Open source and low cost virtual instrumentation system for teaching of electronics in technical education

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Abstract—**This article presents a self-development virtual instrumentation system for teaching of electronics in technical education. The system reproduces the operation of a real function generator and oscilloscope and students can use it freely both at school and at home. The system consists of a software package that runs on different platforms and operating systems (windows and linux) with an optional external module connected by usb. All programs are open source, so there is no cost for students. It is in process of development an external unit that can be built by students at a very low cost, significantly improving system performance.**

Keywords-virtual instrumentation; open source; technical education

I. Introduction

The learning and use of electronic instrumentation is one of the main obstacles in the basic training of technical students. In many cases it is their first contact with measuring instruments whose control is complicated and there is not enough time of use at school to achieve a good knowledge of them. But the high cost of these instruments, especially the oscilloscope, does not allow its acquisition although prices have gone down considerably and there are economic solutions of commercial virtual instrumentation.

To try to overcome these problems, this article presents a low cost and open source virtual instrumentation system for teaching electronics in professional training. The development of this system began 12 years ago as a simple oscilloscope simulator. Since then it was modified to allow data acquisition and generation through the computer sound card, it was designed and built an external module for the computer parallel port and recently we started developing an usb module with a high-speed analog to digital converter. It is also planned the adaptation of the system to new technologies like bluetooth, tablet pc or android phones.

The software developed for this project is open source and free of charge, allowing modification and adaptation by the users for their own purposes. Although the system has been developed under Windows operating system it is planned to migrate to Linux. Hardware modules are dessign with low cost circuits and complexity, so that its construction is possible with existing facilities at technical schools with electronics laboratories.

This system is not intended to replace a real professional laboratory, but its features allow the realization of numerous theoretical and practical activities. The screens can be projected in class for the theoretical explanations and the operation of instruments can be shown in real time.

The system consists of a programmable waveform generator and a two-channel oscilloscope (Fig. 1), which can run in simulation mode, real mode via the computer sound card or with an microcontroller external module connected via parallel port or a high-speed module connected via the USB port.

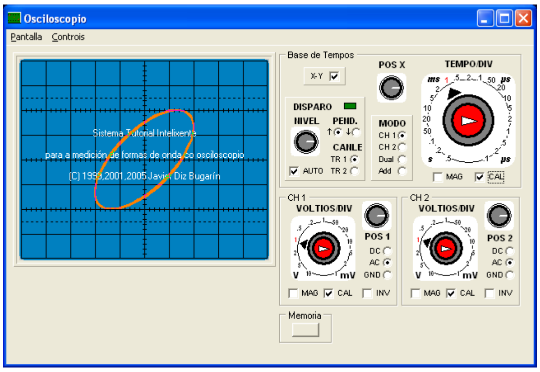

Figure 1. Virtual oscilloscope screen

The program includes a module of guided practices for the training of students in the use of instrumentation or making measures. The final objective would be the development of an intelligent system to control the process of student learning and automatic correction of errors committed. To achieve this objective we have analyzed the most frequent types of errors committed in electronic measures and diagnostic procedures for automatic detection and correction.

II. Phases of the Project

This project has been designed as an open system in constant evolution in function of the educational needs of the author and the new educational degrees that will be implemented. Initial development began in 1998 as a simulation program, in 2001 it was implemented data acquisition through the computer sound card, in 2003 it was developed the first external hardware module for the parallel port, and finally in 2010 began the development of the USB module in which we are currently working.

A. *Simulated mode*

In this mode the program the virtual waveform generators are connected directly to the oscilloscope channels. The screen will show the waveforms generated. The settings of the generators can be changed and the effect of the changes seen on the oscilloscope display. The oscilloscope controls can also be changed to see the effect on the displayed waveforms.

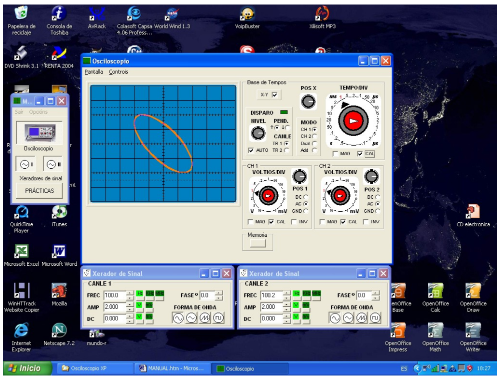

Figure 2. Simulated mode with oscilloscope and signal generators

B. *Real mode with sound card*

In this mode the oscilloscope inputs and generator outputs are connected to the audio channels of the computer's sound card. A real electronic circuit (e. g. an RC network) can be connected to the outputs and inputs to display the waveforms in real time. It can also be displayed the waveform of the voice or a musical piece played on the computer (Fig. 3). The input and output cables (Fig. 4) are connected by crocodile clips to the circuit to be measured. These cables can be constructed by the students as a classroom practice to avoid acquisition and reduce cost.

