LabVIEW IN EDUCATION

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Abstract:
This article presents how LabVIEW environment, and virtual instruments built with it, can be used in education, especially as training tools in *e-learning*. Two virtual laboratories, *Virtual nuclear physics laboratory* and *Virtual digital electronics laboratory* are presented. Also some simulated physics and digital electronics experiments are briefly described, as well as analog-to-digital and digital-to-analog conversion methods.

Keywords: Comenius 2.1, Socrates; e-learning; virtual instrumentation; VccSSe; LabVIEW;

1. Introduction

LabVIEW (***Lab****oratory* ***V****irtual* ***I****nstrument* ***E****ngineering* ***W****orkbench*) is the trademark of the National Instrument Corporation (NI). It is programming environment including all of the tools necessary for instrument control, data storage, data analysis, and data presentation. It uses graphical programming and a graphical language called G. The main goal of LabVIEW is the creation of virtual instruments (VI's) for controlling real measurement systems.

The computer controlled real measurement systems, based on the virtual instruments, are the virtual measurement systems (VIS) built using:

- standard measurement hardware, including instruments with serial, parallel or GPIB interfaces;
- modular instruments, for example, CAMAC, VME or VXIbus instruments;
- PC plug-in boards, PC DAQ add-in cards based on the industry standard ISA, PCI, and PCMCIA buses;
- virtual instrumentation software, such as LabVIEW™ graphical programming environment;
- personal computer (PC).

The personal computer is what makes virtual instrumentation systems possible. The PC, equipped with the VIS software, assemblies all instruments in one system, and coordinates the operating of the instruments during measurements. With the set of the standard PC

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controlled instruments and the PC equipped with the VIS software, one can build a system that performs the functions of traditional instruments and systems but is more flexible. Figure 1 shows virtual instrumentation system with the traditional instruments in the background of the computer.
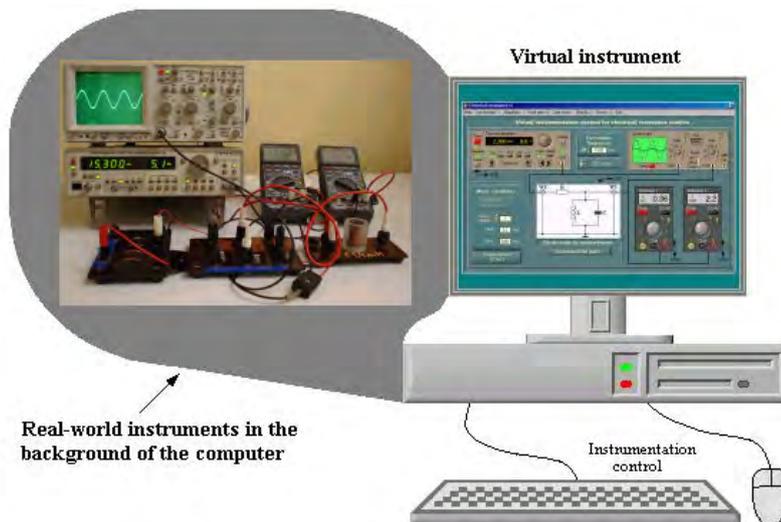

Fig. 1 *Virtual instrumentation system with the traditional instruments in the background of the computer.*

LabVIEW can be used not only for the VI building for real-world measurements but also for the building applications, which simulate real-world instruments or can be useful for the modeling or animation physical processes to present how they run. This is significant characteristic of LabVIEW, which can be used to elaborate tools useful in *e-learning* or, for example, teaching fundamentals of the electronics and for physics experiments demonstration. In this sense, all LabVIEW programs are *Virtual Instruments*, called *VI's* in short.

Modeling and simulations are present very important tools used in research and techniques, especially in metrology and applied physics, for understanding real physical laws and phenomena's, measuring methods and processes, also device operating and instrument execution. For this purpose, virtual instruments can be successfully used. With virtual instruments it is relatively easy to build a wide variety of the computer based applications for process modeling, simulation of the instruments operating or measuring systems execution. So, simulated experiments can be attractive models of the measurement processes used in education.

2. Virtual instruments and virtual laboratories in education

Virtual measurement instrument. The virtual measurement instruments are computer controlled instrumentation systems used for data acquiring, analyzing and results presentation. The control of the physical instruments, which exist in the background of the computer (Fig. 1), may be performed using the computer keyboard, mouse, and display.

