will be needed by the students in their future careers during the use, support or even development of similar applications.

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2 Methodology

2.1 Teaching Methodology

DSIP training is carried out in two sections (semesters), eight 4-hour lectures each. The first section is focused on Digital Signal Processing (DSP), while the second on Digital Image Processing (DIP). The DSP course precedes the DIP one, since the DIP course requires knowledge gained during the DSP course, as images are approached as two dimensional (2-D) signals. A common methodology is followed for every 4-hour lesson (lecture) for both sections. The schematic representation of the followed methodology, which is described in detail below, is displayed in Fig.1.

2.1.1 Course Methodology

On the beginning of each section the students are provided with a set of real data (medical signals and the source code for data retrieval and display. Also they are provided with the source code for a generic Central Application Graphical Environment (CAGE, sCAGE for DSP, iCAGE for DIP). The CAGE is the core for the application development during the course. In every lesson the CAGE is expanded with the new functions implementing the DSIP algorithms that are developed during the specific lesson. At the end of the course, CAGE comprises a

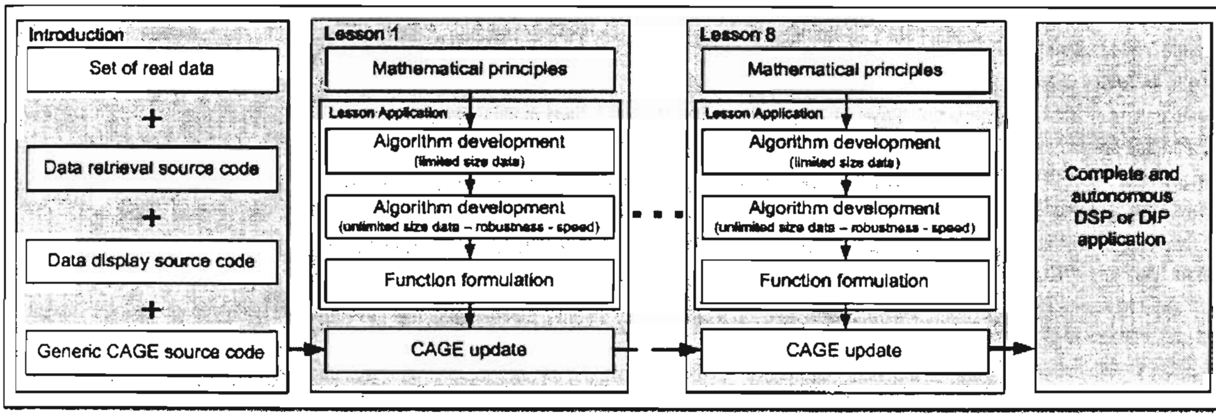

Fig.1. Methodology schematic representation

complete and autonomous application, which can be used for the processing of any type of digital signal or image.

2.1.2 Lesson Methodology

Each lesson is separated in the theoretical section and the laboratory/application section. During the theoretical section the mathematical principles are analyzed and the mathematical formulation of the problem is broken down using examples applied on limited size data (i.e. 4 point signals, 4×4 pixel images).

At the laboratory/application section the students are developing Lesson Applications (LA) that implement the examples they have already been taught during the theoretical section. Initially the students are focused on the algorithm part of the problem, developing LAs for the limited size data in accordance with the theoretical examples. The theoretical examples are also used for the confirmation of the algorithms correctness.

After the algorithm successful development is completed, the LAs are expanded to handle unlimited size data. At this phase the students are concentrated on the flexibility and the speed of the developed algorithms. The development of robust and fast algorithms, which are able to cope with any type of digital signals or images, is requested.

During the next step, the part of the LA code that implements the processing algorithms is isolated and is used to form a number of functions. The trainees are focused on the function robustness and generality. The LA is converted once more so that it can use the formed functions for result confirmation. Also, at this stage, the existing MATLAB functions are used for result correctness confirmation, where this is applicable.

At the final step, the functions are incorporated into CAGE. For this purpose, CAGE's menus and results displays are updated to cooperate with the new functions. All the dialogs for entering the required parameters are also developed and incorporated into CAGE.

2.2 DSP course structure

The eight lessons of the DSP course cover a wide variety of DSP subjects. In particular, the lessons are related to the following topics:

- **Basic properties of digital signals**: The digital signal mathematical representation is analyzed, and the basic calculations (addition, subtraction, multiplication and division) of two digital signals are explained.
- **Convolution and correlation in the time domain**: The formulation of calculating the convolution and correlation of two signals is presented. The physical meaning of convolution and correlation is explained and their properties are analyzed.
- **Discrete Fourier Transform (DFT)**: The formulation of the DFT mathematic relations, the development of the relevant software code and the basic properties of DFT are presented. The general understanding of transferring the signal information from the spatial domain to the frequency domain through the DFT and the meaning of the spectral information included in the DFT's amplitude and phase spectrums are broken down using examples.
- **Convolution and correlation in the frequency domain**: The convolution and correlation of two signals in the frequency domain is analyzed. Examples are used for their calculation and for comparison with the convolution and correlation in the spatial domain.
- **Frequency selection digital filters**: The digital filter development (Ideal, Butterworth, Exponential) is analyzed and their application on signals are presented. The effect of digital filters (Low Pass, High Pass, Band Pass, Band Reject) on the signals is explained using examples.