The sound card is a simple and cheap solution for users with a computer, but the frequency range is very limited and especially has the problem that eliminates continuous voltage present at the input leading to measurement errors.

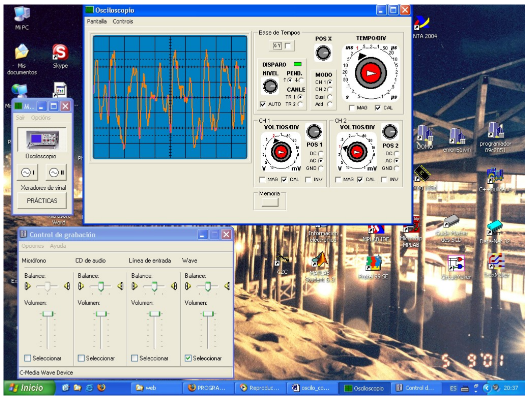

Figure 3. Sound waveform at the virtual oscilloscope

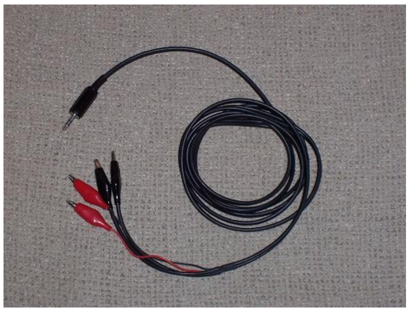

Figure 4. Connection cables for the sound card

C. *External module for the parallel port*

This module was developed in 2003 as part of the Integrated Project course of Telecommunications and Information Systems (STI) at the Ribeira do Louro High School at Porriño (Pontevedra). The main component of the module was a PIC16F876 microcontroller [2] that incorporates an analog to digital converter, and a set of signal conditioning circuits. Fig. 5 shows the schematic developed by the students, Fig. 6 shows the layout of the printed circuit board and Fig 7 the complete prototype.

The main characteristics of this module are:

- Resolution: ±20 mV.
- Maximum voltage: ±80 V.
- Input channels: 2.
- Maximum frequency: 50KHz
- Converter resolution: 9 bits (error del 0.2%)
- Measurement error: <1%
- Data connection: parallel port in standard mode (SPP).

This module had a limited frequency range, although better than the sound card, and problems with the speed of data transmission through the parallel port.