The biggest difference between traditional measurement systems and virtual instrumentation systems is that with virtual instrumentation system the user defines the system functionality and builds a system that exactly meets his needs. With virtual instrumentation, one defines the measurements in a test or control applications, using intuitive software and general-purpose measurement hardware. With virtual instrumentation, modular hardware components make it easy to adapt a single system to a variety of measurement requirements. Virtual instrumentation systems are software based, and because they use personal computers, offer a wide range of connectivity to peripherals, networks and other software applications.

The virtual measurement instruments are successfully used not only in research laboratories or industry, but also in the real secondary school laboratories or in the real student's labs in the universities.

Fig. 2 *Nuclear Physics Laboratory at the Faculty of Physics of the Warsaw University of Technology equipped with computer-controlled experiments.*

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Virtual laboratories. The virtual instruments used in the student laboratories made the experiments more attractive for the students during the laboratory exercises. The virtual instruments, used in the real experiments, not only allow users conduct experiments but also give information concerning physics fundamentals, for example, fundamental theories of the gamma-ray interactions during its passage through the matter, in the case, when the gamma absorption law is experimentally checked. This information can be selected from the menu bar of the virtual instrument – the intensity analyzer - used in such experiment. From the menu bar can be also opened additional applications, which instruct users how to switch on electronics, set correct parameters and run experiment, how to collect and analyze data, and finally, how to prepare laboratory report. The user can also open animation programs developed for demonstration how operate electronic devices, like amplifier and discriminator, and how, step by step, experiment is running.

Figure 2 shows the Nuclear Physics Laboratory at the Faculty of Physics of the Warsaw University of Technology (WUT). The real experiments, devoted to studies of the statistical character of nuclear decay, beta and gamma-rays absorption, and determination of the gamma-rays energy, are computer-controlled experiments. Such and similar real laboratories are usually called *Virtual laboratories.*

An additional profit of the using of the virtual instrumentation in the student nuclear physics labs is costs decreasing by building measuring systems based on ICT - *Information and Communication Technology*, which allows connecting experimental equipment to several laboratory standpoints. Scintillation spectrometers, used in the nuclear physics laboratory are the most expensive part of the experimental equipment in the student physics laboratory shown in Fig. 2. Usually, the high expenses limit multiplying the experiments in the student laboratory, what, as consequence, limits running several identical experiments in parallel. Another limit of the multiplying the nuclear physics experiments is the number of the radiation sources, used during the laboratory work. Building relatively low cost multi-user virtual measuring systems, used to perform nuclear physics experiments in parallel by several users, can solve these problems.

Simulated experiment. The virtual instrument is usually understood as real computer controlled measurement system. Wider understanding of the virtual instrumentation includes also a variety of the computer-based applications for the processes modeling, instrument simulations or execution animations of the measuring systems. Simulated experiments can be downloaded from *Internet* or opened from CD enclosed to the books.

The virtual instruments not only allow users to conduct the experiment but also give full information about it. They present how to switch on electronics; how to set correct values of parameters and run experiment, collect and analyze data, and how to prepare final report document. This information can be selected from menu bar of virtual instruments.

Figure 3 shows *Virtual nuclear physics laboratory* and *Virtual digital electronics laboratory*, which allow users to perform measurements in the same way as in the real nuclear physics or electronics laboratories. The nuclear physics virtual experiments are focused on presenting core aspects and features of gamma radiation. Each experiment is