▪ **Infinite Impulse Response (IIR) filters I**: The development of IIR filters using the *z* transform and the differences of filtering in the frequency domain vs. spatial domain is explained. The simplest type of IIR filters, i.e. Direct Form, is analyzed as an example.

▪ **IIR filters II**: The Cascaded and the Parallel IIR filtering structures are explained in order to make intelligible the comparison between the different types of IIR filters. The advantages and disadvantages of the application on digital signals in relation to the type of the signals are analyzed.

▪ **Finite impulse response (FIR) filters**: The development of FIR filters (Ideal, Butterworth and Exponential), their application on signals in the spatial domain and the windowing technique for ripple elimination is explained. The effect of FIR filtering and its comparison to filtering a signal in the frequency domain are analyzed using examples.

An example of sCAGE application for filtering a signal with added noise using the Butterworth low pass filter is presented in Fig.2.

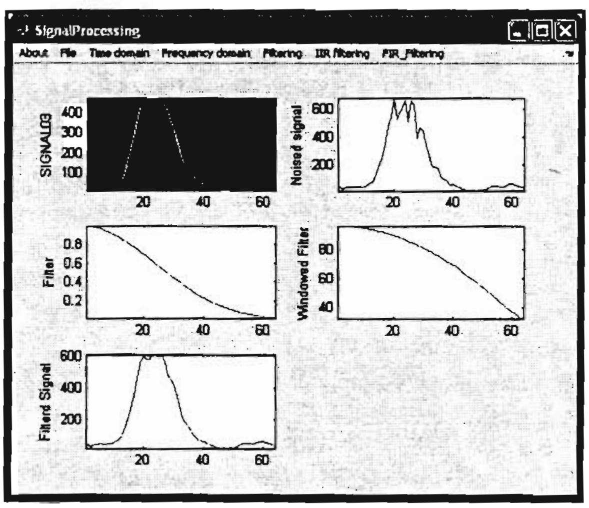

Fig.2. Butterworth low pass filtering

2.3 DIP course

The DIP lessons, in proportion to the DSP ones, cover also a wide area of DIP topics. The lessons are focused on the following:

▪ **Introduction to digital imaging**: The representation of an image using two dimensional arrays is explained. The basic functions for image retrieval and display as well as the generic iCAGE are analyzed.

▪ **Contrast enhancement – windowing techniques**: The contrast enhancement worthiness and the windowing techniques are explained. Three windowing techniques (simple window, double window and non-linear window) are analyzed.

▪ **Contrast enhancement – histogram modification techniques**: The histogram modification techniques, used for contrast enhancement, are explained. The Histogram Equalization (HE) and the Cumulative Distribution Function (CDF) techniques are analyzed and their results are compared to the windowing techniques outcome.

▪ **Time domain image enhancement**: The filtering (masking) methods used for image enhancement in the time domain are explained. The application of smoothing and contrast enhancement masks is analyzed by using examples and the results are compared to the windowing techniques outcome.

▪ **2-D Discrete Fourier Transform**: The mathematic formulation of the two dimensional Discrete Fourier Transform (2D-DFT) is presented and its principles are explained. Emphasis is given to the understanding of image transformation from the spatial to the frequency domain using examples, as well as the spectral information, which is included in the amplitude and phase spectrums.

▪ **Frequency domain image enhancement**: The design of zero phase filters (Ideal, Butterworth, Exponential) and their application on images are analyzed. The effect of digital filters (Low Pass, High Pass, Band Pass, Band Reject) on the images as well as on their amplitude spectrum are explained using examples. Comparison between the results of filtering in the spatial and frequency domain is carried out.

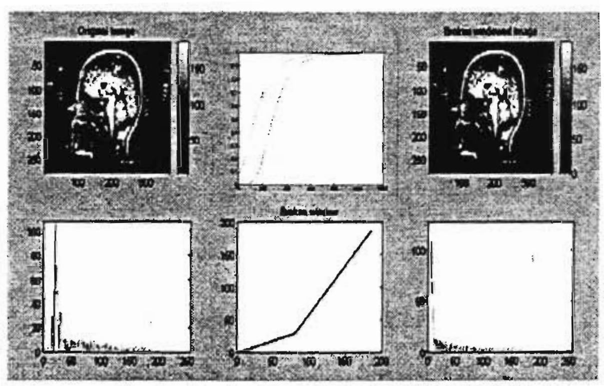

Fig.3. Broken window application

▪ **Image restoration**: The design and application of image degradation models is carried out in order to add artificial noise to diagnostic images. Also, image restoration filter design is explained. Their application and the comparison of their results are analyzed by using examples.

▪ **Image tomographic reconstruction:** The procedure of tomographic reconstruction of an image is explained. The design and application of different filters during the reconstruction are analyzed.

An example of iCAGE application for applying the Broken Window technique for image enhancement is presented in Fig.3.

3 Conclusion

During the courses the students have the opportunity to compare their own programming results to the existing MATLAB functions. By the end of each session the students are able to design and develop an autonomous & complete application. Students not only come to terms with the theory of DSIP, but furthermore they understand how to use this theoretical background in practice. Students obtain useful knowledge and skills that are very appreciated in their further carrier in this certain field of expertise.

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