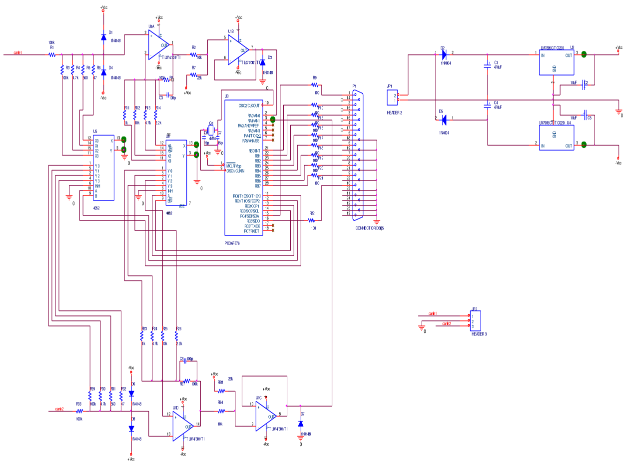

Figure 5. Schematic of the parallel port module

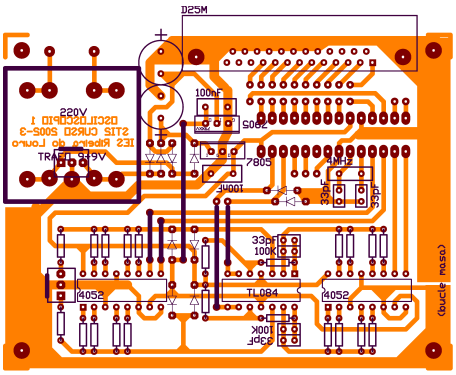

Figure 6. Printed circuit board

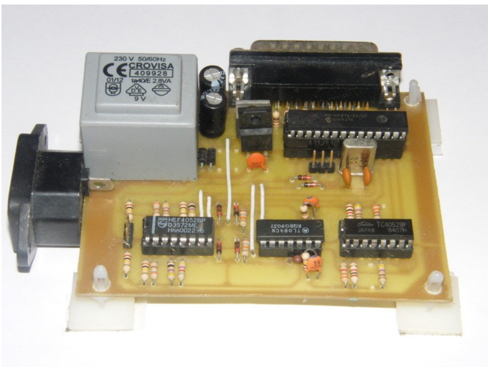

Figure 7. Assembled prototype

D. High speed USB module

The current prototype of external module developed for this project consists of an Atmel 89S4051 microcontroller [3] and a MCP3208 analog-digital converter [4]. This converter is only for the initial development and will be replaced by a high speed converter like the AD9288 [5] . PC connection is via a serial-usb converter FT232R [6]. Figure 8 shows the first prototype of this module already mounted.

All integrated circuits are low cost and if the assembly is done by students the total module cost will also be reduced. The serial-usb converter circuit FT232R has free Windows and Linux drivers and can easily integrate with various development systems (this circuit is the same used in Arduino systems, but also in specialized environments such as Player-Stage). As the AT89S microcontrollers can be programmed in circuit through a specific ISP connector they can be easily reprogrammed for other purposes. Thus, in addition to its use for this project, this module can be used as a generic data acquisition module for computers. The microcontroller programs development has been done with the open source IDE Eclipse-SDCC [7], and for transfer of code to the microcontroller the open source program AVRDUDE [8] has been used.

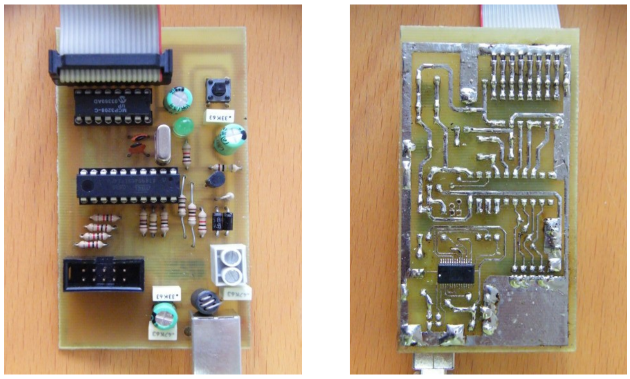

Figure 8. External USB module

III. Guided Practices

The developed system allows difentes uses, for practical lessons in classroom, to make examinations that can be previously programmed by the teacher or as a general purpose instrumentation system in an electronics laboratory. For these purposes the program has a practice editor that can be used by the teacher to prepare sequences of waveforms that will be measured by the students. The predefined practices are based on a study of the most common types of errors committed by the students making measurements with the oscilloscope, which are reviewed below:

A. Common errors in measurement

From the experience gained over several years of daily work with students and from the bibliography [1] we have developed a classification of common mistakes committed when making measured with electronic instrumentation. These errors are due to different causes, from simple confusion in connecting the test leads to errors of theoretical or mathematical calculation:

1) Errors in amplitude measurements

Errors in voltage or current measurements with multimeter or oscilloscope:

- Confusion between voltage and current scales (multimeter)
- Confusión between continuous and alternating scales (multimeter)
- Misreading of scales (confusion between μ and m prefixes, between 1 and 0.1, etc).
- Confusion between divisions and subdivisions in the oscilloscope screen.
- Bad count of divisions in the screen of the oscilloscope or analog multimeter.
- Incorrect mathematical operations: product scale by value.
- Incorrect calculation of peak, peak to peak or rms values.
- Incorrect connection of magnifiers or attenuators in oscilloscope.
- Wrong coupling mode (AC, DC, GND) on the oscilloscope.

2) Errors in time measurements (time, period, frequency)

- Misreading of scales (confusion between μ and m prefixes, between 1 and 0.1, etc).
- Confusion between divisions and subdivisions in the oscilloscope screen.
- Bad count of divisions in the screen of the oscilloscope.
- Incorrect mathematical operations: product scale by value.
- Incorrect connection of magnifiers or attenuators in oscilloscope.

From the above errors a diagnostic protocol will be developed to determine in each case what error (or errors) has been committed. In most cases, when these errors are only one type, it is relatively simple to isolate the cause and guide the students to solve the problem by himself.

B. Diagnostic methods

The following diagnostic methods are proposed for some of the most common mistakes:

1) Incorrect coupling (use of AC mode)

The measurements are all the same value (0 or a constant value). Propose to the student two consecutive measurements of different continuous voltages. If both have the same value is very likely to be committing this type of error.

2) Incorrect reference level

The measures are displaced in the same value. Propose to the student two consecutive measurements of different continuous voltages. If the difference is correct but the sum does not (or each of them separately is wrong) is very likely to be committing this type of error.