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based on the virtual instrumentation in full analogy with the real one used in the real laboratory. The lasting of each step is also the same as in reality. The LabVIEW software is used to carry out all experiments, following the assumption that all results achieved during the virtual research are not the simulated ones, but the earlier achieved in the real life experiments, and skilfully included and combined with the program. Description of underlying physics and as well as operating of the instruments used in the real and virtual experiments is also presented with the sub-programs.
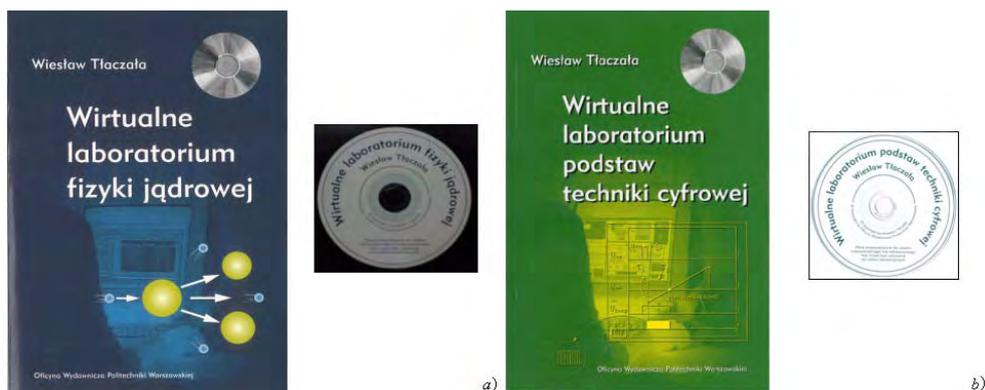

a)   *b)*

Fig. 3 *Virtual labs with simulated experiments easy of approach from CD: a) Virtual nuclear physics laboratory, b) Virtual digital electronics laboratory.*

Data collected during virtual measurements and results obtained in the virtual experiments are close to those obtained in the real experiments. Virtual instrumentation used for radiation intensity and statistics distribution measurements, spectrum presentation and data analysis are exactly the same used in the real nuclear physics experiments. The virtual experiments can be helpful in learning the methodology and measurement performing before preparation and running the real nuclear experiments, and also be familiar with the specific for nuclear physics experiments data analysis. Presented experiments can be also helpful everybody, who wants to be familiar with nuclear techniques and get elementary knowledge about properties of nuclear radiation, but have not possibility to perform experiments in the real nuclear physics laboratory.

Described virtual experiments are easy of approach from CD as executable programs and can be available and useful for student for home training and distance learning before entering the real laboratory – for *e-learning* or in learning known as *blended learning*. On the other hand, the virtual experiment reduces the instrumentation learning time in real physics lab, so that students can concentrate more in the details of the phenomena, and also most of the lab time can be used for data acquisition, verifying results, discussion and

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preparation of the report documents. A virtual experiment provides students the opportunity to perform measurements many times and run experiment at convenient time.

The virtual experiments can be also a part of the home virtual for disabled students or as a part of the virtual physics electronics labs in secondary level schools. Finally, teachers can use them for demonstration during the theoretical lessons. Essential properties of the home virtual laboratories and the virtual laboratories for secondary level schools are that they cost nothing and can be perform at any time using only computers and described software.

Software is very important component of the virtual instrumentation. There are a lot of the software environments, which are used for virtual instrumentation building and education supporting, for instance, *Crocodile Clips, Cabri Geometry II Plus* or *LabVIEW*.

The project partners from the Faculty of Physics of the Warsaw University of Technology were involved in VccSSe project as specialists with a huge expertise and achievements in the area of promoting LabVEW virtual instrumentation as an educational resource. The natural consequence of this was preparation by the project partners from the WUT the set of the simulated experiments based on the LabVIEW.

3. Simulated experiments in Physics

During the first year of the project realization at the Faculty of Physics of the WUT the set of the simulated physics and electronics experiments was developed, using LabVIEW. Two of them, described below, were devoted to studies of the gamma absorption during passage through the matter and determination of the Curie temperature for the ferromagnetic materials.

3.1 Virtual experiment for the gamma rays absorption studies

Passage of gamma rays through the matter. Depending on the type of radiation, its energy and the type of material, reactions with the atoms or nuclei may occur in several ways. The main interactions of gamma rays (photons) with the matter are: Compton scattering, photoelectric effect and pair production.

The total absorption coefficient of gamma rays represents, in fact, the intensity attenuation of the photon beam when it passes through the matter. The gamma-rays intensity decreases exponentially with respect to the thickness of the absorber.

The main aim of the presented experiment is examination of the gamma-rays absorption in the matter. Students perform the measurements of the gamma rays attenuation with respect to the thickness for lead, cooper and aluminium using the experimental set-up shown in Fig. 4. Thus acquired data they use to examine the attenuation law and calculate the absorption coefficients.

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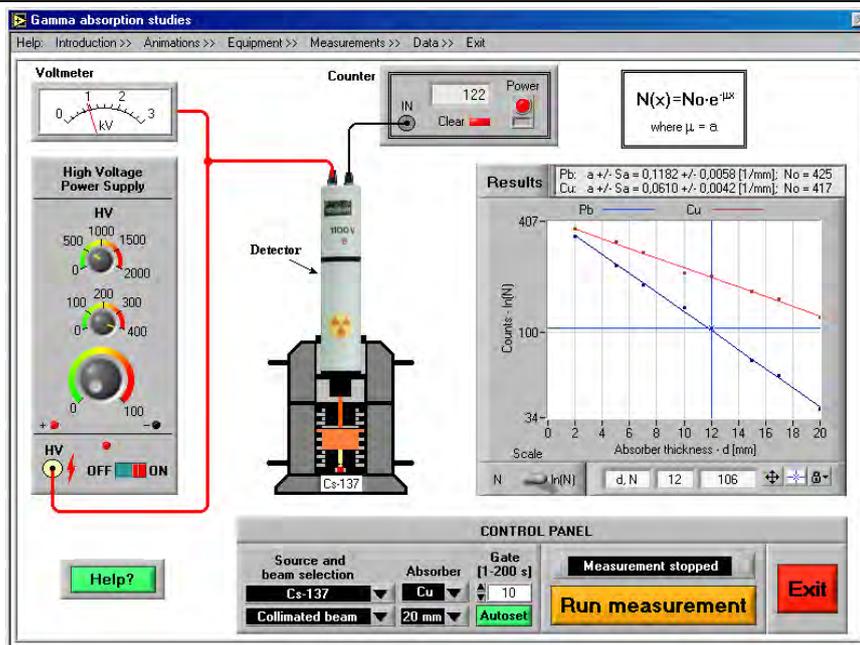

Fig. 4   *The user interface of the virtual experiment for gamma rays absorption studies.*

Before starting data acquiring the experimenter should arrange the virtual spectrometer to the work and select one of two sources, ^{137}Cs or ^{60}Co, to be used.

The experimental set-up arrangement needs to switch on the high voltage power supply, set the correct HV value, and select mode with the collimated beam (Fig. 4). Figure 4 shows the equipment statement after switching on instruments and parameters setting. After the source selection, switching on the instruments, and parameters setting, one can start measurements and perform the virtual experiment.

The user can perform experiment with ^{137}Cs and ^{60}Co sources and examine the gamma-ray absorption law for samples made of lead, cooper and aluminium. After acquiring, data are plotted on the graphs (Fig. 4) commonly with the curves obtained using best linear fitting to data valid for the absorption law transformed into the logarithmic form.

3.2   Virtual experiment for Curie temperature determination for ferromagnetic materials

Curie point for a ferromagnetic material. This experiment is a bit more sophisticated and concerns magnetic properties of solids. As it is well known, ferromagnetic materials

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(usually alloys based on iron) loose their magnetism above certain temperature called the Curie temperature T_c. For example, for iron it is 770 ^{o}C.

Below Tc ferromagnetic materials exhibit spontaneous magnetisation – its elementary magnets (spins) interact with each other in such a way, that they order their directions. Above this temperature thermal fluctuations of spins are so large that material looses its ordering and becomes paramagnetic.

The transition from the ferromagnetic to paramagnetic phase can be observed in a transformer with an iron core. The voltage induced in the secondary coil depends essentially on the value of magnetic permeability of the core. When heating the temperature of the core increases and finally reaches T_c. In this moment the voltage on secondary coil decreases rapidly what may be observed on the graph.
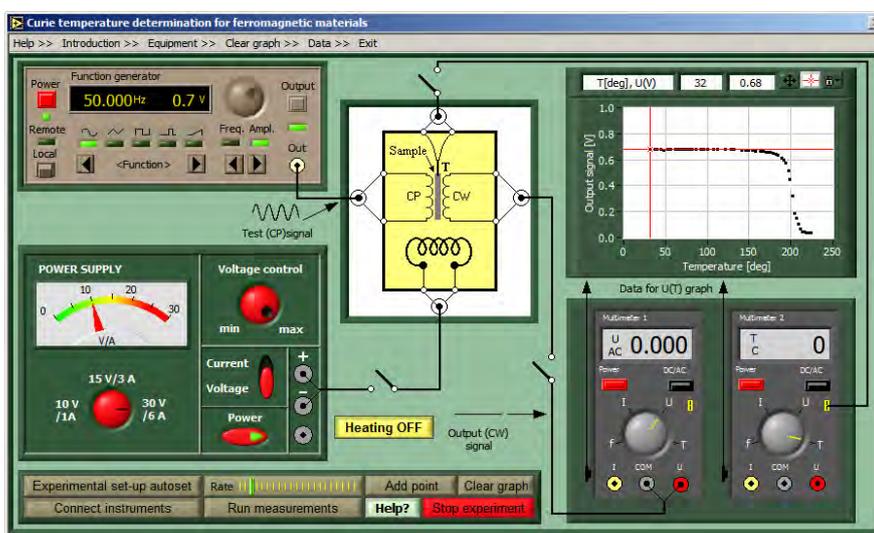