3) Incorrect scale factors

All measurements are multiplied by a constant. Propose to the student two consecutive measurements of different continuous voltages. If both are wrong but it is true that $m_2/r_2=m_1/r_1$ (where $m_{1,2}$ are the measured values and $r_{1,2}$ are the real values) is very likely to be committing this type of error.

4) Measurement of period instead of frequency

In this case it is wrongly associated period (as measured on the screen) and frequency, which is a relatively common failure. Resulting measures are inversely proportional to the frequencies associated. Propose to the student two consecutive measurements of different frequencies. If it holds that $m_2\, r_2=m_1\, r_1$ (where $m_{1,2}$ are the measured values and $r_{1,2}$ are the real values) is very likely to be committing this type of error.

5) Measure of the peak to peak of rms instead of peak value:

In this case there is a proportionality constant of known value (2, $\sqrt{2}$, $\sqrt{3}$). To detect the error it should be checked if the scaling factor matches any of the constants above.

6) Measure the peak value including the dc component

In this case the peak value is increased by a constant that matches the average value of the wave. Propose to the student two consecutive measurements and check if in both cases the peak value is correct by adding the continuous component.

In these typologies of error has not been considered the possibility of concurrent errors, that would require methods of diagnostic much more elaborated, neither sporadic errors that they would be very difficult to detect.

Also it remains pending to discriminate between different causes for each type of error (for example, a scale factor may be due to incorrect scale settings, magnifiers, attenuators and even a misreading of the divisions on the screen by the student, causes that can be individually verified proposing appropriate practices).

C. Predefined practices

Depending on previous study we developed a first set of practices aimed at the detection of the errors considered above. These practices are:

1) Measures of continuous component

This practice consists of a sequence of waveforms with different values of continuous voltage. If the values are incorrect or are always zero would indicate a bad adjustment of the oscilloscope (input switches or vertical position controls).

2) Waveform identification

This practice consists of a sequence of waveforms with the same amplitude but different shapes that must be correctly identified by the student.

3) Frequency measurement

This practice consists of a sequence of waveforms of sinusoidal type and different frequencies that should be approximately measured by the student. Errors can be detected verifying the settings of time base, magnifiers, triggering modes, etc.

4) Waveforms with dc component

This practice consists of a sequence of waveforms of the same frequency and amplitude but different values of dc component (average value). The student should be able to identify peak amplitude and mean value separately. Errors can be detected checking the position of different controls of the oscilloscope.

5) Phase offset between waves

This practice consists of a sequence of waveforms of the same frequency and amplitude but out of phase with each other. The student should be able to measure and calculate the approximate difference of phase between the waves.

D. Edition of practices

The program allows the modification of existing practices or add new ones. For that purpose there is a Wave Edition menu, which presents the parameters of the list of waveforms of each practice. These data can be modified, deleted, added, saved as text files or imported from existing disc files.

IV. Future developments

The final objective of this instrumentation system is developing an intelligent tutoring system that allows for self-training of students in the use of electronic instrumentation. This system would have different applications in both on-site and distance education, and its low cost would allow any student could dispose of it outside school.

The USB module that has been described is a first prototype which is planned various improvements, such as increased speed conversion, incorporating memory for intermediate storage of data, signal conditioning circuits with different settings (scale, offset, etc). This module could be connected to devices like android tablets or mobile phones.

V. Comparison with other instrumentation systems

In recent years there have appeared in the market many alternatives of low cost instrumentation with acceptable performance for academic use. Some examples are Picotech USB oscilloscopes [10], with models of 10Mhz of bandwidth from 150 euros and OWON digital oscilloscopes [9] with models like PDS5022 (25Mhz) with an approximate price of 300 euros.

A widely used commercial system is National Instruments Labview [11]. This system is not open source, but allows the use of self-developed external modules. Its major disadvantage is the high cost of licenses, since a multiple license for academic use costs at least 8000 euros.

The system developed in this project is free if acquisition is made by the computer's sound card, and the external module can be made at a very low cost, as an example the AD9218 converter (40MSPS) has an approximate cost of 10 euros, AT89S4051 microcontroller 2 euros and usb-serial adapter FT232RL 4 euros, and the entire module is estimated at less than 50 euros.

VI. Conclusions

In this article it has been presented a virtual instrumentation system for teaching of electronics. The system is self-developed, low cost and open source. Earlier versions of the system (simulated oscilloscope and sound card acquisition) have been widely used by the author in practical teaching and to perform computer aided tests. It has been detected the need to improve the performance of the system, so it is currently under development a high speed and low cost hardware module with connection via USB.

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