Fig. 5 *The user interface of the virtual experiment for Curie temperature determination for ferromagnetic materials.*

Before starting data acquiring one should arrange the virtual experimental equipment to the work. As usually, the first step is to connect all devices and to prepare them for the measurements by switching on instruments and selecting correct experimental settings. Omission of this step would unable the proper measurement. Figure 5 shows the equipment statement after switching on instruments and parameters setting.

In this experiment user measures the voltage of the secondary coil of the transformer depending on the temperature of the ferromagnetic sample, which is controlled by the heater. Measurement points can be added and removed from the chart. The main goal is to

find the temperature at which there is dramatic fall (or jump) between two plateaux of the voltage waveform – this point represents the so-called Curie temperature.

4. Simulated experiments in digital electronics

In the *Virtual digital electronics laboratory* are presented the fundamentals of the basic digital circuits, like a logic operations, flip-flops, pulse counters, shift registers execution, and digital-to-analog and analog-to-digital conversion methods.

Digital-to-analog converters (DAC) and analog-to-digital converters (ADC) are the fundamental link between analog and digital electronics. The DAC converts the input digital signal into an equivalent analog output signal. The ADC digitizes the analog input signal into a digital value.

4.1 Digital-to-analog converting method with R-2R ladder

There are several ways in which the digital-to-analog converting can be accomplished. One method is the binary weighted resistor techniques based on the circuit with a network of parallel branches, one branch for each bit. Each branch contains a resistance weighted in proportion to the significance of the bit in the digital word. The disadvantage of the weighted resistor method is that its implementation needs to use the precision resistors, because the accuracy and stability depend on the precision of the resistance values. For large numbers of digits, the absolute value of the later resistance can become quite large.

An alternate method is the *R-2R* ladder network (Fig. 6). This network is essentially a current divider. The resistance looking in any direction from any node of the ladder network is 2*R*, what results in the binary weighting.
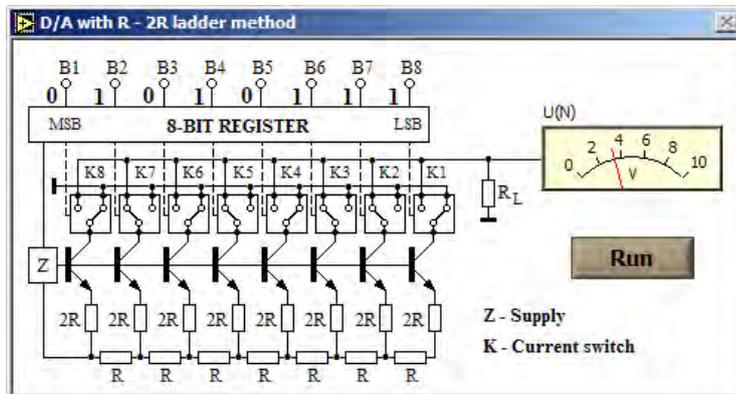

Fig. 6 *The front panel of the application for D/A converting process simulation.*

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The functional block diagram of the DAC, built with the *R-2R* ladder network, is visible on the front panel of the application shown in Fig. 6. Unlike the weighted *R* method, the ladder method only requires resistance of *R* or 2*R*, and the stability of the ladder depends only on the resistance.

The application shown in Fig. 6 simulates D/A converting process. It presents how the input digital words (B1÷B8) are converted into the corresponding output voltages.

4.2 Analog to digital converting methods

Dual slope method of the analog to digital converting. Figure 7a shows modeling of the logic and timing relations for the ADC converter based on the dual-slope method. In this method, the input signal is first used to charge a converter capacitor C (see the circuit in Fig. 9b), which is charged at constant time and a rate set by the current proportional to the analog input signal U_{in}. This capacitor is then run down, i.e. discharged at the constant rate. In this method an integrating amplifier is used to integrate input current. During the time (ΔT) the capacitor charge and run down are taking place; pulses from a constant frequency clock are gated into a scaler. The scaler is gated off at the zero-crossing point. The contents *N* of the scaler is then a number proportional to the analog (height or level) input signal.

Successive approximation method of the analog to digital converting. The successive approximation method is the most widely used technique of analog to digital conversion, also when the input signal is the pulse signal. In last situation, first the duration of the incoming pulse is prolonged at its peak value, and then this peak value is compared to a series of reference voltages to determine the height of the pulse. The converting process can be explained using the VI shown in Fig. 7b true for the 8 bit ADC.
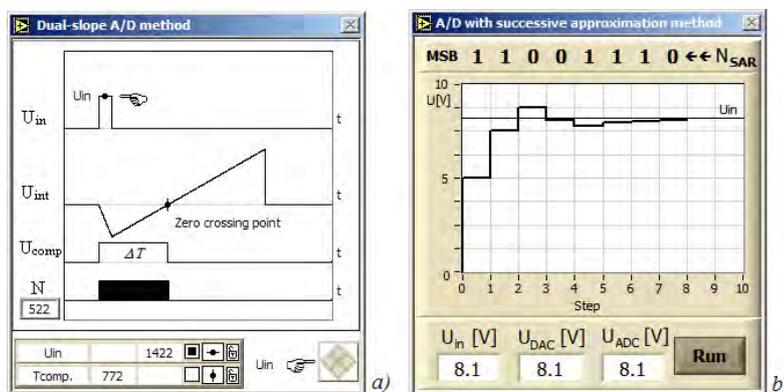

Fig. 7 *The front panels of the applications for A/D converting processes simulation: a) for dual-slope A/D method, b) for A/D with the successive approximation method.*

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If the ADC range is, for instance, 0 to 10 V and the incoming pulse height is 8,1 V, the ADC first compares the peak value to a reference of 5 V. Because the peak value is greater then 5V the MSC bit (most significant bit) of the digital number is set to logic 1. Then the one-half previous reference (2,5 V) is added to make a new reference of 7,5 V and comparison again. Since the signal is greater, the second bit is also set to 1. One-half is again added on to make 8,75 V. This time the peak value is less than reference value, so that the third bit is set to logic 0. Now half is subtracted from the reference and a comparison is made. This continues until the 8 bits (8 steps) is obtained. After ADC calibration the output digital value can be read as $U_{ADC} = a \times N_{SAR}$, where a is calibration coefficient.

4.3   The virtual experiments for digital-to-analog and analog-to-digital converters testing

The virtual experimental arrangement for the DAC and ADC testing simulates the real one, which can be completed, for instance, with the laboratory power supply, digitally controlled power supply, the digital oscilloscope, the digital multimeter, converters to be tested, and PC equipped with the suit software. The experimental set-ups (Fig. 8 and 9) used to perform virtual measurements are completed with models of the real instruments.
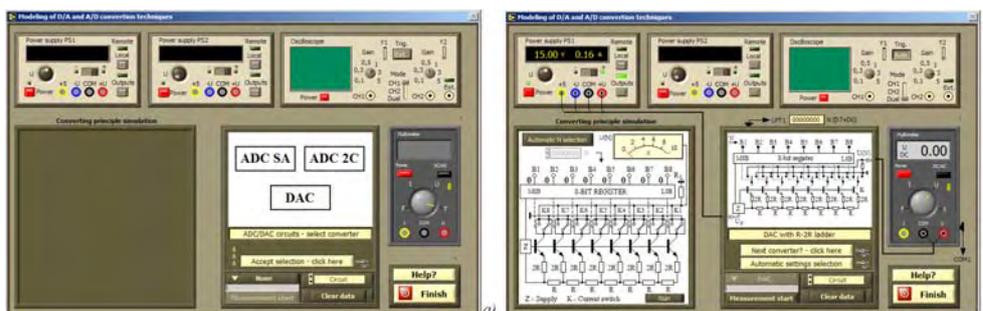

Fig. 8   *The VIS for DAC and ADC testing: a) before converter selection and switching on the virtual instruments, b) after the DAC selection and before measurements.*

Virtual instrumentation system for the digital-analog converters testing. The virtual instrumentation system (VIS) user interface, before VIS preparation to measurements, is shown in Fig. 8a. A user can select the converter to be tested, connect and switch on all instruments, select correct instrument presets, and measurement conditions. The front panel of the VIS contains graphical objects used for mode and parameter settings, measurement control, measurement data presentation and acquired data displaying. The measurement parameters can be set using numeric controls. A user can start measurement with the *Run*

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push button. The current values of the ADC inputs and DAC outputs are displayed in corresponding numeric indicators on the PS and DMM displays.

The user interface of the VIS, after the DAC with R-2R ladder selection, is presented in the Fig. 8b. It shows this interface before running.

Virtual instrumentation systems for the analog-digital converters testing. Figure 9a shows the user interface of the VIS, selected for the successive approximation method presentation and used to control the virtual experiment devoted to studies of the ADC based on this method. The figure shows the running VIS after preparation of the experimental set-up to measurements. Figure 9b presents the user interface of the VIS, selected for the dual-slope method presentation and used for the testing of the ADC based on this method. The figure shows this interface during measurements.

The instrument settings can be selected individually for each instrument independently or automatically and complexity for all instruments used for the VIS building. The data collected during the virtual measurements are not simulated data but the data early obtained during the real measurements in electronics lab and incorporated in the program when the application was built. Therefore, the data collected in the virtual experiment are like those recorded during the real measurements in the real lab. Also the lasting of each step of the measurements is the same as in reality.
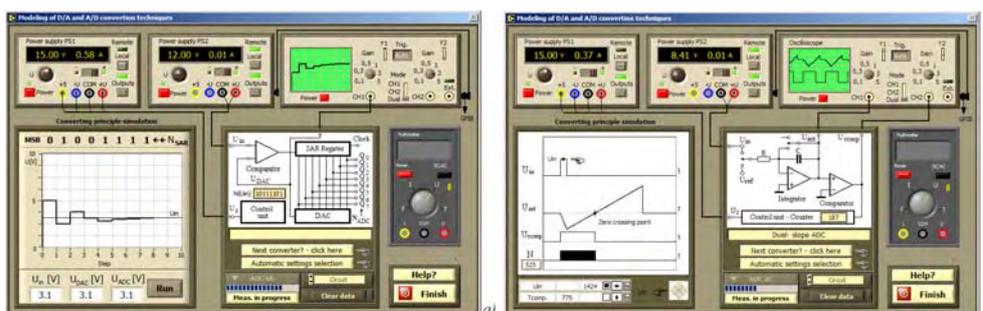

Fig. 9 *The VIS for ADC testing: a) ADC with successive approximation during measurements, b) dual-slope ADC during measurements.*

The user interface of the each of three presented experiments allows experimenter to see how the converter is built what instruments and their settings are needed for the measurements. Also how a digital signal is converted into an equivalent linear signal (for DAC) or an analog signal into a digital signal (for ADC). Last possibility is available with the applications, which simulate conversion processes, placed on the left side of the user interface.

All applications presented in this article are built using LabVIEW.

5. Conclusions

Modeling and simulations are present very important tools used in research and techniques for understanding real physical laws and phenomena's, measuring methods and processes, also device operating and instrument execution. For this purpose, virtual instruments can be successfully used. With virtual instruments it is relatively easy to build a wide variety of the computer based applications for process modeling, and simulation of the instruments operating and measuring systems execution. Simulated experiments can be also attractive models of the measurement processes used in education.

Generally, the simulated experiments can be used in *e-learning* as the modern training tool, which allows pupils and students to be familiar with the experimental arrangements and techniques without physical entering the real laboratory. Additionally, the simulated experiments can be easy used by lecturers for physics phenomenon demonstration during the lessons and also to examine students in the real lab before running real experiments.

Because simulated experiments are easy of approach from CD as executable programs they can be available and useful for a student for home training. A simulated experiment provides students the opportunity to perform measurements many times and run experiment at convenient time.

The virtual experiments can be also a part of the home virtual laboratory for disabled students or as a part of the virtual physics laboratory in secondary level schools. Essential properties of the home virtual laboratories and the virtual laboratories for secondary level schools are that they cost nothing and can be perform at any time using only computers and described software.

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